Water Resources of the Zuni Tribal Lands, McKinley and Cibola Counties, New Mexico

United States Geological Survey Water-Supply Paper 2227

Prepared in cooperation with the Pueblo of Zuni

COVER: The symbolic figure of the Zuni "Rainbow Man" is shown over Dowa Yallane Mesa, a prominent topographic feature near the Pueblo of Zuni.

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By BRENNON R. ORR

Prepared in cooperation with
the Pueblo of Zuni

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Contents

Abstract 1
Introduction 1
Purpose 1
Location and geography 1
System for numbering wells and springs 2
Regional geological history 3
Hydrogeology of ground-water systems 3
Geologic controls of hydrologic characteristics 3
Precambrian units 4
Permian units 4
Triassic units 4
Jurassic units 5
Cretaceous units 5
Tertiary units 6
Quaternary units 6
Structural controls of hydrologic characteristics 7
Regional structural features 7
Fracture systems 8
Aquifer properties 8
Glorieta-San Andres aquifer 9
Sandstone beds within the Chinle Formation 14
Zuni-Dakota aquifer 22
Water-bearing sandstones of the Gallup Sandstone and Crevasse Canyon Formation 24
Bidahochi aquifer 27
Alluvial aquifers 30
Hydrology of surface-water systems 37
The Zuni River and tributaries 37
Availability and quality of surface water 37
Summary 42
References 45
Supplemental information 47
Glossary of selected terms 48
U S Environmental Protection Agency (1976) interim drinking-water standards 50

PLATES

1. Geologic map of Zuni tribal lands, McKinley and Cibola Counties, New Mexico **In pocket**
2. Geologic sections through Zuni tribal lands, McKinley and Cibola Counties, New Mexico **In pocket**

FIGURES

1. Map showing location of study area 2
2. Map showing major structural features in the study area and vicinity 7
3. Map showing potentiometric surface and outcrop area of the Glorieta-San Andres aquifer in the study area and vicinity 10
4 Map showing location and graph showing combined discharge of springs near Ojo Caliente 11

5 Graphs showing results of aquifer tests conducted in wells completed in the Glorieta-San Andres aquifer **13**
6 Trilinear plots of well and spring water-quality analyses derived from the Glorieta-San Andres aquifer **15**
7 Map showing potentiometric surface (September 1979) and outcrop area of the Chinle Formation **17**
8 Map showing location of and section showing lithology penetrated by Zuni wells Z-6, H-1, and Z-4 **18**
9 Graphs showing results of aquifer tests conducted in wells completed in the Chinle Formation **19**
10 Trilinear plots of well and spring water-quality analyses derived from sandstones in the Chinle Formation **21**
11 Map showing potentiometric surface (September 1979) and outcrop area of the Zuni-Dakota aquifer **23**
12 Graphs showing results of short-term recovery tests conducted in wells completed in the Zuni-Dakota aquifer **24**
13 Trilinear plots of well water-quality analyses derived from the Zuni-Dakota aquifer **25**
14 Map showing potentiometric surface (November 1979) and outcrop area of the Gallup Sandstone and the Crevasse Canyon Formation **26**
15 Trilinear plots of well water-quality analyses derived from the Gallup Sandstone and Crevasse Canyon Formation **28**
16 Map showing water-table contours (September 1979) and outcrop area of the Bidahochi Formation **29**
17. Seismic profiles of the pre-Tertiary buried surface underlying the Bidahochi Formation, North Purchase Area **31**
18 Trilinear plots of well water-quality analyses derived from the Bidahochi Formation **32**
19. Map showing water-table contours and distribution of channel alluvium **33**
20. Map showing location and graph showing combined discharge of springs near Pescado **35**
21 Trilinear plots of well and spring water-quality analyses derived from alluvial aquifers **36**
22 Map showing Zuni River drainage basin upstream from the New Mexico-Arizona State line **38**
23 Graphs showing mean and median monthly discharge of the Zuni River near Black Rock, 1911–30 and 1969–79 water years **39**
24 Graphs showing mean monthly, calendar-year, and water-year precipitation for weather stations at McGaffey and Black Rock, 1911–30 and 1969–79 **41**
25 Graph showing mean and median monthly discharge of the Rio Nutria, 1969–79 water years **42**

TABLES

1 Approximate thickness, lithology, and water-supply characteristics of rocks in the study area **52**
2 Records of wells and springs on and adjacent to Zuni tribal lands **54**
3 Water-quality analyses from wells and springs on and adjacent to Zuni tribal lands (including trace-element and radiochemical analyses from selected wells and springs) **66**
4 Reservoirs along the Zuni River and its tributaries **74**
5 Water-quality and sediment analyses from streams **75**

Metric Conversion Factors

In this report values for measurements except water-quality measurements are given in inch-pound units only The following table contains factors for converting to metric units

Multiply inch-pound units	By	To obtain metric units
inch	25 4	millimeter
foot	0 3048	meter
foot per mile	0 1894	meter per kilometer
foot squared per day	0 0929	meter squared per day
cubic foot per second	0 02832	cubic meter per second
acre	4047	square meters
acre-foot	1233	cubic meter
mile	1 609	kilometer
square mile	2 590	square kilometer
gallon per minute	0 06309	liter per second
gallon per minute per foot	0 207	liter per second per meter
ton	0 9072	metric ton or tonne

National Geodetic Vertical Datum of 1929 (NGVD of 1929) A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level " NGVD of 1929 is referred to as sea level in this report

Water Resources of the Zuni Tribal Lands, McKinley and Cibola Counties, New Mexico

By Brennon R. Orr

Abstract

An evaluation of the water resources of the Zuni tribal lands in west-central New Mexico was made to determine the yield, variability, and quality of water available to the Pueblo of Zuni This study is needed to aid in orderly development of these resources

Rocks of Permian to Quaternary age supply stock, irrigation, and domestic water to the Zuni Indians The Glorieta Sandstone and San Andres Limestone (Glorieta-San Andres aquifer) of Permian age and sandstones in the Chinle Formation of Triassic age provide most of this water supply

Water in the Glorieta-San Andres aquifer is confined by minimal-permeability shales and is transmitted through the aquifer along interconnected solution channels and fractures Water-level and water-quality information indicate greater hydraulic conductivities along the southern boundaries of Zuni tribal lands

Well yields from the Glorieta-San Andres aquifer are as much as 150 gallons per minute, and aquifer transmissivity ranges from 30 to 1,400 feet squared per day Long-term, water-level declines of as much as 29 feet have been measured near pumping centers at Black Rock Multiple-well aquifer tests are needed to further define aquifer properties (storage, transmissivity, and leakage from confining units) and the effects of well design on well yields Dissolved-solids concentrations in water from the aquifer range from 331 to 1,068 milligrams per liter Calcium and sulfate are the predominant ions

Water in sandstones of the Chinle Formation is confined by adjacent shales and is transmitted along interconnected fractures Well yields range from 5 to 125 gallons per minute, and aquifer transmissivity ranges from 40 to 1,400 feet squared per day Water-level declines of as much as 27 feet have been measured near Zuni Village Dissolved-solids concentrations in water from the aquifer range from 215 to 1,980 milligrams per liter Sodium and bicarbonate are the predominant ions

Other sources of ground water are used primarily for livestock watering by means of windmills, with the exception of buried alluvial channel deposits along the Rio Pescado These deposits provide domestic and irrigation water through springs and wells to Pescado and Black Rock

The Bidahochi Formation of Miocene and Pliocene age could potentially provide an additional supply of water chemically suitable for most uses Seismic-reflection techniques are being used to locate buried channels eroded in the rocks underlying the Bidahochi Formation These buried channels may contain thicker sections of saturated sands and gravels that could be developed for stock and domestic use

INTRODUCTION

Purpose

In recent years, the population of the Pueblo of Zuni has increased rapidly with a corresponding rapid expansion of the Tribe's economy Consequently, demand on existing water supplies is increasing. Additional municipal and domestic water supplies will be required in order to meet the continuing increase in population and water use For this reason, the U S Geological Survey, in cooperation with the Pueblo of Zuni, conducted a comprehensive water-resources study of the Zuni tribal lands This report provides an analysis of the hydrology of ground- and surface-water systems and chemical quality and availability of water from wells, springs, and streamflow on Zuni tribal lands that will aid in the design of new supplies

Location and Geography

The study area encompasses approximately 620 square miles of tribally owned and reservation land in west-central New Mexico (fig 1) Land-surface altitudes range from 6,000 feet on the Zuni River at the State line to about 7,500 feet in the Zuni Mountains in the northeastern part of the study area and in the southeastern part of the study area Precipitation ranges from 12 to 17 inches annually, and streams flow intermittently Vegetation consists predominantly of piñon, juniper, sage, and range grasses, with ponderosa pine forests at higher altitudes.

Much of the Zuni population is centered around Black Rock and Zuni Village Other smaller communities include the villages of Pescado, Nutria, and Ojo Caliente The Zuni population increased from 4,700 to 6,450 between 1965 and 1975, and continued population increase is anticipated (Pueblo of Zuni, 1976)

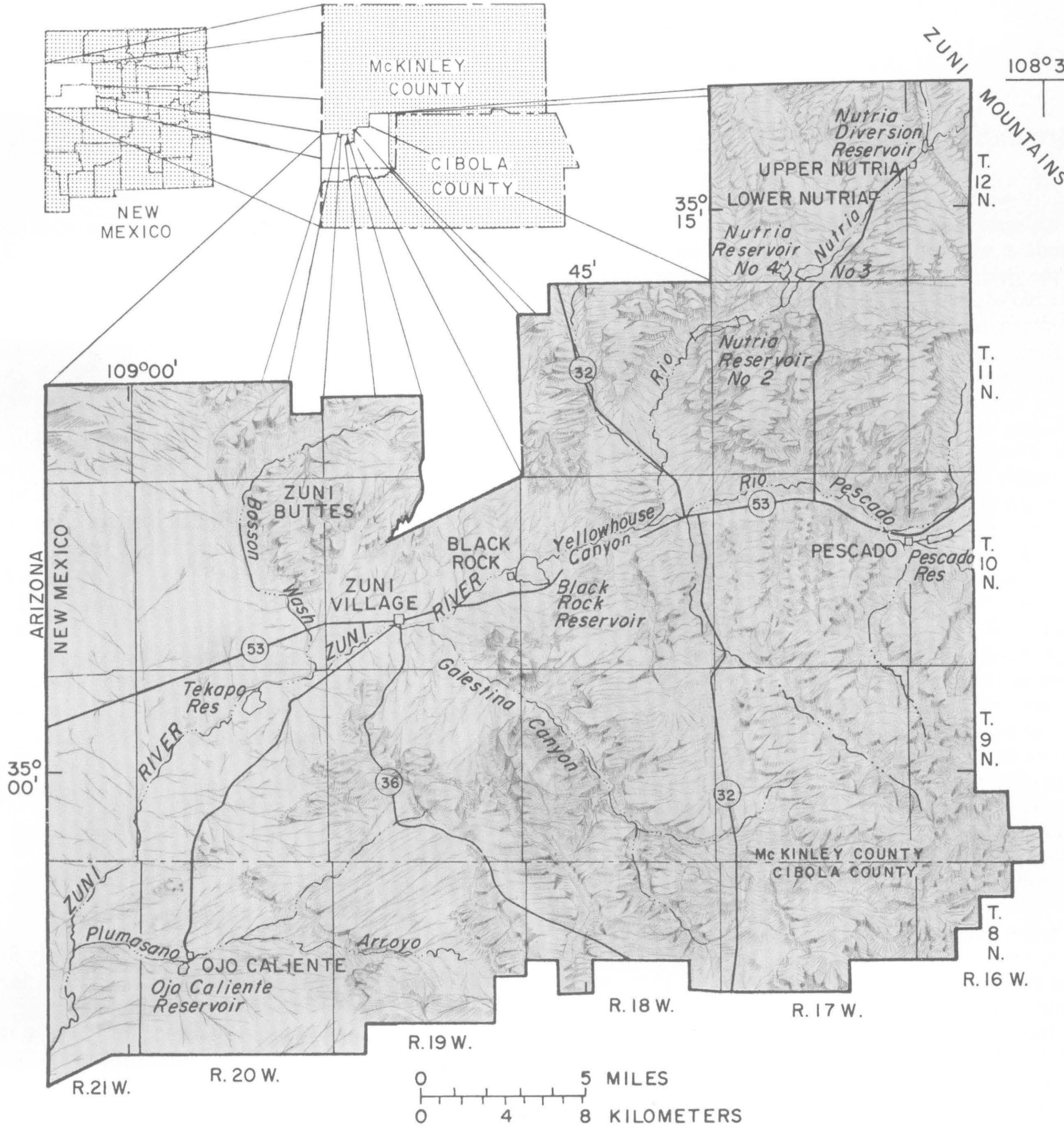


Figure 1. Location of study area.

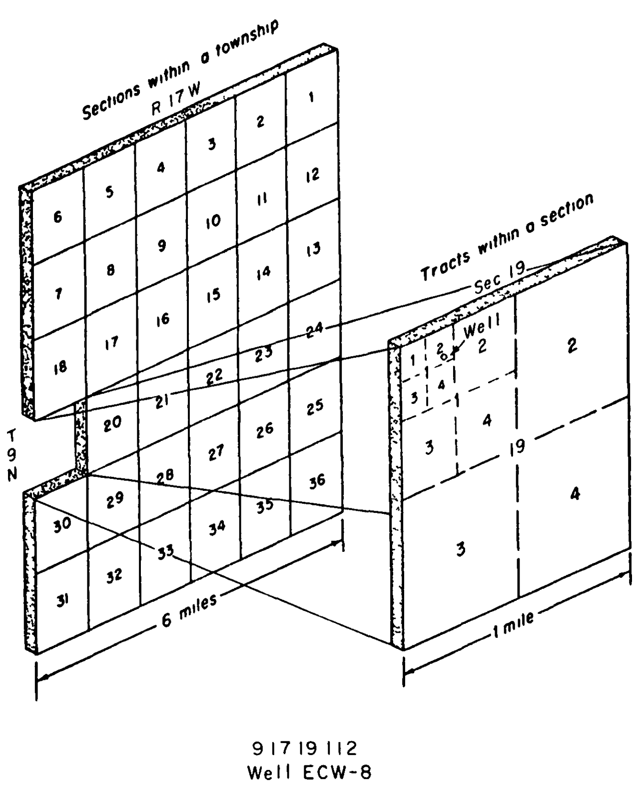
The Zuni economy has traditionally been dependent on the raising of sheep and cattle, and agriculture, both of which require easily obtainable water resources. Jewelry manufacture and tourism have become more recent Zuni industries. In the future, mining of natural resources, such as coal and uranium, may contribute to the local economy.

System for Numbering Wells and Springs

The location of wells and springs in this report is identified by a number based on the common subdivision of lands into townships, ranges, and sections. Section lines are extended from sectionized lands across previously unsectionized areas for the purpose of accurately locating wells, springs, and other features

The location number based on the township-range system is divided by periods into four segments The first indicates the township north of the New Mexico Base Line, and the second denotes the range west of the New Mexico Principal Meridian The third segment is the number of the section within the township, and the fourth indicates the tract within which the well or spring is situated To determine the fourth segment of the location number, the section is divided into four quarters numbered 1, 2, 3, and 4 for the NW¼, NE¼, SW¼, and SE¼, respectively Where map accuracy permits, these quarters are further subdivided down to the nearest 10-acre tract The numbers are based on a 1-mile square section that is determined from the southeast corner of the section The use of zeros in the fourth segment of the location number indicates that the well or spring could not be accurately located For example, well number 10 19 28 400 would indicate that the well could not be located any closer than the southeast quarter of section 28

The following diagram shows the method of numbering the wells according to the township-range system



9 17 19 112
Well ECW-8

System of numbering wells

REGIONAL GEOLOGICAL HISTORY

Deposition of sedimentary rocks in what is now west-central New Mexico began in early Paleozoic times Thick sequences of sandstone, limestone, and shale were deposited on the Precambrian crystalline surface Periods of marine, transitional, and continental deposition were frequently interrupted by periods of uplift and erosion During Late Cretaceous and early Tertiary times, regional tectonic forces formed several large domal uplifts, including the Zuni uplift, encircling the San Juan Basin in northwestern New Mexico Regional folding related to this mountain-building episode took place on the southwestern flanks of the Zuni uplift, forming several northwest-trending anticlinal and synclinal structures Subsequent erosional periods carved cuesta valleys and ridges, as well as deep, steep-walled canyons, across this area of broad structural deformation

HYDROGEOLOGY OF GROUND-WATER SYSTEMS

The most dependable and readily available supply of water in the study area is obtained from aquifers underlying Zuni tribal lands Development of aquifers within the study area has been restricted to wells in or near populated areas and, to a lesser extent, to isolated stock wells The Glorieta-San Andres aquifer and the water-bearing sands of the Chinle Formation currently provide most of the municipal, domestic, and stock water for the Zuni Tribe (pls 1 and 2) The Gallup Sandstone, Bidahochi Formation, and alluvial deposits provide most of the remaining ground-water supply Other potential supplies remain undeveloped because of the depths to water, small hydraulic conductivities, excessive dissolved-solids concentrations, or distance to areas of need

Geologic Controls of Hydrologic Characteristics

The lithology of geologic formations helps to determine hydrologic characteristics of an aquifer The grain size and the cementing material affect the ability of the rock to store and transmit fluid The soluble minerals that are present in the rocks affect the chemical composition of water passing through them The approximate thickness, lithology, and water-supply characteristics of rocks in the study area are summarized in table 1, p 52

Precambrian Units

Granitic crystalline rocks form the Precambrian basement that underlies Zuni tribal land These rocks are not exposed in the study area but are exposed to the northeast in the center of the Zuni Mountains The Precambrian basement underlying the study area is overlain by 2,500 feet or more of sedimentary rocks Water quality probably is unsuitable for most uses,and hydraulic conductivity probably is small enough to preclude the Precambrian basement rocks as potential sources for additional Zuni ground-water supplies

Permian Units

Abo and Yeso Formations—The Abo Formation and the overlying Yeso Formation (Lee and Girty, 1909) unconformably overlie the Precambrian granitic basement rocks These two Permian rock units, which consist of more than 900 feet of interbedded sandstone, siltstone, limestone, and anhydrite, are not exposed in the study area No water wells have been completed in either unit in the study area, and future development is doubtful because of the great depth, presumed small hydraulic conductivity, and presumed unsuitable water quality

Glorieta Sandstone—The Glorieta Sandstone (Keyes, 1915) conformably overlies the Yeso Formation and consists of buff to white, medium-grained, well-sorted, crossbedded, and well-cemented sandstone The Glorieta Sandstone was deposited in the intertidal zone of Permian seas throughout much of north-central New Mexico Near Zuni Village, the Glorieta Sandstone is approximately 200 feet thick Exposures are located in canyons eroded into the southwestern flank of the Zuni Mountains (pl 1) The Glorieta Sandstone underlies all the study area

San Andres Limestone—The San Andres Limestone (Lee and Girty, 1909) conformably overlies the Glorieta Sandstone and consists of gray to pink, fossiliferous, thick-bedded limestone that was deposited in a marine environment throughout much of New Mexico and adjoining States The San Andres is considered to be the equivalent of the Kaibab Formation in Arizona (Momper and Tyrrell, 1957, p 23) The San Andres Limestone is approximately 100 feet thick in the vicinity of Zuni Village Local variations in thickness are the result of karst dissolution during periods of erosion The San Andres Limestone underlies all the study area and is exposed near Nutria and Ojo Caliente (pl 1)

Within the study area, the Glorieta Sandstone and the San Andres Limestone are considered as one aquifer because they are hydraulically connected The San Andres Limestone probably yields more water than the Glorieta Sandstone because the San Andres contains a well-developed system of interconnected solution channels and caverns that increase the hydraulic conductivity The Glorieta-San Andres aquifer consists of the oldest and deepest geologic units from which water is obtained within the study area Three municipal wells, Black Rock PHS well (10 19 13 444), Black Rock well 3 (10 19 24 122b), and Zuni well F-5 (10 19 27 112), are completed in this aquifer (table 2 at back of report) Two stock wells, Cities Service Zuni-1 (9 18 5 324) and the Sam Pablamo well (12 16 5 000), also produce water from the Glorieta-San Andres aquifer Springs near Nutria (12 16 8 314 and 12 16 17 232) and near Ojo Caliente (8 20 16 324, 8 20 20 422, and 8 20 21 144) are points of surface discharge from the Glorieta-San Andres aquifer

Triassic Units

Chinle Formation—The Chinle Formation (Gregory, 1915) unconformably overlies the San Andres Limestone The Chinle in the study area includes rocks described as belonging to the Monitor Butte Member and Petrified Forest Member Rocks previously identified as the Moenkopi (?) Formation are considered part of the Chinle in this report because of lithologic and hydrologic similarities within the study area

The Petrified Forest Member of the Chinle Formation at Zuni may be further subdivided on the basis of available well data into the lower and upper parts separated by the Sonsela Sandstone Bed The lower part consists of approximately 600 feet of channel deposits of grayish-red, white, and purple mudstone and siltstone The Sonsela Sandstone Bed consists of approximately 100 feet of grayish-red to brown channel sandstone, conglomerate, and interbedded siltstone and mudstone shale The upper part consists of approximately 600 feet of fluvial grayish-red to reddish-brown mudstone and siltstone with some interbedded, lenticular sandstone

The Chinle underlies most of the study area It is exposed at places along the Nutria monocline and at Zuni Village where erosion has removed the overlying units (pl 1) Across much of the western one-third of the study area, the Chinle is found in the shallow subsurface, mantled by Tertiary eolian sands Shale outcrops occur as easily weathered clayey mounds and slopes, and sandstones are exposed as cliffs and ledges

The Sonsela Sandstone Bed and sand lenses in the upper part of the Chinle contain water The entire municipal supply for Zuni Village is produced from these units. At least 38 wells across the central part of the study area supply water for municipal and stock use from these units (table 2) Contact spring seepage commonly occurs in the Chinle along canyon walls

Wingate Sandstone—The Rock Point Member of the Wingate Sandstone (Dutton, 1885) is Late Triassic in age and conformably overlies the Chinle Formation The Rock Point Member is the only member of the Wingate present in the study area Exposures consist of fluvial reddish-orange to reddish-brown siltstone and fine-grained sandstone The Rock Point Member forms shaley ledges and cliffs where exposed (pl 1) and is found in the subsurface throughout much of the eastern two-thirds of the study area, where it is approximately 150 feet thick

Well RWP-17 (10 18 22 333b) is completed in the Wingate (table 2) No springs of consequence are known to discharge from the Wingate

Jurassic Units

Zuni Sandstone—The Zuni Sandstone (Dutton, 1885) unconformably overlies the Wingate Sandstone The Zuni Sandstone includes the lateral equivalents of the Cow Springs Sandstone and the Entrada Sandstone. The Westwater Canyon Member of the Morrison Formation occurs above the Zuni Sandstone in the northern part of the study area. This unit is included as part of the Zuni Sandstone for hydrologic purposes The Zuni Sandstone consists of reddish-brown to buff, fine- to coarse-grained, massively crossbedded eolian sandstone Exposures form steep-walled cliffs where capped with the Dakota Sandstone and form rounded hills elsewhere (pl 1) The Zuni Sandstone occurs in the subsurface throughout the eastern one-half of the study area and is approximately 500 feet thick.

At least five stock wells produce water from the Zuni Sandstone. These wells are RWP-25 (8 17 2 314), ECW-8 (9 17.19 112), ECW-1 (11 18.21.132) (Zuni and Dakota Sandstones), RWP-38 (11 20 22 211), and RWP-37 (11 20 27 314) (table 2).

Cretaceous Units

Dakota Sandstone—The Dakota Sandstone (Meek and Hayden, 1862) unconformably overlies the Zuni Sandstone The Dakota Sandstone consists of very pale orange to very pale brown, fine- to coarse-grained, well-indurated sandstone interbedded with yellowish-gray and carbonaceous shale and thin coal seams in places The Dakota was deposited in an intertidal to fluvial environment It is exposed throughout the central one-third of the mapped area (pl 1) and underlies the eastern one-half of the study area Exposures form a caprock on the more easily weathered Zuni Sandstone and form dip slopes on the sides of cuesta valleys The Dakota Sandstone in the study area is approximately 150 feet thick The lower contact is angularly unconformable, with the Dakota resting on progressively older rocks to the south

Seven wells obtain stock water from the Dakota Sandstone These wells are the Ericho well (9 17 22 000), ECW-13 (10 16 32 144), ECW-6 (10 17 35 412), ECW-10 (11 17 28 143), the Loncesion well (11 18 5 424), ECW-1 (11 18 21 132) (also completed in the Zuni Sandstone), and RWP-34 (11 18 27 411) (table 2) No springs of consequence are known to discharge from this unit within the study area, however, several springs flow from the Dakota near Lupton, north of the study area

Mancos Shale—The Mancos Shale (Cross, 1899) intertongues with the underlying Dakota Sandstone and the overlying Gallup Sandstone The Mancos Shale in the study area consists of gray to black, carbonaceous, fissile shale that was deposited in a marine environment The Mancos has been removed by erosion throughout much of the western two-thirds of the study area, it is exposed as weathered, mounded slopes and cuesta valley floors (pl 1) and occurs in the subsurface throughout the eastern one-third of the study area The Mancos Shale is approximately 300 to 400 feet thick

The Mancos Shale, generally characterized by very small hydraulic conductivity, probably is a confining unit for adjacent and intertonguing rocks The Mancos has little potential as a source of usable ground water within the study area

Gallup Sandstone—The Gallup Sandstone (Sears, 1925) intertongues with the underlying Mancos Shale The Gallup Sandstone consists of pink to tan, fine- to coarse-grained sandstone interbedded with some carbonaceous shale and thin coal seams Extensive erosion has removed the Gallup Sandstone from most of the western two-thirds of the study area (pl 1) In the eastern one-third of the study area, the Gallup Sandstone crops out as a caprock over the more easily weathered Mancos Shale and occurs in the subsurface, underlying the Dilco Coal Member of the Crevasse Canyon Formation Gallup Sandstone outcrops also are exposed in the southwestern part of the study area The Gallup Sandstone was deposited in a littoral to nonmarine environment on the boundaries of the regressional Cretaceous seas The Gallup consists of the lower unit, approximately 225 feet thick, and the upper unit, approximately 200 feet thick, separated in places by upper tongues of the Mancos Shale

Wells completed in the Gallup Sandstone within the study area include the Epaloose well (7.21 3 122a), RWP–26 (8.20 33 422), Miller's well (9 16 34 412), ECW–22 (10 17 9 244), Nutria campground well (11 17 5 322), ECW–14 (11 17 24 432), Z–6R (11 18 1 000), RWP–32 (12 16 7 331), and Bowannie well (12.17 24 442) (table 2).

Crevasse Canyon Formation—Rocks of the Crevasse Canyon Formation (Allen and Balk, 1954) conformably overlie the Gallup Sandstone In the study area, these rocks are assigned to the Dilco Coal Member (Sears, 1925) and the Bartlett Barren Member (Sears, 1925) They consist of a thick section of dark, carbonaceous shale and coal seams interbedded with gray to brown, lenticular siltstone and sandstone, and were deposited in Cretaceous swamps and flood plains Lithologic logs from mineral-exploration drill holes indicate thicknesses greater than 500 feet in the extreme northern part of the study area Outcrops remain across the northeastern one-fourth of the study area (pl 1), but extensive erosion has removed members of the Crevasse Canyon Formation elsewhere

At least four wells in the study area supply water from sandstone units within the members of the Crevasse Canyon Formation These wells include RWP–28 (11 16 8 131), RWP–29 (12 16 30 242), ECW–16 (12 17 15 213), and Z–7R (12 17.32 323) (table 2)

Tertiary Units

Bidahochi Formation—The Bidahochi Formation (Reagan, 1924), Miocene and Pliocene in age, consists of white to very pale brown, loosely consolidated fluvial sandstone interbedded with gravelly conglomerate and volcanic ash The Bidahochi Formation was deposited over the pre-Tertiary beveled surface of the ancestral Little Colorado River (Cooley and others, 1969, p A-17) These basinal deposits extend eastward into New Mexico Thick sequences of the Bidahochi Formation blanket the western one-fourth of the study area, and vestiges remain as isolated exposures on mesas in other parts of the study area (pl 1). Thicknesses may be more than 650 feet in places

Four stock wells, RWP–27 (10 20 8 243), Irrigation well 1 (10 20 18 314), RWP–30 (10 21 11 221), and RWP–24 (10 21 23 322), produce water from the Bidahochi Formation (table 2) No spring discharge of consequence is known, but some contact spring seepage occurs along upstream reaches of Willow Wash (9 19 31 323)

Quaternary Units

Buried channel deposits—As much as 150 feet of alluvium, consisting of unconsolidated sand and gravel, is buried under basalt along the Rio Pescado and Zuni River. These deposits are saturated, and the water that moves through them is confined in places by interbedded clays, they yield water to springs at Pescado and Black Rock and to domestic wells along the Rio Pescado valley

Basalt flows—Regional volcanism took place during a 1-million-year interval during late Cenozoic time This volcanism was responsible for a series of basalt flows that moved down the Rio Pescado and Zuni River valleys and ended at Black Rock (pl 1) This well-jointed, black vesicular basalt is dated at 0 70 ± 0 55 million years (Laughlin and others, 1979) Source areas are to the east of the study area Test holes in Yellowhouse Canyon penetrated as much as 29 feet of basalt, and wells at Black Rock penetrated as much as 24 feet The basalt is not known to yield water to wells or springs

Surficial deposits—Surficial deposits in the study area include alluvium, terrace deposits, eolian deposits, and colluvium (pl 1) Alluvium and terrace deposits are composed of clay, silt, sand, and gravel that were deposited in a fluvial environment along drainage systems Eolian deposits include active and stabilized dunes and a veneer of sand overlying older rocks Colluvium consists of boulders and talus slides along hills and cliffs

Wells completed in the alluvium of the Zuni River valley produce water for stock and domestic use The thickness of the alluvium in the Zuni River valley ranges from a few feet along valley margins to more than 200 feet in places Well F–5 (10 19 27 112) penetrated 145 feet of alluvium, the Leo Nastacio well (10 19 30 232) penetrated 152 feet, and the Bowman Pewa well (9 20 4 000) penetrated 235 feet At least 33 wells are known to produce water from alluvium in the study area (table 2) The average depth of wells completed in alluvium along the Zuni River generally is less than 20 feet These wells commonly are hand dug

Structural Controls of Hydrologic Characteristics

A geologic structure may be defined as the physical arrangement and modification of the rock masses of an area through deformational processes such as faulting, folding, and igneous intrusion Geologic structures are of hydrologic importance because they significantly affect hydraulic conductivity, the distribution of recharge and discharge areas, the direction of ground-water flow, the chemical quality of water, and surface-drainage characteristics

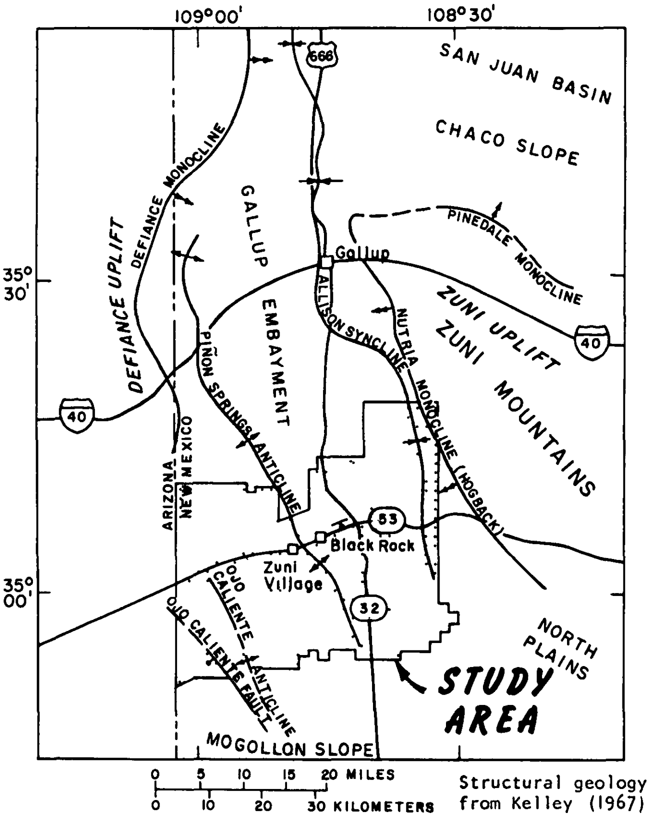


Figure 2. Major structural features in the study area and vicinity.

Regional Structural Features

Zuni tribal lands lie within the southern boundary of the Colorado Plateau province, which encompasses parts of northwestern New Mexico, northeastern Arizona, southeastern Utah, and southwestern Colorado Regional structural features in the study area are related to Late Cretaceous and early Tertiary geologic uplift and folding The features include the Zuni uplift to the northeast and the Gallup embayment over which most of the study area lies (fig 2) Other regional structures that help to define the regional hydrologic system include the San Juan Basin to the north, the Defiance uplift to the northwest, and the Mogollon slope to the southwest These structural features and the more localized features associated with them exert a significant control on the ground-water and surface-water systems in the study area

The Zuni uplift consists of a northwest-trending, asymmetrical dome that marks the southern boundary of the San Juan Basin The Zuni uplift, 75 miles long and 30 miles wide, is bounded on the north by the Pinedale monocline and the Chaco slope and on the southwest by the Nutria monocline (fig 2) The Nutria monocline, known locally as the Hogback, crosses the northeastern part of the study area and extends northward to Gallup Along the monocline, Permian through Cretaceous rocks dip to the southwest at near vertical angles where they pass over the margin of the uplift

Structural relief across the Zuni uplift is approximately 5,500 feet (Kelley, 1951, p 126), but post-uplift beveling of the domal structure has removed much of the overlying rock units, exposing a core of Precambrian granitic rocks at the center, banded by progressively younger rocks toward the margins

The Gallup embayment is an elongate, northward-plunging structural depression bounded by the Zuni uplift on the east, the Defiance uplift on the west, and the Mogollon slope on the south This feature extends northward across the Chaco slope to join the San Juan Basin in northwestern New Mexico. The Gallup embayment, also known as the Gallup sag, is 8–28 miles wide and approximately 70 miles long (Kelley, 1967, p 29) The steeply dipping beds of the Nutria monocline and the Defiance monocline form the eastern and western sides of the Gallup embayment The embayment floor, in contrast to the steep sides, is of moderate structural relief

Several synclinal and anticlinal folds modify the relatively flat structural floor of the Gallup embayment (pls 1 and 2, fig 2) The Allison syncline extends along the eastern side of the embayment, parallel to the Nutria monocline, and marks the structural trough of the embayment The Piñon Springs anticline extends from the southern boundary of the study area northwestward along Galestina Canyon, passes between the villages of Zuni and Black Rock, and terminates west of Gallup The Ojo Caliente anticline, a northwest-trending fold in the southwestern part of the study area, is bounded on the southwest by a feature known as the Ojo Caliente fault, which is either a large-displacement fault or a steep monoclinal fold The geometry of this feature is difficult to ascertain because of the Tertiary and Holocene deposits blanketing the area Other minor folds parallel to regional structural features modify the limbs of these larger features within the Gallup embayment

Fracture Systems

The movement of ground water can be significantly affected by fractures in rocks The capability of a rock to store and transmit water is improved by an increase in the number of interconnected fractures in a given rock volume This increase commonly occurs in areas that have undergone structural deformation associated with faults and folds Rock jointing, a result of compressional or tensional forces on rocks, is usually associated with tectonic features such as uplift, folding, and removal of overlying rocks Rock joints are defined as fractures along which no displacement has occurred Faults, in contrast, have had displacement along planar surfaces. Joints and faults are hydrologically important because they modify rock permeability, aid in weathering, and help to control the development of surface-drainage systems

Geohydrologic data from the study area indicate a relationship between the density of joint systems and their proximity to regional structural features These data consist of mineral-exploration lithologic logs, aerial photographs, drill-hole tests, and onsite observations Analyses of aquifer-test data from Chinle Formation wells located along the axis of the Piñon Springs anticline indicate that the capability of the rocks to transmit water is significant, but the storage capability is minimal This combination of aquifer characteristics indicates a fracture system in which the fractures readily transmit fluid but have a relatively small capacity for storage The tests conducted in wells in this area between the villages of Zuni and Black Rock indicate that well yields and aquifer characteristics are variable. The variable yields may be attributed in part to lithologic changes in the producing units but are probably closely related to the number of interconnected fractures that are intercepted by the individual wells

Additional evidence for a structure-related fracture system includes geologic-exploration data. Lost circulation of drilling fluid was observed in boreholes drilled by the Bokum Corporation along the eastern flank of the Piñon Springs anticline (pl. 1) This fluid loss is indicative of zones of fracturing within the rocks The U S Bureau of Reclamation preliminary investigation of the Yellowhouse Dam site noted a zone of fracturing in the Zuni Sandstone along Yellowhouse Canyon walls (U S Bureau of Reclamation, 1973, p 29)

Aerial photographs and topographic maps of tribal lands clearly show a well-developed joint and fracture system along the axis of the Piñon Springs anticline The predominant trends include one joint set parallel to the axis and oriented between north 40° west and north 50° west and a perpendicular joint set oriented between north 40° east and north 50° east Galestina Canyon, which follows the anticlinal axis, probably developed along the related joint and fracture system Tributaries to Galestina Canyon generally are developed along the perpendicular joint set A small-displacement fault north of Yellowhouse Canyon is apparently the result of movement along this perpendicular set

Aquifer Properties

The six aquifers that currently provide a source of water in the study area are the Glorieta Sandstone and San Andres Limestone (Glorieta-San Andres aquifer), sandstones within the Chinle Formation, the Zuni and Dakota Sandstones (Zuni-Dakota aquifer), sandstones in the Gallup Sandstone and Crevasse Canyon Formation, the Bidahochi Formation (Bidahochi aquifer), and alluvium Recharge, discharge, direction and rate of ground-water flow, and water quality are determined by specific characteristics of these aquifers These characteristics are defined in the glossary of selected terms (Supplemental Information) as excerpted from Lohman and others (1972)

Recharge to ground-water systems in the study area occurs in places where the rock units are exposed to direct precipitation and where water in streams and reservoirs comes into contact with aquifer outcrops Additional contributions to water in aquifers occur in the form of leakage or inflow from adjacent rock units Recharge areas are determined, to a large extent, by geologic structure Extensive outcrop areas exist in places where structural uplift and subsequent erosion have exposed permeable rock units Structural deformation has enhanced hydraulic conductivity, allowing for increased recharge on outcrops and inflow from adjacent geologic units.

The chemical composition of ground water is dependent on several environmental factors These factors include the chemical composition of water entering the system, lithologic composition, hydraulic conductivity, and temperature of the rock, geologic structure, and the residence time of the water as it passes through the rock Each of these factors affects the type and the volume of material that is dissolved or carried in suspension by the water

As water comes into contact with specific rock units, the more soluble rock constituents dissolve and the chemical composition of the water changes to reflect the geologic medium The relation between the composition of the rock and the chemical quality of water passing through the rock is indicated by Piper trilinear diagrams Piper trilinear diagrams show the chemical composition of water in terms of millie-quivalent percentages of the major cations (calcium, magnesium, and sodium-potassium) and the major anions (carbonate-bicarbonate, sulfate, and chloride)

Water may be discharged naturally from aquifers by flow to other aquifers, evapotranspiration, or by flow to the land surface through springs Different mechanisms are responsible for different types of springs Spring discharge may occur in places where fractures connect the land surface with an artesian aquifer whose potentiometric surface is higher than the land surface Springs also may occur in places where water-bearing units are intersected by canyons These springs are referred to as perched springs because the ground-water system supplying them generally is perched above the regional flow system by underlying confining units A third type of spring discharge occurs along alluvium-filled channels where water is brought to the surface because a barrier in the channel alluvium has backed up underflow In the study area, spring discharge includes both seasonal seepage in stream channels and canyon walls and large perennial springs that provide a year-round source of irrigation, stock, and domestic water supply

Discharge from ground-water systems also takes place in the form of well pumpage Water removed from a flow system by pumping is ultimately diverted from points of natural discharge Excessive overdraft caused by well pumpage can result in large declines in the potentiometric surface and decreased flow from springs

Glorieta-San Andres Aquifer

The Glorieta Sandstone and the San Andres Limestone form a hydraulically interconnected aquifer as much as 300 feet thick in the study area Most water in this aquifer is transmitted along solution channels within the San Andres Limestone The Glorieta Sandstone probably is characterized by small hydraulic conductivity

There is considerable potential for recharge to the Glorieta-San Andres aquifer on outcrop areas along the southwestern flank of the Zuni Mountains and across the basalt-covered subcrop areas of the North Plains (fig 3) Recharge occurs by direct precipitation or by surface flow across the outcrop areas Water infiltrates along fractures and solution channels that have developed along the structural features associated with the Zuni uplift

Several springs located on the outcrop of the Glorieta-San Andres aquifer probably represent rejection of available recharge This rejected recharge takes place because the aquifer is unable to transmit all available recharge water (Theis, 1940, p 277) Many of these springs are found along the northern outcrop boundaries

Discharge from the Glorieta-San Andres aquifer occurs at large springs near Ojo Caliente in the southwestern part of the study area These springs, Rainbow and Sacred Springs (8 20 21 144 and 8 20 20 422), are related to the Ojo Caliente anticline, which uplifted the Glorieta Sandstone and San Andres Limestone (pl 1) Subsequent erosion removed the overlying rocks and exposed the Glorieta-San Andres aquifer Fractures and solution channels associated with the anticline permit upward movement of water from the confined Glorieta-San Andres aquifer to the surface These springs have provided a subregional point of discharge for a great length of time, as is indicated by the development of cavernous solution features in the outcrop of San Andres Limestone to the south and by the occurrence of extensive, thick travertine deposits capping the hills around the springs Travertine is formed by the rapid chemical precipitation of calcium carbonate in solution in water by evaporation around the mouth of a spring

The springs near Ojo Caliente have long been developed for crop irrigation and for domestic, religious, and recreational use These springs are located along the south side of a wide valley flanked on both sides by sandstone, conglomerate, and shale of the Chinle Formation. Two main springs have been developed near Ojo Caliente (fig 4) Rainbow Spring is encircled by a rock-lined pit approximately 30 feet in diameter Water issues into the base of the pit through openings filled with loose sand Water from this spring is piped to the north side of the Ojo Caliente Reservoir where it is diverted for irrigation and domestic use Sacred Spring has been developed by the construction of earthen dikes surrounding the spring area Water from this spring is piped to irrigation distribution points along the south side of the reservoir

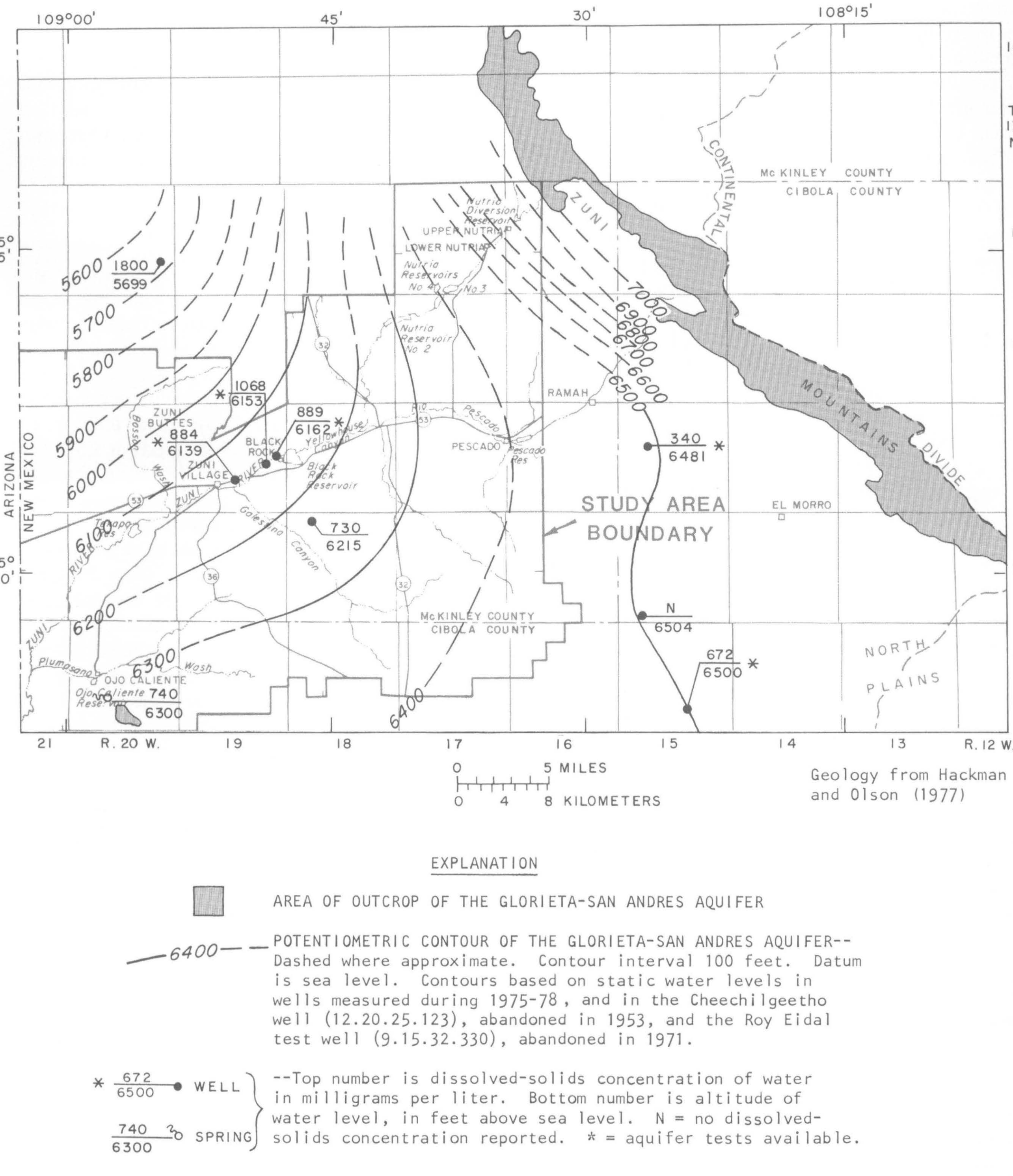


Figure 3. Potentiometric surface and outcrop area of the Glorieta-San Andres aquifer in the study area and vicinity.

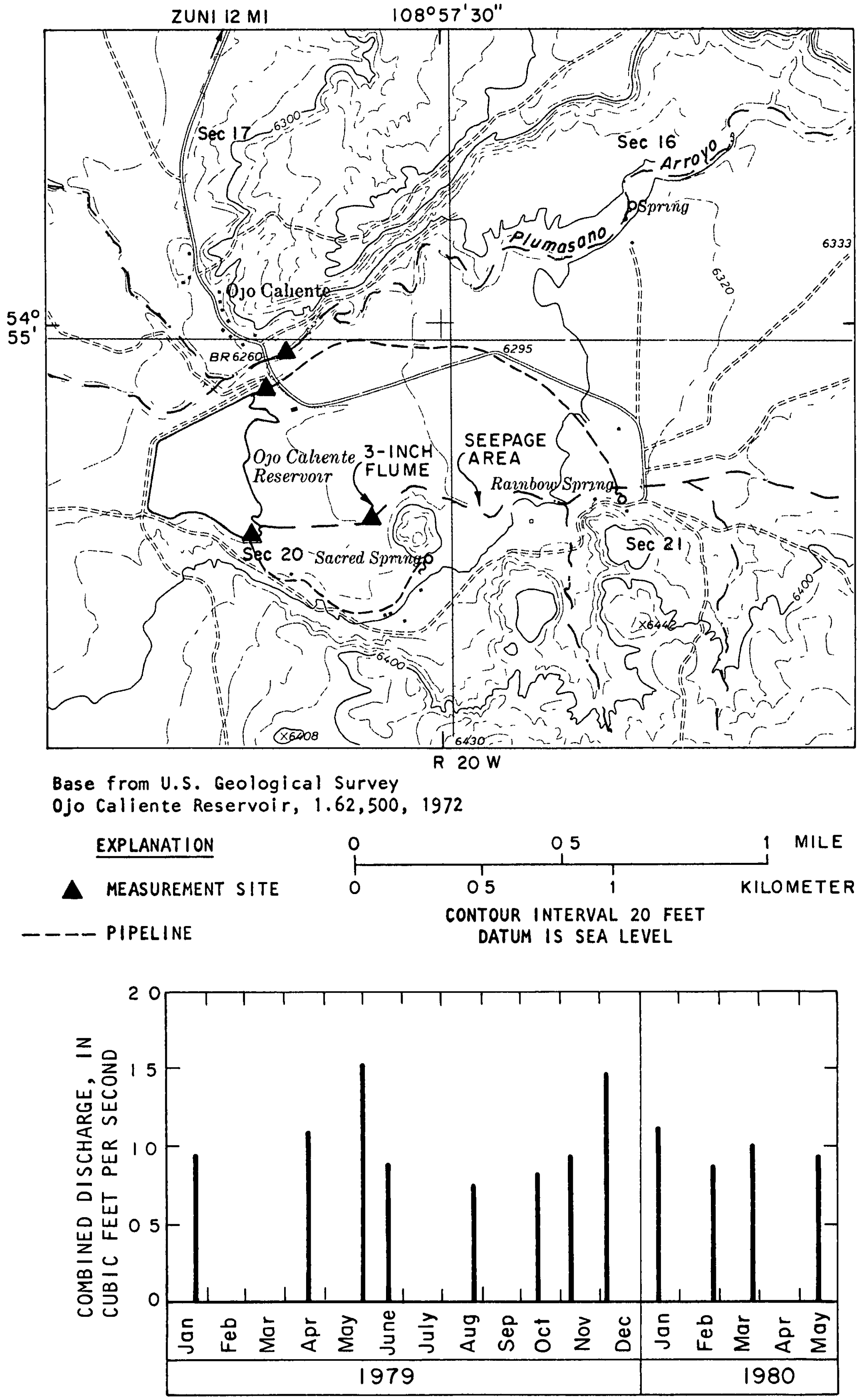


Figure 4. Location and combined discharge of springs near Ojo Caliente

A seepage area lies between Rainbow Spring and Sacred Spring This seepage area is drained by a system of open ditches that divert flow to the reservoir Additional water moves laterally through the valley alluvium to be discharged along the walls of Plumasano Arroyo to the north

Periodic discharge measurements at the springs (fig 4) indicate that the average combined discharge from the springs is approximately 1 cubic foot per second or 450 gallons per minute with a total annual discharge of 720 acre-feet Discharge during the period of measurements ranged from 670 gallons per minute on May 31, 1979, to 315 gallons per minute on August 22, 1979 This decrease may be caused by increased phreatophyte water consumption at the springs during summer months and by irrigation management of water levels in the springs Discharges from 54 to 67 gallons per minute have been measured flowing into Plumasano Arroyo for an additional 87 to 109 acre-feet per year

A potentiometric-surface map was constructed for the Glorieta-San Andres aquifer from altitudes of water levels in the few existing wells in and adjacent to the study area (fig 3) Potentiometric contours of the Glorieta-San Andres aquifer indicate the westward movement of water across the eastern one-half of the study area The direction of ground-water flow in this aquifer changes to the northwest across the western one-half of the study area

The potentiometric gradient changes across the study area To the north, the contours are close together, indicating steeper potentiometric gradients (as much as 90 feet per mile) To the south, the contours are more widely spaced, indicating flatter gradients (as small as 12 feet per mile)

Much of the water recharged on the Zuni Mountains moves west to discharge at Ojo Caliente The remaining water of the Glorieta-San Andres aquifer in the study area moves slowly westward and northwestward into Arizona A northwest-trending fault crossing the southwestern flank of the Ojo Caliente anticline may bring Cretaceous rocks of small hydraulic conductivity into fault contact with the Glorieta-San Andres aquifer This fault may provide a no-flow boundary for the Glorieta-San Andres aquifer and may funnel ground water to the northwest

Water levels in wells completed in the Glorieta-San Andres aquifer near Zuni and Black Rock villages have declined steadily The water level in the City Services A-1 stock well (9 18 5 324), 4 miles southeast of Black Rock, has declined 23 feet from 1963 to 1980 (table 2). The water level in Zuni well F-5 (10 19 27 112), 2 5 miles southwest of Black Rock, has declined 12 feet from 1973 to 1978 The water level in Black Rock well 3 (10 19 24 122b) has declined 29 feet from 1968 to 1978 These widespread declines are probably the result of pumping from Black Rock well 3, in service since 1968, and from the Black Rock PHS supply well (10 19 13 444), in service since 1975

Single-well aquifer tests have been attempted in several wells completed in the Glorieta-San Andres aquifer (fig 5) These wells include Black Rock well 3, Zuni well F-5, and the Black Rock PHS supply well, all located within several miles of the Piñon Springs anticline Boundary conditions related to regional structures (recharge or no-flow boundaries) probably did not affect those single-well tests because these boundaries are many miles away from the tested wells

Black Rock well 3 was drilled in 1968 to a total depth of 1,060 feet (table 2) The hole was cased and cemented to a depth of 810 feet, and a 6-inch-diameter perforated liner was installed from 810 feet to 1,060 feet Lithologic logs indicate a section of 85 feet of San Andres Limestone and 170 feet of Glorieta Sandstone penetrated by the perforated liner in this well

A step-drawdown and recovery test was conducted on Black Rock well 3 by the U S Bureau of Indian Affairs on March 27–28, 1968 (fig 5) This test consisted of pumping at a rate of 23 4 gallons per minute for 1 hour, increasing to a rate of 35 gallons per minute for 1 5 hours, and finally to a rate of 50 5 gallons per minute for 13 5 hours A drawdown of 221 feet was measured after pumping 16 hours at an average pumping rate of approximately 47 gallons per minute, indicating a 16-hour specific capacity of 0 21 gallon per minute per foot of drawdown A semilog method for analyzing recovery of a step-drawdown test (Harrill, 1970, p C212–C213) was used to estimate a transmissivity of approximately 300 feet squared per day (fig. 5)

Zuni well F-5 was drilled in 1973 to a depth of 1,161 feet (table 2) The hole was cased and cemented to a depth of 1,108 feet with 6-inch-diameter casing The interval between 1,108 and 1,161 feet remained open hole A loss of drilling fluid was noted at 1,155 feet, indicating that the borehole had intersected a permeable zone, probably the result of solution channeling or fracturing The total producing interval is described in lithologic logs as consisting of 53 feet of San Andres Limestone

Pumping and recovery tests were conducted on Zuni well F-5 by the U S Bureau of Indian Affairs on February 13, 1973 Semilog plots of drawdown and recovery (fig 5) were used to calculate a trans-

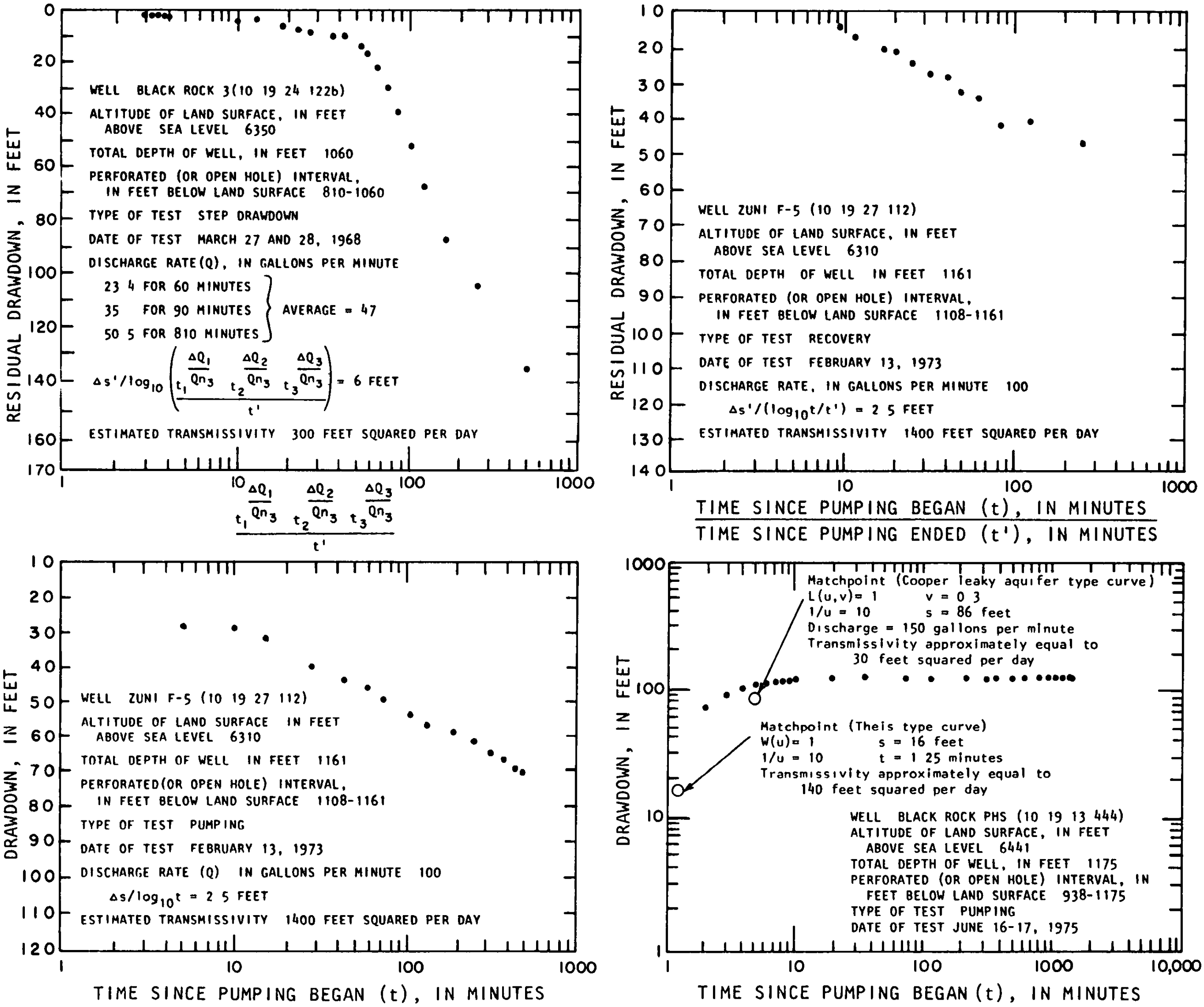


Figure 5. Results of aquifer tests conducted in wells completed in the Glorieta-San Andres aquifer

missivity of approximately 1,400 feet squared per day, a value significantly larger than that for Black Rock well 3 The specific capacity of this well could not be accurately determined because of insufficient test duration, but it is probably much larger than the 16-hour specific capacity for Black Rock well 3

The Black Rock PHS well was drilled in 1975 to a total depth of 1,175 feet (table 2) Steel casing was installed to a depth of 938 feet, and the interval from 938 feet to 1,175 feet was kept open hole This 237-foot interval probably includes a complete section of San Andres Limestone and most of the Glorieta Sandstone

Pumping and recovery tests were conducted on the Black Rock PHS well by the U S Geological Survey on June 16–17, 1975 (fig 5) The well was pumped at a rate of 150 gallons per minute for 24 hours with a drawdown of 133 feet, indicating a 24-hour specific capacity of 1 1 gallons per minute per foot of drawdown Curve-matching techniques were used to estimate a range of transmissivities from a logarithmic curve of drawdown versus time (fig 5) A Theis curve match results in a transmissivity estimate of approximately 140 feet squared per day, and a Cooper leaky-confined curve match results in a transmissivity estimate of approximately 30 feet squared per day

In the Theis solution, initial well losses were assumed to be 18 – 30 feet (estimated from a comparison between pumping and recovery tests), and the

Theis curve match was obtained using the early-time drawdown minus assumed well losses and the very late-time drawdown values Well-bore storage and well losses probably affect this method in the pumping well, and the late-time drawdowns allow for a wide range of curve matches In the Cooper solution, although an adequate curve match was obtained, well-bore storage and well losses in the pumping well again affect a determination of transmissivity

The actual value of transmissivity in the vicinity of the PHS supply well probably is within this range of estimates The drawdown curve probably is affected by well-bore storage, well losses, release from storage in confining units, flow anisotropy from fractures, and partial penetration of the aquifer

The results of these single-well aquifer tests are approximate at best In order to accurately determine aquifer characteristics such as the storage coefficient and transmissivity, and in order to better evaluate hydrologic effects resulting from boundary conditions, fractures, and leakage from adjacent confining units, carefully controlled aquifer tests with multiple observation wells are needed

The wide range in values of transmissivity and specific capacity for the wells completed in the Glorieta-San Andres aquifer reflects lateral changes in fracture and solution-channel porosity as well as different techniques of well construction Larger yields can be expected in wells that intercept more interconnected fractures Wells in which the casing is cemented and gun-perforated may have smaller yields in the fractured and solution-channeled rocks of the Glorieta-San Andres aquifer

Water-quality data for the Glorieta-San Andres aquifer consist of analyses or partial analyses from seven wells and four springs in or adjacent to the study area (table 3 at back of report) Trilinear plots of these data show similarities in the relative concentration of constituents (fig 6) Predominant ionic constituents included calcium, ranging from 78 milligrams per liter at Nutria Spring to 162 milligrams per liter in Black Rock well 3, and sulfate, ranging from 35 milligrams per liter at an unnamed spring near Nutria to 555 milligrams per liter in Black Rock well 3 Relatively large concentrations of calcium and sulfate ions probably reflect the occurrence of soluble evaporates, such as gypsum, within the Glorieta-San Andres aquifer Other ionic constituents included magnesium, sodium, bicarbonate, and chloride

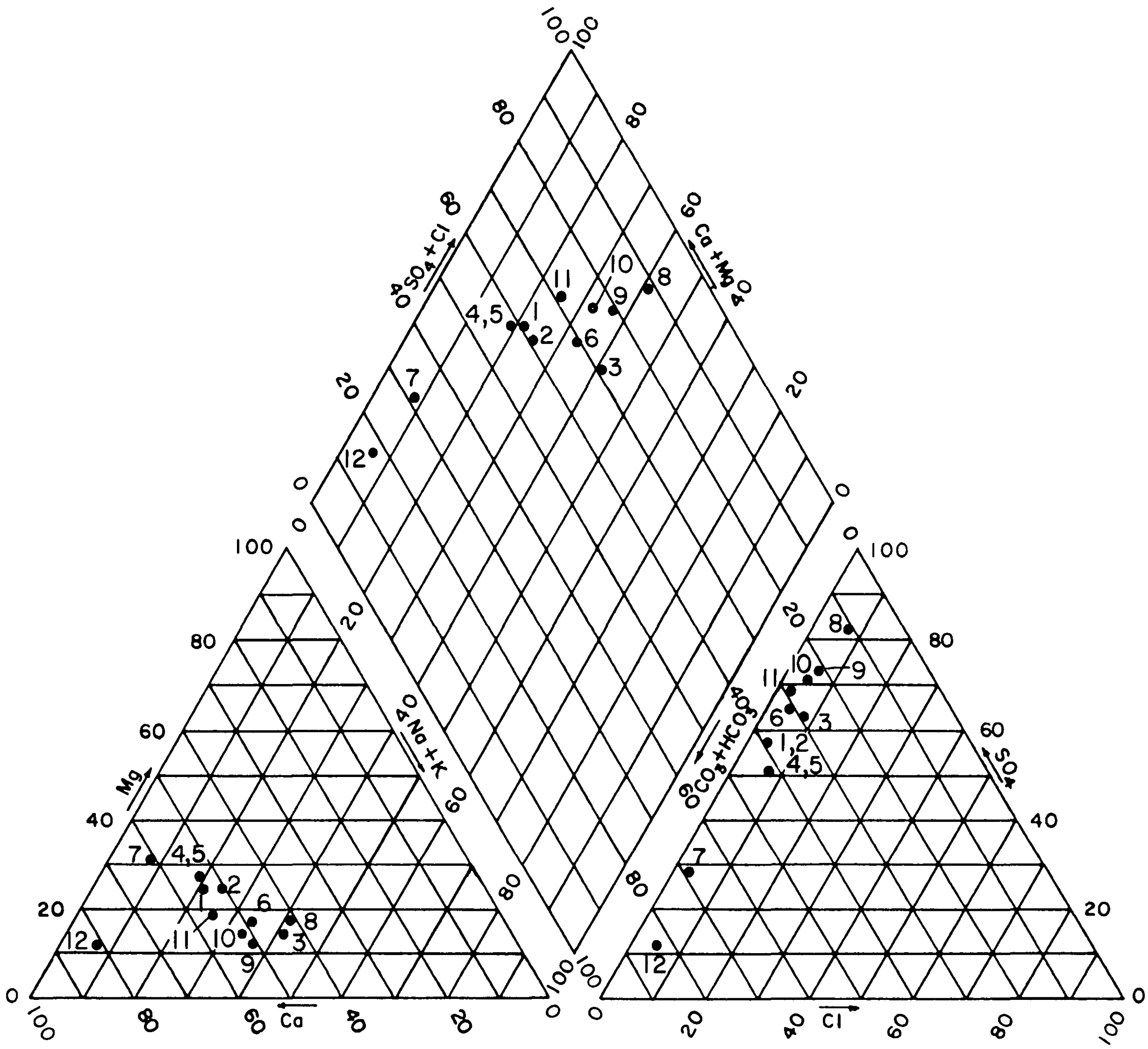
Dissolved-solids concentrations normally increase with distance from the recharge areas, mainly due to increases in calcium and sulfate Water from the unnamed spring near Nutria had the smallest dissolved-solids concentration (331 milligrams per liter) Black Rock well 3 had the largest dissolved-solids concentration (1,068 milligrams per liter) Water from the springs near Ojo Caliente (Sacred Spring and Rainbow Spring), farther from outcrop areas, contained smaller concentrations of dissolved solids (740 – 761 milligrams per liter) than did wells near Zuni and Black Rock villages (table 3, fig 6) This anomaly may be caused by a more developed solution-channel system along the southern side of the study area between the Zuni Mountains and the springs This system also may be indicated by the greater separation of the contours to the south on the potentiometric-surface map of the Glorieta-San Andres aquifer (fig 3) Water from seepage to Plumasano Arroyo (8 20 16 324) contained larger concentrations of sodium, sulfate, and chloride, which may be the result of the leaching of salts from the irrigated lands around the springs near Ojo Caliente Concentrations of sulfate in Glorieta-San Andres waters generally exceed the recommended U S Environmental Protection Agency secondary standards for drinking water (Supplemental Information). Other constituents are within acceptable limits

If it becomes necessary to further evaluate the availability and quality of water in the Glorieta-San Andres aquifer, deep exploratory wells drilled along the southern boundary of Zuni tribal lands could provide information on the more developed flow system in that area Properly designed multiple-well tests would be useful in further evaluation of characteristics of the Glorieta-San Andres aquifer

Sandstone Beds within the Chinle Formation

Recharge to the sandstone beds within the Chinle Formation takes place on outcrop areas that are exposed to direct precipitation and surface-water runoff The major recharge areas in the study area are the exposures along the Nutria monocline (fig 7) Additional recharge may take place where sandstone units are exposed near Ojo Caliente Erosion of the easily weathered Chinle mudstone and siltstone along the Nutria monocline created extensive cuesta valleys, exposing the permeable rocks of the Sonsela Sandstone Bed and other sandstones within the lower and upper parts of the Petrified Forest Member Surface water from the large drainage areas along the southwestern flanks of the Zuni Mountains flows across these cuesta valleys to contribute recharge to the exposed sandstone Recharge to the Chinle takes place primarily along fractures and bedding planes

Erosional beveling of the anticline near Ojo Caliente exposed concentric bands of interbedded sandstone and shale within the Chinle The easily weath-



Number on figure	Well or spring name	Location number	Dissolved-solids concentration, in milligrams per liter
1	Ramah 2	8.15 27 311	667
2	Ramah 1	8 15 27 342	572
3	Plumasano Arroyo Spring	8 20.16.324	966
4	Sacred Spring	8.20 20 422	740
5	Rainbow Spring	8 20 21 144	761
6	City Services A-1	9.18.5.324	730
7	Ramah Mutual	10 15 17.414	340
8	Black Rock PHS	10 19.13.444	889
9	Black Rock 3	10 19 24 122b	1068
10	do	do	994
11	Zuni F-5	10 19.27 112	884
12	Unnamed spring near Nutria	12.16.17.214	331

Figure 6. Trilinear plots of well and spring water-quality analyses derived from the Glorieta-San Andres aquifer

ered shales form gentle cuesta valleys and badlands The sandstones form broad benches and slopes that dip away from the anticlinal axis Some of these outcropping sandstones, most prominently, the Sonsela, can be correlated with sandstone penetrated at depth in wells Intermittent-stream channels draining extensive upland basins cut across these outcrops Surface-water runoff in these channels probably contributes to recharge along fractures

Additional recharge may take place along the fractured zone related to the Piñon Springs anticline This fractured zone overlies and penetrates the Chinle However, because fractures tend to close as depth increases, this recharge component probably is significant only to the shallow, discontinuous sandstones in the upper part of the Petrified Forest Member of the Chinle

The adjacent mudstones and siltstones confine the water moving through the sandstones of the Chinle Water levels in wells completed in these confined systems rise above the tops of producing units, and some wells have been known to flow at the land surface

Local discharge from the Chinle takes place at small springs and seeps where the water-bearing units are at or near the land surface Discharge also takes place laterally into alluvium-filled channels such as the Zuni River valley The municipal wells supplying Zuni Village account for part of the local discharge from the Chinle Withdrawals from wells completed in the Chinle at Zuni Village from July to December 1979 indicate a pumping rate of approximately 450 acre-feet per year The remaining water in the Chinle moves west to join a regional flow system Much of this water may discharge to the alluvium along the Puerco River in Arizona

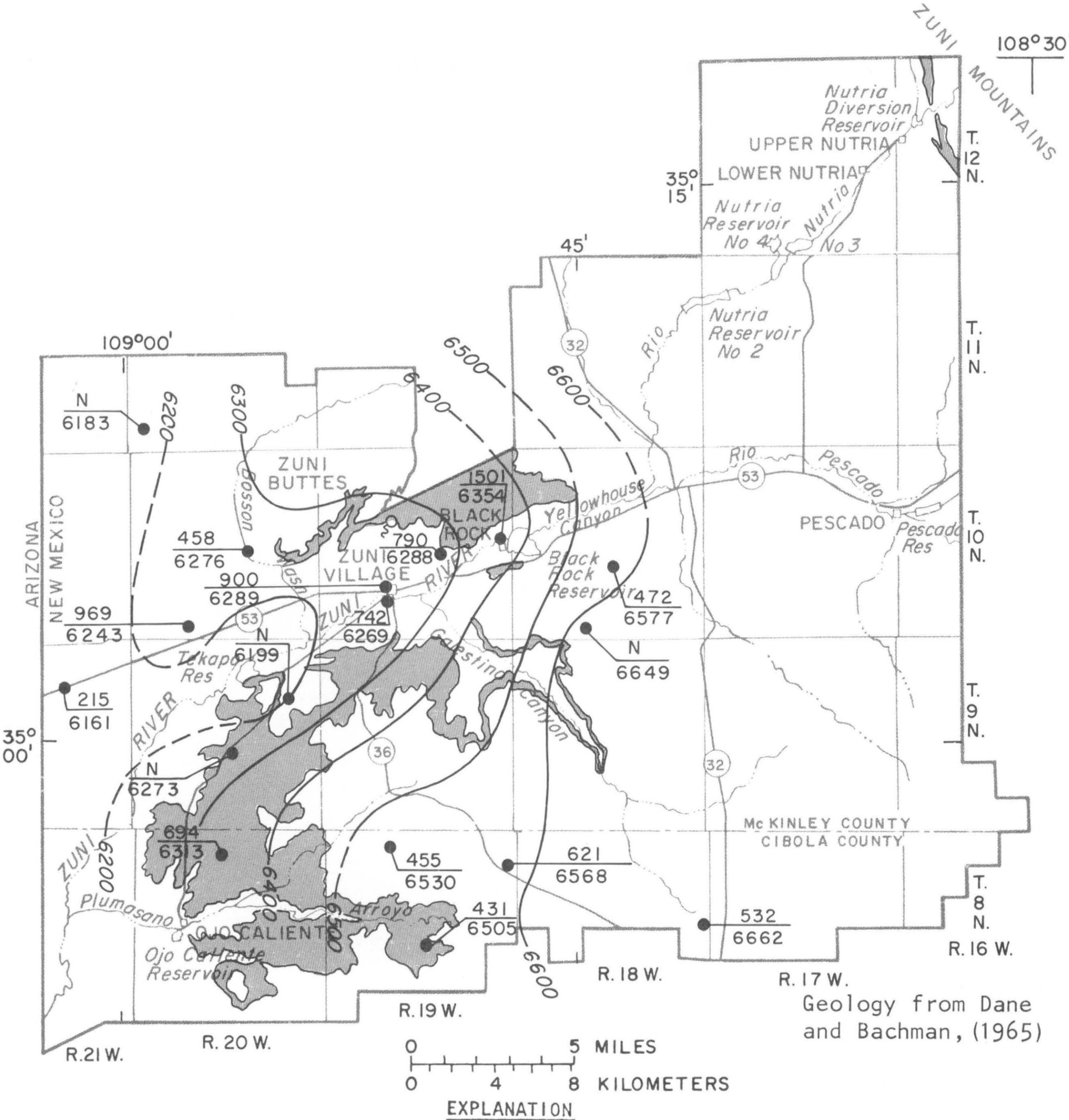
A potentiometric-surface map was constructed based on water-level altitudes in wells completed in the Chinle in the study area (fig 7) This potentiometric surface indicates a predominantly westward movement of ground water away from recharge areas in the Zuni Mountains Recharge to the exposed Chinle sandstones near Ojo Caliente adds a northwest component to the direction of ground-water flow A potentiometric trough following the Zuni River valley indicates that local discharge to valley alluvium is occurring in places where water-bearing sandstones have been cut by the Zuni channel This trough may also be enhanced by municipal pumpage at Zuni Village The hydraulic gradient in the Chinle generally ranges from 20 to 100 feet per mile across the study area (fig 7)

Recharge to sandstones within the upper part of the Petrified Forest Member may result in a locally perched ground-water supply The sandstone beds that supply stock well RWP–33 (9 19 20 132) (table 2) probably represent such a perched system The producing sandstone in this well, if extrapolated to the north, is present in the Chinle exposure south of Zuni Village and probably is not hydraulically connected with deeper water-bearing sandstones This anomalous data point was not used in the potentiometric-surface contouring

Well yields from sandstones in the Chinle range from 5 to 125 gallons per minute (table 2). The wide range of well yields, although in part related to pump capacity and well construction, probably represents changes in fracture-system development from place to place Most wells having larger yields are located in the vicinity of the Piñon Springs anticline, where structural fracturing is most developed

Moderate declines in water levels have taken place in municipal-supply wells in response to pumpage (table 2) Zuni well F–1 (10 19 28 343) had a decline of 23 feet from 1953 to 1978, Zuni well F–2 (10 19 33 121), 27 feet from 1954 to 1978, and Zuni well F–3 (10 19 28 141), 24 feet from 1957 to 1978 Stock wells located away from pumping centers have shown little or no decline over the years

Zuni municipal well Z–6 (10.19.22 231) was drilled to a total depth of 400 feet in 1976 (table 2) The well was cased and perforated in the water-bearing intervals that were determined from borehole geophysical logs (fig 8) These intervals consist of 88 feet of sandstone and shale from a depth interval of 122 to 210 feet and 47 feet of sandstone from a depth interval of 345 to 392 feet (Sonsela Sandstone Bed of the Petrified Forest Member) A recovery test was conducted on well Z–6 on August 1, 1978, after a pumping period of more than 1 day Because the actual pumping time was unknown, semilog plots of residual drawdown versus time since pumping started divided by time since pumping ended were constructed for assumed pumping periods of 1 and 20 days By applying this approach, the sensitivity of transmissivity calculations to variations in the length of assumed pumping periods was found to be not significant The resultant curves were used to calculate a transmissivity of approximately 40 feet squared per day (fig 9) and an average hydraulic conductivity of approximately 0 30 foot per day for the water-producing intervals or approximately 0.85 foot per day if the lower perforated section is assumed to be much more permeable than the upper perforated section



EXPLANATION

AREA OF OUTCROP OF THE CHINLE FORMATION

6500 POTENTIOMETRIC CONTOUR OF SANDSTONES OF THE CHINLE FORMATION--Dashed where approximate. Contour interval 100 feet. Datum is sea level.

694/6313 WELL--Top number is dissolved-solids concentration of water, in milligrams per liter. Bottom number is altitude of the water level, in feet above sea level. N = no dissolved-solids concentration reported.

SPRING

Figure 7. Potentiometric surface (September 1979) and outcrop area of the Chinle Formation.

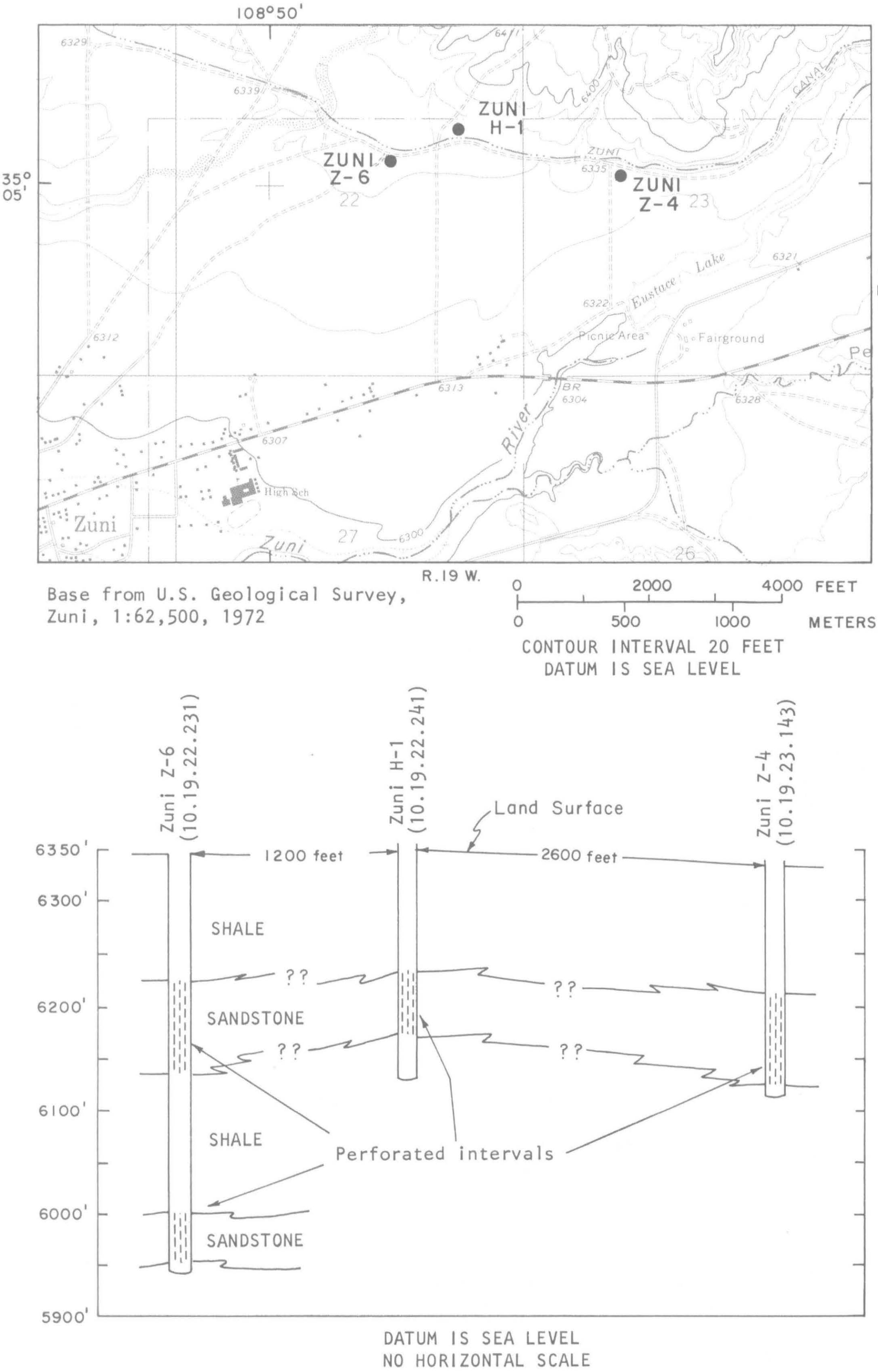


Figure 8. Location of and lithology penetrated by Zuni wells Z-6, H-1, and Z-4.

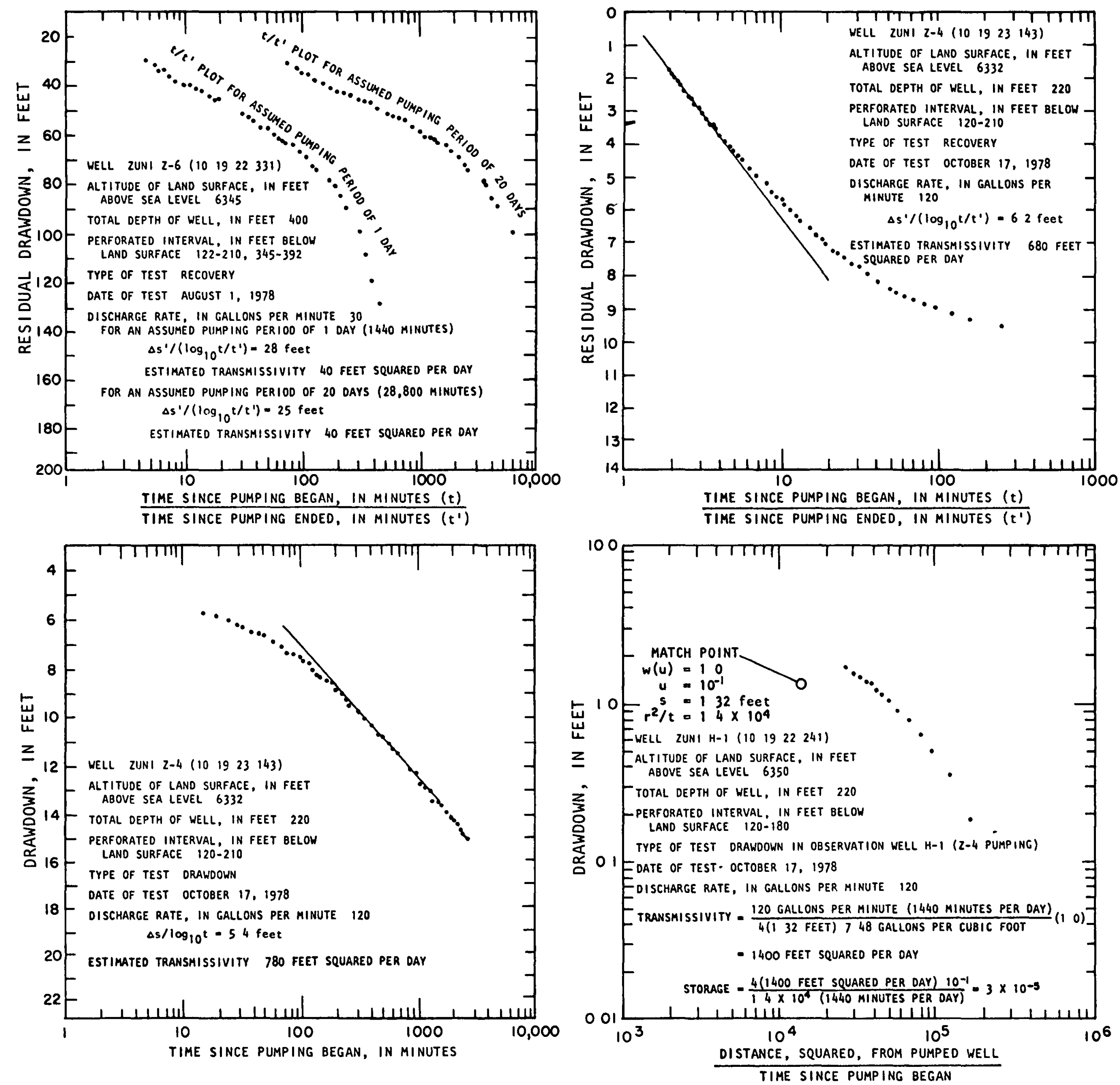


Figure 9. Results of aquifer tests conducted in wells completed in the Chinle Formation

During the recovery test on well Z-6, water-level changes were monitored in Zuni well H-1 (10 19 22 241), 1,200 feet northeast of well Z-6 (fig 8) Observations indicated that pumping and recovery of well Z-6 had little or no effect on water levels in well H-1, which, according to geophysical logs, is completed only in the upper sandstone penetrated in well Z-6

Zuni municipal well Z-4 (10 19 23 143) was drilled in 1976 to a total depth of 220 feet (table 2) Geophysical logs are available to a depth of 100 feet in a nearby hole that caved in during drilling Well Z-4 is perforated at a depth interval of approximately 120 to 210 feet Geophysical information from the upper part of the hole and from correlation with well Z-6 indicate that well Z-4 probably is perforated through the equivalent of the upper sandstone that is penetrated by well Z-6 (fig 8)

Pumping and recovery tests were conducted on well Z-4 on October 17, 1978 (fig 9). A transmissivity of approximately 680 to 780 feet squared per day was calculated from these tests The hydraulic conductivity was estimated to be 8 feet per day for the producing interval of 90 feet

During these tests, water-level changes were monitored in well H-1, 2,600 feet northwest of well Z-4. Water levels in well H-1 rapidly responded to pumping and recovery of well Z-4. During the 4-hour pumping interval, the water level in well H-1 declined 1.6 feet.

Drawdown values in well H-1 were plotted on logarithmic paper against the distance squared from well Z-4 divided by the time since pumping began (fig. 9). This drawdown curve was superimposed on a Theis-type curve to compute estimates of transmissivity and storage. The transmissivity estimate from the H-1 test was 1,400 feet squared per day, a value twice the estimate computed from the pumping and recovery test in well Z-4. The storage coefficient computed from the H-1 test was 3×10^{-5}.

The Theis method for aquifer-test analysis assumes homogeneity, isotropy, and infinite extent of the aquifer. These assumptions are not completely fulfilled in the sandstone aquifers of the Chinle Formation. These aquifers are characterized by abrupt lateral changes in texture typical of fluvial deposits where lenticular bodies of coarse-grained channel sandstone interfinger with fine-grained siltstone. In addition, fracturing of the aquifer occurred in response to regional folding. This fracturing probably enhanced the hydraulic conductivity of the aquifers, but it also increased the potential for anisotropy of the aquifers with respect to ground-water flow.

Regional recharge and no-flow boundaries are more than 20 miles from the tested wells. It is doubtful that these boundaries affected the aquifer tests. The estimates of transmissivity and storage computed from the Z-4 and H-1 tests may be affected by local inhomogeneities and anisotropy resulting from lithologic changes and fractures in the Chinle Formation. Driller's logs and geophysical logs from adjacent wells indicate abrupt lateral changes from coarse- to fine-grained sediments within the aquifer. Fracturing of the aquifer may be more pronounced because of the proximity of the well sites to the axis of the Piñon Springs anticline. Carefully designed tests using a production well and several observation wells would be needed in the event that better defined values of transmissivity and storage were desired from sandstone aquifers in the Chinle Formation.

Specific-capacity data have been collected from 13 Zuni wells that produce water from the sandstone units of the Chinle (table 2). The values of specific capacity range from 0.027 to 0.6 gallon per minute per foot of drawdown and average 0.23 gallon per minute per foot of drawdown. They have been used to estimate transmissivity utilizing a technique discussed in detail by Theis (Theis and others, 1954, p. 1-11). A storage coefficient of 5×10^{-5} was assumed for the water-bearing sandstones based on Lohman's technique for estimating storage (Lohman, 1972, p. 8). Estimated values of transmissivity range from approximately 5 to 140 feet squared per day with an average estimated transmissivity of 50 feet squared per day.

Little well-construction information is available for many of the wells for which specific-capacity values were obtained. These specific-capacity values may be affected by well-construction methods and by partial penetration of the aquifer; thus, actual values of transmissivity may be larger than the estimates based on specific-capacity values.

Specific-capacity and transmissivity values for the Sonsela Sandstone Bed in adjacent areas range from 0.026 to 0.085 gallon per minute per foot of drawdown and from 17 to 45 feet squared per day for the Fort Wingate area (Shomaker, 1971, p. 70) and 0.20 gallon per minute per foot of drawdown and 20 feet squared per day for the Navajo-Hopi area (Cooley and others, 1969, p. A-47). Values of specific capacity and transmissivity that are estimated or calculated from available data in the study area generally are within these accepted regional values. The much higher transmissivity calculated from the Z-4 pumping-recovery test is probably representative of a localized, extensively fractured zone along the axis of the Piñon Springs anticline.

Chemical analyses of water samples collected from wells producing from the Chinle are included in table 3. Piper trilinear plots of these analyses generally indicate that water in the Chinle is rich in sodium and bicarbonate (fig. 10), in contrast to the calcium- and sulfate-enriched water of the underlying Glorieta-San Andres aquifer (fig. 6).

The predominant dissolved constituents included sodium, ranging in concentration from 39 to 650 milligrams per liter; bicarbonate, ranging from 136 to 662 milligrams per liter; chloride, ranging from 5.6 to 350 milligrams per liter; and sulfate, ranging from 4.8 to 900 milligrams per liter. Other dissolved constituents, including calcium, magnesium, potassium, and carbonate, generally had smaller concentrations in water in the Chinle. Dissolved-solids concentrations ranged from 215 to 1,980 milligrams per liter, with an average of 725 milligrams per liter; alkalinity ranged from 96 to 543 milligrams per liter, with an average of 288 milligrams per liter.

Larger concentrations of sodium probably are due to the ionic-exchange properties of shale interbedded with sandstone of the Chinle. A detailed discussion of these exchange properties can be found in

Number on figure	Well or spring name	Location number	Dissolved-solids concentration, in milligrams per liter
1	ECW-7	8 18 24 221	532
2	ECW-4	8 19 4 321	455
3	ECW-5	8 19.12 211	621
4	ECW-18	8 19 22 313	431
5	Lower Willow Wash Spring	8 20 1 322	922
6	RWP-35	8 20 4 344	694
7	Chavez Spring	8 20 8 443	480
8	do	do	968
9	Ondelacy	9 18 19 423	1980
10	Dowa Yallane Spring	9 19 1 144	246
11	ECW-2	9 21 11 314	215
12	RWP-17	10 18 22 333b	472
13	Zuni Z-6	10 19 22 231	790
14	Zuni H-1	10 19 22.241	474
15	Zuni Z-3	10 19 22 244	802

Number on figure	Well or spring name	Location number	Dissolved-solids concentration, in milligrams per liter
16	Zuni Z-2	10 19 22 421	709
17	Zuni Z-5	10 19 22 433	826
18	Zuni Z-1 (Curtis)	10 19 23 134	486
19	Zuni Z-4	10 19.23 143	622
20	Black Rock 2	10 19 24 221	1561
21	Zuni F-4	10 19.28 131	760
22	Zuni F-3	10 19 28 141	910
23	Pat Kelsey	10.19.28 314	967
24	Zuni F-1	10.19 28 343	742
25	do.	do.	874
26	Zuni F-2	10.19 33 121	1003
27	Bosson Ranch	10 20 22 211	458
28	ECW-9	10.20 32 421	969
29	Spring	11 20 34 244	229
30	16T-545	12 21 24 423	339

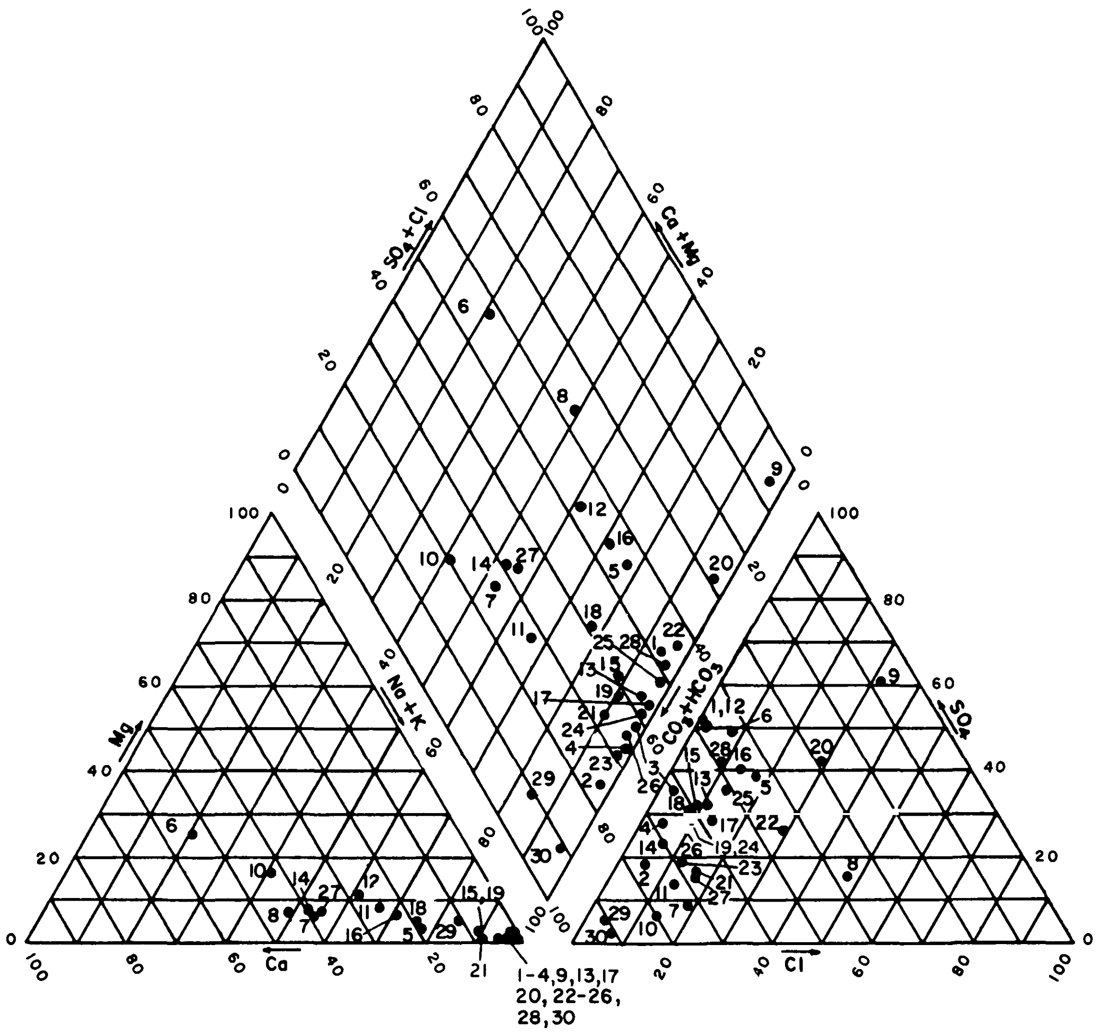


Figure 10. Trilinear plots of well and spring water-quality analyses derived from sandstones in the Chinle Formation.

Hem (1970) Bicarbonate concentrations may reflect dissolution of carbonate cement within the aquifer Large concentrations of sulfate may represent the weathering of sulfide minerals, such as pyrite, which are present within the Chinle shale Dissolved constituents may be expected to increase in concentration with distance from the point of recharge

Concentrations of dissolved solids in Zuni well F-1 (10 19 28 343) and well F-2 (10 19 33 121) have increased since these wells were drilled The specific-conductance value, an indicator of the dissolved ionic material in water, has increased from 936 micromhos in 1953 to 1,400 micromhos in 1980 in well F-1 and from 1,250 micromhos in 1953 to 1,620 micromhos in 1972 in well F-2 (table 2) These increases in specific-conductance values with time may represent some leakage of water containing larger concentrations of dissolved solids from adjoining shales in response to local pumping stress

Exploratory drilling and multiple-well aquifer tests, particularly in areas of intense fracturing, are needed to further evaluate the availability and quality of water in sandstones of the Chinle Formation Mapping of lineaments based on satellite imagery and interpretation of aerial photographs can be used to locate fractured zones Periodic monitoring of concentrations of dissolved solids in water from public-supply wells would be useful in defining trends in water chemistry related to pumping

Zuni-Dakota Aquifer

The Zuni-Dakota aquifer has a thickness of more than 700 feet of potentially water-bearing sandstone that underlies the eastern one-half of the study area (pl 1) These rocks are considered as one hydrologic unit because of the predominant sandstone lithology and the lack of major intervening units of small hydraulic conductivity Recharge to this aquifer may take place on the almost vertical exposures along the Nutria monocline and on the exposures that form a dip slope across the central one-third of the study area (fig 11) Recharge probably occurs from runoff and direct precipitation on outcrops Water probably moves through the Zuni-Dakota aquifer as intergranular flow and along fractures related to regional structures

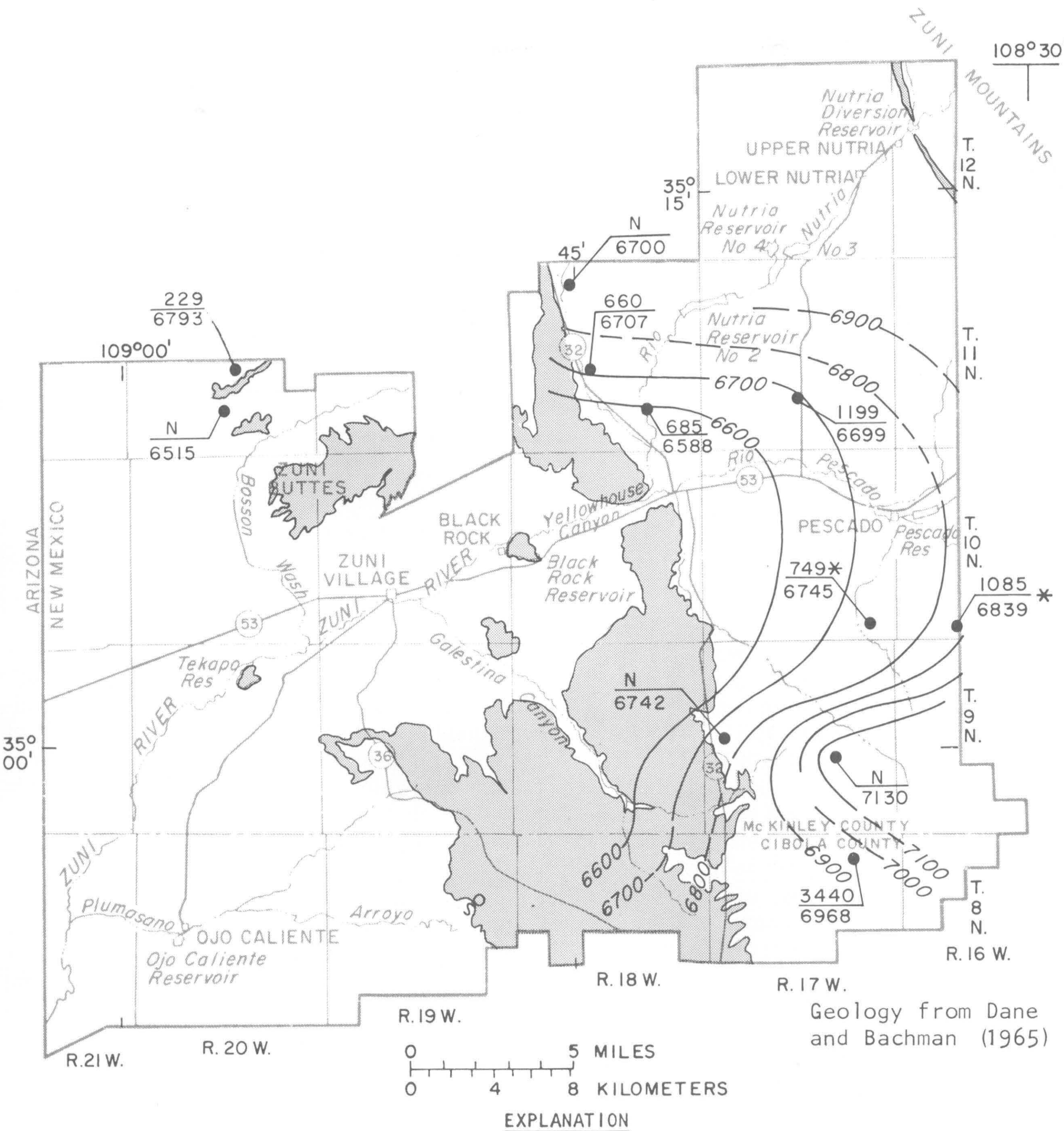
A potentiometric map constructed on the basis of the few wells completed in this aquifer indicates that flow is westward across the study area at a gradient ranging from 50 to 100 feet per mile (fig 11) Flow lines drawn perpendicular to the potentiometric contours converge toward Yellowhouse Canyon, sections 10 and 11, T 10 N, R 18 W, indicating possible discharge to shallower units such as the channel alluvium

Eleven wells are known to be completed in either the Zuni Sandstone or the Dakota Sandstone in the study area (table 2) Summers (1972, p 57) reported a hydraulic conductivity of 1 6 feet per day for well ECW-1 (11 18 21 132) completed in both the Zuni and Dakota Sandstones A specific capacity of 0 97 gallon per minute per foot of drawdown was obtained for this well in 1934 Specific-capacity values for wells completed only in the Zuni Sandstone include 0 14 gallon per minute per foot of drawdown for wells RWP-38 (11 20 22 211) and RWP-37 (11 20 27 314) Summers (1972, p 57) reported transmissivities from 7 1 to 13 4 feet squared per day and hydraulic conductivities from 0 083 to 0 16 foot per day for wells completed in the Dakota Sandstone Estimates of transmissivity from 1 to 7 feet squared per day were made for wells ECW-13 (10 16 32 144) and ECW-6 (10 17 35 412) from short-term recovery tests conducted on May 30, 1979 (fig 12) Both wells are completed in the Dakota Sandstone A hydraulic conductivity of 0 07 foot per day was estimated for well ECW-6 from these tests A specific capacity of 0 07 gallon per minute per foot of drawdown was calculated for well ECW-10 (11 17 28 143), another well completed in the Dakota Sandstone

Larger transmissivities and improved well yields in the Zuni-Dakota aquifer may be expected where increased fracturing has taken place as a result of structural deformation A zone of increased fracturing has been noted previously along the eastern limb of the Piñon Springs anticline (Summers, 1972, fig 9) Fracturing may be expected to decrease eastward as the Zuni-Dakota aquifer is more deeply buried by the younger Cretaceous sediments

Water-quality analyses are available for wells completed in either the Zuni or the Dakota Sandstones (table 3) Major dissolved constituents included sodium, ranging in concentration from 24 0 to 376 milligrams per liter, bicarbonate, ranging in concentration from 146 to 387 milligrams per liter, and sulfate, ranging in concentration from 11 0 to 2,047 milligrams per liter

Trilinear plots of water-quality analyses from wells in the Zuni-Dakota aquifer are shown in figure 13 Well RWP-25 (8 17 2 314), well RWP-38 (11 20 22 211), and Jones Ranch well PM-3 (12 20 17 133) produce water from the Zuni Sandstone Water samples collected from wells in recharge areas (RWP-38 and PM-3) typically are enriched in calcium and bicarbonate, in contrast to the calcium-



EXPLANATION

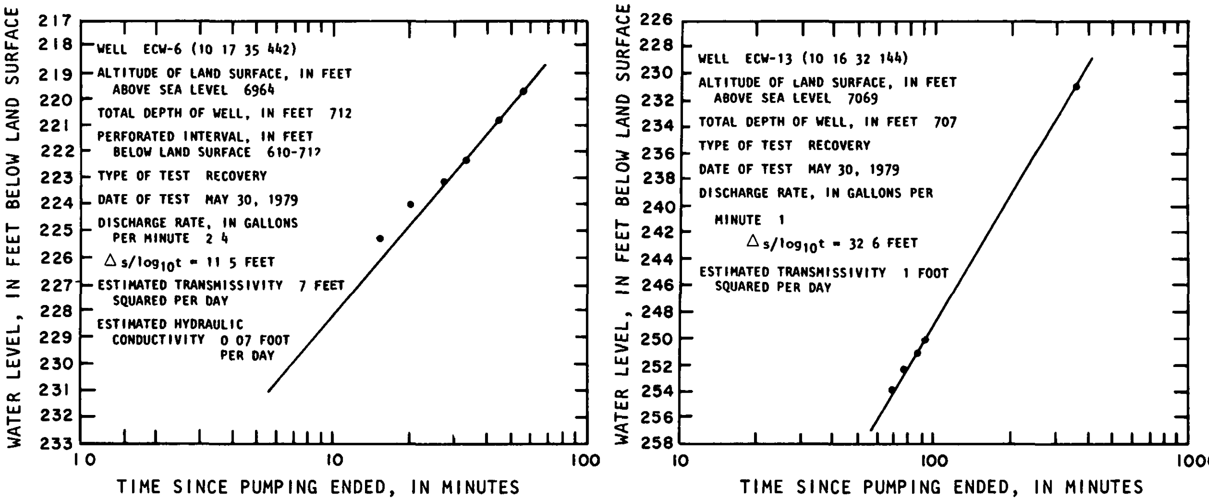
AREA OF OUTCROP OF THE ZUNI-DAKOTA AQUIFER

6600 — POTENTIOMETRIC CONTOUR OF THE ZUNI-DAKOTA AQUIFER--Dashed where approximate. Contour interval 100 feet. Datum is sea level.

3440 / 6968 WELL--Top number is dissolved-solids concentration of water, in milligrams per liter. Bottom number is altitude of the water level, in feet above sea level. N = no dissolved-solids concentration reported. * = aquifer tests are available

SPRING

Figure 11. Potentiometric surface (September 1979) and outcrop area of the Zuni-Dakota aquifer.



NOTE THESE ANALYSES ARE ESTIMATES BECAUSE THE RESIDUAL DRAWDOWN COULD NOT BE DETERMINED WITHOUT AN ACCURATE MEASUREMENT OF STATIC WATER LEVEL AND t/t' COULD NOT BE DETERMINED WITHOUT THE KNOWLEDGE OF THE TIME PUMPING BEGAN HOWEVER, THIS TEST DOES PROVIDE AN ESTIMATE OF THE MAGNITUDE OF TRANSMISSIVITY IN THE VICINITY OF THE WELL

Figure 12. Results of short-term recovery tests conducted ın wells completed ın the Zunı-Dakota aquıfer

and sulfate-enrıched water ın well RWP–25 (8 17 2 314), a well some dıstance from recharge areas Analyses are avaılable from wells ECW–13 (10 16 32 114), ECW–6 (10 17 35 412), ECW–10 (11 17 28 143), and RWP–34 (11 18 27 411), all of whıch are completed ın the Dakota Sandstone The range of constıtuent concentratıons ın these waters ıs small (table 3), and the trılınear plots (fig 13) ındıcate water typıcally enrıched wıth sodıum and sulfate Sulfate concentratıons may ıncrease as water movıng through the Dakota Sandstone comes ın contact wıth sulfides or selenıte Excessıve sodıum concentratıons may result from ıon exchange ın interbedded shales wıthın the Dakota

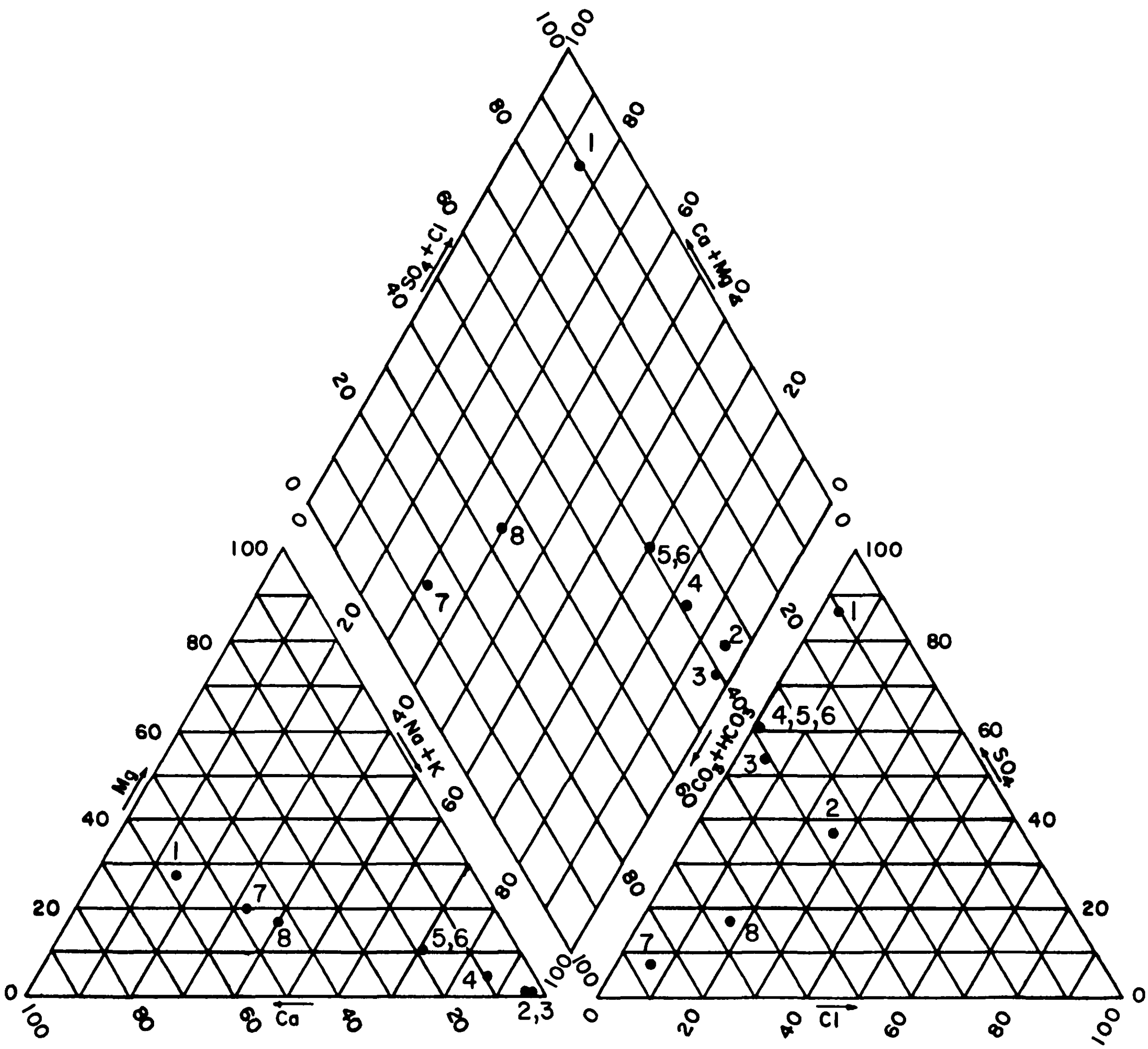
Water from well RWP–25, completed ın the Zunı Sandstone, contaıned sıgnıficantly larger concentratıons of dıssolved solıds than were found ın water from the Dakota Sandstone The sulfate concentratıon was partıcularly excessıve (2,047 mıllıgrams per lıter) Well RWP–38 and the Jones Ranch well PM–3 produced water that had sıgnıficantly smaller concentratıons of dıssolved solıds The concentratıons of dıssolved solıds ın these wells were 189 and 246 mıllıgrams per lıter, compared wıth a range of 668 to 1,199 mıllıgrams per lıter ın wells of the Dakota and 3,440 mıllıgrams per lıter ın RWP–25 The smaller concentratıon of dıssolved materıal probably ıs related to localızed recharge to the Zunı Sandstone where ıt ıs exposed or thınly mantled wıth Tertıary sands of the Bıdahochı Formatıon and Holocene alluvıum Well RWP–25, ın contrast, ıs approxımately 15 mıles from the recharge area. Water pumped from thıs well has traveled at great depth through the Allıson synclıne ın rocks that have smaller hydraulıc conductıvıty because of the depth of burıal The excessıve sulfate concentratıon may ındıcate the dıssolutıon of gypsum or oxıdatıon of sulfide mınerals wıthın the Zunı Sandstone

Hydrologıc ınformatıon from the few wells completed ın the Zunı-Dakota aquıfer ın or adjacent to the study area ındıcates that the potentıal of thıs aquıfer as a permanent source of water for publıc supply or ırrıgatıon ıs lımıted However, ıf ıt becomes necessary to further evaluate the avaılabılıty and qualıty of water from the Zunı-Dakota aquıfer, deep test wells could be drılled along the Allıson synclıne

Water-Bearing Sandstones of the Gallup Sandstone and Crevasse Canyon Formation

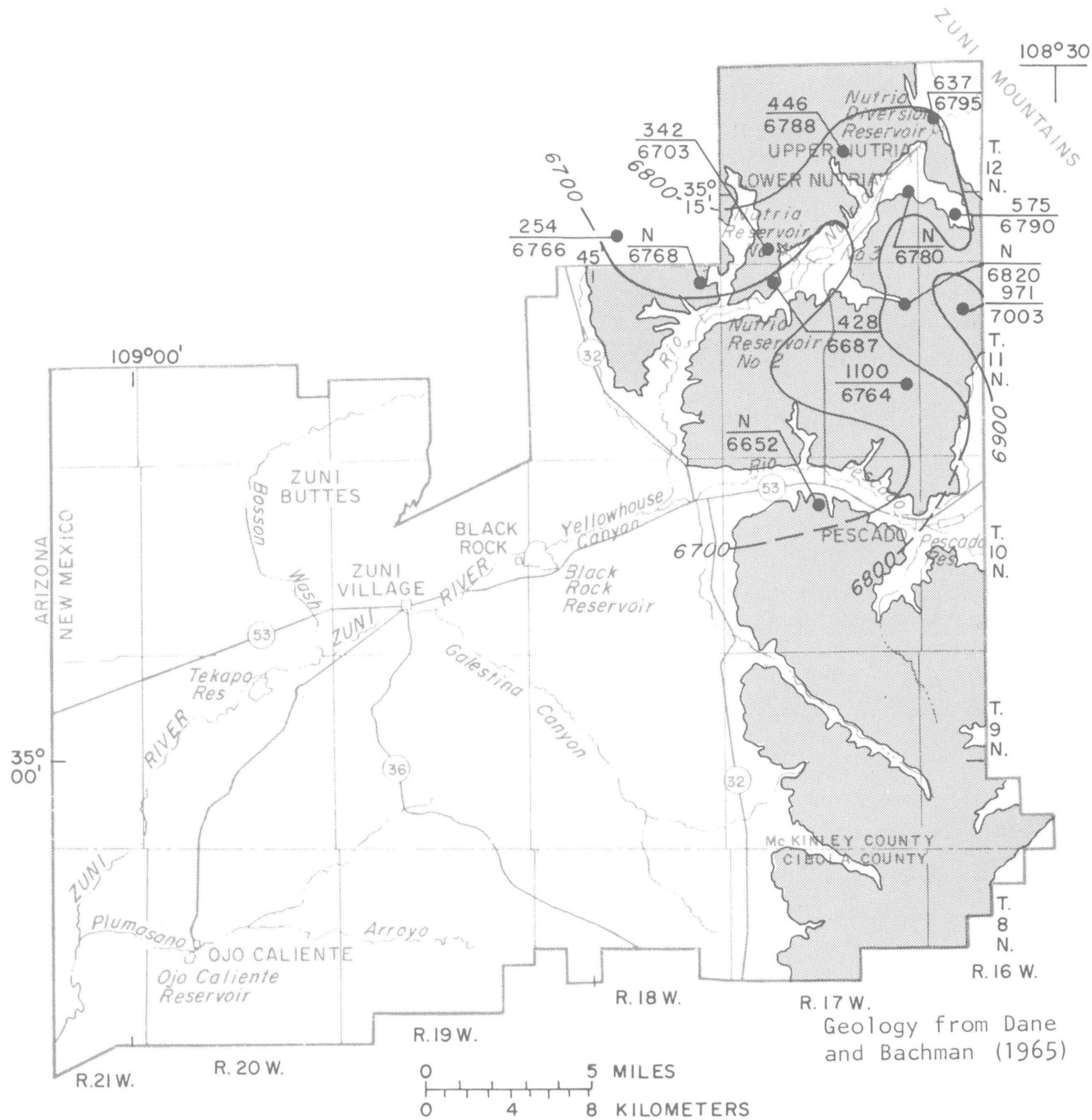
Sandstones wıthın the Gallup Sandstone and the Crevasse Canyon Formatıon yıeld water to stock wells across the eastern one-thırd of the study area These sandstones generally are ınterbedded wıth shales that have small hydraulıc conductıvıty and do not form a unıfied aquıfer system

Local recharge to these sandstones takes place on outcrops by ınfiltratıon of surface runoff along fractures and joınts Recharge areas ınclude broad mesas ıncısed by stream draınages (fig 14)



Number on figure	Well name	Location number	Dissolved-solids concentration, in milligrams per liter
1	RWP-25	8.17. 2.314	3440
2	ECW-13	10.16.32.144	1085
3	ECW-6	10.17.35.412	749
4	ECW-10	11.17.28.143	1199
5	RWP-34	11.18.27.411	685
6	do.	do.	668
7	RWP-38	11.20.22.211	189
8	Jones Ranch PM3	12.20.17.133	246

Figure 13. Trilinear plots of well water-quality analyses derived from the Zuni-Dakota aquifer



EXPLANATION

AREA OF OUTCROP OF THE GALLUP SANDSTONE AND CREVASSE CANYON FORMATION

6700 — POTENTIOMETRIC CONTOUR IN THE GALLUP SANDSTONE AND CREVASSE CANYON FORMATION--Dashed where approximate. Contour interval 100 feet. Datum is sea level.

1100 / 6764 WELL--Top number is the dissolved-solids concentration of water, in milligrams per liter. Bottom number is altitude of the water level, in feet above sea level. N = no dissolved-solids concentration reported.

Figure 14. Potentiometric surface (November 1979) and outcrop area of the Gallup Sandstone and the Crevasse Canyon Formation.

The Rio Nutria and Rio Pescado drainages are well entrenched in the Gallup Sandstone and Crevasse Canyon Formation across the study area These drainages are an avenue for localized ground-water discharge from the sandstone units cut by them Altitudes of water levels in wells indicate the movement of water from recharge areas on the higher mesas toward points of discharge to the alluvium along the Rio Nutria and Rio Pescado valleys (fig 14) Localized discharge may occur as seepage to talus slopes along the valley margins or to channel-fill material in places where the sandstone units are truncated North of the study area, ground water in areas where these units are not incised by surface drainages probably moves northward along the Allison syncline to join a regional flow system near Gallup, New Mexico

Well yields of 4 to 5 gallons per minute are reported from several stock wells completed in sandstone units of the Gallup Sandstone or the Crevasse Canyon Formation in the study area (table 2) Summers (1972, p 57) reported a specific capacity of 0 04 gallon per minute per foot of drawdown, a transmissivity of approximately 2 feet squared per day, and a hydraulic conductivity of 0 13 foot per day for the Gallup Sandstone in the study area A specific capacity of 0 20 gallon per minute per foot of drawdown was measured in the Bowannie well (12 17 24 442), which is producing from the Gallup Sandstone (table 2)

Potential water supplies within the thin, discontinuous sandstone beds of the Crevasse Canyon Formation are locally recharged Where ground water is present in these sandstone beds, it probably is perched and has little potential for extensive development Minor ground-water supplies could be developed in the northeast part of the study area To the south, where the Crevasse Canyon Formation is breached by canyons, the sandstone beds generally are unsaturated.

In the Navajo-Hopi area, Cooley and others (1969, table 7) reported a range of specific capacities from 0 03 to 4 78 gallons per minute per foot of drawdown for wells completed in the Gallup Sandstone and from 0 03 to 0.64 gallon per minute per foot of drawdown for wells completed in the Crevasse Canyon Formation Wells in the study area completed in these units can be expected to have specific capacities nearer to the lower limits of these ranges Transmissivities probably will be less than 10 feet squared per day, and well yields probably will be less than 10 gallons per minute Potential ground-water supplies from the Gallup Sandstone and Crevasse Canyon Formation are limited by the lateral extent of the perched, saturated units, particularly in the Crevasse Canyon Formation

Piper trilinear plots indicate that no single chemical composition is typical of water from the Gallup Sandstone or Crevasse Canyon Formation in the study area (fig 15) This probably is due, at least in part, to the lateral changes in lithology common to these units Shales tend to cause larger sodium concentrations through ion exchange, the presence of sulfides or sulfates in the rocks tends to cause larger sulfate concentrations in the ground water

Dissolved solids in water from wells completed in either the Gallup Sandstone or the Crevasse Canyon Formation (table 3) ranged in concentration from 254 to 1,100 milligrams per liter, bicarbonate, from 183 to 402 milligrams per liter; and sulfate, from 6 2 to 530 milligrams per liter Concentrations of dissolved constituents tend to increase with the distance the water must travel from the point of recharge Most wells probably are located close to points of surface recharge, and the concentrations of dissolved solids are correspondingly small

Bidahochi Aquifer

Very little runoff takes place over the outcrop of the Bidahochi aquifer, as indicated by the limited drainage system that commonly terminates in closed depressions on the Bidahochi surface. Precipitation on the extensive exposures of the Bidahochi and overlying dune deposits is either returned to the atmosphere through evapotranspiration or is quickly absorbed by the permeable sands and gravels of the Bidahochi On the average, evapotranspiration greatly exceeds infiltration, as is typical of arid areas of the Southwest Water that is recharged moves downward to a thin zone of saturation above the relatively impermeable Triassic shales

A map of the water table in the Bidahochi aquifer was contoured on the basis of well data (fig 16) The westward-dipping water table in the northwestern corner of the study area generally parallels the gradient of the underlying Zuni erosional surface shown by Akers (1964, pl 2)

Channels and remnant ridges on the Zuni erosional surface probably exert a significant control over the occurrence of ground water and the saturated thickness of overlying Bidahochi sands and gravels Akers (1964, pl 2) indicated the existence of a major buried channel near the State line north of State Highway 53 This buried channel and tributary channels probably direct locally recharged ground water westward into Arizona Remnant ridges between drainage channels may lie very close to the

Number on figure	Well name	Location	Dissolved-solids concentration, in milligrams per liter
1	Ramah 13 *	7.16.21.342	475
2	Epaloose *	7.21. 3.122a	1010
3	Irrigation 3*	8.20.31.321	725
4	Miller *	9 16 34 412	531
5	Nutria Camp-ground *	11.17. 5.322	428
6	ECW-14 *	11.17.24.432	1100
7	RWP-32 *	12.16. 7.331	632
8	16T-567 *	12.18.28.434	254
9	RWP-28 +	11.16. 8.131	971
10	RWP29 +	12.16.30.242	575
11	ECW-16 +	12 17 15.213	446
12	Z-7R +	12.17 32 323	342

WELL COMPLETED IN.

* Gallup Sandstone

\+ Crevasse Canyon Formation

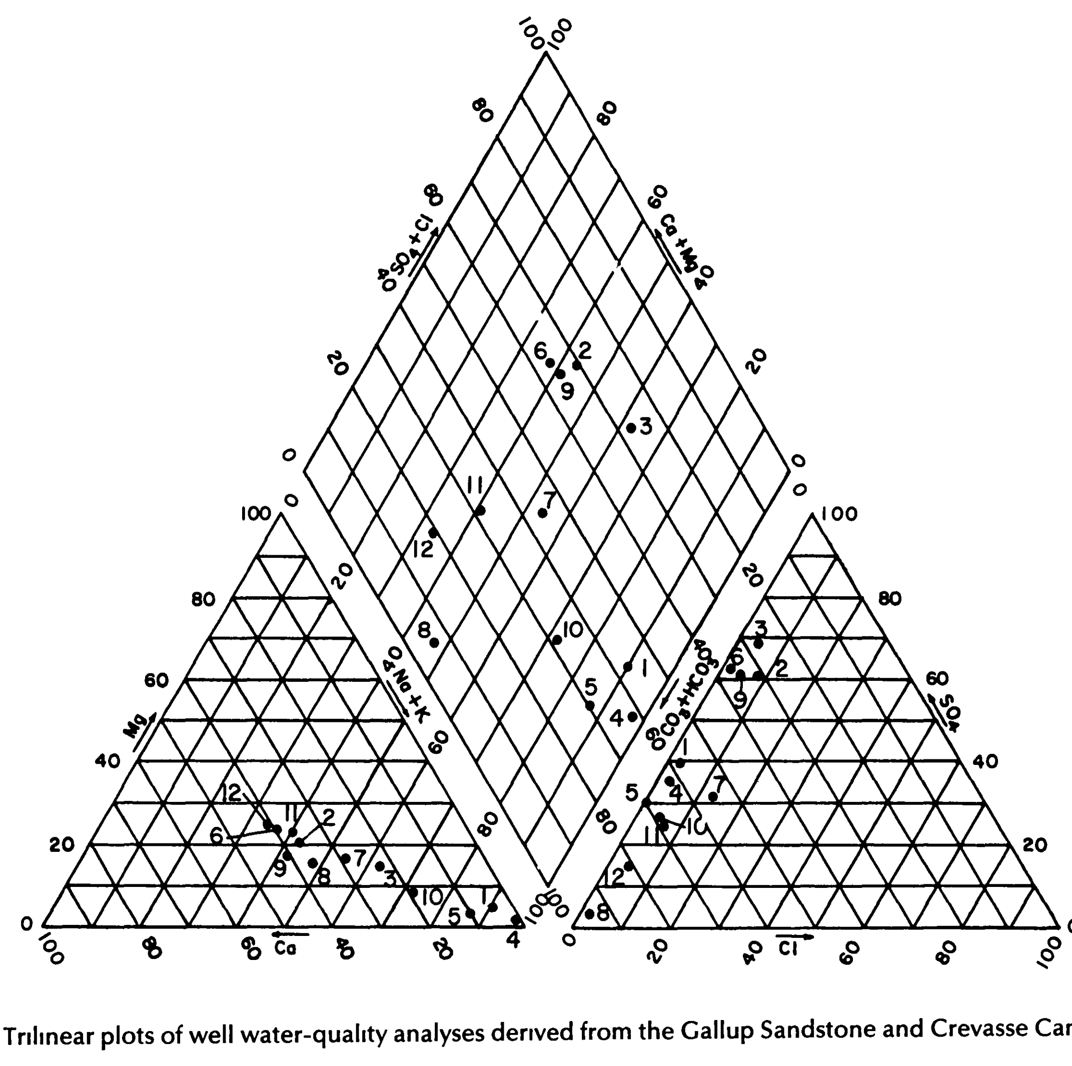
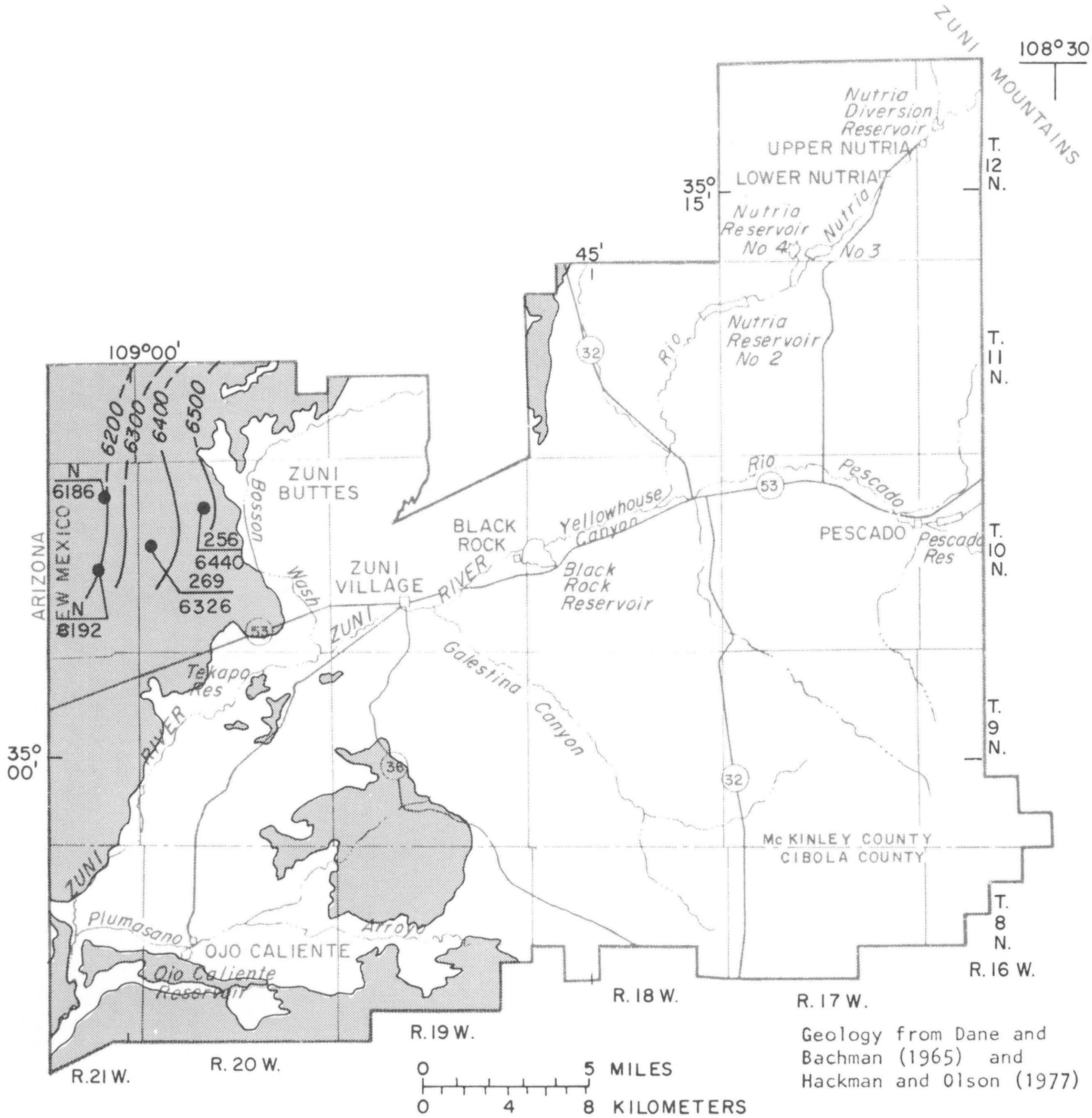


Figure 15. Trilinear plots of well water-quality analyses derived from the Gallup Sandstone and Crevasse Canyon Formation



EXPLANATION

AREA OF OUTCROP OF THE BIDAHOCHI FORMATION AND OVERLYING EOLIAN DEPOSITS.

—6200— WATER TABLE CONTOUR OF THE BIDAHOCHI AQUIFER--Dashed where approximate. Contour interval 100 feet. Datum is sea level.

269/6326 WELL--Top number is dissolved-solids concentration of water, in milligrams per liter. Bottom number is the altitude of the water level, in feet above sea level. N = no dissolved-solids concentration reported.

Figure 16. Water-table contours (September 1979) and outcrop area of the Bidahochi Formation.

altitude of the water table, and saturated thicknesses may be minimal or nonexistent over these ridges

From 25 to 50 feet of saturated Bidahochi sediments are penetrated in most of the wells across the western side of the study area (table 2) The Winter Cattle well (11 21 23 000) was drilled to a total depth of 650 feet before it was abandoned as a dry hole Irrigation well 1 (10 20 18 314) penetrates 204 feet of Quaternary alluvium and Bidahochi that overlie Triassic bedrock The saturated thickness in Irrigation well 1 is 25 feet, in 1939, the well reportedly yielded 44 gallons per minute with no measurable drawdown (table 2) This well probably is completed in transmissive sands and gravels that fill a buried channel at that site Yields from other wells completed in the Bidahochi in the area range from 3 to 15 gallons per minute Yields, specific capacities, and transmissivities may be expected to vary greatly from location to location depending upon the orientation of the buried drainage system, the saturated thickness, and the type of material (sand, gravel, silt, or clay) penetrated

A preliminary 1-mile seismic-reflection survey was conducted in July 1979 by Charles B Reynolds and Associates (written commun , 1979) under contract with the U S Geological Survey The purpose of this survey was to determine whether seismic-reflection techniques could be used to locate buried channels in the Bidahochi in future ground-water investigations. The survey was conducted north from well RWP–30 (10 21 11 221) and indicated the existence of an irregular buried surface thought to be Triassic bedrock that was traversed by erosional channels

Seismic data indicate that the topographic relief of the buried Triassic surface is approximately 200 feet (fig 17) As much as 550 feet of Tertiary and younger deposits overlie buried channels along the seismic line, and as much as 300 feet of these deposits cover buried ridges This seismic technique appears to be effective in locating the buried channels, which presumably contain thicker saturated sections of Bidahochi sands and gravels. However, test drilling is needed to confirm the reliability of this technique and to further evaluate the potential water supply available in the Bidahochi Formation

The Bidahochi aquifer typically produces water enriched with calcium and bicarbonate, as indicated by trilinear plots of three analyses from wells (fig 18) Dissolved-solids concentrations were small, ranging from 256 to 269 milligrams per liter, calcium ranged in concentration from 53 to 64 milligrams per liter, and bicarbonate ranged in concentration from 117 to 143 milligrams per liter (table 3) Other dissolved constituents included magnesium, sodium, chloride, and sulfate

The predominant sand and gravel stratigraphy of the Bidahochi Formation has a direct effect on the quality of water from the Bidahochi Larger hydraulic conductivities prevent the buildup of large concentrations of dissolved material by decreasing the travel time from the point of recharge The concentrations of the predominant constituents, calcium and bicarbonate, probably are derived from the calcium carbonate that loosely cements the Bidahochi Formation

Alluvial Aquifers

Alluvial deposits in the study area primarily are limited to the main drainageways, such as the Rio Nutria, Rio Pescado, and Zuni River, and to smaller tributary drainages (fig 19) Recharge to the alluvium is derived from stream runoff and direct precipitation Additional inflow comes from ground-water flow from aquifers incised by the alluvium-filled channels

Water in alluvium moves in the same general direction as surface flow and is under water-table conditions, except for the buried channel deposits along the Rio Pescado Because these saturated sands apparently are confined by overlying sediments, water levels in wells rise above the zone of saturation

Natural discharge from the alluvium takes place from springs and seeps along the channel bottoms of the Zuni River, Rio Nutria, and Rio Pescado This flow either reinfiltrates within a short distance downstream or is lost to evaporation Phreatophytic vegetation along the stream channels removes additional water from the alluvium through transpiration Other discharge takes place in the form of spring diversions at Pescado and Black Rock and pumpage from domestic wells

Water levels in wells completed in alluvium generally are between 5 and 40 feet below land surface (table 2) Most wells completed in the alluvium are dug wells, and the total depths of these wells are only a few feet below the water table Yields from these wells generally are less than 10 gallons per minute

Two large springs, referred to locally as the Upper Pescado Spring (10 17 12 442) and the Lower Pescado Spring (10 17 12 431), have long provided water for the Zuni Tribe at Pescado Village Water from the springs flows from saturated alluvium underlying the basalt flow along the Rio Pescado valley

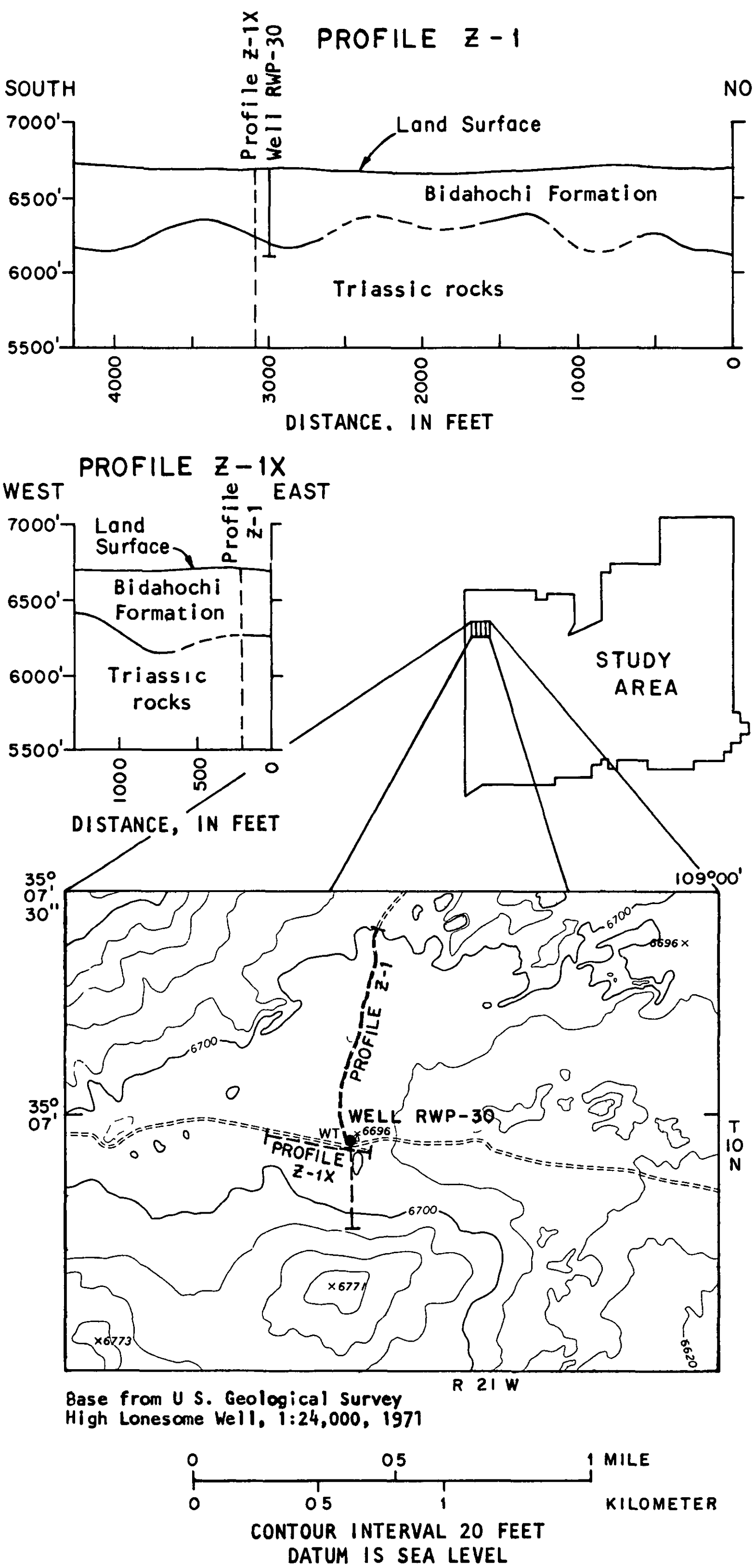
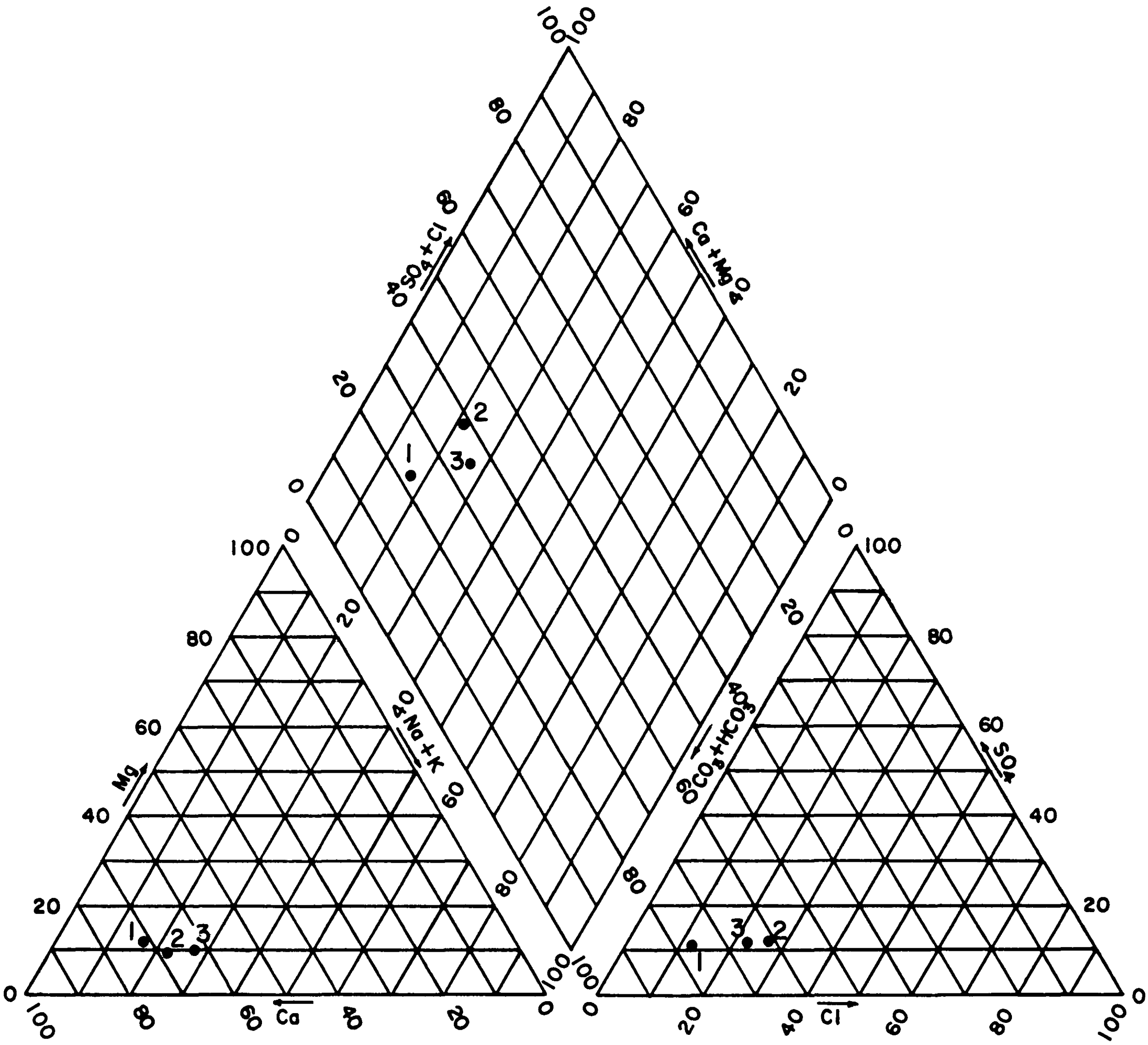
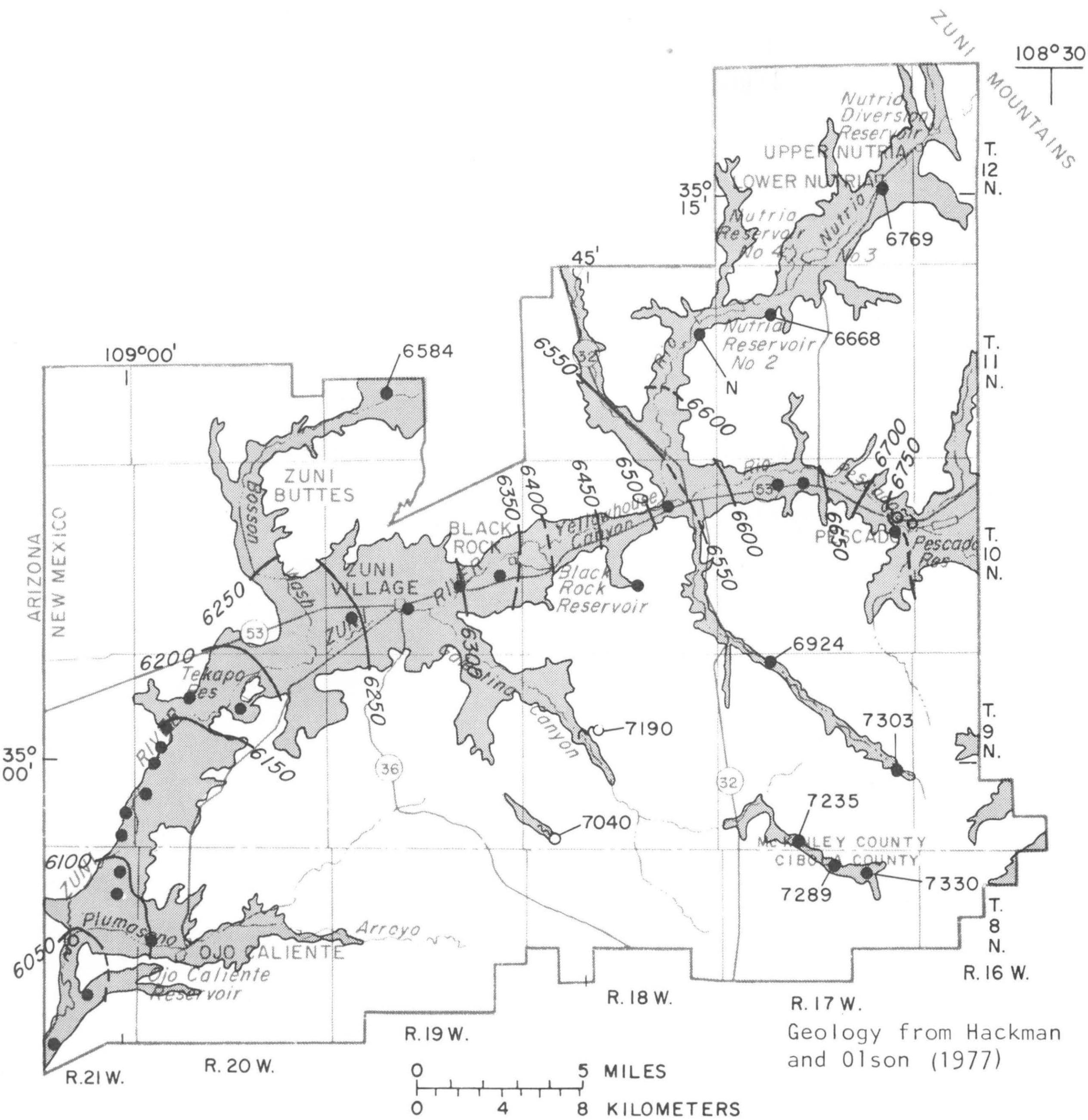


Figure 17. Seismic profiles of the pre-Tertiary buried surface underlying the Bidahochi Formation, North Purchase Area



Number on figure	Well name	Location number	Dissolved-solids concentration, in milligrams per liter
1	RWP-27	10.20. 8.243	256
2	Irrigation 1	10.20.18.314	269
3	do.	do.	263

Figure 18. Trilinear plots of well water-quality analyses derived from the Bidahochi Formation.



EXPLANATION

AREA OF DISTRIBUTION OF ALLUVIUM

6050 — — WATER-TABLE CONTOUR IN ALLUVIUM--Dashed where approximate. Contour interval 50 feet. Datum is sea level.

7235 ● WELL
7190 ○ SPRING
--Number is the altitude of water table, in feet above sea level. N = no water level reported. Some altitudes omitted to prevent crowding. See table 2 for altitudes.

Figure 19. Water-table contours and distribution of channel alluvium.

Development of the upper spring has included the construction of a rectangular stone-masonry reservoir, headgates, and a ditch-distribution system The lower spring has been developed by the construction of an earthen dike, rock retaining wall, and headgate. Recently, both springs have been made part of a pipeline-distribution system that ultimately discharges to the Rio Pescado upstream from a concrete irrigation-diversion structure

A series of periodic discharge measurements have been made at the Pescado Springs since 1978 in order to determine the volume and the variability of flow (fig 20) Measurements shown in figure 20 represent the flow from both springs Measured discharges ranged from 0 87 cubic foot per second on December 4, 1979, to 1.60 cubic feet per second on February 25, 1980 The average discharge for this period was approximately 1 1 cubic feet per second, or 500 gallons per minute, for a total annual flow of approximately 800 acre-feet Irrigation return flow and overflow from the diversion on the Rio Pescado infiltrate to the channel alluvium or are lost to evaporation Some variability in discharge throughout the year is due to changes in water levels within the spring reservoirs Fluctuations may be attributed, in part, to runoff across the recharge areas. Changes in storage in nearby Pescado Reservoir also may have some effect on spring discharge.

Alluvial seepage of perhaps 200 to 300 gallons per minute has been partly developed for community use at Black Rock This seepage emerges from buried channel deposits exposed where an arroyo has been incised around the north side of the Pescado basalt flow A collection gallery known locally as the "spring house" (10 19 13 224) has been constructed in the arroyo channel Water from the spring house is pumped to Black Rock, where it is mixed with more mineralized water from the two wells completed in the Glorieta-San Andres aquifer (PHS well and Black Rock well 3)

The concentrations of dissolved solids in water from alluvial aquifers ranged from 207 to 2,940 milligrams per liter (table 3) Major cations were calcium, ranging in concentration from 34 to 500 milligrams per liter, magnesium, from 2.4 to 560 milligrams per liter; and sodium, from 22 to 1,000 milligrams per liter Major anions were bicarbonate, ranging in concentration from 79 to 540 milligrams per liter, chloride, from 18 to 1,100 milligrams per liter, and sulfate, from 3 4 to 2,200 milligrams per liter. Nitrate concentrations ranged from 0 31 to 86 milligrams per liter

No distinctive chemical composition of water is indicated by water-quality analyses from wells completed in alluvium within the study area, however, local water-quality similarities exist as a result of geohydrologic conditions The similarities are shown on trilinear plots of chemical analyses (fig 21) Alluvial wells in upland tributary canyons produce water with large concentrations of calcium, sodium, and sulfate In the buried channel deposits of the Rio Pescado, water has a small dissolved-solids concentration Major ions are calcium and bicarbonate In alluvial wells near Zuni Village, water has large concentrations of sodium and chloride The predominant ions in the water along the downstream reaches of the Zuni River typically are calcium, sodium, and sulfate.

Water-quality variations in different alluvial wells and springs are the result of several factors, including the lithology of alluvium, the source of recharge to the alluvium, and the potential for surface contamination. Clay minerals within the alluvium enhance the ion-exchange process, increasing dissolved sodium in the water and decreasing some of the divalent cations (calcium, magnesium, and iron) Salts that accumulate in the soil from evaporation and transpiration are flushed into the alluvial aquifer by periodic flooding, increasing the dissolved-chloride and dissolved-solids concentrations Inflow to the alluvium from adjacent aquifers locally increases the dissolved constituents found in those waters Finally, the quality of water in shallow alluvial wells in the Zuni River valley is more easily affected by surface processes such as flooding, waste-disposal contamination, and seasonal fluctuations in precipitation

The susceptibility of alluvial water to surface contamination and the limited extent of alluvial aquifers in the Zuni study area preclude extensive use of this water resource If it becomes necessary to further evaluate the availability and quality of water in the alluvium, test wells could be drilled in the Zuni River valley southwest of Zuni Village and in the buried channel deposits along the Rio Pescado

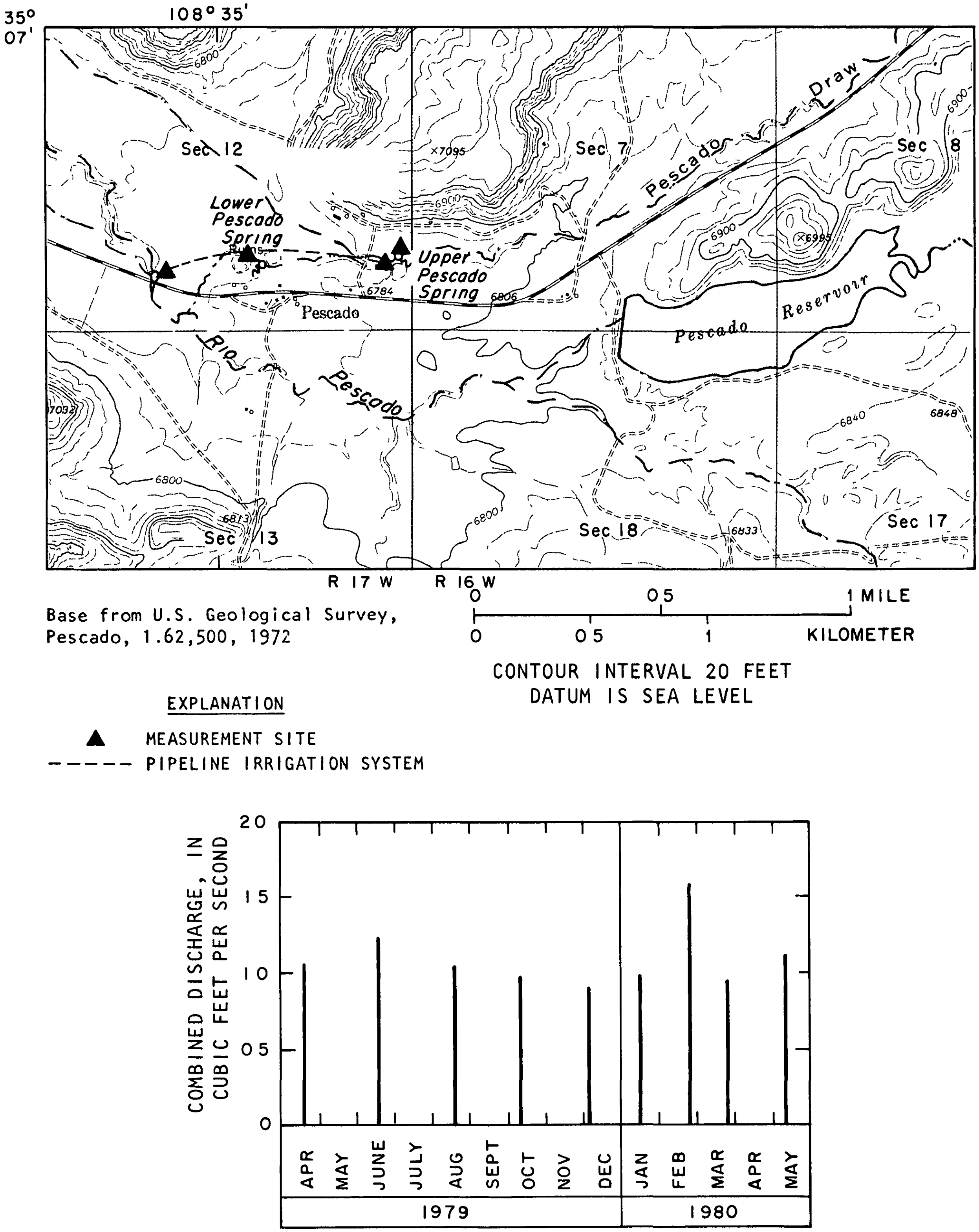


Figure 20. Location and combined discharge of springs near Pescado

Number on figure	Well or spring name	Location number	Dissolved-solids concentration, in milligrams per liter
1	RWP-31	8.21.12.312	1821
2	ECW-20	8.21.26.321	1143
3	ECW-19	9.17. 5.112	2290
4	Stock well	9.17.33.324	2940
5	Spring catchment	9.18.16.242	218
6	A-1	9.20. 8.223	1850
7	Pablito Chavez	9.20.18.434	457
8	Romancito	9.21.25.433	695
9	Lower Pescado Spring	10.17.12.431	319
10	Upper Pescado Spring	10.17.12.442	300

Number on figure	Well or spring name	Location number	Dissolved-solids concentration, in milligrams per liter
11	Fidel Chahate	10.17.12.433	370
12	Yellowhouse test hole 7	10.18.11.143	570
13	Black Rock Spring	10.19.13.224	252
14	do	do	293
15	Black Rock 1	10.19.24.122a	454
16	St. Anthony Mission	10.19.28.114	2899
17	Nastacio	10.19.30.232	541
18	Hand pump well	12.17.23.244	1098
19	Cheechilgeetho	12.20.25.123	207

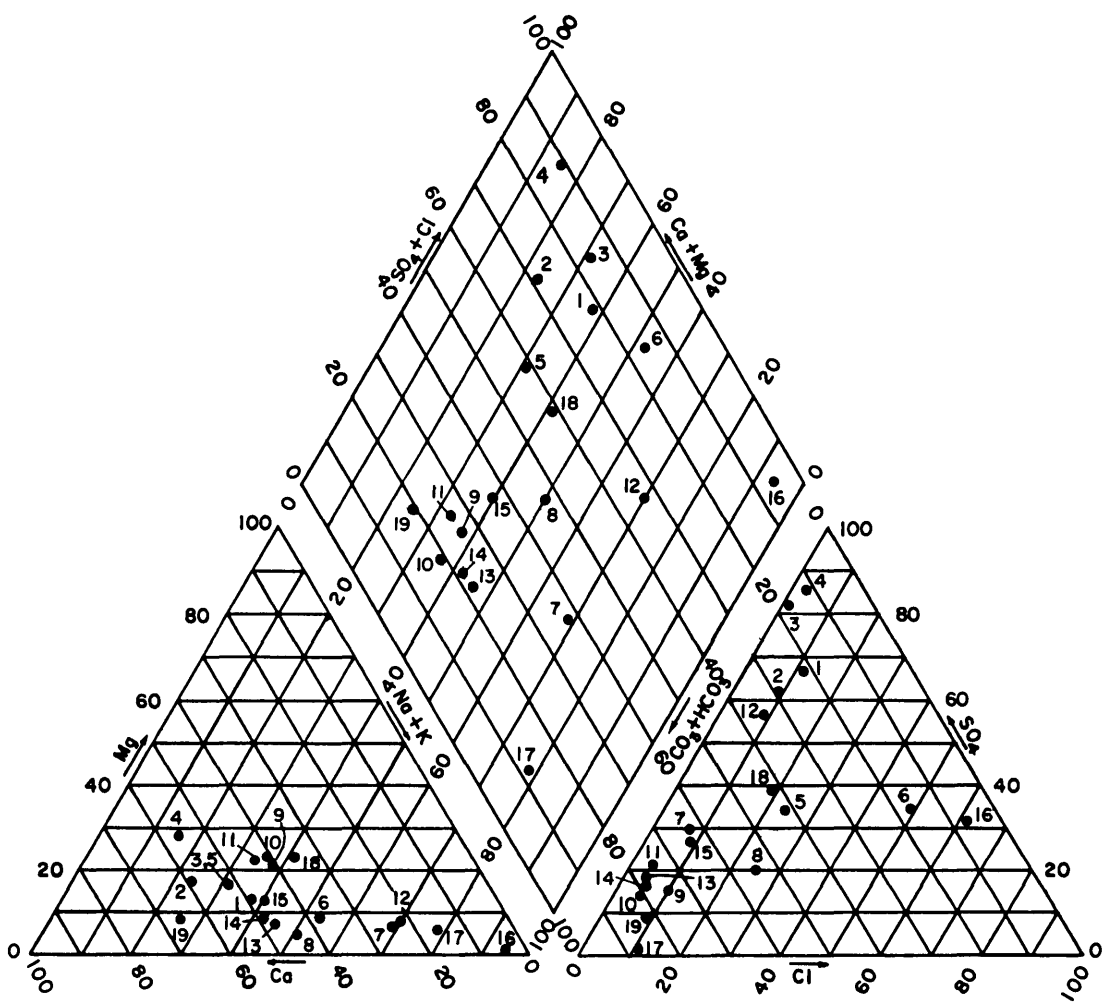


Figure 21. Trilinear plots of well and spring water-quality analyses derived from alluvial aquifers

HYDROLOGY OF SURFACE-WATER SYSTEMS

The Zuni River and Tributaries

The Zuni River and its tributaries contribute surface-water runoff to the Colorado River drainage system of east-central Arizona and west-central New Mexico The total drainage area for the Zuni River upstream from where it leaves the study area at the New Mexico–Arizona State line is about 1,300 square miles (fig 22) This area consists of the Zuni River headwaters on the southwestern flanks of the Zuni Mountains, the northern one-half of the Ramah Navajo tribal lands, and most of the Zuni tribal lands Approximately 100 square miles of the Zuni basin near El Morro is a closed drainage system and does not contribute surface flow to the Zuni River (fig 22). The Zuni River drainage basin is bounded on the north by the Puerco River watershed, on the east by the Continental Divide, and on the south by the headwaters of the Little Colorado River

The Zuni River begins at the confluence of the Rio Pescado and the Rio Nutria, 4½ miles upstream from Black Rock Village, flows to the southwest, passing through Zuni Village, and flows out of New Mexico in the extreme southwestern corner of Zuni tribal lands The Zuni River flows across east-central Arizona to join the Little Colorado River approximately 13 miles northwest of Concho, Arizona.

The Zuni River, the Rio Pescado, and the Rio Nutria flow intermittently in the study area, except for short reaches that flow perennially in response to discharge from springs. Periods of sustained flow commonly occur during spring runoff, and sporadic flows occur in response to summer rainfall Other tributary arroyos to the Zuni River flow only in response to intense, localized rainfall

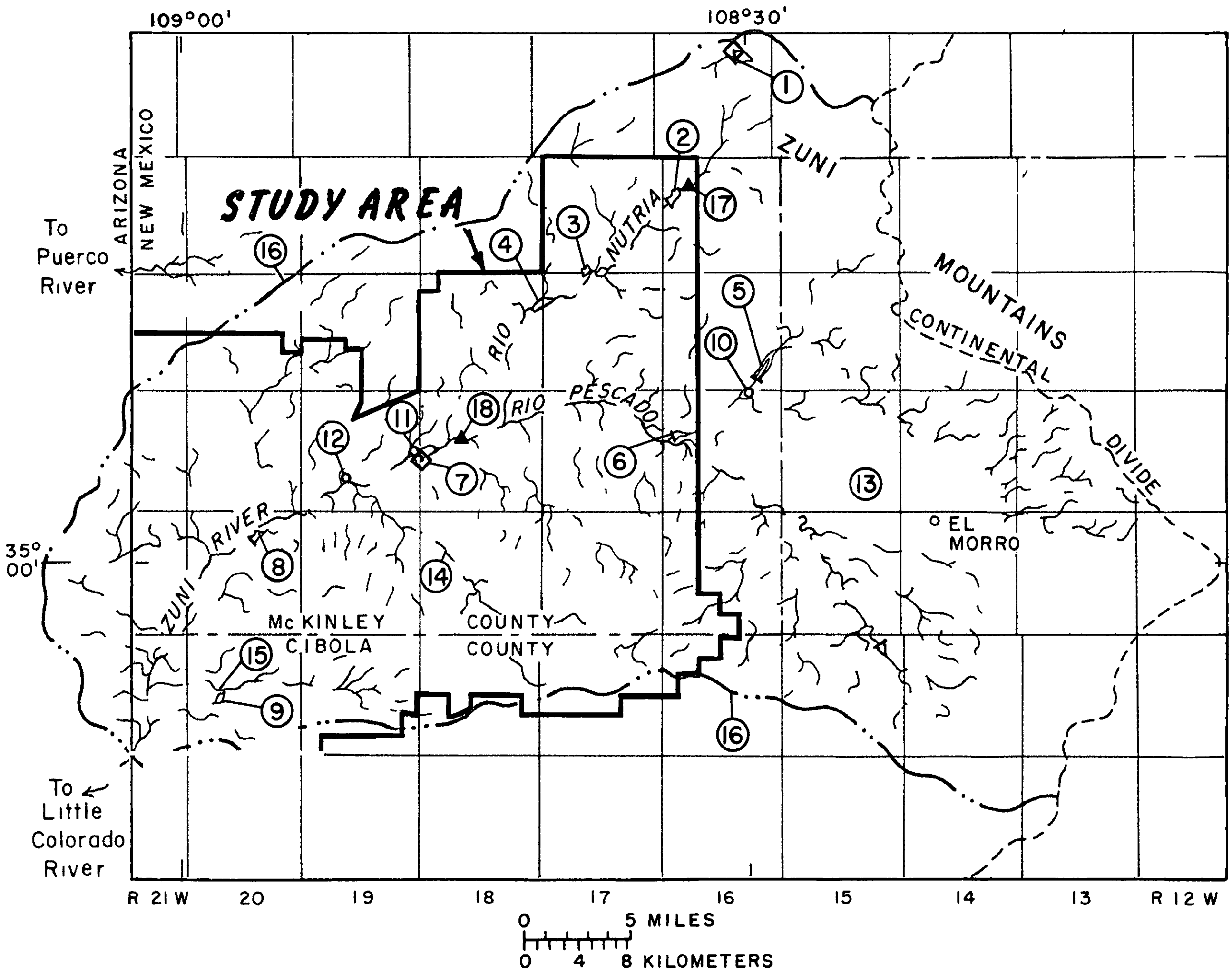
Stream discharge from the Zuni River and tributaries varies greatly because of annual and seasonal fluctuations in the distribution of precipitation A series of small- to medium-sized dams have been constructed in order to better use the surface-water supply and to provide some protection from floods Dams are located near the villages of Nutria, Pescado, Black Rock, Zuni, and Ojo Caliente, and at the upper end of Galestina Canyon (fig 22). Several structures not in the study area, including McGaffey and Ramah Dams (fig. 22), help to control the runoff of the Zuni River and its tributaries

Availability and Quality of Surface Water

Stream-runoff data were collected for the Zuni River at Black Rock during 1903–05 and 1908–30 These records consist of the total yearly runoff in acre-feet for 1903–05 and 1908–10 and total monthly runoff in acre-feet and cubic feet per second for 1911–30 measured at Black Rock Reservoir (U S Geological Survey, 1954, p 532) Runoff volumes into Black Rock Reservoir for these periods of record were calculated by adding or subtracting the appropriate change in reservoir storage to measured releases from Black Rock Reservoir Evaporation losses from the reservoir surface were not considered Daily and monthly stream-discharge records have been collected by the U S Geological Survey from October 1969 to the present (1981) at a streamflow-gaging station on the Rio Nutria near Ramah (09386900) and at a streamflow-gaging station on the Zuni River 2 miles upstream from Black Rock Reservoir (09386950) (fig 22). The Rio Nutria gage monitors discharge from a total drainage area of 71 4 square miles in the Zuni Mountains, and the Zuni River gage monitors discharge from a total area of 810 square miles The drainage area monitored by the earlier reservoir gage at Black Rock (through 1930) was 5 8 square miles larger than that monitored by the present gage

Total monthly discharges into Black Rock Reservoir from 1911 to 1930 were used to calculate average monthly discharges for the Zuni River for the period of record (fig 23) at the Black Rock gage During this period, spring runoff normally began in February and ended in May Runoff from summer storms began in July and ended in October, peaking in July Runoff during the remaining months was minimal The average runoff for the Zuni River at Black Rock during this period was about 26 cubic feet per second or 19,000 acre-feet per year The mean monthly discharges on the Zuni River at Black Rock for 1911–30 are significantly weighted by several years of extreme flow, as is indicated by a comparison between the mean and median monthly discharges (fig 23)

Mean monthly flow for the Zuni River above Black Rock from October 1969 to September 1979 (U S Geological Survey, 1969–79) is shown in figure 23 Flow past the gage during this period occurred primarily during the spring snowmelt runoff and during late summer thunderstorms For the period of record, runoff varied erratically from year to year



EXPLANATION

◇ U.S. WEATHER BUREAU STATION
(1) McGAFFEY RESERVOIR
(2) NUTRIA DIVERSION DAM
(3) NUTRIA RESERVOIRS 3 AND 4
(4) NUTRIA RESERVOIR 2
(5) RAMAH RESERVOIR
(6) PESCADO RESERVOIR
(7) BLACK ROCK RESERVOIR
(8) TEKAPO RESERVOIR
(9) OJO CALIENTE RESERVOIR
(10) RAMAH VILLAGE
(11) BLACK ROCK VILLAGE
(12) ZUNI VILLAGE
(13) CLOSED DRAINAGE AREA
(14) GALESTINA CANYON
(15) PLUMASANO ARROYO
(16) BOUNDARY OF THE ZUNI RIVER DRAINAGE BASIN UPSTREAM FROM THE NEW MEXICO-ARIZONA STATE LINE
(17) U.S. GEOLOGICAL SURVEY STREAMFLOW-GAGING STATION 09386900 (RIO NUTRIA NEAR RAMAH, NEW MEXICO)
(18) U.S. GEOLOGICAL SURVEY STREAMFLOW-GAGING STATION 09386950 (ZUNI RIVER ABOVE BLACK ROCK, NEW MEXICO)

Figure 22. Zuni River drainage basin upstream from the New Mexico-Arizona State line.

Mean monthly discharges for the Zuni River above Black Rock for 1969–79 indicate the distribution of surface-water runoff (fig 23) However, the mean monthly discharge is based upon such a short period of record that it may not reflect long-term trends. Spring runoff normally began in February and ended in May, with a peak in April. Late summer runoff began in July and ended in October, with a peak in August Frequent and extended no-flow periods occurred in other months The average flow for the Zuni River above Black Rock for October 1969 to September 1979 was about 11 cubic feet per second or about 8,000 acre-feet per year, 11,000 acre-feet per year less than for 1911–30 The mean monthly values are again significantly weighted by several periods of extreme flows, as indicated by a comparison between mean and median discharges (fig 23)

The construction of reservoirs on Zuni River tributaries (table 4) probably accounts for much of the decrease in flow in the Zuni River at Black Rock between 1911–30 and 1969–79 The completion of reservoirs, including the Nutria and Pescado Reservoirs in the 1930's, Ramah Reservoir in 1936, and many smaller flood- and erosion-control structures built since then, has increased the capacity for upstream storage and corresponding losses to evaporation and seepage Evaporation losses from reservoirs in the Zuni study area total approximately 54 inches per year (Kohler, Norderson, and Baker, 1959, pl 2), the greatest losses (73 percent) take place from May to September. The surface area of reservoirs upstream from Black Rock Reservoir totals approximately 1,400 acres (table 4) With an average evaporation rate of 54 inches per year, this area would account for an annual evaporation loss of more than 6,300 acre-feet from these reservoirs Because these reservoirs are not filled to capacity throughout the year, this value probably is a maximum

The 1,400 acres of reservoir surface area upstream from Black Rock Reservoir include approximately 900 acres within the study area Downstream, Black Rock Reservoir, Bolton, Eustace, Tekapo, and

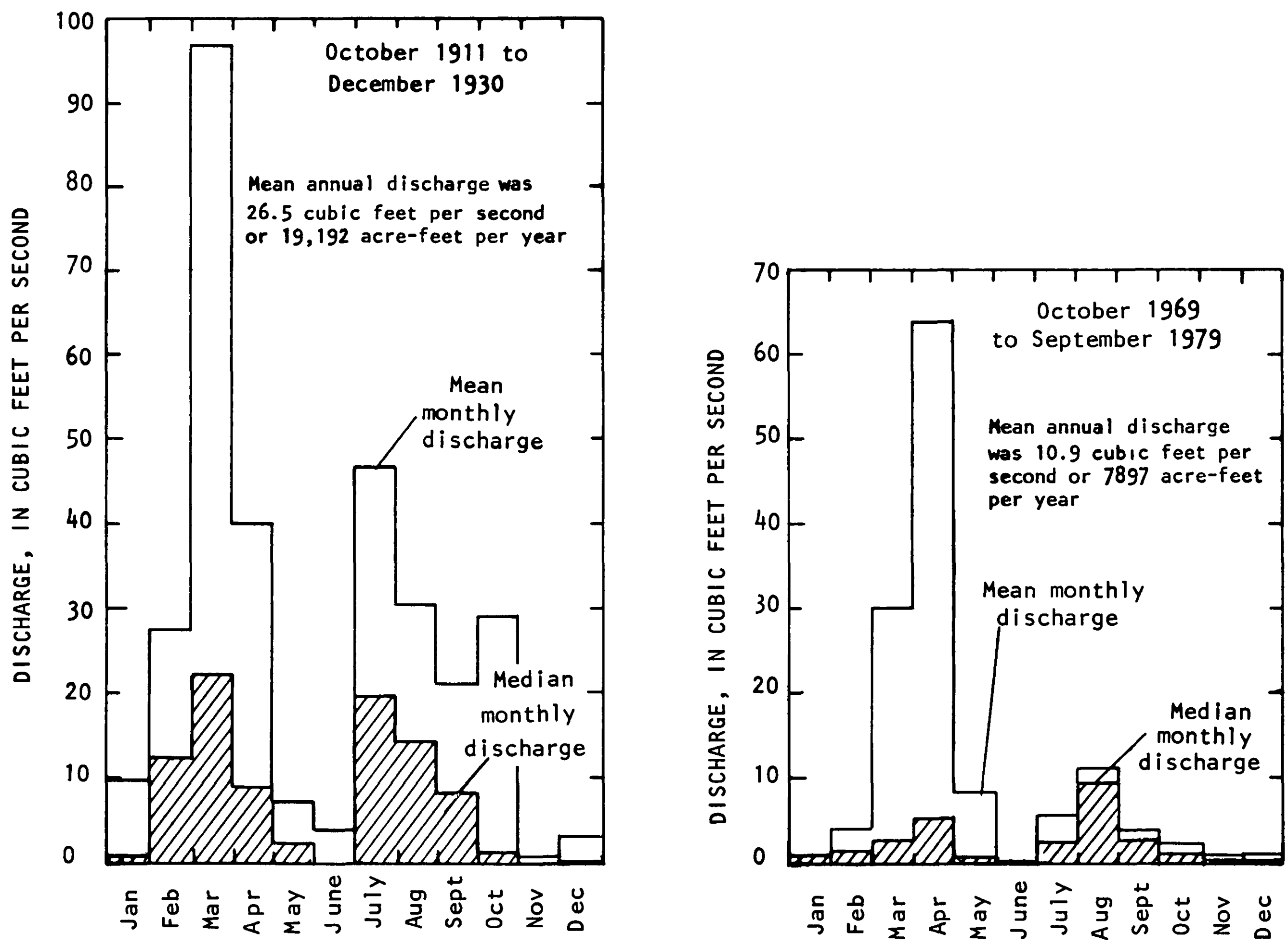


Figure 23. Mean and median monthly discharge of the Zuni River near Black Rock, 1911–30 and 1969–79 water years

Ojo Caliente Reservoirs add an additional 630 acres of surface area within the study area, for a total of approximately 1,500 acres. Based on an annual evaporation rate of 54 inches, approximately 6,800 acre-feet of water are lost to evaporation each year from the reservoirs within the study area Again, this volume probably is an overestimate because it is calculated assuming that each reservoir is full year-round However, the calculation does not take into account the surface area of the smaller erosion- and flood-control reservoirs, some of which contain water year-round (Galestina reservoirs) and others which hold water for short intervals in response to floods. Evaporation losses from the combined on- and off-tribal land storage facilities (approximately 2,000 acres of surface area) could be as much as 9,000 acre-feet annually

Seepage through reservoirs increases recharge to aquifers in the study area This seepage may also contribute to a decrease in flow in the Zuni River

Decreases in precipitation probably had a less significant effect on runoff than did evaporation losses Long-term records of precipitation are available for McGaffey Ranger Station (McGaffey 4 SE), located on the northern headwaters of the Rio Nutria, and for Black Rock (Zuni Federal Aeronautics Administration Station), located at the downstream end of the drainage area monitored by the gaging station above Black Rock Reservoir (fig. 24) For 1911–30, excluding 1914 and 1915 when no data were available, the mean annual precipitation at McGaffey was 17 26 inches with a median value of 16 60 inches For 1969–79, the mean annual precipitation at McGaffey was 17.17 inches with a median value of 16.88 inches At Black Rock during 1911–30, the mean annual precipitation was 12 33 inches with a median value of 12.60 inches. At Black Rock during 1969–79, excluding 1974 when no data were available, the mean annual precipitation was 11 95 inches with a median value of 11 72 inches The mean annual precipitation for 1911–30 was 0 09 inch greater at McGaffey and 0.38 inch greater at Black Rock than for 1969–79 This decrease in the mean annual precipitation probably is not sufficient to explain a decrease of 59 percent in the mean annual discharge for the Zuni River above Black Rock for these two periods of record

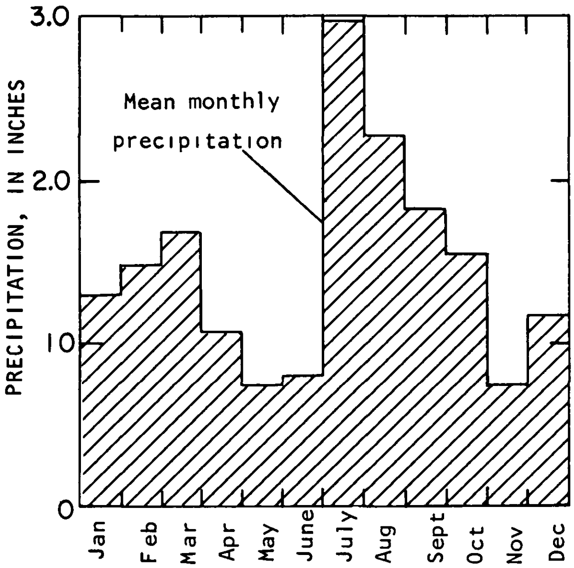
Shifts in seasonal precipitation also may account for minor changes in discharge between the two periods Precipitation data are tabulated for the water year (October–September) and for the cooler winter months (November–March) for McGaffey and Black Rock for 1911–30 and 1969–79 (fig 24). The average percentages of annual precipitation in winter at McGaffey were 36 percent for 1911–30 and 41 percent for 1969–79. The average percentages of annual precipitation in winter at Black Rock were 30 percent for 1911–30 and 36 percent for 1969–79 These trends toward increased precipitation during the winter could decrease surface flow by sublimation losses of winter snowpack

In summary, evaporation losses and seepage into ground-water systems from reservoirs probably account for much of the decrease in Zuni River discharge Less significant factors in this decrease include differences in the average annual precipitation rates and changes in the seasonal distribution of precipitation for the two periods of record

Average monthly discharges at the Rio Nutria gage are shown for October 1969 to October 1979 (fig 25) Base flow at this station is sustained almost continuously by discharge from a spring of the Glorieta-San Andres aquifer in the vicinity of the gage A period of high flow from snowmelt runoff normally begins in February and ends in May, with a peak in April Late summer rainfall does not significantly affect the flow pattern at this gage, partly because of the small drainage area and the relatively dense vegetative cover.

Four water samples were collected from the Zuni River upstream from Black Rock Reservoir from November 1979 to February 1980 (table 5) The first two samples were collected at low flow on the recessions of small winter flows The second two samples were collected during periods of high flow that resulted from the spring snowmelt runoff. The concentrations of dissolved solids for the samples taken during low flow were 426 and 517 milligrams per liter The concentrations of dissolved solids in the samples taken during high flows were 178 and 180 milligrams per liter

The smaller concentrations of dissolved constituents in the high-flow waters possibly can be attributed to the relationship between quality of the flow component from bank storage and the quality of the flow component from direct runoff Bank-storage water is water that is absorbed during periods of higher flow by the permeable sands and gravels adjacent to the stream channel. As flow decreases, this water begins to move back toward the stream to be discharged from bank storage Water in bank storage has had the opportunity to dissolve material from the alluvium and has a greater concentration of dissolved solids The direct-runoff component of flow represents water derived directly from precipitation or snowmelt This water has not had the opportunity to dissolve much soluble material As the direct-runoff



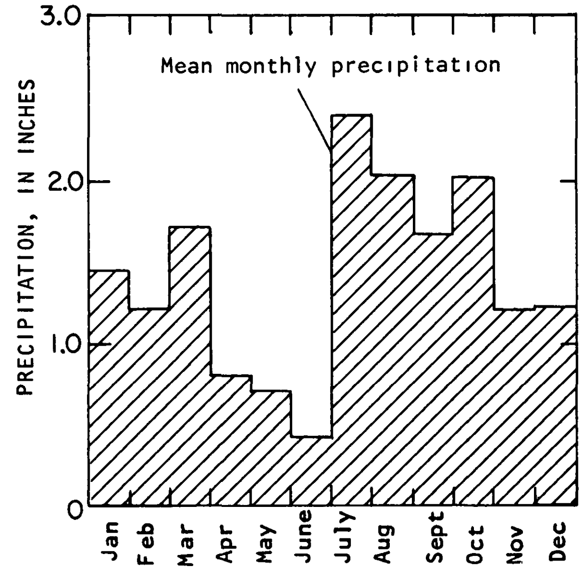
McGAFFEY RANGER STATION (1911-30)

Mean annual precipitation

Calendar year . . .. .17.26 inches
Water year (October-September) .17 40 inches

Mean winter (November-March) precipitation

Total .. .. .6.22 inches
As percentage of mean
water-year precipitation . .... 36 percent



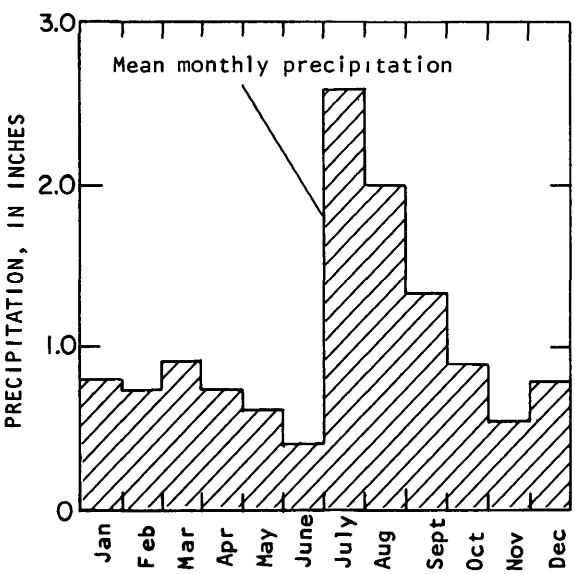
McGAFFEY RANGER STATION (1969-79)

Mean annual precipitation

Calendar year .. .. 17 17 inches
Water year (October-September).... 16.65 inches

Mean winter (November-March) precipitation:

Total .... 6.91 inches
As percentage of mean
water-year precipitation ....40.7 percent



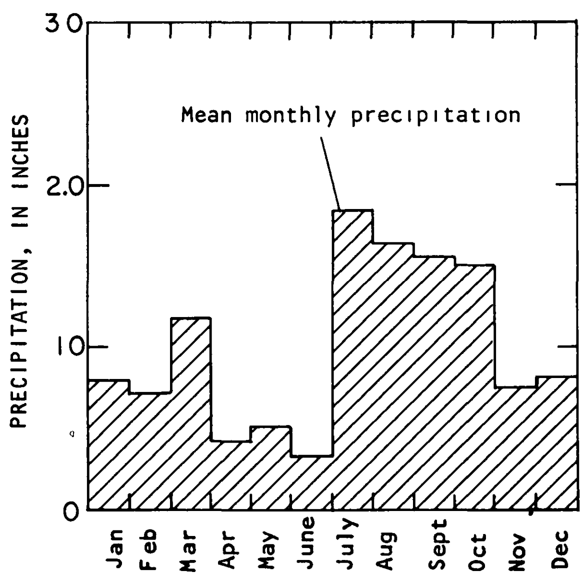
BLACK ROCK (1911-30)

Mean annual precipitation

Calendar year . ...12 33 inches
Water year (October-September). 12 76 inches

Mean winter (November-March) precipitation

Total .. . . 3 88 inches
As percentage of mean
water-year precipitation ....30 percent



BLACK ROCK (1969-79)

Mean annual precipitation

Calendar year . 11 95 inches
Water year (October-September) 12 20 inches

Mean winter (November-March) precipitation

Total .. . ..4 40 inches
As percentage of mean
water-year precipitation . 36 percent

Figure 24. Mean monthly, calendar-year, and water-year precipitation for weather stations at McGaffey and Black Rock, 1911-30 and 1969-79

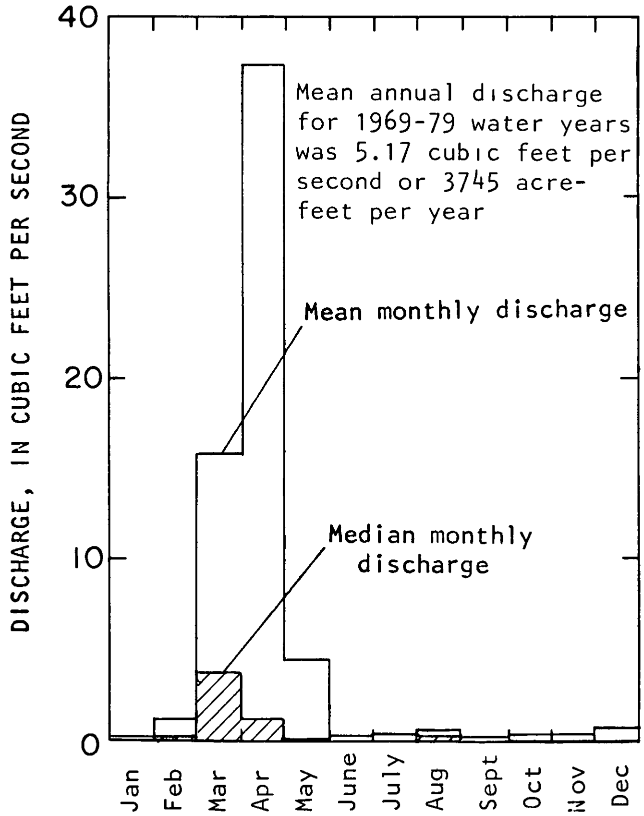


Figure 25. Mean and median monthly discharge of the Rio Nutria, 1969–79 water years.

component increases during a flow, the hydraulic head in the stream increases, decreasing or even reversing the flow gradient from bank storage As this occurs, the bank-storage component is decreased or eliminated, decreasing the dissolved-solids concentration in runoff Conversely, on the flow recession, the bank-storage water begins to move back toward the stream where it mixes with the surface flow The water becomes more mineralized as the flow recession continues This relationship between the volume of discharge and the dissolved-solids concentration appears to be true for the Zuni River and its tributaries However, more water samples taken at different discharge rates need to be collected and analyzed in order to more accurately determine the relationship between runoff and water quality

Reservoir water is derived primarily from high-flow runoff (table 5) Water losses from evaporation on the reservoir surfaces concentrate dissolved solids in the reservoir water, and the water quality can be expected to deteriorate somewhat from the less mineralized inflow resulting from periods of high runoff.

Reaches of the Rio Pescado, Rio Nutria, and Zuni River flow perennially in response to discharge from springs Concentrations of dissolved material along these reaches during low flows reflect the water chemistry of the aquifers supplying these springs (table 3) The water quality of Ojo Caliente Reservoir also reflects ground-water quality because the reservoir principally is supplied by spring flow

Sediment transported by the Zuni River and its tributaries has had a significant effect on the availability of the surface-water supply. Black Rock Reservoir had an original storage capacity of 15,800 acre-feet in 1908 By 1944, the storage capacity had been decreased by sedimentation to 2,600 acre-feet (U S. Geological Survey, 1954, p 532) Much of this sediment accumulation may have occurred during a few years of significant precipitation and runoff, but no sediment-load data are available to support this possibility An additional 15,000 acre-feet of storage capacity had been lost within the same time period in reservoirs upstream from Black Rock Reservoir as a result of sedimentation and flood damage

Sediment-load data have been collected at the Zuni River streamflow gage above Black Rock since October 1979. These data and the discharges at the time of sample collection are shown in table 5 Sediment loads range from 25 milligrams per liter at a discharge of 0 85 cubic foot per second (November 7, 1979) to 2,090 milligrams per liter at a discharge of 441 cubic feet per second (April 18, 1980) Available sediment-load data on the Zuni River indicate that greater discharges carry more sediment per unit volume Additional information would be useful, including the distribution of sediment load during flood peaks and subsequent flow recessions, in order to better define the relationship between runoff and sediment load

SUMMARY

Major structural features in the Gallup embayment, such as the Nutria monocline, Allison syncline, Piñon Springs anticline, and Ojo Caliente anticline, affect regional hydrologic systems. Recharge areas, aquifer permeability, directions of ground-water flow, and points of subregional and regional discharge are significantly controlled by these features

Ground-water supplies for the Zuni Tribe are derived primarily from six aquifer systems, ranging in age from Permian to Quaternary These aquifer systems are the Glorieta-San Andres aquifer, sandstones within the Chinle Formation, the Zuni-Dakota aquifer, the water-bearing sandstones of the Gallup Sandstone and Crevasse Canyon Formation, the Bidahochi Formation, and alluvial deposits along river channels

The Glorieta-San Andres aquifer consists of as much as 300 feet of Permian sandstone and limestone. It is exposed on the southwestern flanks of the Zuni Mountains and near Ojo Caliente.

Recharge to the Glorieta-San Andres aquifer takes place along the southwestern flanks of the Zuni Mountains and across the basalt-covered subcrop in the North Plains to the east. Water moves under artesian conditions through fractures and solution channels in a west and northwest direction across the study area. Springs at Ojo Caliente, in the southwestern part of the study area, provide a point of subregional discharge of approximately 450 gallons per minute. Water-level and chemical data indicate the development of a system with greater hydraulic conductivity from east to west along the southern parts of the study area. The Ojo Caliente fault, which is not well defined at the surface, may be an effective barrier to westward flow.

Wells completed in the Glorieta-San Andres aquifer at Black Rock Village supply water for municipal use. During a 10-year period, pumpage from these wells may have caused water-level declines of as much as 29 feet in nearby wells completed in the Glorieta-San Andres aquifer. Transmissivities determined from aquifer tests range from 30 to 1,400 feet squared per day, specific capacities range from 0.21 to 1.1 gallons per minute per foot of drawdown, well yields range from 50 to 150 gallons per minute. Well yields are affected by the number of fractures intercepted in the well and by well-construction techniques. Smaller yields may be expected from wells completed by casing, cementing, and gun-perforating the producing intervals.

The Glorieta-San Andres aquifer in the study area typically produces water enriched with calcium and sulfate, and dissolved-solids concentrations range from 331 to 1,068 milligrams per liter. Chemical quality may be expected to deteriorate with distance from the outcrop and in areas of smaller hydraulic conductivity.

The Chinle Formation, approximately 1,300 feet thick, contains interbedded sandstones as much as 100 feet thick, the most prominent of which is the Sonsela Sandstone Bed of the Petrified Forest Member. Recharge to these sandstones takes place along the Nutria monocline. Some additional recharge may take place where the beveling of the Ojo Caliente anticline has exposed the sandstones within the Chinle. The adjoining shales are confining units, and water moves westward across the study area under confined conditions along fractures and bedding planes. The hydraulic gradient ranges from 20 to 100 feet per mile. A trough in the potentiometric surface of the Chinle Formation along the Zuni River indicates that discharge is occurring to the alluvium.

Well withdrawals from the Chinle were approximately 450 acre-feet during 1979. Well yields range from 5 to 125 gallons per minute, with larger yields noted along the fractured zone associated with the axis of the Piñon Springs anticline. Water-level declines of as much as 27 feet during 24 years have been measured near the center of pumping at Zuni Village. Water levels in stock wells located away from this pumping center show little or no decline. Transmissivities determined from aquifer tests on municipal wells at Zuni Village range from 40 to 1,400 feet squared per day, specific capacities range from 0.027 to 0.6 gallon per minute per foot of drawdown. A storage coefficient of 3×10^{-5} was calculated from a multiple-well aquifer test. The Chinle characteristically produces water enriched with sodium and bicarbonate, and dissolved-solids concentrations range from 215 to 1,980 milligrams per liter.

The Zuni-Dakota aquifer, including approximately 700 feet of Jurassic and Cretaceous sandstones, provides water to at least 11 stock wells in the eastern one-half of the study area. Recharge takes place on exposures along the Nutria monocline. Water moves westward through fractures under artesian conditions created by adjoining confining shales. Flow gradients range from 50 to 100 feet per mile. Local discharge may take place to channel deposits along the Zuni River in Yellowhouse Canyon.

Wells in the Zuni-Dakota aquifer generally have been completed in one of the two water-bearing units, and few data are available on the combined potential for transmittal and storage of ground water. A hydraulic conductivity of 1.6 feet per day for the Zuni and Dakota Sandstones and transmissivities from 1.0 to 13.4 feet squared per day for the Dakota Sandstone have been reported. Specific capacities range from 0.07 to 0.97 gallon per minute per foot of drawdown. These values are similar to values reported for lateral equivalents of the Zuni-Dakota aquifer in other areas. In places where fracturing is more extensive, for example, along the eastern limb of the Piñon Springs anticline, transmissivity values and well yields may be larger.

The Zuni-Dakota aquifer within the study area typically produces water enriched with sodium, bicarbonate, and sulfate, dissolved-solids concentrations range from 189 to 3,440 milligrams per liter. Water quality may be expected to deteriorate with distance from the outcrop.

Saturated sandstones within the Gallup Sandstone and Crevasse Canyon Formation yield water to at least 14 stock wells in the eastern one-third of the study area. Local recharge to these rocks takes place on mesa-top exposures The Rio Nutria and Rio Pescado drainage systems breach these rocks, providing for localized discharge to the channel alluvium More deeply buried Gallup and Crevasse Canyon units probably transmit ground water northward along the plunging Allison syncline to join a regional flow system near Gallup

Yields from wells completed in the Gallup Sandstone or Crevasse Canyon Formation in the study area range from 4 to 5 gallons per minute, specific capacities range from 0 04 to 0 20 gallon per minute per foot of drawdown, a transmissivity of 2 feet squared per day was reported These values are at the lower limits of ranges determined for the same units within the Navajo-Hopi area. Water-bearing units generally are thin and discontinuous in the study area, and transmissivities of less than 10 feet squared per day may be expected

No single chemical composition appears to be typical of the dissolved constituents in water from the Gallup Sandstone and Crevasse Canyon Formation. This is due in part to the variable lithology and discontinuous nature of the water-yielding units Dissolved-solids concentrations range from 254 to 1,100 milligrams per liter, and water quality may be expected to deteriorate with distance from the point of recharge

The loosely consolidated sands of the Bidahochi Formation quickly absorb precipitation, which percolates downward to a thin zone of saturation above bedrock The westward movement of ground water is controlled by a buried drainage system developed on the erosional surface of the pre-Bidahochi bedrock.

Saturated thicknesses of the Bidahochi penetrated by wells in the study area range from 25 to 50 feet, yields range from 3 to 44 gallons per minute The thickest saturated sections may be expected in buried drainage channels eroded into the bedrock surface Seismic-reflection techniques are being used to locate these buried channels on the Triassic surface

The Bidahochi Formation typically produces water enriched with calcium and bicarbonate. Dissolved-solids concentrations range from 256 to 269 milligrams per liter

Alluvium along the Rio Nutria, Rio Pescado, and Zuni River provides a source of stock, irrigation, and domestic water Alluvial aquifers are recharged primarily by surface runoff, but they also receive water discharged from other ground-water systems Water in the alluvium moves downstream under water-table conditions, except in the confined buried-channel deposits underlying a basalt flow along the Rio Pescado Discharge takes place through evapotranspiration and from springs and wells.

Springs at Pescado Village, producing from the buried-channel deposits, yield approximately 500 gallons per minute or approximately 800 acre-feet per year for irrigation and domestic supply Spring flow at Black Rock Village supplements available ground-water supplies Shallow, hand-dug wells along alluvial channels provide small quantities of water for stock Water levels in most of these wells are between 5 and 40 feet below the land surface, and yields are less than 10 gallons per minute

Concentrations of dissolved solids in water from the alluvium range from 207 to 2,940 milligrams per liter Alluvial water is not characterized by any particular set of dissolved constituents. Alluvial water tends to reflect the lithologic characteristics of the local alluvium, the source of recharge (surface or other ground water), and contamination from the surface

Surface runoff across the study area is carried almost entirely by the Zuni River and its tributaries For 1911–30, annual discharge of the Zuni River at Black Rock averaged about 26 cubic feet per second for a total of about 19,000 acre-feet per year For 1969–79, annual discharge averaged about 11 cubic feet per second for a total of about 8,000 acre-feet per year The decrease in the average annual flow (11,000 acre-feet) was partly caused by the post-1930 construction of several reservoirs upstream from Black Rock Reservoir Reservoir construction after 1930 increased the surface area of reservoirs upstream from Black Rock Reservoir to 1,400 acres Evaporation losses from these additional reservoirs could be as much as 6,300 acre-feet per year Total evaporation losses for all reservoirs on Zuni tribal lands and areas upstream could be as much as 9,000 acre-feet per year. Seepage from these reservoirs to ground-water systems, although not lost to potential use, constitutes an additional depletion of surface runoff Changes in annual rates of precipitation and seasonal shifts in precipitation, which may affect total runoff, possibly have a less significant role in the decrease of flow in the Zuni River. A shift toward increased winter precipitation may have resulted in additional sublimation losses from the snowpack.

Low-flow concentrations of dissolved solids for the Zuni River were 426 and 517 milligrams per liter Concentrations during spring runoff were 178 and 180 milligrams per liter Water quality of surface flow is dependent upon the ratio between the contribution of flow from the more mineralized bank-storage component and the less mineralized direct-runoff component Water quality generally is less mineralized during higher flows Reservoir water, normally derived from the less mineralized direct runoff, becomes more mineralized due to evaporation losses Low-flow water quality in perennial reaches reflects the dissolved constituents of the ground water providing base flow

Measured sediment loads in the Zuni River ranged from 25 milligrams per liter at a discharge of 0 85 cubic foot per second to 2,090 milligrams per liter at a discharge of 441 cubic feet per second Larger discharges are capable of transporting greater sediment loads because of the increase in flow velocities More data are needed to better define the relationship between runoff and total sediment load

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SUPPLEMENTAL INFORMATION

Glossary of Selected Terms

The following definitions include excerpts from Lohman and others (1972) These definitions are included to aid the reader in an understanding of general terminology used in this report For a more detailed discussion of these and other hydrologic terms, the reader is referred to the report by Lohman and others (1972)

Anticline. Sedimentary rocks are normally deposited in flat-lying strata When subjected to uplift or other tectonic forces, these strata become distorted or folded The folded strata are described as anticlines, synclines, or monoclines Anticlines form concave-downward structural ridges, synclines form concave-upward troughs, and monoclines are described as a local steepening in the dip of the rock strata

Aquifer. An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs

The term aquifer was defined by O E Meinzer from a geological concept in which water bodies are classified in accordance with stratigraphy or rock types Meinzer clearly intended that an aquifer include the unsaturated part of the permeable unit

Conductivity, hydraulic, K. Hydraulic conductivity, K, replaces the term "field coefficient of permeability," P which embodies the inconsistent units gallon, foot, and mile If a porous medium is isotropic and the fluid is homogeneous, the hydraulic conductivity of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow

Hydraulic conductivity can have any units of length divided by time suitable to the problem involved In data tabulations of the Geological Survey, hydraulic conductivity may be expressed in feet per day and, so that the work of the Geological Survey may be readily interpreted in other countries, also in meters per day Thus,

$$K = -\frac{ft^3}{day\ ft^2\ (-ft\ ft^{-1})} = ft\ day^{-1}$$

$$K = -\frac{m^3}{day\ m^2\ (-m\ m^{-1})} = m\ day^{-1}$$

Hydraulic conductivity is dependent primarily on the nature of the pore space, the type of liquid occupying it, and the strength of the gravitational field

Confining bed. Confining bed is defined as a body of "impermeable" material stratigraphically adjacent to one or more aquifers In nature, however, its hydraulic conductivity may range from about zero to some value distinctly less than that of the aquifer Its conductivity relative to that of the aquifer it confines needs be specified or indicated by a suitable modifier such as slightly permeable or moderately permeable

Ground water, confined. Confined ground water is under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of distinctly lesser hydraulic conductivity than that of the material in which the confined water occurs

Artesian is synonymous with confined Artesian water and artesian water body are equivalent respectively to confined ground water and confined water body An artesian well is a well deriving its water from an artesian or confined water body The water level in an artesian well stands above the top of the artesian water body it penetrates

Ground water, perched. Perched ground water is unconfined ground water separated from an underlying body of ground water by an unsaturated zone Its water table is a perched water table It is held up by a perching bed whose permeability is minimal

Perched ground water may be either permanent, where recharge is frequent enough to maintain a saturated zone above the perching bed, or temporary, where intermittent recharge is not great or frequent enough to prevent the perched water from disappearing from time to time as a result of drainage over the edge of or through the perching bed

Ground water, unconfined. Unconfined ground water is water in an aquifer that has a water table

Head, static, h. The static head is the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point

The static head is the sum of the elevation head, h_e, and the pressure head, h_p, that is, $h = h_e + h_p$ Under conditions to which Darcy's law may be applied, the velocity of ground water is so small that the velocity head, $h_v = v^2/2g$, is negligible

Hydraulic gradient [dimensionless]. The hydraulic gradient is the change in static head per unit of distance in a given direction If not specified, the direction generally is understood to be that of the maximum rate of decrease in head

Isotropy. Isotropy is that condition in which all significant properties are independent of direction Although no aquifers are isotropic in detail, models based upon the assumption of isotropy have been shown to be valuable tools for predicting the approximate relationship between discharge and potential in many aquifers

Monocline. See Anticline

Porosity, n [dimensionless]. The porosity of a rock or soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume It may be expressed as a decimal fraction or as a percentage With respect to the movement of water only the system of interconnected interstices is significant (See "Porosity, effective ")

Porosity, effective, [dimensionless]. Effective porosity refers to the amount of interconnected pore space available for fluid transmission It is expressed as a percentage of the total volume occupied by the interconnecting interstices Although effective porosity has been used to mean about the same thing as specific yield, such use is discouraged

Potentiometric surface. The potentiometric surface is a surface which represents the static head As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer More than one potentiometric surface is then required to describe the distribution of head The water table is a particular potentiometric surface

Specific capacity. The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well It varies slowly with duration of discharge which should be stated when known If the specific capacity is constant except for the time variation, it is roughly proportional to the transmissivity of the aquifer

The relation between discharge and drawdown is affected by the construction of the well, its development, the character of the screen or casing perforation, and the velocity and length of flow up the casing If the well losses are significant, the ratio between discharge and drawdown decreases with increasing discharge, it is generally possible roughly to separate the effects of the aquifer from those of the well by step drawdown tests In aquifers with large tubular openings the ratio between discharge and drawdown may also decrease with increasing discharge because of a departure from laminar flow near the well, or in other words, a departure from Darcy's law

Specific yield, [dimensionless]. The specific yield of a rock or soil is the ratio of (1) the volume of water which the rock or soil, after being saturated, will yield by gravity to (2) the volume of the rock or soil The definition implies that gravity drainage is complete

In the natural environment, specific yield is generally observed as the change that occurs in the amount of water in storage per unit area of unconfined aquifer as the result of a unit change in head Such a change in storage is produced by the draining or filling of pore space and is therefore dependent upon particle size, rate of change of the water table, time, and other variables Hence, specific yield is only an approximate measure of the relation between storage and head in unconfined aquifers It is equal to porosity minus specific retention

Storage, bank. The change in storage in an aquifer resulting from a change in stage of an adjacent surface-water body is referred to as bank storage

Storage coefficient, S [dimensionless]. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head

In a confined water body the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer, similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer In an unconfined water body, the amount of water derived from or added to the aquifer by these processes generally is negligible compared to that involved in gravity drainage or filling of pores, hence, in an unconfined water body the storage coefficient is virtually equal to the specific yield

Stream, gaining. A gaining stream is a stream or reach of a stream whose flow is being increased by inflow of ground water

Stream, losing. A losing stream is a stream or reach of a stream that is losing water to the ground

Syncline. See Anticline

Transmissivity, T. Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient It replaces the term "coefficient of transmissibility" because by convention it is considered a property of the aquifer, which is transmissive, whereas the contained liquid is transmissible However, though spoken of as a property of the aquifer, it embodies also the saturated thickness of the aquifer (b) and the properties of the contained liquid It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths

Water table. The water table is that surface in a ground-water body at which the water pressure is atmospheric It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water In wells which penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists (See also "Ground water, perched ")

U.S. Environmental Protection Agency (1976) interim drinking-water standards

Constituent	Maximum concentration, in milligrams per liter
Arsenic	0 05
Barium	1 00
Cadmium	010
Chromium	05
Lead	05
Mercury	002
Nitrate (as N)	10 0
Selenium	01
Silver	05
Endrin	0002
Lindane	004
Methoxychlor	1
Toxaphene	005
Chlorophenoxy 2, 4 - D	1
Chlorophenoxy 2, 4, 5 - TP Silvex	01
Fluoride	

Temperature		
Degrees Fahrenheit	Degrees Celsius	
53 7 and below	12 0 and below	2 4
53 8 to 58 3	12 1 to 14 6	2 2
58 4 to 63.8	14 7 to 17 6	2 0
63 9 to 70 6	17 7 to 21 4	1 8
70 7 to 79 2	21 5 to 26 2	1 6
79 3 to 90 5	26 3 to 32 5	1 4

The following maximum concentrations for secondary constituents are provided as a guide

Constituent	Concentration, in milligrams per liter except as noted
Alkalinity	30 - 500
Bicarbonate	700
Calcium	75 - 200
Carbonate	350
Chloride	250
Color	15 units
Odor	3 units
Conductance	1,000 micromhos
Copper	3
Hardness	250
Iron	0 3
Magnesium	125
Manganese	0 05
pH	6 0 - 8 5 units
Potassium	1,000
Sodium	200
Sulfate	250
Turbidity (field test)	1 - 5 T U
Zinc	5

Modified from U S Environmental Protection Agency, 1976

TABLES 1–5

Table 1. Approximate thickness, lithology, and water-supply characteristics of rocks in the study area

System or series	Formation or rock type	Symbol on tables and maps	Approximate thickness, in feet	Lithology	Water-supply characteristics
Quaternary	Alluvium	Qal	0–200	Sand, gravel, silt, and clay deposited along surface drainages	Yields from shallow stock wells generally less than 10 gallons per minute
	Buried channel deposits		150	Channel deposits of sand, gravel, silt, and clay underlying basalt along Rio Pescado and upstream reaches of Zuni River	Domestic irrigation supply from springs and wells, spring discharges as much as 500 gallons per minute
	Basalt	Qb	24–59	Flows along the Rio Pescado	Not known to yield water to well or springs
Tertiary	Bidahochi Formation	Tb	0–650	Fluvial deposits of sandstone, conglomerate, and volcanic ash	Locally water yielding, stock wells yield from 3 to 44 gallons per minute
Cretaceous	Crevasse Canyon Formation	Kc	> 500	Siltstone, shale, sandstone, and coal deposited in swamps and flood plains	Locally water yielding, stock wells generally yield 4 to 5 gallons per minute
	Gallup Sandstone	Kg	> 425	Non-marine and littoral sandstone, shale, and coal	
	Mancos Shale	Km	300–400	Marine, carbonaceous shale	Minimal permeability, confining unit
	Dakota Sandstone	Kd	150	Intertidal to fluvial sandstone, shale, and coal	Both formations are used primarily for stock supply, wells yield from 1 to 32 gallons per minute
Jurassic	Zuni Sandstone	Jz	500	Wind-deposited, crossbedded sandstone	
Triassic	Wingate Sandstone	TRw	150	Fluvial siltstone and sandstone	May be locally water yielding
	Chinle Formation	TRc	1,300	Fluvial siltstone and shale with bedded channel sandstone	Zuni municipal supply, well yields from 5 to 125 gallons per minute

Permian	San Andres Limestone	Ps	Pgs	100	Marine, fossiliferous limestone	"Glorieta-San Andres aquifer", municipal wells yield as much as 150 gallons per minute, springs discharge as much as 450 gallons per minute at Ojo Caliente
	Glorieta Sandstone	Pg		200	Intertidal sandstone, well cemented	
	Yeso and Abo Formations	Py, Pa		900	Interbedded sandstone, siltstone, limestone, and anhydrite	No information available in the study area
Precambrian	Crystalline	p€		—	Granitic crystalline rocks	No information available in the study area

Table 2. Records of wells and springs on and adjacent to Zuni tribal lands

Name of well or spring Geographical or place names, names of owners, or numerical assignments are tabulated in most cases in order to aid in well or spring identification

Location Wells and springs are located in this table to the nearest 10-acre plot as described in the text Wells and springs whose exact locations are not known are designated by zeros in the three-digit locator (for example, 11 21 23 000) When two or more wells are located within the same 10-acre plot, they are designated with alphabetic descriptors following the three-digit locator (10 19 28 123a, 10 19 28 123b, and so forth)

Altitude The altitude of land surface is obtained from U S Geological Survey 7½-minute topographic maps unless otherwise noted Left blank where well or spring is not accurately located

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Ramah 13 ------------------	7 16 21 342	7,115	589	8	540–589	Kg	96	08-03-53
							211	07-15-69
Epaloose ------------------	7 21 3 122a	6,040	—	8½	—	Kg	Flowing	06-19-79
	7 21 3 122b	6,040	—	4	—	Kg	-1 0	06-19-79
	7 21 3 122c	6,040	—	dug	—	Qal	3 0	06-19-79
Ramah 2 ------------------	8 15 27 311	7,478R	3,590	8⅝	3,246–3,590	Pgs	978	05-14-75
Ramah 1 ------------------	8 15 27 342	7,445R	3,574	8	3,345–3,574	Pgs	954	05-10-73
RWP–25 ------------------	8 17 2 314	7,380	1,175	6⅝	1,000–1,175	Jz	196	07-28-72
							411 9	05-30-79
Irrigation 3 ----------------	8 17 2 322	7,380	57	6⅝	—	Qal	50 4	06-20-79
	8 17 3 142	7,320	—	dug	—	Qal	31 0	06-20-79
Seferino -------------------	8 17 8 413	7,300	—	—	—	—	—	—
ECW–7 -------------------	8 18 24 221	7,219	1,460	6⅝	1,400–1,460	—	606	- -35
							557	06-20-79
ECW–4 -------------------	8 19 4 321	6,885	590	6⅝	493–590	—	351	- -34
							355	10-12-78
ECW–5 -------------------	8 19 12 211	7,325	1,115	6⅝	1,009–1,115	—	755	- -35
Spring ---------------------	8 19 13 114	6,995	—	—	—	Jz	—	—
ECW–18 ------------------	8 19 22 313	6,725	495	6⅝	416–495	TRc	221 0	07-28-72
							220 0	10-12-78
Lower Willow Wash Spring-------------------	8 20 1 322	6,540	—	—	—	TRc	—	04-07-78
RWP–35 ------------------	8 20 4 344	6,359	515	6	—	TRc	30	- -61
							45 8	07-21-72
							45 9	06-21-78
Chavez Spring-------------	8 20 8 443	6,260	—	—	—	TRc	—	
Plumasano Arroyo Spring-------------------	8 20 16 324	6,290	—	—	—	Pgs Qal	—	
	8 20 18 333	6,180	86	6	—	Qal	69 4	05-31-79
Sacred Spring -------------	8 20 20 422	6,300	—	—	—	Pgs	Flowing	1978-79

Water producing interval Feet below land surface

Geologic unit abbreviations Pgs, Glorieta-San Andres aquifer, ℞c , Chinle Formation, ℞w , Wingate Sandstone, Jz, Zuni Sandstone, Kd, Dakota Sandstone, Kg, Gallup Sandstone, Kc, Crevasse Canyon Formation, Tb, Bidahochi Formation, Qal, alluvium

Specific conductance Micromhos per centimeter at 25 degrees Celsius

Other abbreviations p, pumping, R, reported, pb, plugged back, NA, no access, UTM, unable to measure, ABND, abandoned, GL, geophysical logs available, DST, drill stem test, —, no data

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
7 9	0 02	3½	07-29-53	760	—	8 8	08-31-71	Domestic, stock
4 (flowing)	—	—	06-19-79	1,250	16 0	7 3	06-19-79	Bokum exploration well
—	—	—	—	—	—	—	—	Bokum exploration well
—	—	—	—	2,200	18 0	7 8	06-19-79	Stock
69	41	8	05-14-75	989	36 0	7 9	05-14-75	Domestic, municipal
88	48	24	05-11-73	1,000	33 0	8 3	05-11-73	Domestic, municipal
3	—	—	—	3,440	23 0	8 0	07-28-72	Stock
—	—	—	—	—	—	—	—	Abandoned stock
—	—	—	—	—	—	—	—	Stock
—	—	—	—	—	—	—	—	—
12	27	10	05-22-35	700	—	8 3	08-31-79	Stock, GL
12 5	28	—	- -34	740	18 0	8 8	08-01-72	Stock
6 2	0 13	—	07-01-35 07-12-70	990	18 0	8 8	08-01-72	Stock
—	—	—	—	—	—	—	—	—
—	—	—	—	730	22 0	9 0	08-01-72	Stock
5	—	—	—	1,850	13 5	—	04-07-78	—
8	03	—	- -61	1,050	18 0	7 5	08-09-72	Stock
0	—	—	02-26-80	1,400	9 5	7 1	02-26-80	Collection gallery for stock
54–67	—	—	—	1,150	28 0	8 1	06-19-79	Lateral seepage from Ojo Caliente Springs through alluvium
—	—	—	—	—	—	—	—	—
See remarks	—	—	1978–79	1,100	22 0	7 3	06-21-78	Irrigation, combined discharge for Sacred Spring and Rainbow Spring is 450 gallons per minute

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Rainbow Spring	8 20 21 144	6,320	—	—	—	Pgs	Flowing	1978-79
Irrigation 3	8 20 31 321	6,260	225	6⅝	—	Kg	192 4	08-21-79
RWP–26	8 20 33 422	6,510	600	6⅝	—	Kg	300	- -72
							434 6	08-21-79
	8 21 1 000	—	—	—	—	Qal	17 8	08-02-72
RWP–31	8 21 12 312	6,130	71	6⅝	—	Qal	45 9	07-27-72
							43 2	11-28-78
Collection Gallery	8 21 15 243	6,100	—	—	—	Qal	8 4	12-05-79
ECW–20	8 21 26 321	6,061	15	Dug	—	Qal	1 1	07-27-72
	8 21 34 000	6,066R	—	—	—	—	0 4	07-27-72
Roy Eidal Test	9 15 32 330	7,197R	3,110	8⅝	2,858–2,940	Pgs	693 (DST)	05-23-71
Miller's	9 16 34 412	7,160	125?	8	—	Kg	98 4?	06-20-79
ECW–19	9 17 5 112	6,950	30	36	—	Qal	6 8	07-31-72
							25 7	06-20-79
ECW–8	9 17 19 112	7,190	660	6⅝	550–650	Jz	440	- -35
							447 8	10-12-78
Ericho	9 17 22 000	7,480R	688	5½	610–688	Kd	350	07-26-73
COA–21	9 17 24 132	7,310	24	—	—	Qal	11	07-31-72
							6 8	05-29-79
	9 17 33 324	7,270	40	Dug	—	Qal	35 1	06-20-79
Cities Service Zuni-1	9 18 5 324	6,473	2,591	7⅝	—	Pgs	235	- -63
							250	08-01-72
							258 4	04-05-78
							258 1	02-26-80
Spring Catchment	9 18 16 242	7,190	—	—	—	Qal	—	—
Warren Ondelacy	9 18 19 423	7,292	1,230	6⅝	—	TRc	—	—
Mullen Canyon Spring	9 18 31 442	7,040	—	—	—	Qal	—	—
Dowa Yallane Spring	9 19 1 144	6,390	—	—	—	TRc	—	—
RWP–33	9 19 20 132	6,900	400	5⅝	366–400	TRc	131 4	07-28-72
							145 2	10-12-78
Upper Willow Wash Spring	9 19 31 323	6,680	—	—	—	Tb?	—	—
Pewa	9 20 4 000	—	352	—	169–352	TRc	34	- -71
Louie Chavez	9 20 7 444	6,166	—	—	—	Qal	UTM	12-05-79
A–1	9 20 8 223	6,190	—	—	—	Qal	17	07-26-72
Tekapo	9 20 10 313	6,190	15	6	—	Qal	11 6	06-21-78
RWP–39 (Bica)	9 20 11 443	6,300	780	6⅝	220–230 330–345	TRc	97 0	09-05-79
Pablito Chavez	9 20 18 432	6,170	18	Dug	—	Qal	16 0	06-21-78

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
See remarks for Sacred Spring	—	—	1978–79	1,050	22 0	7 0	06-19-79	Irrigation
10	—	—	- -39	900	18 0	7 6	08-21-79	Stock
—	—	—	—	—	—	—	—	Stock
—	—	—	—	—	—	—	—	—
1 2	0 07	—	11-28-78	2,450	—	7 5	07-27-72	Stock
				2,600	11 0	7 4	11-28-78	
—	—	—	—	—	—	—	—	Stock
—	—	—	—	1,600	23 0	7 9	07-27-72	Stock
—	—	—	—	—	—	—	—	Old artesian well
—	—	—	—	—	—	—	—	Wildcat petroleum test, plugged back to surface, GL
—	—	—	—	850	20 0	9 0	07-28-72	Stock, pump column leaking
—	—	—	—	2,720	—	8 2	07-31-72	Stock
				2,870	17 0	7 8	06-20-79	
6	—	—	- -35	—	—	—	—	Stock
6	—	—	- -73	—	—	—	—	—
11?	—	—	07-31-72	—	—	—	—	Stock
—	—	—	—	2,900	14 0	6 8	06-20-79	Stock
10	0 01	—	04-27-64	980	30 5	7 9	04-27-64	Wildcat petroleum test, plugged back to 1,574, stock GL
				1,140			05-04-64	
Seep	—	—	04-06-78	362	17 0	—	04-06-78	Stock
5	06	6	11-23-72	2,650	14 0	8 9	08-21-79	Stock, gasoline powered Jenson pump jack
Est 50	—	—	—	—	—	—	—	—
Est 45	—	—	04-05-78	500	16 5	—	04-05-78	—
10	—	—	- -61	700	12 0	—	10-21-78	Stock
—	—	—	—	910	11 0	—	04-07-78	—
5 5	—	—	10-19-71	—	—	—	—	—
—	—	—	—	—	—	—	—	Filled to surface 12-05-79
5	—	—	07-26-72	2,880	14 0	7 8	07-26-72	—
—	—	—	—	—	—	—	—	—
5	02	8	04-08-76	—	—	—	—	Stock
—	—	—	—	830	—	7 9	07-27-72	Stock

Table 2. Records of wells and springs on and adjacent to Zuni tribal lands – Continued

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Hugh Nastacio	9 20 19 142	6,160	19	Dug	—	Qal	18	07-27-72
							17 9	06-21-78
ECW-3 (old)	9 20 22 312a	6,275	552	6⅝	487–552	TRc	Flowing	1935
							Flowing	1972
ECW-3 (new)	9 20 22 312b	6,275	—	6⅝	—	TRc	3 2	07-27-72
							1 6	03-20-78
	9 20 30 114	6,160	21	Dug	—	Qal	17 3	06-21-78
Spring	9 20 34 214	6,420	—	—	—	TRc	—	—
ECW-2	9 21 11 314	6,292	475	8	351–475	TRc	131 2	07-26-72
Romancito	9 21 25 433	6,140	17 5	Dug	—	Qal	2 1	07-27-72
							14 0p	12-05-79
	9 21 36 322	6,128	8 5	24	—	Qal	6 8	12-05-79
Ramah Mutual	10 15 17 414	7,100	3,150	8	—	Pgs	615	09-14-73
							619	01-18-75
ECW-13	10 16 32 144	7,069	707	6⅝	—	Kd	229 5	05-30-79
	10 17 4 342	6,680	77	4½	—	Qal	33 4	04-18-79
Old Sawmill	10 17 5 442	6,680	—	—	—	Qal	46 1	08-02-71
ECW-22	10 17 9 244	6,850	282	7	240–282	Kg	187	- -42
							198 3	10-11-79
Lower Pescado Spring	10 17 12 431	6,760	—	—	—	Qal	—	—
Fidel Chahate	10 17 12 433	6,770	93	6⅝	—	Qal	27 0	07-31-80
Upper Pescado Spring	10 17 12 442	6,780	—	—	—	Qal	—	—
	10 17 12 434	6,770	—	—	—	Qal	—	—
ECW-6	10 17 35 412	6,964	712	6⅝	610–712	Kd	250	01-29-35
							279	07-31-72
							219	05-30-79
Yellowhouse Test Hole 7	10 18 11 141	6,531R	102	1¼	82–102	Qal	0 4	08-14-71

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
—	—	—	—	—	—	—	—	—
1 5	—	—	- -35	—	—	—	—	Stock
5	0 05	—	- -35					
—	—	—	—	—	—	—	—	Stock
—								
—	—	—	—	—	—	—	—	Stock
—	—	—	—	—	—	—	—	
9	13	—	- -34	350	17 0	8 4	08-01-72	Stock
10	—	—	- -72	990	13 0	7 2	07-27-72	Stock
1 5	—	—	11-05-79	900	14 0	7 5	12-05-79	
—	—	—	—	—	—	—	—	—
40	33	24	09-14-73	—	32 0	—	09-14-73	Municipal, GL
33	34	24	01-18-75	550	—	8 0	09-30-75	
1	—	—	05-29-79	1,780	16 0	8 8	07-31-72	Stock
				1,890			05-29-79	
—	—	—	—	—	—	—	—	Domestic, completed in buried channel deposits
—	—	—	—	—	—	—	—	Completed in buried channel deposits
4	—	—	- -42	—	—	—	—	Stock, coal mine well
See Remarks	—	—	—	420	14 0	7 6	06-18-79	Stock, irrigation, completed in buried channel deposits, combined discharge for Upper and Lower Pescado Springs is 500 gallons per minute
25	—	—	- -70	640	—	8 0	01-04-71	Domestic, completed in buried channel deposits
See Remarks	—	—	—	410	14 5	7 7	06-18-79	Stock, irrigation, completed in buried channel deposits, combined discharge for Upper and Lower Pescado Springs is 500 gallons per minute
—	—	—	—	—	—	—	—	Hand pump, completed in buried channel deposits
12	14	—	05-02-35	1,190	20 0	8 8	07-21-72	Stock
2 4	04	—	05-29-79					
—	—	—	—	900	—	8 3	- -71	Bureau of Reclamation test hole, completed in buried channel deposits

Table 2. Records of wells and springs on and adjacent to Zuni tribal lands – Continued

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Yellowhouse Test Hole 6 ---	10 18 11 143	6,529R	244	1¼	162–244	Qal	Flowing	08-09-71
RWP–17 (old) -------------	10 18 22 333a	6,610	37	30	—	Qal	33 5	08-08-72
							32 2	04-06-78
RWP–17 (new) ------------	10 18 22 333b	6,610	112	5	—	TRw	33 2	04-06-78
RWP–41 ------------------	10 18 33 344	6,895	520	6⅝	270–310	TRc	246 0	07-31-80
					450–468			
Lister Oil test --------------	10 19 2 414	6,580	1,636	4½	—	—	—	—
Black Rock Spring ---------	10 19 13 224	6,400	—	—	—	Qal	—	—
Black Rock PHS -----------	10 19 13 444	6,441	1,175	8	938–1,175	Pgs	279	06-17-75
Joe Haskie Spring ---------	10 19 15 113	6,400	—	—	—	TRc	—	—
Zuni Z–6 -----------------	10 19 22 231	6,345	400	6	122–210	TRc	56 7	08-02-78
					345–392			
Zuni H–1 -----------------	10 19 22 241	6,350	220	6	120–180	TRc	54 4	03-20-78
Zuni Z–3 -----------------	10 19 22 244	6,340	100	6	—	TRc	46 0	03-20-78
Zuni Z–2 -----------------	10 19 22 421	6,335	120	5	—	TRc	37 9	03-20-78
Zuni Z–5 -----------------	10 19 22 433	6,320	590	6⅝	—	TRc	31 9	03-20-78
Shopping Center ----------	10 19 22 443	6,313	70	6	—	TRc	21 2	03-09-78
Mormon Church ----------	10 19 22 444	6,310	27	6	—	Qal	16 0	08-03-72
Zuni Z–1 (Max Curtis) -----	10 19 23 134	6,340	80	6⅝	—	TRc	40 3	01-15-80
Zuni Z–4 -----------------	10 19 23 143	6,332	220	6	120–210	TRc	35 2	10-17-78
Black Rock 1 --------------	10 19 24 122a	6,350	160	13	10–70	Qal	9 8	02-27-80
Black Rock 3 --------------	10 19 24 122b	6,350	1,060	8	810–1,060	Pgs	168 3	03-27-68
							197	05-30-78
Black Rock 2 --------------	10 19 24 221	6,454	932	6	624–932	TRc	64	- -57
							99 6	04-07-78
Zuni F–5 -----------------	10 19 27 112	6,310	1,161	6	1,108–1,161	Pgs	158 6	02-13-73
							171	04-14-78
Saint Anthony Mission ----------------	10 19 28 114	6,285	120	—	—	Qal	—	—
Zuni F–4 -----------------	10 19 28 131	6,285	610	10	—	TRc	Flowing	- -67
Zuni F–3 -----------------	10 19 28 141	6,285	556	6	244–259	TRc	19	- -57
					516–556		43 4	03-21-78
Pat Kelsey ----------------	10 19 28 314	6,275	250	6	—	TRc	—	—

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
33	—	—	08-09-71	—	—	—	—	Bureau of Reclamation test hole, completed in buried channel deposits
14	—	—	- -35	1,250	18 0	8 3	07-31-72	Stock, dug well
8 8	73	—	08-08-72	770	13 0	8 0	08-08-72	Stock
5 7	—	—	—	—	—	—	—	Stock, also known as Frank Vacit well 4
—	—	—	—	—	—	—	—	Well plugged back to surface in 1970
50–75 Est	—	—	—	405	14 0	7 7	02-26-80	Municipal, completed in buried channel deposits
150	1 12	24	06-17-75	1,380	27 5	7 2	- -75	Municipal
				1,150	21 0	7 2	02-27-80	
Seepage	—	—	02-26-80	—	—	—	—	Undeveloped
30	—	—	03-21-78	1,150	—	8 8	07-06-76	Municipal, producing interval from well log
—	—	—	—	776	15 0	7 6	07-27-78	Municipal, unused, GL, producing interval from well log
—	—	—	—	950	—	8 6	06-04-75	Municipal, GL
				1,360			07-07-76	
—	—	—	—	1,230	—	8 4	07-06-76	Well sands badly, unused, GL
14	—	—	—	1,170	20 5	8 8	07-06-76	Municipal, GL
—	—	—	—	—	—	—	—	Unused
—	—	—	—	—	—	—	—	Domestic
50	—	—	- -76	880	—	8 1	12-17-75	Municipal
84			11-05-79					
75			1979-80					
120	7 4	4	10-17-78	940	—	8 7	07-06-76	Municipal
55 5	58	8	06-18-51	780	—	7 9	07-22-66	Irrigation
127	1 32	48	07-07-66					
50	23	16	- -68	1,470	26 6	7 8	03-27-68	Municipal, GL
				1,400		7 7	08-03-72	
13 5	02	10	- -57	2,510	20 0	8 4	08-03-72	Municipal
100	15	8	02-13-73	1,200	26 6	7 7	02-13-73	Unused, observation well, GL
—	—	—	—	5,080	20 0	8 3	08-03-72	
55	—	—	- -72	1,400	—	8 2	- -72	Municipal
32			1979-80	1,330			08-03-72	
60	41	3	- -57	1,700	18 0	8 7	08-03-72	Municipal
30			- -72	1,520			08-03-72	
60			1979-80					
—	—	—	—	1,570	20 0	8 4	08-03-72	Domestic

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Zuni F-1	10 19 28 343	6,292	1,500	8	500–530	TRc	Flowing	- -53
			650 (pb)				22 6	03-21-78
Zuni F-6	10 19 29 214	6,285	620	6	350–381	TRc	62 7	02-27-80
					434–439			
					509–520			
					597–618			
Nastacio	10 19 30 232	6,275	152	6⅝	—	Qal	30 9	03-20-78
Zuni F-2	10 19 33 121	6,298	492	8⅝	180–200	TRc	8	- -54
					320–340		35 4	03-21-78
					430–500			
RWP-27	10 20 8 243	6,591	600	6⅝	—	Tb	154 9	07-25-72
							150 6	09-28-78
Irrigation 1	10 20 18 314	6,503	204	6⅝	170–204	Tb	175	- -39
							196 5	07-26-72
							177 0	09-04-79
Bosson Ranch	10 20 22 211	6,337	102	6⅝	80–100	TRc	60	07-19-57
							61 1	07-25-72
							61 4	09-28-78
ECW-9	10 20 32 421	6,333	575	6⅝	509–575	TRc	122 6	07-26-72
							90 4	03-20-78
RWP-30	10 21 11 221	6,696	551	6⅝	500–551	Tb	510	07-10-79
RWP-24	10 21 23 322	6,622	480	6⅝	450–480	Tb	324 0	07-26-72
							430 4	09-05-79
RWP-28	11 16 8 131	7,047	105	6⅝	—	Kc	48	- -58
							44 5	09-27-78
Nutria Campground	11 17 5 322	6,889	450	6⅝	396–450	Kg	220	- -63
							231 5	07-31-72
							201 9	11-06-79
	11 17 8 322	6,693	36	Dug	—	Qal	25 6	07-31-72
							24 5	04-06-78
Solomon	11 17 12 211	6,870	134	4	—	Kc	73	07-12-57
							49 8	08-01-72
							49 4	09-27-78
ECW-14	11 17 24 432	6,920	438	6⅝	190–258	Kg	122 0	07-12-57
					301–323		159 7	11-06-79
					366–410			
ECW-10	11 17 28 143	6,771	760	6⅝	675–760	Kd	130	- -35
							77 8	08-15-72
							72 1	04-06-78
Z-6R	11 18 1 000	7,150R	500	—	115–383	Kg	382 5	11-07-75
Loncesion	11 18 5 424	6,980	380	6⅝	355–365	Kd	280	07-15-72
	11 18 13 000	6,700R	—	Dug	—	Qal	—	—
ECW-1	11 18 21 132	6,752	345	6⅝	65–345	Jz	45	- -34
						Kd	47 9	07-31-72
							45 4	07-31-78
RWP-34	11 18 27 411	6,661	220	6⅝	150–220	Kd	76 1	08-10-72
							73 2	09-28-78

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
51	34	2	- -53	936	20 0	8 7	- -53	Municipal
20			- -69	1,190			08-03-72	
30			1979–80	1,400	20 0	8 3	07-30-80	
—	—	—	—	—	—	—	—	Municipal
30	—	—	- -72	990	—	8 3	08-02-72	Stock
100R	—	—	- -53	1,250	16 0	—	- -53	Municipal
96	0 20	—	07-06-66	1,620	20 0	8 3	08-03-72	
83			1979–80					
3	—	—	- -72	450	14 0	7 7	07-25-72	Stock
44	—	—	05-01-39	360	17 5	8 4	09-05-79	Stock, no drawdown when pumped at 44 gallons per minute in 1939
6	—	—	- -64	800	16 0	7 8	07-25-72	Stock
5 5	31	—	08-17-72					
18	13	—	- -36	1,600	14 5	—	03-20-78	Stock
				1,300	20 5	8 3	09-04-79	
—	—	—	—	—	—	—	—	Abandoned, stock
12	—	3	- -56	—	—	—	—	Stock, GL
1 5	04	—	08-16-72	1,360	—	8 6	08-16-72	Stock
10	—	2	- -63	700	22 0	8 8	07-31-72	Domestic
				720			04-06-78	
—	—	—	—	—	—	—	—	Unused
—	—	—	—	—	—	—	—	Abandoned, stock
4	—	5	06-15-36	1,300	14 0	7 6	11-06-79	Stock
6	0 07	10	06-12-25	1,760	—	—	11-05-63	Stock
				1,810		8 1	07-31-72	
				2,000	13 5		04-06-78	
1-2	—	—	11-07-75	—	—	—	—	GL
20	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
32	97	—	12-12-34	1,020	—	—	10-22-63	Stock
8 4	84	—	08-11-72	850	13 0	—	04-07-78	
2 9	11	—	08-10-72	1,030	—	8 4	07-31-72	Stock
				1,100	14 5	8 4	04-06-78	

Name of well or spring	Location	Altitude	Total depth (feet)	Casing diameter (inches)	Water producing interval	Geologic unit	Water level (feet below land surface)	Date
Gonzales	11 19 20 444	6,620	60	6⅝	—	Qal	39 9	07-26-72
							35 5	09-28-78
Spring	11 19 29 233	6,660	—	—	—		—	—
RWP-38	11 20 22 211	7,020	500	6⅝	—	Jz	227 1	09-05-79
RWP-37	11 20 27 314	6,664	248	6⅝	100–248	Jz	150	- -64
							150 0	07-26-72
							149 4	09-28-78
Irrigation 2	11 20 31 112	6,738	715	8	650–715	ᵲc	555 2	09-05-79
Spring	11 20 34 244	6,440	—	—	—	ᵲc	—	—
Winter Cattle	11 21 23 000	6,900	650	—	—	Tb	Dry	—
Sam Pablamo	12 16 5 000	7,000	423	6⅝	—	Pgs	10	- -72
Spring	12 16 6 211	7,000	—	—	—	Pgs	—	—
RWP-32	12 16 7 331	6,860	100	6⅝	—	Kg	40	- -50
							69 2	08-01-72
							64 8 p	09-27-78
Nutria Spring	12 16 8 314	6,860	—	—	—	Pgs	—	—
Spring near Nutria	12 16 17 214	7,060	—	—	—	Pgs	—	—
RWP-29	12 16 30 242	6,860	228	6⅝	78–94	Kc	71 8	08-01-72
					202–209		103 p	09-27-78
ECW-16	12 17 15 213	6,900	594	6⅝	295–325	Kc	106 0	08-01-72
					340–357		111 6	11-06-79
					465–490			
					546–554			
Hand pump	12 17 23 244	6,780	—	—	—	Qal	13 0	08-12-75
John Bowannie	12 17 24 442	6,780	546	6⅝	510–546	Kg	Flowing	08-12-75
Z-7R	12 17 32 323	6,868	215	6⅝	158–183	Kc	165	- -76
16T-567	12 18 28 434	7,320	635	6⅞	445–635	Kg	464	09-02-76
Jones Ranch PM-3	12 20 17 133	6,990	580	6	220–245	Jz	128 3	09-24-73
Cheechilgeetho School	12 20 25 123	6,810	1,607	5	1,350–1,607	Pgs	1,111	06-04-52
16T-545	12 21 24 423	6,839	541	6⅝	241–420	ᵲc	94	07-07-67

Production data								
Well yield (gallons per minute)	Specific capacity (gallons per minute per foot)	Pumping duration (hours)	Date	Specific conductance	Temperature (degrees Celsius)	pH (units)	Date	Remarks
—	—	—	—	—	—	—	—	Stock
0	—	—	12-04-79	—	—	—	—	Ephemeral
11	14	8	03-01-76	240	19 5	8 1	09-05-79	Stock
12	14	4	- -64	340	—	—	07-26-72	Stock
15	—	—	- -39	1,250	—	—	07-26-72	Stock
0 1	—	—	03-26-80	388	8 0	8 4	03-26-80	Stock, horizontal drive point - rock collapsed into spring area
—	—	—	—	—	—	—	—	Abandoned
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—
—	—	—	—	1,030	—	—	10-23-63	Stock
				1,190	16 0	8 2	08-01-72	
50	—	—	—	573	11 0	—	12-14-50	—
1	—	—	03-26-80	500	4 0	8 2	03-26-80	—
6	—	—	- -58	900	14 5	7 8	11-06-79	Stock
5	—	9	- -36	811	—	8 0	11-13-79	Stock
—	—	—	—	1,660	12 0	8 2	08-01-72	—
25 (flowing)	0 20	—	—	—	—	—	—	—
10	—	—	04-01-76	660	—	7 9	04-01-76	Well near Carbon Coal Company drill hole
—	—	—	—	420	—	8 5	06-20-73	GL
5	0 07	8	09-24-73	410	—	8 0	09-24-73	Domestic
3 6	—	—	- -52	2,880	23 0	—	06-12-52	Well plugged back to
				2,760			06-13-52	100 feet
10	—	3½	07-07-67	530	—	9 2	10-11-72	Stock

Table 3. Water-quality analyses from wells and springs on and adjacent to Zuni tribal lands (including trace-element and radiochemical analyses from selected wells and springs)

Name of well or spring Geographical or place names, names of owners, or numerical assignments are tabulated in most cases in order to aid in well or spring identification

Location Wells and springs are located to the nearest 10-acre plot as described in the text Wells and springs whose location is not known exactly are designated by the use of zeroes in the three-digit locator (for example, 7 21 3 000)

Specific conductance Micromhos per centimeter at 25 degrees Celsius

Part A—Water-quality analyses from wells and

				Major cations				Major anions				
Name of well or spring	Location	Date	Temperature (°C)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)
Ramah 13	7 16 21 342	08-31-71	—	8 0	3 7	162	T	245	19	8 2	156	T
Epaloose	7 21 3 122a	06-19-79	16 0	120	40	160	4 5	305	0	45	480	0 01
Spring[1]	7 21 3 000	07-27-72	—	132	559	282	5 9	232	25	110	722	62
Ramah 2	8 15 27 311	05-14-75	36 0	120	36	42	7 0	257	0	19	300	0
Ramah 1	8 15 27 342	05-11-73	33 0	116	34	60	3 9	248	11	19	305	—
RWP–25	8 17 2 314	07-28-72	23 0	557	156	171	6 3	260	18	74	2,047	—
ECW–7	8 18 24 221	08-31-79	—	6 4	5	170	1 0	256	0	5 9	210	14
ECW–4	8 19 4 321	08-01-72	18 0	2 0	1 2	176	1 6	302	30	16	70	4 34
ECW–5	8 19 12 211	08-01-72	18 0	2 0	1 2	214	2 4	297	33	12	168	62
ECW–18	8 19 22 313	08-01-72	22 0	2 0	T	164	2 7	247	32	14	101	62
Lower Willow Wash Spring	8 20 1 322	04-07-78	13 5	56	6 5	260	3 0	—	—	91	280	49
RWP–35	8 20 4 344	08-09-72	18 0	128	38	57	3 9	328	T	35	296	62
Chavez Spring	8 20 8 443	07-27-72	—	64	6 1	102	3 9	296	10	57	34	—
Do	do	02-26-80	9 5	140	140	180	4 4	341	0	290	120	8 1
Plumasano Arroyo Spring	8 20 16 324	06-19-79	28 0	140	30	150	5 0	268	0	43	450	25
Sacred Spring	8 20 20 422	06-21-78	22 0	140	40	55	5 7	310	0	32	300	05
Rainbow Spring	8 20 21 144	06-19-79	22 0	140	41	54	5 8	329	0	32	310	01
Irrigation 3	8 20 31 321	08-21-79	18 0	51	19	160	4 1	183	0	21	370	02
RWP–31	8 21 12 312	07-27-72	11 0	279	46	245	T	310	26	117	864	1 9
ECW–20	8 21 26 321	07-27-72	23 0	222	40	98	5 1	270	32	67	554	31
Miller's	9 16 34 412	07-28-72	20 0	2 0	1 2	196	1 2	272	33	8 9	151	62
ECW–19	9 17 5 112	07-31-72	17 0	361	71	250	5 1	299	18	18	1,344	1 2
	9 17 33 324	06-20-79	14 0	500	150	160	3 6	317	0	50	1,900	86
Cities Service-Zuni 1	9 18 5 324	05-04-64	30 5	124	26	93	10 2	218	9 3	18	396	25
Spring Catchment	9 18 16 242	04-06-78	17 0	41	8 3	22	11	79	—	28	56	1 40

[1]Might be sample from well 7 21 3 122c

Abbreviations T, the constituent is noted, but in quantities too small to measure, mg/L, milligrams per liter, µg/L, micrograms per liter, pCi/L, picocuries per liter, °C, degrees Celsius, Pgs, Glorieta-San Andres aquifer, ℞c, Chinle Formation, ℞w, Wingate Sandstone, Jz, Zuni Sandstone, Kd, Dakota Sandstone, Kg, Gallup Sandstone, Kc, Crevasse Canyon Formation, Tb, Bidahochi Formation, Qal, alluvium, Lab, laboratory conducting analysis BIA, Bureau of Indian Affairs Laboratory, USGS, U S Geological Survey Laboratory, <, less than, —, no data

springs on and adjacent to Zuni tribal lands

						Hardness							
Silica (mg/L)	Iron (mg/L)	Fluoride (mg/L)	Phosphate as ortho-phosphate (mg/L)	Boron (mg/L)	Total alkalinity $CaCO_3$ (mg/L)	Non-carbonate (mg/L)	Ca/Mg (mg/L)	Specific conductance	Dissolved solids (mg/L)	pH (units)	Sodium adsorption ratio	Lab	Geologic unit
—	0 02	1 0	T	0 28	201	—	35	760	475	8 8	11 91	BIA	Kg
9 6	3 2	30	—	—	250	210	460	1,250	1,010	7 3	3 20	USGS	Kg
—	T	88	T	28	191	369	560	2,200	1,584	7 8	5 19	BIA	Qal
15	01	70	0 09	30	211	270	450	989	667	7 9	90	USGS	Pgs
—	3 5	46	02	12	204	226	430	1,010	672	8 3	1 25	BIA	Pgs
—	03	42	02	T	213	1,817	2,030	3,440	3,440	8 0	1 65	BIA	Jz
11	05	70	—	—	210	0	18	700	532	8 3	17 0	USGS	℞c
—	08	1 2	T	82	248	—	10	740	455	8 8	24 16	BIA	℞c
—	43	4 4	T	1 16	243	—	10	990	621	8 8	29 4	BIA	℞c
—	08	2 2	05	72	203	—	5 0	730	431	9 0	30 59	BIA	℞c
16	99	1 6	—	—	340	0	170	1,850	922	—	8 80	USGS	℞c
—	02	58	T	T	269	206	475	1,050	694	7 5	1 13	BIA	℞c
—	T	42	T	05	243	—	185	830	480	7 8	3 25	BIA	℞c
15	01	60	—	—	280	130	410	1,400	968	7 1	3 90	USGS	℞c
14	02	50	—	—	220	250	470	1,150	966	8 1	3 00	USGS	Pgs-Qal
14		50	03	12	250	260	510	1,100	740	7 3	1 10	USGS	Pgs
15	01	50	—	—	270	250	520	1,050	761	7 0	1 0	USGS	Pgs
9 5	01	30	—	—	150	56	210	900	725	7 6	4 9	USGS	Kg
—	0 02	0 29	T	0 42	254	631	885	2,450	1,821	7 5	3 58	BIA	Qal
—	01	28		12	222	498	720	1,600	1,143	7 9	158	BIA	Qal
—	18	92	0 02	42	223	—	10	850	531	9 0	26 94	BIA	Kg
—	02	52	T	05	245	945	1,190	2,720	2,290	8 2	2 61	BIA	Qal
8 8	3 2	30	—	—	260	1,600	1,900	3,315	2,940	6 8	1 60	USGS	Qal
—	01	—	T	50	179	220	—	1,140	730	7 9	1 99	BIA	Pgs
6 0	02	10	—	—	65	72	140	362	218	—	0 80	USGS	Qal

Table 3. Water-quality analyses from wells and springs on and adjacent to Zuni tribal lands (including trace-element and radiochemical analyses from selected wells and springs) - Continued

Name of well or spring	Location	Date	Temperature (°C)	Major cations: Calcium (mg/L)	Major cations: Magnesium (mg/L)	Major cations: Sodium (mg/L)	Major cations: Potassium (mg/L)	Major anions: Bicarbonate (mg/L)	Major anions: Carbonate (mg/L)	Major anions: Chloride (mg/L)	Major anions: Sulfate (mg/L)	Major anions: Nitrate (mg/L)
Ondelacy	9 18 19 442	08-21-79	14 0	14	1 0	650	1 1	—	—	350	900	02
Dowa Yallane Spring	9 19 1 144	04-05-79	16 5	36	8 0	39	1 8	219	0	22	14	21
Upper Willow Wash Spring	9 19 31 323	04-07-78	11 0	64	10	96	1 5	244	0	66	120	13
A-1	9 20 8 223	07-26-72	14 0	214	33	349	2 0	252	17	514	495	2 1
Pablito Chavez	9 20 18 432	07-27-72	—	62	7 3	117	T	315	10	23	126	12
ECW-2	9 21 11 314	08-01-72	17 0	18	3 6	53	2 3	136	10	18	24	9 9
Romancito	9 21 25 433	12-05-79	14 0	98	6 7	130	1 1	293	0	100	110	19
Ramah Mutual	10 15 17 414	09-30-75	32 0	74	25	12	1 6	251	7 3	7 5	84	62
ECW-13	10 16 32 114	07-31-72	16 0	14	2 4	376	4 7	336	28	171	333	62
Lower Pescado Spring	10 17 12 431	06-18-79	14 0	42	14	43	3 2	244	—	19	39	80
Fidel Chahate	10 17 12 433	12-15-70	—	58	19	49	3 5	284	15	12	70	1 9
Upper Pescado Spring	10 17 12 442	06-18-79	14 5	40	14	39	3 2	244	—	10	35	82
ECW-6	10 17 35 412	07-31-72	20 0	6 0	1 2	248	4 7	229	26	21	299	62
Yellowhouse Testhole 7	10 18 11 141	- -71	—	41	7 9	146	T	192	T	32	250	—
RWP-17 (new)	10 18 22 333b	08-08-72	13 0	44	9 7	110	T	198	19	7 1	190	0 62
Black Rock Spring	10 19 13 224	08-03-72	—	46	4 9	46	0 78	209	10	8 9	43	4 3
Do	do	02-26-80	14 0	47	4 3	52	1 0	232	0	10	40	1 2
Black Rock PHS	10 19 13 444	02-27-80	21 0	110	27	120	9 1	87	0	34	540	03
Zuni Z-6	10 19 22 231	07-06-76	—	8 0	1 2	281	1 6	404	31	55	201	42
Zuni H-1	10 19 22 241	07-22-78	15 0	67	7 0	100	3 9	341	0	19	91	77
Zuni Z-3	10 19 22 244	07-07-76	—	24	3 6	283	3 1	453	26	51	202	56
Zuni Z-2	10 19 22 421	07-06-76	—	58	9 7	207	2 0	342	7 6	64	245	56
Zuni Z-5	10 19 22 433	07-06-76	20 5	4 0	T	299	2 4	387	29	62	174	56
Zuni Z-1 (Max Curtis)	10 19 23 134	12-15-75	—	40	3 6	182	78	360	T	34	144	62
Zuni Z-4	10 19 23 143	07-06-76	—	16	1 2	202	1 6	311	16	32	129	1 5
Black Rock 1	10 19 24 122a	07-22-66	—	71	13	70	2 0	302	5 1	25	103	1 24
Black Rock 3	10 19 24 122b	03-28-68	26 6	155	22	124	8 5	198	T	33	551	25
Do	do	08-03-72	—	162	27	114	11	226	T	28	555	62
Black Rock 2	10 19 24 221	08-03-72	20 0	14	2 4	540	1 2	384	31	277	507	62
Zuni F-5	10 19 27 112	02-13-73	26 6	150	29	79	4 3	229	T	11	442	12
St Anthony Mission	10 19 28 114	08-03-72	20 0	46	2 4	1,042	3 1	143	21	1,084	748	62
Zuni F-4	10 19 28 131	08-03-72	—	24	1 2	292	2 0	560	24	88	109	62
Zuni F-3	10 19 28 141	08-03-72	18 0	6 0	1 2	331	9 0	354	32	164	189	1 2
Pat Kelsey	10 19 28 314	08-03-72	20 0	6 0	1 2	365	T	662	32	73	157	0 62
Zuni F-1	10 19 28 343	08-03-72	20 0	4 0	1 2	461	T	394	32	48	181	62
Do	do	07-30-80	20 0	5 2	30	330	2 0	439	—	67	240	02

Silica (mg/L)	Iron (mg/L)	Fluoride (mg/L)	Phosphate as ortho-phosphate (mg/L)	Boron (mg/L)	Total alkalinity $CaCO_3$ (mg/L)	Hardness Non-carbonate (mg/L)	Hardness Ca/Mg (mg/L)	Specific conductance	Dissolved solids (mg/L)	pH (units)	Sodium adsorption ratio	Lab	Geologic unit
4 0	04	2 8	—	—	96	0	39	2,650	1,980	8 9	45	USGS	℞c
16	01	40	—	—	180	0	120	500	246	—	1 50	USGS	℞c
20	01	1 7	—	—	200	1 0	200	910	500	—	2 90	USGS	Tb?
—	T	92	T	72	207	463	670	2,880	1,850	7 8	586	BIA	Qal
—	T	64	02	20	259	—	185	830	457	7 9	3 73	BIA	Qal
—	T	25	02	T	112	—	60	350	215	8 4	2 89	BIA	℞c
20	04	30	—	—	240	32	270	900	695	7 5	3 40	USGS	Qal
14	T	37	T	T	206	57	275	550	340	8 0	0 30	BIA	Pgs
—	T	3 8	T	66	278	—	45	1,780	1,085	8 8	24 38	BIA	Kd
35	01	30	—	—	200	0	160	420	319	7 6	1 50	USGS	Qal
—	35	44	04	—	—	—	223	600	370	8 4	1 42	BIA	Qal
35	01	30	—	—	200	0	160	410	300	7 7	1 40	USGS	Qal
—	T	2 1	T	42	188	—	20	1,190	749	8 8	24 15	BIA	Kd
—	—	68	T	—	157	—	135	900	570	8 3	547	BIA	Qal
—	0 01	0 44	T	T	163	—	150	770	472	8 0	3 89	BIA	℞w
—	T	37	05	T	172	—	135	460	252	8 0	1 73	BIA	Qal
18	45	30	25	—	190	0	140	405	293	7 7	1 90	USGS	Qal
4 4	80	60	03	—	71	320	390	1,150	889	7 2	2 70	USGS	Pgs
—	20	86	04	70	383	—	25	1,150	790	8 8	24 40	BIA	℞c
14	03	70	43	19	280	0	200	776	474	7 6	3 10	USGS	℞c
—	02	56	02	62	415	—	75	1,360	802	8 6	14 21	BIA	℞c
—	02	64	T	55	296	—	185	1,230	709	8 4	6 62	BIA	℞c
—	05	1 6	33	70	365	—	10	1,330	826	8 8	41 11	BIA	℞c
—	T	T	T	03	295	—	115	880	486	8 1	7 37	BIA	℞c
—	13	60	T	55	283	—	45	940	622	8 7	13 12	BIA	℞c
—	07	40	006	02	252	0	125	780	454	7 9	2 00	BIA	Qal
—	15	1 3	T	10	162	315	477	1,470	1,068	7 8	2 48	BIA	Pgs
—	02	1 3	T	28	186	329	515	1,400	994	7 7	2 18	BIA	Pgs
—	T	6 0	T	2 0	315	—	45	2,510	1,561	8 4	35 04	BIA	℞c
—	55	1 0	T	12	188	307	495	1,190	884	7 7	1 55	BIA	Pgs
—	T	1 8	T	98	117	8	125	5,080	2,899	8 3	40 56	BIA	Qal
—	T	1 9	T	58	459	—	65	1,330	760	8 2	15 75	BIA	℞c
—	T	2 0	T	72	290	—	20	1,520	910	8 7	32 15	BIA	℞c
—	0 06	0 50	0 18	0 34	543	—	20	1,570	967	8 4	35 51	BIA	℞c
—	T	2 6	02	82	323	—	15	1,190	742	8 7	30 42	BIA	℞c
11	04	1 9	06	—	360	0	14	1,400	874	8 3	38 01	USGS	℞c

Table 3. Water-quality analyses from wells and springs on and adjacent to Zuni tribal lands (including trace-element and radiochemical analyses from selected wells and springs) - Continued

Name of well or spring	Location	Date	Temperature (°C)	Major cations: Calcium (mg/L)	Major cations: Magnesium (mg/L)	Major cations: Sodium (mg/L)	Major cations: Potassium (mg/L)	Major anions: Bicarbonate (mg/L)	Major anions: Carbonate (mg/L)	Major anions: Chloride (mg/L)	Major anions: Sulfate (mg/L)	Major anions: Nitrate (mg/L)
Nastacio---------	10 19 30 232	08-02-72	—	34	7 3	189	T	542	25	44	3 4	62
Zuni F-2 --------	10 19 33 121	08-03-72	20 0	8 0	1 2	356	T	561	19	66	251	62
RWP-27 --------	10 20 8 243	07-25-72	14 0	64	6 1	17	1 17	143	14	20	21	33
Irrigation 1 ------	10 20 18 314	07-26-72	—	62	4 9	22	2 0	117	11	43	27	34
Do --------------	do	09-05-79	17 5	53	4 9	25	2 6	134	—	34	23	7 3
Bosson Ranch ---	10 20 22 211	07-25-72	16 0	62	7 3	108	T	306	25	53	61	1 6
ECW-9 ---------	10 20 32 421	09-04-79	28 5	6 1	50	350	2 2	451	0	51	320	11
RWP-28 --------	11 16 8 131	08-16-72	—	140	34	160	5 5	315	12	21	471	62
Nutria Campground --------	11 17 5 322	07-31-72	22 0	14	2 4	145	2 0	267	24	5 3	105	62
ECW-14 --------	11 17 24 432	11-06-79	14 0	140	50	15	5 2	390	—	15	530	09
ECW-10 --------	11 17 28 143	07-31-72	13 5	34	12	367	6 3	387	21	12	547	62
ECW-1 ---------	11 18 21 132	10-23-63	13 0	—	—	—	—	—	—	8 9	434	—
RWP-34 --------	11 18 27 411	07-31-72	—	42	13	172	4 7	228	15	1 8	327	62
Do --------------	do	08-10-72	14 5	42	12	167	T	214	20	5 3	320	62
RWP-38 --------	11 20 22 211	09-05-79	19 5	32	8 2	24	1 2	159	0	7 2	11	1 4
Spring -----------	11 20 34 244	03-26-80	8 0	8 8	2 1	78	70	207	—	5 6	10	69
RWP-32 --------	12 16 7 331	08-01-72	16 0	74	27	158	8 2	402	19	60	196	0 62
Nutria Spring ---	12 16 8 314	12-14-50	11 0	78	26	8 5	—	283	—	8 0	72	0 50
Spring near Nutria --------	12 16 17 214	03-26-80	4 0	100	8 3	8 5	1 70	317	—	10	35	0 08
RWP-29 --------	12 16 30 242	11-06-79	14 5	41	9 8	170	3 8	402	—	20	120	0 13
ECW-16 --------	12 17 15 213	11-13-79	—	56	21	69	4 2	329	0	20	90	0 14
Hand pump -----	12 17 23 244	08-01-72	12 0	126	51	171	2 0	349	13	122	337	86
Z-7R-----------	12 17 32 323	04-01-76	—	60	22	55	2 7	367	T	11	53	T
16T-567 --------	12 18 28 434	06-20-73	—	34	8 5	49	2 4	218	16	3 6	6 2	0 25
Jones Ranch PM-3 ---------	12 20 17 133	09-24-73	—	38	8 5	39	2 0	146	14	28	37	11
Cheechilgeetho School --------	12 20 25 123	06-13-52	—	—	—	586	—	249	7	340	656	—
16T-545 --------	12 21 24 423	10-11-72	—	4 0	T	124	T	194	51	13	4 8	0 62

						Hardness							
Silica (mg/L)	Iron (mg/L)	Fluoride (mg/L)	Phosphate as ortho-phosphate (mg/L)	Boron (mg/L)	Total alkalinity $CaCO_3$ (mg/L)	Non-carbonate (mg/L)	Ca/Mg (mg/L)	Specific conductance	Dissolved solids (mg/L)	pH (units)	Sodium adsorption ratio	Lab	Geologic unit
—	03	1 0	02	58	444	—	115	990	541	8 3	7 67	BIA	Qal
—	T	54	02	34	460	—	25	1,620	1,003	8 3	31 00	BIA	TRc
—	T	21	T	12	118	67	185	450	256	7 7	54	BIA	Tb
—	T	20	T	1 9	96	79	175	470	269	8 0	72	BIA	Tb
22	02	40	—	—	110	43	150	360	263	8 4	90	USGS	Tb
—	T	33	T	50	251	—	185	800	458	7 8	3 46	BIA	TRc
10	40	6 2	—	—	370	0	17	1,300	969	8 3	37	USGS	TRc
—	T	35	T	T	—	231	490	1,360	971	8 6	3 14	BIA	Kc
—	T	1 5	T	20	219	—	45	700	428	8 8	9 38	BIA	Kg
15	—	40	—	—	320	240	560	1,300	1,100	7 6	2 80	USGS	Kg
—	02	39	T	T	318	—	135	1,810	1,199	8 1	13 75	BIA	Kd
—	—	—	—	—	—	—	—	1,020	—	—	—	USGS	Jz
—	T	29	02	12	187	—	160	1,030	685	8 4	5 93	BIA	Kd
—	T	25	T	T	176	—	155	970	668	8 9	5 85	BIA	Kd
21	06	30	—	—	130	0	110	240	189	8 1	1 00	USGS	Jz
17	73	30	—	—	170	0	31	325	229	8 1	6 10	USGS	TRc
—	0 01	0 56	T	0 20	330	—	295	1,190	632	8 2	3 99	BIA	Kg
8 4	—	30	—	—	—	—	341	573	341	—	—	USGS	Pgs
11	03	20	—	—	260	24	280	500	331	8 2	0 20	USGS	Pgs
10	—	1 9	—	—	330	0	140	900	575	7 8	6 20	USGS	Kc
22	01	40	—	—	270	0	230	811	446	8 0	2 00	USGS	Kc
—	T	52	03	28	286	239	525	1,660	1,098	8 2	33 32	BIA	Qal
—	T	98	02	19	301	—	240	660	342	7 9	1 6	BIA	Kc
—	T	26	T	11	179	—	120	420	254	8 5	1 95	BIA	Kg
—	T	30	03	T	120	10	130	410	246	8 0	1 49	BIA	Jz
—	—	80	—	—	—	0	107	2,760	—	—	—	USGS	Pgs
—	18	—	T	32	—	—	10	530	339	9 2	17 11	BIA	TRc

Table 3. Water-quality analyses from wells and springs on and adjacent to Zuni tribal lands (including trace-element and radiochemical analyses from selected wells and springs) - Concluded

Part B—Trace-element and radiochemical

Well or spring	Location	Geologic unit	Date of sample	Arsenic (µg/L)	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)
Black Rock Spring--	10 19 13 224	Qal	02-26-80	2 0	200	4 0	0 0	1 0	0 0	60	0 0
Black Rock PHS----	10 19 13 444	Pgs	02-27-80	2 0	20	16	0	0	0	340	0
Zuni Z-6 -----------	10 19 22 231	₨c	07-06-76	4 0	T	T	T	—	T	—	T
Zuni Z-3 -----------	10 19 22 244	₨c	07-07-76	4 0	10	T	T	—	T	—	T
Zuni Z-2 -----------	10 19 22 421	₨c	07-06-76	4 4	41	T	T	—	T	—	T
Zuni Z-5 -----------	10 19 22 433	₨c	07-06-76	8 9	T	T	T	—	T	—	T
Zuni Z-4 -----------	10 19 23 143	₨c	07-06-76	3 0	20	T	T	—	T	—	T
Zuni F-1 -----------	10 19 28 343	₨c	07-30-80	1 0	40	1 0	0	4 0	3 0	20	0
ECW-1 ------------	11 18 21 132	Kd	06-19-80	1 0	40	1 0	0	0	1 0	—	0
Z-7R---------------	12 17 32 323	Kc	04-01-76	5 4	T	T	T	—	T	—	—

analyses from selected wells and springs

Selenium (μg/L)	Silver (μg/L)	Zinc (μg/L)	Gross alpha as natural uranium (pCi/L)		Gross beta as cesium 137 (pCi/L)		Gross beta as strontium 90 (pCi/L)		Gross alpha as uranium-sodium (μg/L)		Dissolved potassium 4Q (pCi/L)	Dissolved uranium (μg/L)
			dissolved	suspended	dissolved	suspended	dissolved	suspended	dissolved	suspended		
2 0	1 0	10	4 3	—	< 1 8	—	< 1 8	—	< 52	—	0 7	1 7
0	0	30	< 110	—	9 3	—	9 5	—	< 160	—	6 8	< 6
T	T	—	—	—	—	—	—	—	—	—	—	—
T	T	—	—	—	—	—	—	—	—	—	—	—
T	T	—	—	—	—	—	—	—	—	—	—	—
T	T	—	—	—	—	—	—	—	—	—	—	—
T	T	—	—	—	—	—	—	—	—	—	—	—
0	0	30	< 10	—	< 7 3	—	< 7 0	—	< 15	—	1 5	5 0
0	0	3 0	< 8 2	< 0 4	< 5 5	< 0 7	< 5 3	< 0 7	< 12	< 0 6	—	—
T	T	—	—	—	—	—	—	—	—	—	—	—

Table 4. Reservoirs along the Zuni River and its tributaries

[R, recreation, I, irrigation, S, sediment control, —, no data Modified from Rossillon and Lewandowski, 1969, Summers, 1972]

Reservoir name	Stream	Date completed	Drainage area (square miles)[1]	Capacity (acre-feet/date)	Surface area (acres)	Use	Irrigated area (acres)	Remarks
McGaffey	Rio Nutria	—	—	—	12	R	—	—
Nutria Diversion	Rio Nutria	1922	80	15/1969	25	I	1,503	Replaced in 1932 because washed out, repaired in 1974
Nutria No 3	Rio Nutria	1934	68	461/1968	265	S	0	Original capacity 1,076 acre-feet
Nutria No 4	Rio Nutria	1938	(2)	878/1969	88	R	0	—
Nutria No 2	Rio Nutria	1932	31	2560/1969	418	R	0	Failed in 1933, rebuilt in 1934
Ramah	Rio Pescado	Early 1900's	58	13,000/1969	482	I	—	Failed and rebuilt in 1910, failed in 1930's, rebuilt in 1936
Pescado	Rio Pescado	1931	68	720/1969	120	I	1,250	Raised top, 1943
Black Rock	Zuni River	1908	692	2,600/1969	436	I,F,R	3,603	—
Eustace	Zuni River	1958–59	7	230/1969	32	R	3,603	—
Tekapo	Zuni River	—	—	300/1972	104	I	315	—
Ojo Caliente	(3)	—	—	250/1972	61	I,R	1,553	—

[1]Excluding drainages contributing to upstream reservoirs
[2]Receives water from Nutria No 3
[3]Receives water from Ojo Caliente Spring

Table 5. Water-quality and sediment analyses from streams

[All measurements in milligrams per liter unless otherwise noted, —, no data, analyses by U S Geological Survey]

Part A.—Water-quality analyses

Stream	Rio Nutria above Nutria	Zuni River above Black Rock					
Date of collection	02-22-80	06-20-79	11-07-79	01-18-80	02-22-80	02-26-80	04-09-80
Instantaneous discharge (cubic feet per second)	31	200	0 85	3 9	227	56	771
Water temperature (degrees Celsius)	2 0	12 5	6 0	3 0	4 5	3 0	10 5
Calcium	29	35	59	69	31	35	—
Magnesium	7 9	17	21	24	11	8 1	—
Sodium	4 3	27	65	78	18	17	—
Potassium	1 1	3 7	5 3	4 7	3 2	3 3	—
Bicarbonate	115	207	305	329	134	122	—
Carbonate	—	—	—	—	—	—	—
Chloride	3 1	6 5	15	24	7 2	11	—
Sulfate	16	40	89	140	36	29	—
Nitrate	3 1	0	0	—	4 0	—	—
Silica	9 4	6	21	15	4 9	8 8	—
Iron (micrograms per liter)	—	20	—	50	—	560	—
Fluoride	3	4	3	3	3	2	—
Phosphate as orthophosphate	21	—	—	—	03	—	—
Boron (micrograms per liter)	—	—	110	—	—	—	—
Total alkalinity as calcium carbonate	94	170	250	270	110	100	—
Noncarbonate hardness	11	0	0	1 0	13	11	—
Calcium-magnesium hardness	110	160	230	270	120	120	—
Specific conductance (micromhos per centimeter at 25°Celsius)	224	370	681	828	310	287	—
Dissolved solids	128	232	426	517	178	180	—
pH (units)	8 0	8 1	8 4	8 0	8 0	7 8	—
Sodium adsorption ratio (SAR) (unitless)	2	9	1 9	2 1	7	7	—

Table 5. Water-quality and sediment analyses from streams - Concluded

Part B.—Sediment analyses

Stream	Date of sample collection	Instantaneous discharge (cubic feet per second)	Water temperature (degrees Celsius)	Sediment, suspended	Remarks
Zuni River above Black Rock-----	06-20-79	200	12 5	44	
Do	11-07-79	88	6 0	25	99 percent smaller than 0 062 millimeter
Do	11-13-79	1 3	2 0	111	—
Do	12-17-79	2 0	1 0	45	92 percent smaller than 0 062 millimeter
Do	01-18-80	3 9	3 0	216	—
Do	02-11-80	2 2	2 0	121	—
Do	02-22-80	247	4 5	962	88 percent smaller than 0 062 millimeter
Do	03-06-80	195	8 5	217	—
Do	03-10-80	126	7 0	206	—
Do	03-12-80	106	12 0	203	—
Do	03-14-80	94	11 0	216	—
Do	03-18-80	157	—	441	—
Do	03-24-80	290	4 0	427	—
Do	04-02-80	94	13 5	137	—
Do	04-04-80	98	13 5	1,320	—
Do	04-06-80	162	6 5	453	—
Do	04-09-80	771	10 5	388	—
Do	04-18-80	441	17 0	2,090	—
Do	05-14-80	7 8	16 0	27	—
Do	06-06-80	0 25	21 0	39	—

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