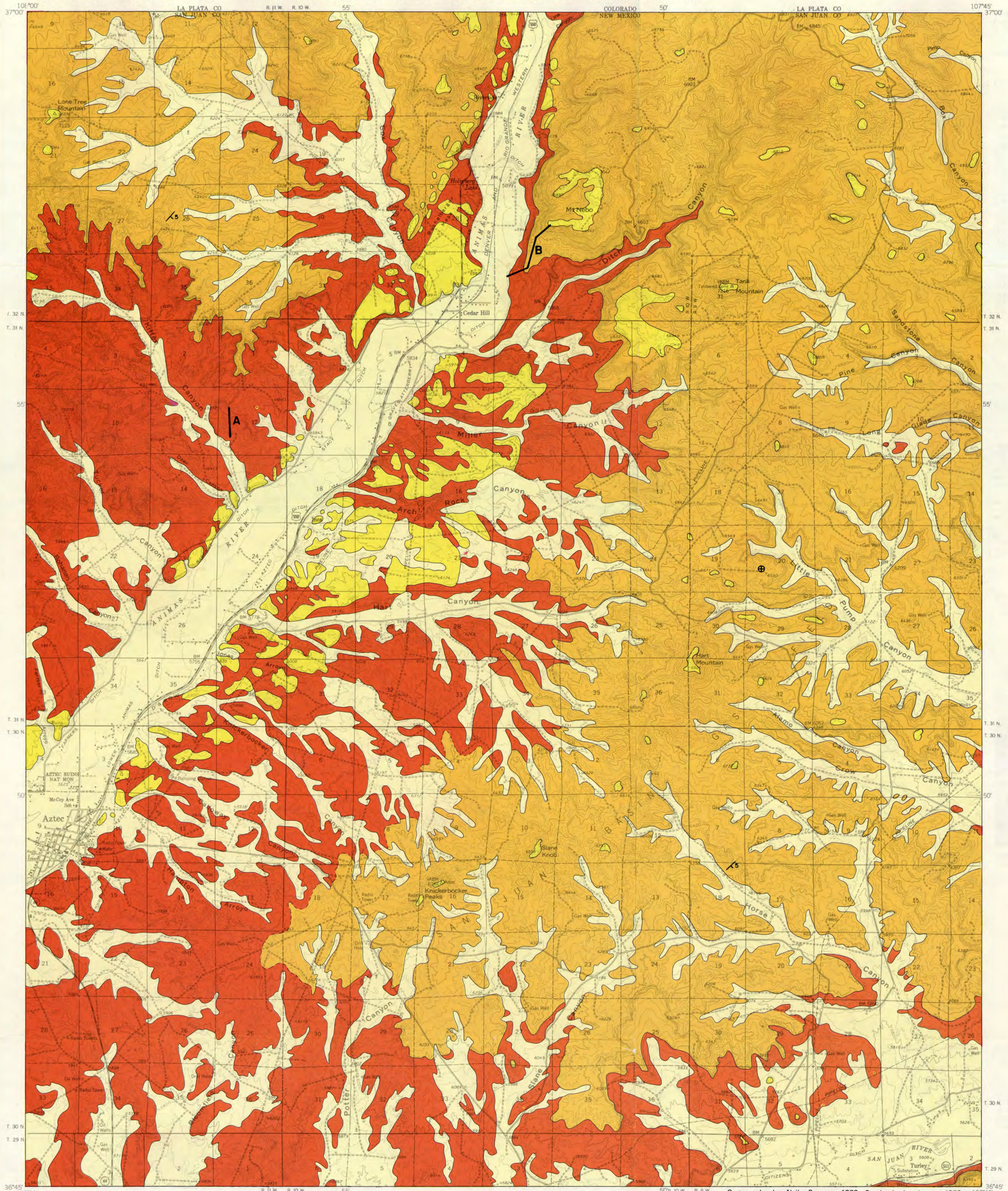
NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

HYDROGEOLOGIC SHEET I

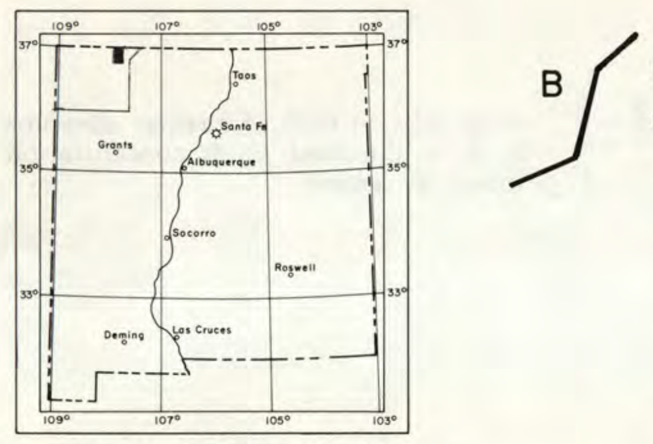
Hydrogeology of Aztec quadrangle, San Juan County, New Mexico

by Daniel R. Brown and William J. Stone

1979



Cartography by Neila Pearson, 1978, Stephanie Landregan, 1979



INDEX MAP OF NEW MEXICO
showing location of Aztec quadrangle in San Juan County

B — Lines of section shown in fig. 4

APPROXIMATE MEAN DECLINATION 1979

Qal Alluvium (Quaternary) — *Valley fill deposits of gravel, sand, silt, and clay*

Qtp Terrace and pediment deposits (Quaternary) — *Veneers of gravel and sand along valleys and on mesa tops*

Tsj San Jose Formation (Eocene) — *Yellow, coarse, conglomeratic, crossbedded and massive sandstone; gray, green, and purple claystone, shale, and siltstone*

Tn Nacimiento Formation (Paleocene) — *Gray, green, and purple claystone, shale, and siltstone; gray and yellow coarse, conglomeratic crossbedded and massive sandstone*

Strike and dip of beds

$\underline{\perp}^5$ *Inclined* ⊕ *Horizontal*

1 1/2 0 1 2 3 4 mi
1 .5 0 1 2 3 4 5 km
SCALE 1:62500
CONTOUR INTERVAL 40 FEET DATUM IS MEAN SEA LEVEL

FIGURE 3— GEOLOGIC MAP OF AZTEC QUADRANGLE.

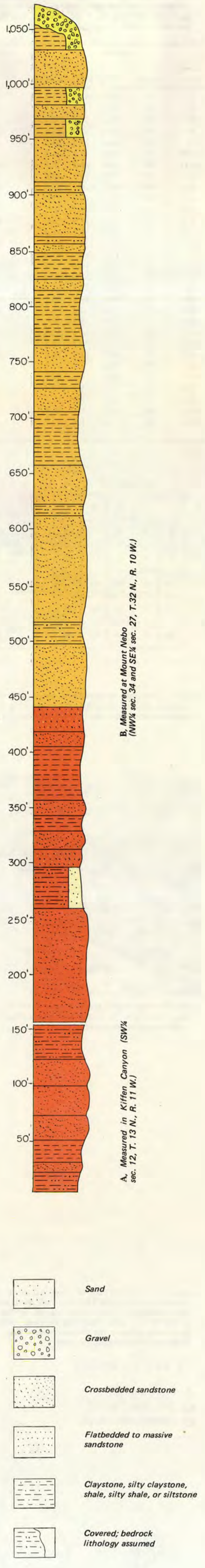


FIGURE 4 —COMPOSITE STRATIGRAPHIC COLUMN FOR ROCKS AT THE SURFACE IN AZTEC QUADRANGLE.

Abstract

The Aztec 15-minute quadrangle lies about 15 mi northeast of Farmington in northeastern San Juan County, New Mexico, near the center of the San Juan structural basin. Although drained by the Animas and San Juan Rivers, the area is semiarid to arid. Quaternary alluvium or terrace deposits, together with the San Jose and Nacimiento Formations (Tertiary), cover the surface. The area has relied heavily on surface-water supplies, but population growth is intensifying competition for this water. Because virtually all surface water is appropriated, water for future municipal or industrial use must be either ground water or negotiated surface water. The most significant source of ground water is the Quaternary alluvium in the river valleys: yields of up to 500 gpm are possible; total dissolved-solids content ranges from about 300 to 1,900 ppm. Sandstones of the San Jose Formation offer the best potential for a bedrock source of ground water. Yields of up to 1,200 gpm have been predicted for this unit east of the study area. Total dissolved-solids content of spring waters from the San Jose ranged from 110 to 1,528 ppm. The underlying Nacimiento Formation has yielded variable quantitites and qualities of ground water; the coarse sandstones in the upper part of this unit have the best potential. The Ojo Alamo Sandstone, underlying the Nacimiento, is the only unit of those not exposed in the area that has any potential for ground-water development. Reported yields range from 35-180 gpm; total dissolved-solids content may exceed 1,000 ppm, but values ranging from 360 to 824 ppm have been reported outside the Aztec quadrangle. Deeper units are too costly to develop and hold waters of inferior quality for most uses.

THE HYDROGEOLOGIC SHEET SERIES

1 Before 1971 the New Mexico Bureau of Mines and Mineral Resources published most of its water-resource data in the Ground-water Report series. That series was discontinued in 1971 and superseded by the Hydrologic Report series. Both series have presented results of water-resource studies of large areas (one or more counties). On the other hand, published results of water-resource studies of smaller areas have been scattered among other Bureau publications (Stone, 1976). Many of these studies, published in the Bureau's Circular series, lack the illustrations typical of the Hydrologic Reports. To facilitate the documentation, distribution, and use of the results of water-resource studies of small areas, a new series—Hydrogeologic Sheets—is initiated with this report on the Aztec quadrangle. The specific objectives of this series are to provide a single outlet for water-resource studies of small areas, to present results in a condensed and convenient style with emphasis on illustrations, and to make basic water-resource information for small areas available at less cost than is possible for the Hydrologic Reports. Paragraphs are numbered to facilitate citation.

2 Technical terms used in the text are explained in the section on Hydrogeologic Principles (found in the box on back of this sheet). Most quantitative information is given in English units, followed by metric units in parentheses. Chemical concentrations are given only in English units (ppm—parts per million). For concentrations less than 7,000 ppm, the ppm and mg/l (milligrams per liter, the metric equivalent) values are about the same. Values for elevation, distance, depth, thickness, and volume are often estimated or generalized for regional applications and thus are often rounded to the nearest hundred units. Metric equivalents for such values are rounded to the nearest five units. Where the English values are small or obviously precise, we have attempted to present similarly precise metric equivalents. Metric equivalents were calculated by multiplying English units by conversion factors as follows:

English unit ×	**conversion factor** =	**metric unit**
acres (not abbreviated)	0.4047	hectares (ha)
acre-feet (acre-ft)	0.0012335	cubic hectometers (hm^3)
feet (ft)	0.3048	meters (m)
feet squared per day (ft^2/d)	0.0929	meters squared per day (m^2/d)
gallons (gal)	0.00379	cubic meters (m^3)
gallons per minute (gpm)	5.45	cubic meters per day (m^3/d)
gallons per minute (gpm)	0.0639	liters per second (l/s)
gallons per day (gpd)	0.003785	cubic meters per day (m^3/d)
inches (not abbreviated)	2.54	centimeters (cm)
miles (mi)	1.6093	kilometers (km)
square miles (mi^2)	2.59	square kilometers (km^2)

3 All wells, springs, and samples are identified in the tables by two numbers. The first is a short letter-numeral combination in which the letter identifies the aquifer and the numeral is a field number assigned during inventorying or sampling. Because this letter-numeral combination is the shorter designation, it is used on the maps and figures and in the text.

4 The other system of numbering used is that used by the New Mexico State Engineer and is based on the township, range, and section land grid (fig. 1 on back of sheet). In this system each well or spring has a unique location number consisting of four parts separated by periods: 31N.10W.24.213. The first part refers to the township, the second designates the range, and the third identifies the section (fig. 1A). The fourth part locates the well or spring within the section to the nearest 10-acre tract (fig. 1B): each section is divided into quarters, which are assigned numbers such that the northwest quarter is number 1, the northeast quarter is number 2, the southwest quarter is number 3, and the southeast quarter is number 4. Each quarter section is then divided into quarters numbered in the same manner. Each quarter-quarter section is similarly divided and numbered. If the location of a well or spring cannot be determined to quarter-quarter section or quarter-quarter-quarter section, a zero is used in the appropriate position in the fourth part of the number. A well designated 31N.10W.24.213 is located in the SW¼NW¼NE¼ sec. 24, T. 31 N., R. 10 W. (fig. 1). A spring located in the NW¼ sec. 31, T. 2 S., R. 1 W. would be numbered 2S.1W.31.100. In unsurveyed areas, locations are approximated by constructing a township grid on the best available map. In this report, all townships are N., and all ranges are W.; therefore, compass designations are not used in location numbers. Location 31N.10W.24.213 will read 31.10.24.213.

era	system	series	stratigraphic unit	general lithology	approximate maximum thickness (ft)	depth to top of unit (ft)	maximum anticipated well yields (gpm)	water quality	remarks
Cenozoic	Quaternary	Holocene	valley fill	gravel, sand, silt, clay	100	at surface	500	TDS: 308–1,923 ppm	water table fluctuates 10-20 ft seasonally
		Pleistocene	terrace and pediment deposits	gravel, sand	30	at surface	could be high where saturated	not able to sample; probably quite good	not saturated; small quantities of perched water locally
	Tertiary	Eocene	San Jose Fm.	conglomeratic sandstone, mudstone	1,000	surface-30	1,200	TDS(springs): 110-1,528ppm	specific capacity generally < 2 gpm/ft
		Paleocene	Nacimiento Fm.	mudstone, sandstone	2,000	surface-1,000	100	TDS: 1,004-6,754 ppm SC: 1,120-4,500 μmhos	one well flowed to height of 2 ft above ground surface
			Ojo Alamo Ss.	conglomeratic sandstone, carbonaceous mudstone	225	700 - 3,000 (1,500 avg)	200	not able to sample	no wells known to tap this unit in study area; major aquifer elsewhere

FIGURE 2—GENERALIZED STRATIGRAPHY AND WATER-RESOURCE INFORMATION FOR THE AZTEC QUADRANGLE; TDS = total dissolved solids, SC = specific conductance.

THE AZTEC QUADRANGLE

5 The Aztec 15-minute quadrangle is located about 15 mi (25 km) northeast of Farmington in northeastern San Juan County, New Mexico. The population of about 7,000 people includes the communities of Aztec, Cedar Hill, and Turley. Aztec (population 6,000) is the San Juan County seat.

6 Land use and economy in the Aztec quadrangle are dominated by the petroleum industry and agriculture. Approximately 400 wells have been drilled since the discovery in 1920 of natural gas 1 mi (1.6 km) south of Aztec (Barnes, 1950). In the valleys, approximately 4,000 acres (1,620 ha) are irrigated for farming; the uplands are used for grazing beef cattle.

7 Residents of the area have relied heavily on surface-water supplies derived from the Animas and San Juan Rivers. As the regional population has grown with the increased industrial activity (especially energy-resource development), the competition for this limited surface water has intensified. However, virtually all surface water has been appropriated, and water for future use must be either ground water or negotiated surface water.

8 In response to growing interest in ground-water resources in northwestern New Mexico, the State Engineer declared the San Juan Basin an underground water basin on July 29, 1977. The purpose of declaring such basins is to protect existing surface-water rights from possible impairment by uncontrolled ground-water development. Once a basin is declared, its ground water is subject to appropriation, and development is strictly regulated. The detailed rules governing declared basins have been listed by the New Mexico State Engineer's Office (1966), and the ramifications of basin declaration have been suggested by Shomaker and Stone (1976).

9 Ground water has accounted for less than one percent of all water used in San Juan County because: 1) surface water has been readily available, 2) ground water has been considered to be too deep or too saline for use, and 3) little has been compiled on the ground-water potential of the area. In an effort to better define the ground-water resources of northwestern New Mexico, the U.S. Geological Survey, the New Mexico Bureau of Mines, and the Office of the State Engineer are cooperating in a study of the San Juan Basin. Although such a study is necessarily regional in scope, some appreciation of the water-resource situation on a local scale is being provided by detailed studies of selected 15-minute quadrangles. Because the Aztec quadrangle was one of those studied in conjunction with the large basinwide project, this report is intended in part to characterize the water-resource situation in the northern part of the basin—especially that of small communities experiencing water shortages because of reliance on surface-water supplies. The main purpose of this report, however, is to summarize the hydrogeology and ground-water potential of the Aztec quadrangle.

10 We wish to thank A. J. Budding and Allan Sanford, Geoscience Department, New Mexico Institute of Mining and Technology, for use of the department's triaxial apparatus and portable seismic unit. Subsurface data were obtained through A. R. Kendrick, New Mexico Oil Conservation Commission, Aztec, and Robert Bieberman, New Mexico Bureau of Mines and Mineral Resources. Chemical analyses were made under the direction of Lynn Brandvold, New Mexico Bureau of Mines and Mineral Resources. The use of water-well records on file with the U.S. Geological Survey, Albuquerque, and El Paso Natural Gas Company, Farmington, is also gratefully acknowledged.

REGIONAL SETTING

11 The topography is dominated by the flat-topped Mesa Mountains, which extend from Colorado into the northern part of the area, and by the extensively eroded divide between the Animas and San Juan Rivers. Numerous intermittent streams have cut narrow, steep-walled canyons through the sandstones and shales at the surface in the area. The maximum relief is greater than 1,600 ft (480 m), with a low elevation of 5,600 ft (1,707 m) in the river valleys and a high elevation of 7,216 (2,199 m) at Tank Mountain in the northeast. Local relief may exceed 1,000 ft (305 m) where undercutting along rivers has caused steep, high bedrock cliffs. In the southern and western parts of the areas, where shales cover the surface, badland topography has developed.

12 The Aztec quadrangle is drained by two major perennial streams: the Animas and San Juan Rivers. The Animas River rises in the San Juan Mountains of Colorado and flows southwesterly across the quadrangle, draining approximately 140 mi^2 (360 km^2) of the quadrangle. The average annual discharge is 814,200 acre-ft (1,005 hm^3) 4 mi (6.4 km) north of Cedar Hill (Cooper and Trauger, 1967). The San Juan River also rises in the San Juan Mountains of Colorado and flows westerly across the southeastern corner of the quadrangle, draining about 100 mi^2 (260 km^2) of the study area. The average annual discharge is 943,300 acre-ft (1,165 hm^3) at Archuleta, New Mexico, just outside the quadrangle to the east (Cooper and Trauger, 1967).

13 The climate is arid to semiarid with an average annual precipitation at Aztec Ruins National Monument of 9.33 inches (23.7 cm) for the period 1901 through 1960 (Maker and others, 1971). Almost half (45.4 percent) of the annual precipitation occurs from July through October. Most falls during intense thunderstorms in which runoff is great. The mean monthly temperature for July is 74° F (23° C) and for January is 29° F (-1.7° C); the mean annual temperature is 51.3° F (10.7° C). Winds are predominantly from the southwest. Annual class A pan evaporation at nearby Farmington averages 67.37 inches (171.12 cm) for the period 1948-1962 (Cooper and Trauger, 1967).

14 Six soil associations have been mapped and described in the quadrangle area (Maker and others, 1971). Soils developed on the Quaternary alluvium include the following associations: the Werlow-Fruitland-Turley, Doak-Shiprock, and Hilly gravelly land. All have slight to high irrigation potential. The soils developed on the Tertiary deposits include the following associations: Persayo-Farb, Badland-rock land, and Travessilla-rock land—none generally suited for irrigation.

15 The quadrangle is situated near the center of the San Juan structural basin, a broad, northwest-southeast-trending depression that formed during the Laramide orogeny. The basin is asymmetrical, with steeper dips or tilting of strata along the northeast margin; it is also deep and contains a thick sequence of sedimentary rocks. The total stratigraphic record exceeds 14,000 ft (4,270 m), as proved in the El Paso Natural Gas Company well near Gobernador (sec. 7, T. 29 N., R. 5 W.).

16 Quaternary alluvium or terrace deposits, together with the San Jose and Nacimiento Formations (Tertiary), cover the surface in the Aztec quadrangle (figs. 2, 3, and 4). The position of the contact between the Nacimiento Formation (Paleocene) and the overlying San Jose Formation (Eocene) has always posed a problem in the northern part of the San Juan Basin. In the south, the San Jose Formation lies on the Nacimiento Formation with angular unconformity (Baltz and West, 1967). In the north, however, the apparent continuous deposition in Paleocene and Eocene times (Reeside, 1924; Simpson, 1948) caused the gradational nature of the contact there. Its location has differed by as much as 5 mi on maps by Reeside (1924) and Dane and Bachman (1965). Fig. 3 shows this contact remapped in detail.

17 Criteria used in mapping the Nacimiento-San Jose contact were similar to those of Reeside (1924, p. 46): the contact was generally placed at the base of the first thick, erosion-resistant, coarse-grained sandstone above which a sandstone lithology dominated and surpassed shale lithology in thickness (fig. 5). In numerous places the contact is easily located by these criteria because a good portion of the Nacimiento Formation is exposed below. From these and other localities, the contact can be traced laterally with relative ease. In other areas, however, the contact is partially covered or uncertain because the San Jose Formation is poorly represented owing to erosion.

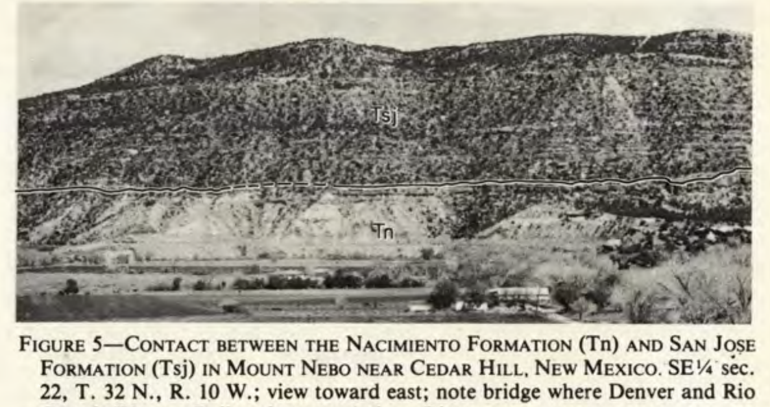


FIGURE 5—CONTACT BETWEEN THE NACIMIENTO FORMATION (Tn) AND SAN JOSE FORMATION (Tsj) IN MOUNT NEBO NEAR CEDAR HILL, NEW MEXICO. SE¼ sec. 22, T. 32 N., R. 10 W.; view toward east; note bridge where Denver and Rio Grande Western Railroad crosses Animas River.

18 The Nacimiento-San Jose contact varies in elevation across the study area—not surprising in view of the stream-channel origin of the San Jose sandstones. The most significant irregularity is the low near the Animas River in T. 32 N., R. 10 W., where the contact drops from an elevation of greater than 6,300 ft to less than 6,200 ft (1920-1990 m).

19 A major change in lithology of the lower part of the San Jose Formation is the much higher sandstone/shale ratio in the southeastern part of the study area. Basal sandstones in the northern part of the area seldom exceed 93 ft (28 m) in thickness; to the southeast more than 320 ft (98 m) of continuous sandstone were measured in the San Jose Formation in SW¼ sec. 19, T. 30 N., R. 8 W. (Brown, 1976, appendix A, measured section 8).

AQUIFERS

Valley fill (Quaternary)

20 The valleys of the Animas and San Juan Rivers and their major tributaries are partially filled with alluvium consisting of gravel, sand, silt, and clay (fig. 3). These materials, deposited by streams in Pleistocene and Recent time, are being eroded by gullying that began regionally about 1880 (Bryan, 1928).

21 In the valley of the Animas River, the alluvium consists predominantly of sand and gravel. This material is outwash from Pleistocene glaciers in the San Juan Mountains to the north (Bandoian, 1969). Most driller's logs report the thickness of the alluvium in the Animas Valley to be 40-100 ft (12-30 m). The average thickness appears to be approximately 60 ft (18 m) and generally occurs in the center of the valley. At the sites of two anomalous reported values for alluvium thickness (170 ft and 308 ft; 52 and 94 m), the depth to bedrock was determined with a small portable seismic unit. Soundings showed the alluvium to be less than 100 ft (30 m) thick in both cases and so compatible with the regional average.

22 Few data exist concerning the thickness of the valley fill of the San Juan River in the study area. The highest value on record is 54 ft (16.5 m) at well A25 (table 1). Rapp (1959) reported a maximum thickness of about 80 ft (25 m) for this aquifer in the Farmington area. This value may also apply to the Aztec quadrangle because well A25 probably only partially penetrates the alluvium. Area drillers admitted that they try to avoid going so deep that they encounter the underlying bedrock because salty waters are often concentrated near this contact.

23 The alluvial deposits of the Animas and San Juan River systems are the most important source of ground water in the Aztec quadrangle and provide moderate supplies of water to numerous shallow wells (table 1). While no yield data are available, a local driller reported that most domestic wells in the Animas River alluvium yield 10-20 gpm (55-110 m^3/d). He suggested that these values might be increased tenfold with improved construction and development, (John Gilbert, personal communication). Yields of up to 500 gpm (2,725 m^3/d) from properly completed wells in 70 ft (21 m) of similar saturated alluvium at Farmington were reported by Rapp (1959, p. 11).

24 The saturated thickness of the Animas River alluvium varies with the water-table position and the thickness of the valley fill. The water table fluctuates considerably throughout the year, depending on recharge by precipitation, irrigation, and Animas River flow. Because all of these are highest in the spring and summer and lowest in the winter, the water table is highest in August and drops to its lowest level during March.

25 An example of the seasonal water-table fluctuation comes from the Bishop well (A9, table 1 and fig. 9). Following a spring and summer of very high runoff in the Animas River, the depth to water on August 8, 1975, was 7.9 ft (2.4 m). After a very dry winter, the depth to water on February 26, 1976, was 19.3 ft (5.9 m). The owner reported that this drop of 11.4 ft (3.5 m) is typical.

26 In the numerous tributary canyons and arroyos of the Animas and San Juan Rivers, five wells were located that are believed to be completed in valley fill. Four have been abandoned in favor of small earthen reservoirs that had been constructed nearby to capture surface runoff.

27 The quality of water from the Animas River valley-fill aquifer is generally good. The average of 10 analyses of ground water samples is 43 percent sulphate, 18 percent sodium, 15 percent bicarbonate, 14 percent calcium, 4.5 percent chloride, 4 percent magnesium, and 0.5 percent potassium (table 3, fig. 9). These waters would be classified as calcium, magnesium, sodium, sulfate, bicarbonate waters (fig. 10). The average total dissolved-solids content is 732 ppm, and values range from 308 to 1,923 ppm. The quality of this water is generally good for two reasons: 1) the water is pumped from relatively clean sands and gravels (low in muddy matrix that contains readily soluble materials) and 2) the aquifers are near the surface and are recharged with relatively fresh water by runoff, irrigation return flow, and direct precipitation.

Terrace deposits (Quaternary)

28 Bandoian (1969) mapped six separate terrace levels in the Animas River valley. These features are actually outwash terraces, traceable to late Pleistocene moraines in the San Juan Mountains, Colorado (Richmond, 1965). The positions of these terrace levels, not distinguished on the geologic map (fig. 3), vary from 70-470 ft (21-143 m) above the present level of the Animas River. The terraces are capped by deposits of coarse, rounded gravels and sands varying in thickness from 6-18 ft (1.8-5.5 m) and are commonly overlain by up to 12 ft (3.7 m) of fine wind-blown material or loess.

29 In addition to the six terrace levels, remnants of higher gravelled surfaces occur on many topographic highs. One, the Mesa Mountain surface, is partially preserved on both sides of the Animas River, just south of the Colorado border, at an elevation of 6,800-7,000 ft (2,072-2,134 m). Gravel deposits associated with this surface are 20-30 ft (6-9 m) thick (Bandoian, 1969, p. 53). Atwood and Mather (1932) suggested that this surface is part of their San Juan peneplain, formed in late Pliocene time by erosion of the late Tertiary volcanic plateau occupying much of the San Juan region of Colorado. The significance of another high surface recognized by Bandoian is unclear (Brown, 1976, p. 31).

30 Although the terrace deposits probably hold small quantities of water, they are relatively thin; most recharge is probably lost through drainage at springs, evaporation, or infiltration into the bedrock below. Where the gravels are thicker and the water becomes temporarily perched on an impermeable layer, storage may exceed such losses; small yields could be expected, with quantity being directly related to saturated thickness.

31 Chemical analyses were not made, but water quality is likely to be best where precipitation has been the main source of recharge.

San Jose Formation (Eocene)

32 The San Jose Formation covers approximately half of the surface area of the Aztec quadrangle (fig. 3). This unit generally consists of coarse, yellow, cliff-forming sandstones interbedded with olive-green, gray, and purple shales and white slope-forming sandstones. The predominance of one lithology over the other was used by Baltz and West (1967) to subdivide the San Jose Formation into four intergrading members in ascending order: the Cuba Mesa, Regina, Llaves, and Tapacitos Members. This fourfold subdivision, used by Baltz and West in mapping on the Jicarilla Apache Indian Reservation, does not apply in the Aztec quadrangle. Possibly only the lower member (Cuba Mesa) is present. A major lithologic change was noted in the northern part of the area where part of the San Jose Formation is dominated by shale (fig. 4).

33 In the study area, the San Jose Formation consists predominantly of buff and yellow, conglomeratic, coarse to very coarse grained, thick-bedded sandstones (Brown, 1976). These sandstones, more abundant in the lower part of the formation, have a thickness of up to 320 ft (98 m) per layer and form steep cliffs in most places. In some localities, the thinner sandstones are lenticular and local, but most of the thicker units are continuous and can be traced in outcrop for 2-3 mi (3-5 km).

34 The San Jose shales are silty to sandy in texture and include interbedded, olive-green, light- to dark-gray, and purple shales, claystones, and siltstones as well as a few slope-forming gray-white sandstones.

35 The San Jose Formation was described by Reeside (1924) as lying "nearly horizontal" in the study area, but in T. 32 N., R. 12 W., he assigned it an easterly dip of one degree. Cross sections prepared by Brown (1976, pls. 4 and 5) show dips are southeasterly at 5° except locally where strata are horizontal.

36 Relatively few wells have been drilled in the San Jose Formation. Cooper and Trauger (1967) suggested, however, that the San Jose Formation, together with parts of the underlying Nacimiento Formation, "should be considered an important reservoir of large volume" in the eastern part of the San Juan Basin. These authors reported yields of up to 200 gpm (1,090 m^3/d); Baltz and West (1967) predicted yields of up to 1,200 gpm (6,540 m^3/d) from San Jose aquifers. The average total depth of 43 wells, reported by Baltz and West (1967, p. 28) to be in various members of the San Jose Formation on the Jicarilla Apache Indian Reservation, is 213 ft (65 m). Reported yields range from 0.2-60 gpm (1.09-327 m^3/d) and specific capacities range from 0.07-1.04 gpm/ft (0.2-0.7 l/s/m) of drawdown.

37 In the Aztec quadrangle, eight water wells are known to be completed in the San Jose Formation (table 1). Most of these wells were drilled in the 1950's by the El Paso Natural Gas Company to obtain drilling water. Most of the wells are now plugged or inaccessible, but company records report yields of 6-40 gpm (32-218 m^3/d) from individual sandstone units having thicknesses of 25-123 ft (8-38 m). Total depths range from 118-585 ft (36-178 m).

38 The San Jose sandstones have the properties of good aquifers: grains are generally well sorted and porosities of up to 25 percent have been determined microscopically (Brown, 1976, appendix B). Because of the lack of pumping-test data for the San Jose aquifers, measurement of the hydraulic conductivity of various San Jose sandstones was attempted in the laboratory by means of a triaxial compression apparatus. The crumbly nature of even the best surface samples that could be obtained made testing difficult. A hydraulic conductivity of .000605 cm/sec was determined for a small core subjected to a confining pressure of 600 psi (pounds per square inch) or 4140 kN/m^2 (kilonewtons per square meter), which simulates a depth of about 600 ft (185 m) (Brown, 1976, appendix F).

39 At various localities and elevations, springs issue from coarse San Jose sandstones. These springs are estimated to have discharges of less than 2 gpm (10 m^3/d); all issue at sandstone/shale contacts. The springs are generally marked by an overhang of coarse sandstone caused by undercutting and washing out of the softer shale below and the presence of cottonwood trees or other phreatophytes. Most springs in the study area are fenced and developed for stock by means of pipes, metal tanks, or concrete reservoirs.

40 Chemical analyses were not available for the El Paso Natural Gas Company water wells tapping the San Jose Formation. In the present study the quality of water from aquifers of the San Jose Formation has been determined only for spring waters (table 4). The average of analyses of 11 spring samples shows dissolved constituents in the following proportions: 28 percent calcium, 27 percent sulphate, 20 percent bicarbonate, 14 percent sodium, 8 percent magnesium, 2 percent chloride, and 0.4 percent potassium. Like those from the alluvium, these waters would also be classified as calcium, magnesium, sodium, sulfate, bicarbonate waters (fig. 10). Total dissolved-solids content of waters from the 11 springs averaged 515 ppm, varying from 110-1,528 ppm. The water quality is usually quite good and is comparable to that of waters from the alluvium (fig. 9)—probably because the water in both cases has not traveled far from the surface, has traveled through relatively clean sediment or rock material, and has been in the aquifer a relatively short time. Water can be expected to deteriorate in quality after traveling along a sandstone-shale interface or after coming to rest on weathered shale.

Nacimiento Formation (Paleocene)

41 The Nacimiento Formation covers more than a quarter of the surface area of the Aztec quadrangle (fig. 3). The formation generally consists of gray, olive-green, and purple shales and gray-white to yellow, soft to hard sandstones. In the study area, it is approximately 2,000 ft (610 m) thick. Electric logs from oil and gas wells show it to be silty or sandy throughout, but particularly so near the upper and lower boundaries (both gradational). Baltz and West (1967) discussed the Ojo Alamo–Nacimiento contact and suggested that intertonguing of Nacimiento sandstones is responsible for the apparent increased thickness of the Ojo Alamo Sandstone in the northern part of their study area. Such intertonguing was also pointed out by Powell (1973) and has been observed in areas north and south of Farmington.

42 The sandy nature of the upper part of the Nacimiento Formation is particularly noticeable near Cedar Hill in T. 31 N., R. 10 W. Here, thick, coarse-grained sandstones are indistinguishable from those of the overlying San Jose Formation. These Nacimiento sandstones are also prominent at Mount Nebo (fig. 4).

43 Throughout most of its thickness, the Nacimiento Formation cannot be expected to yield large quantities of water to wells because of the discontinuous, silty nature of its sandstones (Brimhall, 1973). In its upper part, where more extensive coarse sandstones occur, the Nacimiento can provide valuable sources of good-quality water (Cooper and Trauger, 1967). Baltz and West (1967) reported a yield of 42 gpm (229 m^3/d) from a 20-ft (6-m) sandstone in the upper part of the Nacimiento Formation on the Jicarilla Apache Reservation. Specific capacity of this well is only 0.07 gpm/ft (.01 l/s/m) of drawdown.

44 Brimhall (1973) reported on a major Nacimiento aquifer of local importance, the Kaime Ranch aquifer, in Canyon Largo about 30 mi (48 km) southeast of Aztec. This predominantly sandstone aquifer is estimated to cover approximately 5 mi^2 (13 km^2); one well there flows a full 8-inch (20-cm) stream from a perforated interval of 400 ft (122 m).

45 In the Aztec quadrangle, 21 water wells are known to be completed in the Nacimiento Formation (table 1); nine are El Paso Natural Gas Company water wells with reported yields from 16-100 gpm (87-545 m^3/d). Several of these wells have been completed in two to four intervals to exploit total perforated intervals of 20-150 ft (6-45 m) (table 1).

46 Three other nondomestic wells in the study area have been completed in the Nacimiento (table 1): the Port of Entry well is 750 ft (228.6 m) deep, the Knickerbocker Butte Water Well No. 1 is approximately 900 ft (275 m) deep and is completed in four horizons to obtain water for drilling purposes, and the Atlantic State No. 1 well is 520 ft (158.5 m) deep and is completed in three horizons for a total perforated thickness of 55 ft (16.8 m).

47 Nine domestic wells drilled into the Nacimiento Formation have an average depth of approximately 115 ft (35 m) and average depth to water after completion of 24 ft (7.3 m) (table 1). Being confined by overlying shales, many Nacimiento sandstone aquifers are artesian. The R. Valencia well, in sec. 35, T. 30 N., R. 9 W., was reported to flow forming a fountain rising 2 ft (.6 m) above ground level (table 1). The Kaime Ranch aquifer of Brimhall (1973) was also reported to be artesian.

48 Because of its shaly lithology, the Nacimiento Formation yields water of generally poor quality. Chemical analyses of four water samples are given in table 3. Total dissolved-solids content of these samples range from 1,004 to 6,754 ppm. Sodium, calcium, and sulfate are the prominent dissolved constituents (table 3, fig. 9). These waters would be classified as calcium, sodium, chloride, sulfate waters (fig. 10).

49 Field values of specific conductance obtained for water from six shallow wells believed to be completed in the Nacimiento Formation range from 1,120 to 4,500 μmhos and average 2,073 μmhos (tables 2 and 3). Two other wells penetrating this unit, but not presently in use, yield impotable waters according to the owners.

Ojo Alamo Sandstone (Tertiary)

50 The Ojo Alamo lies beneath the Nacimiento Formation and is not exposed in the Aztec quadrangle. However, in cliffs east of the La Plata River near Farmington, this formation consists of 158 ft (48.2 m) of thick-bedded, coarse-grained to very coarse grained, crossbedded, conglomeratic sandstone (Brown, 1976, appendix A). Intertonguing at the upper contact causes irregularity at the top of this unit (fig. 6). In the Aztec quadrangle, the Ojo Alamo Sandstone lies at a depth averaging approximately 1,500 ft (460 m) and has an average thickness of about 100 ft (30 m) (figs. 7 and 8).

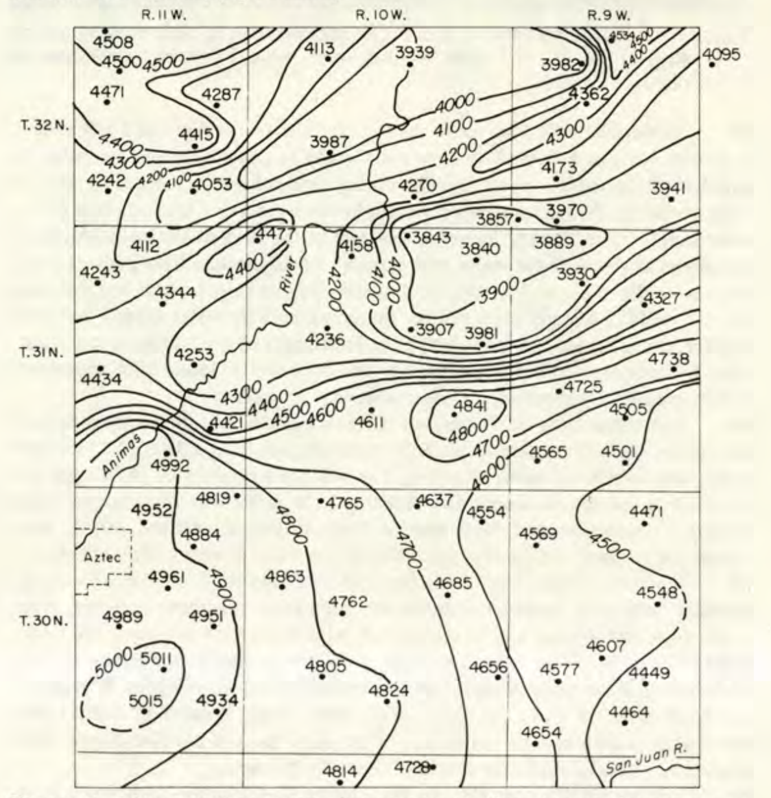


FIGURE 6—MAP SHOWING STRUCTURE OF TOP OF OJO ALAMO SANDSTONE IN AZTEC QUADRANGLE.

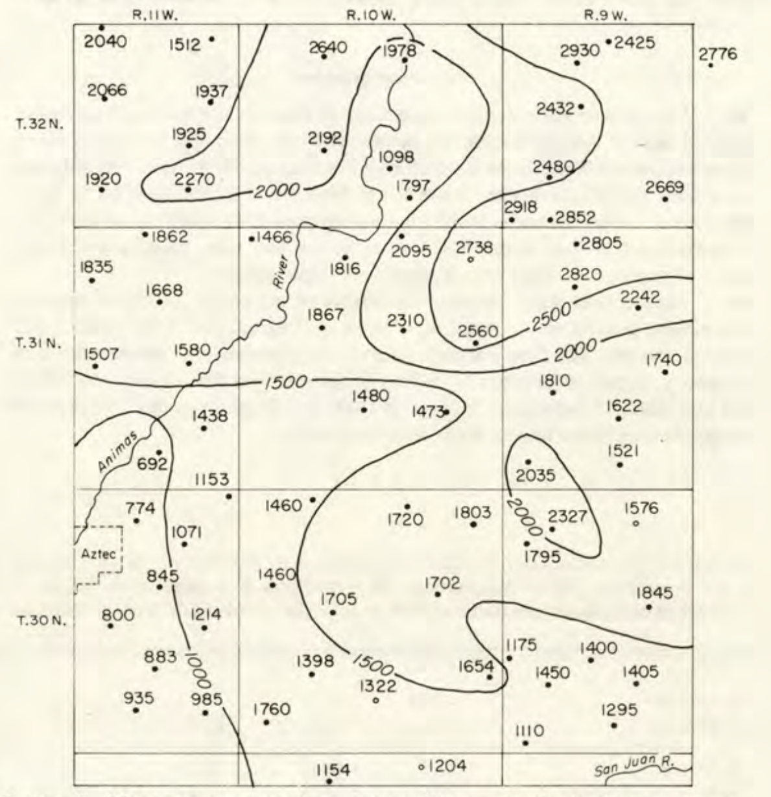


FIGURE 7—MAP SHOWING DEPTH TO TOP OF OJO ALAMO SANDSTONE IN AZTEC QUADRANGLE.

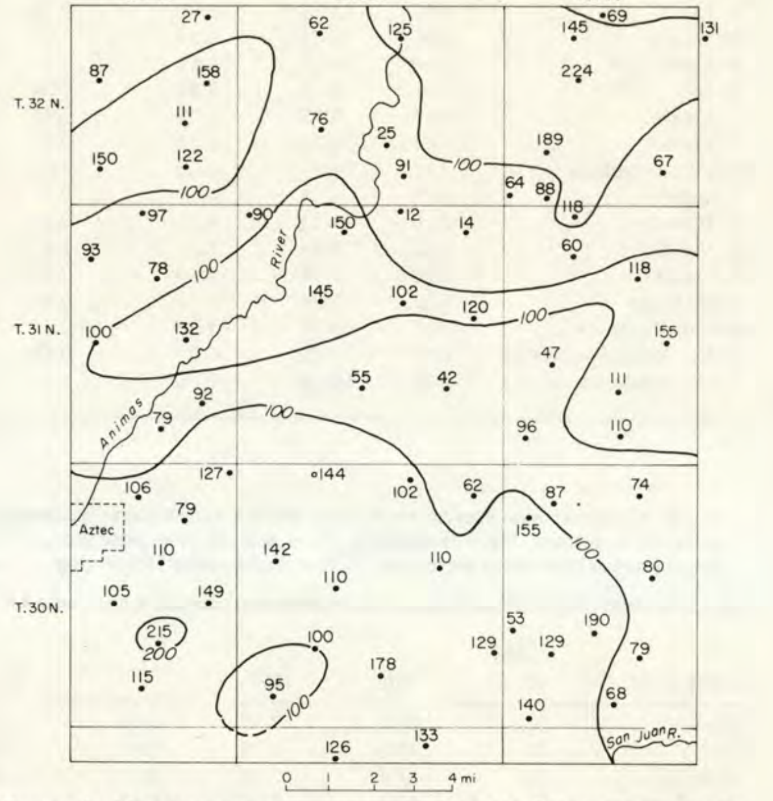


FIGURE 8—MAP SHOWING THICKNESS OF OJO ALAMO SANDSTONE IN AZTEC QUADRANGLE.

continued on back

continued from front

51 In the Aztec quadrangle, no water wells are known to penetrate the Ojo Alamo Sandstone. However, according to Brimhall (1973), this unit is a major source of ground water elsewhere in the San Juan Basin. He pointed out that the coarser channel sandstones have the greatest potential for producing good supplies of water. Brimhall reported six wells completed in the Ojo Alamo Sandstone with yields ranging from 35-180 gpm (190-981 m^3/d), specific capacities ranging from .20-1.02 gpm/ft., transmissivities ranging from 425-1,230 gpd/ft, and storage coefficients ranging from .0002-.0067.

52 Chemical analysis of waters from the Ojo Alamo was not possible owing to lack of access. Water qualities reported from elsewhere, however, are generally good, ranging from 360 to 824 ppm total dissolved solids from wells up to 747 ft (227 m) deep. Rapp (1959) reported that wells tapping Ojo Alamo Sandstone to the south and east of Farmington produce quantities sufficient for domestic and stock needs; however, the water typically exceeds 1,000 ppm total dissolved solids and is high in sulphate. Although large quantities of water may be present in the Ojo Alamo, electric logs indicate poor quality at the depths encountered in the study area.

Older deposits (Jurassic-Cretaceous)

53 Several rock units beneath the Ojo Alamo Sandstone contain or consist of porous sandstone and are no doubt water bearing. At shallow depths and near outcrops to the west or south of the Aztec quadrangle, these units yield domestic or larger supplies of poor to good quality water. However, all these units are so deep under the study area that drilling is impractical and waters obtained are likely to be saline. The potential of deep aquifers in selected areas of the San Juan Basin was summarized by Shomaker and Stone (1976).

WATER USE AND SUPPLY

Municipalities

54 The town of Aztec obtains all of its water from the Animas River and stores it in a reservoir north of town (fig. 11). Doubled in size in 1975, the reservoir now has a storage capacity of approximately 7,000,000 gal (26,530 m^3). The municipal water-treatment plant, located at the reservoir, treats and distributes an average of 1,600,000 gpd (6,055 m^3/d). The Aztec municipal water supply has an average total dissolved-solids content of 550 ppm (New Mexico Interstate Stream Commission and New Mexico State Engineer's Office, 1975). The river water is treated with alum (to settle out sediment), copper sulphate (to kill algae), and chlorine (to kill bacteria).

FIGURE 11—AZTEC MUNICIPAL RESERVOIR AND TREATMENT PLANT. SE¼ sec. 3, T. 30 N., R. 11 W.; view toward west; note irrigated agriculture in background.

55 Numerous wells near Aztec tap the alluvium of the Animas River valley. Collector wells or a field of shallow wells could be constructed in the valley to supplement the surface-water supplies during times of peak consumption or low river discharge. Such an operation would, however, increase the depletion of the river supply by artificially inducing recharge in the area of the wells. Another possibility is storing river water underground for use in low flow periods. This process could result in degradation in quality of the stored water but deserves further study. The only potential for obtaining potable water from a bedrock aquifer near the town of Aztec lies in the sandstones of the Nacimiento Formation. Exploratory drilling would have to be conducted to locate such sandstone bodies and identify the potential water quantity and quality.

56 The community of Turley, on the San Juan River, in the southeastern part of the study area, obtains water for domestic use from a 32-ft (9.75-m) well in the San Juan River valley alluvium. The well has a capacity of 16,000 gpd (60 m^3/d), but the system stores only 8,000 gal (30 m^3) (New Mexico Interstate Stream Commission and New Mexico State Engineer's Office, 1975). Five houses are presently on the system; quality of the water is reportedly quite good.

57 When increased water supply becomes necessary for Turley, more wells or collectors could be constructed in the San Juan River alluvium; however, river water depletion will have to be considered. Alternatives are diversion and treatment of San Juan River water and tapping the nearby San Jose Formation. Use of San Juan River water depends on the availability of water rights. Withdrawing water from the San Jose would likely prove costly because of drilling and distribution expenses. The sandstones of the upper part of the Nacimiento Formation may also be a possible source of water for this area.

58 The people of Cedar Hill, on the Animas River, obtain their water from individual wells, completed mostly in the valley alluvium. Cedar Hill faces essentially the same future water supply alternatives and considerations as does Turley.

Petroleum industry

59 The oil and gas companies operating in the area use water primarily for drilling and developing their wells. In the 1950's much of this water was taken from wells in the Nacimiento and San Jose Formations. Now, however, only one such well, the Knickerbocker Butte Water Well No. 1 (table 1), is being used. Most other water required is bought from irrigation-ditch cooperatives along the Animas and San Juan Rivers and trucked to the well sites. Good gravel roads make all parts of the quadrangle accessible to these tankers.

60 Should river water become unavailable or too costly for the oil and gas companies, ground water would have to be used again. Old water wells in the Nacimiento and San Jose Formations could be reopened and deepened where necessary, or new wells could be drilled. In the southern part of the area, where the Ojo Alamo Sandstone is only about 1,000 ft (300 m) deep, this source could be tapped if only fair quality water were required.

Irrigated agriculture

61 Irrigation along the Animas and San Juan Rivers constitutes the largest single use of water in the Aztec quadrangle. Approximately 3,500 acres (1,400 ha) of land are irrigated along the Animas River, and several hundred acres are irrigated along the small portion of the San Juan River (fig. 12). All irrigation water is derived from these rivers; ground water is not used at present. Based on the county average, the amount of surface water used for irrigation is approximately 9,000 acre-ft (11 hm^3) annually (New Mexico Interstate Stream Commission and New Mexico State Engineer's Office, 1975).

62 Surface waters are presently used for irrigation in San Juan County because they are readily available to the irrigable lands of the river valleys and are cheaper to obtain than are large supplies of ground water. If other supplies are not found, some irrigated lands may have to be retired in the foreseeable future to provide surface waters for the growing population and expanding energy industry and to offset (at least partially) new ground-water appropriations.

63 In most cases irrigation water need not be as fresh as water used for domestic or industrial purposes. If leaching and drainage are adequate, water having 1,500 ppm total dissolved solids can be used on most plants; and many moderately salt-tolerant crops can be irrigated with water of up to 2,000 ppm (Panel on promising technologies in arid land water developments, 1974). For this reason, ground water that might be considered unsuitable for domestic or industrial use may offer a solution to the predicted shortage of irrigation water. An important factor to consider in using slightly saline irrigation waters, however, is that fresh surface waters or nearby ground water can be contaminated.

64 The San Jose, Nacimiento, and Ojo Alamo probably hold water of sufficient quantity and quality to be used for irrigation. The San Jose Formation is likely to have the greatest potential, but further testing is required. Smaller quantities are likely in the Nacimiento Formation, and poorer quality is likely in the Ojo Alamo Sandstone.

Farm and rural dwellings

65 Several hundred farms and rural homes are located along the Animas and San Juan Rivers in the Aztec quadrangle. Most of these homes have shallow water wells, usually less than 100 ft deep, dug or drilled into the alluvium of the river valleys. A few wells are drilled into the Nacimiento Formation.

66 While complete data are not available, up to 10 percent of these rural residents probably use river water, stored and treated in a cistern, for domestic use. In many cases, river water is used because the quality of local ground water is too poor for domestic use.

67 In the areas away from the major river valleys most wells used for stock water have been abandoned in favor of surface water supplies. This water is collected in surface reservoirs where small arroyos have been dammed by earthen structures to trap runoff.

68 Few homes are located in the northern part of the study area. Should rural water supplies be required there in the future, the upper part of the Nacimiento Formation is very sandy and appears to have the properties of a good aquifer, although water quality is quite variable (table 3).

69 In areas away from the river valleys where the San Jose Formation is present, it appears to be the best potential source of ground water because of its position at the surface, overall coarse and sandy nature, broad extent, and generally good water quality (tables 1 and 3).

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TABLE 1—RECORDS OF WELLS IN THE AZTEC QUADRANGLE; See fig. 9 for locations. EPNG = El Paso Natural Gas Corp.; Qal = alluvium, Tsj = San Jose Formation, Tn = Nacimiento Formation; D = domestic, S = stock, I = industrial, P & A = plugged and abandoned; SC = specific conductance; * indicates chemical analysis given in table 3; — means information not available.

owner or well name	field no.	location no.	approx. elev. (ft)	total depth (ft)	water depth (ft)/date	principal aquifer	total aquifer thickness (ft)	well type	year constructed	use	pump type	chemical analysis?	remarks
Cox Canyon	A1	32.11.23.100	6,400	–	53/9-75	Qal	–	drld	–	S	W	–	P&A
B. Heizer	A2	32.10.15.100	5,945	35	–	Qal	35	dug	–	D,S	E	*	water softener used
W. Head	A3	32.10.15.200	5,920	30	15/9-74	Qal	30	dug	–	D	E	–	24-inch steel casing
F. Clark	A4	32.10.21.400	5,920	104	24/9-74	Qal	–	drld	1962	D,S	E	*	3 sands: 45, 60, 97 ft
H. Knowlton	A5	32.10.28.400	5,925	35	16/9-74	Qal	35?	drld	1967	D,S	E	–	S.C. = 1000 μmhos
A. Flaherty	A6	32.10.32.400	5,820	30	–	Qal	30?	dug	–	D	–	*	not potable
C. Lanier	A7	32.10.33.200	5,870	55	45-55/?	Qal	55?	dug	1950?	D,S	–	*	
C. Saller	A8	32.10.33.400	5,920	64	36/9-74	Qal	64?	dug	–	D	E	–	S.C. = 1025 μmhos
M. Bishop	A9	31.11.24.400	5,745	40	8/9-74	Qal	40?	dug	–	D,S	E	*	water softener used
F. Randalmon	A10	31.11.26.100	5,680	57	–	Qal	57?	drld	–	–	–	*	
A. Hill	A11	31.11.26.400	5,720	39	23/8-75	Qal	39?	drld	1961	D,S	E	*	set in coarse gravel
L. Long	A12	31.11.26.400	5,770	70	–	Qal	70?	drld	–	I	E	–	S.C. = 1120 μmhos
G. Foster	A13	31.11.34.300	5,670	60	7/8-75	Qal	60?	drld	–	D	E	*	
L. Likes	A14	30.11.34.400	5,680	47	20/?	Qal	47?	drld	1974	D	E	*	
A. Karlan	A15	31.10.4.200	5,760	–	14/9-74	Qal	–	dug	–	D	E	–	S.C. = 780 μmhos
unknown	A16	31.10.5.200	5,834	–	–	Qal	–	dug	–	D,S	E	–	S.C. = 1100 μmhos
Pan Am Petrol.	A17	31.10.5.000	5,810	27?	–	Qal	–	–	–	I?	–	*	
J. Hollar	A18	31.10.6.400	5,795	30	–	Qal	–	drld	1950	D	E	*	strong odor, staining
C. Smith	A19	31.10.8.100	5,790	–	5/9-74	Qal	–	dug	1952	D	E	–	S.C. = 760 μmhos
E. Flaherty	A20	31.10.18.100	5,780	30	16/9-74	Qal	30?	drld	1950	D,S	E	*	taps shallow spring
J. Boston	A21	30.11.4.400	5,640	50	35/9-74	Qal	35?	drld	–	D,S	E	–	S.C. = 890 μmhos
C. Van Dusen	A22	30.11.9.000	–	–	–	Qal	–	–	–	–	–	*	
A. Moore	A23	30.11.10.000	–	32	–	Qal	–	agrd	1958	–	E	–	
R. Chavez	A24	29.9.3.200	5,612	16	6/10-74	Qal	–	dug	1960	D,S	E	–	S.C. = 460 μmhos
M. Jacquez	A25	29.9.4.100	5,615	54	36/10-74	Qal	–	drld	1958	D	E	–	S.C. = 820 μmhos
C. Gurule	A26	29.9.4.100	5,610	45	–	Qal	45?	drld	–	D	E	*	
R. Gutierrez	A27	29.9.4.400	5,575	20	9/10-74	Qal	–	dug	1911	D	N	–	S.C. = 595 μmhos
EPNG, Barnes #2	S2	32.11.23.300	6,200	585	–	Tsj	126?	drld	1953	I	–	–	P&A
EPNG, Schwertfeger #4	S11b	31.9.10.300	6,520	462	–	Tsj	100	drld	1952	I	–	–	P&A
EPNG, Riddle #1D	S12	31.9.17.300	6,490	550	–	Tsj	40	drld	1953	I	–	–	yielded 6 gpm; P&A
EPNG, Barret #1	S13	31.9.19.000	6,560	517	–	Tsj	55	drld	1952	I	–	–	yielded 20 gpm; P&A
EPNG, Barret #2	S14	31.9.20.200	6,260	202	–	Tsj	30	drld	–	I	–	–	yielded 20 gpm; P&A
Little Pump	S15	31.9.28.100	6,180	100+	51/2-76	Qal-Tsj	–	drld	–	S	–	*	not used
EPNG, Schwertfeger #1	S16	31.9.27.300	6,080	120	–	Tsj	25	drld	–	I	–	–	yielded 40 gpm
EPNG, Schwertfeger #2	S17	31.9.27.400	6,080	118	–	Tsj	34	drld	1952	I	–	–	yielded 20 gpm
EPNG, Turner #1	S20	30.10.13.000	6,480	425	345/?	Tsj	–	drld	–	I	–	–	
EPNG, Florance #1	S22	30.10.24.200	6,280	293	–	Tsj	–	drld	1953	I	–	–	yielded 20 gpm
EPNG, Barnes #1	N1	32.11.24.200	6,200	105	–	Tn	35	drld	1953	I	–	–	
EPNG, Horton #1	N2	32.11.29.300	6,400	588	–	Tn	55	drld	1953	I	–	–	outside Aztec quad.
EPNG, Neal #6	N3	32.11.33.200	6,150	321	–	Tn	48	drld	1953	I	–	–	
N.M. Port of Entry	N4	32.10.16.400	5,680	750	51/3-75	Tn	–	drld	–	D	–	*	
M. Randalmon	N5	31.11.24.300	5,700	173	7/9-74	Tn	–	drld	–	–	–	–	not potable
R. Pettijohn	N6	31.11.34.300	5,720	95	69/9-74	Tn	–	drld	1960	D	E	–	S.C. = 2240 μmhos
G. Saline	N7	31.11.35.300	5,720	–	8/9-74	Tn	–	drld	1952	D	E	–	S.C. = 1575 μmhos
EPNG, Lucerne #1	N8	31.10.10.200	6,120	455	–	Tn	67	drld	1955	I	–	–	yielded 25 gpm
EPNG, Kelly	N10	31.10.14.300	6,250	555	–	Tn	28	drld	1954	I	–	–	P&A
EPNG, Riddle #20	N11	31.9.20.300	6,520	510	–	Tn	150?	drld	1953	I	–	–	yielded 50 gpm
K. McCament	N13	30.11.19.100	5,575	143	24/9-74	Tn	–	drld	1968	S	E	–	S.C. = 1240 μmhos
Atlantic, State #1	N14	30.10.2.100	6,360	520	–	Tn	55	drld	1954	I	–	*	yielded 30 gpm
B. Redding	N15	30.10.3.400	6,400	320	50/?	Tn	–	drld	1975	D	E	*	
Hartman	N16	30.10.20.300	6,190	–	91/?	Tn	–	drld	–	S	W	–	
EPNG, Riddle #1	N17	30.10.23.200	6,280	311	–	Tn	20	drld	1952	I	–	–	yielded 20 gpm
EPNG, Knickerbocker #1	N18	30.10.23.400	6,219	886	–	Tn	–	drld	1972	I	E	*	
Slane Canyon	N19	30.10.27.100	6,180	–	53/9-75	Tn	–	drld	–	S	W	–	
EPNG, Quigley #1	N20	30.9.6.300	6,320	396	–	Tn	37	drld	1953	I	–	–	yielded 16 gpm
EPNG, Wood River #1	N21	30.9.8.200	6,200	258	–	Tn	123	drld	–	I	–	–	yielded 25 gpm
R. Valencia	N22	30.9.35.300	5,620	30	2+/10-74	Tn	–	drld	–	D,S	E	–	S.C. = 4500 μmhos
C. Pacheco	N23	29.9.5.300	5,600	30	13/10-74	Tn	–	drld	1960	–	N	–	not used
F. Montoya	N24	29.9.6.400	5,630	48	22/10-74	Tn	–	drld	1962	D	E	–	S.C. = 1750 μmhos

TABLE 2—RECORDS OF SPRINGS IN THE AZTEC QUADRANGLE; see fig. 9 for locations. Tsj = San Jose Formation, Tn = Nacimiento Formation; D = domestic, S = stock; * indicates chemical analyses given in table 4.

spring name	field no.	location no.	approx. elev. (ft.)	source	use	chemical analysis	remarks
Cave	S1	32.11.14.300	6,350	Tsj	S	*	good flow
Cattail	S3	32.10.13.200	6,900	Tsj	S	*	occurs in arroyo
High Hopes	S4	32.10.17.400	6,700	Tsj	–	*	
Arch Rock	S7	31.10.31.300	6,500	Tsj	S	*	
Hart #1	S8	31.10.25.300	6,450	Tsj	D,S	*	developed
Last Chance	S10	31.9.5.300	6,750	Tsj	S	–	once supported cave dwellers and homestead
Hidden	S11a	31.9.6.200	6,750	Tsj	S	*	much alkali precipitant
Cottonwood	S18	31.9.31.400	6,430	Tsj	S	*	occurs in Alamo Canyon
Mud	S19	30.10.2.200	6,550	Tsj	S	*	dry
Jackson	S23	30.10.14.200	6,500	Tsj	S	–	dry
Hog	S24	32.9.15.300	6,780	Tsj	S	–	dry
Ice	S25	32.9.29.300	6,800	Tsj	–	–	dry
Garrison	N9	31.10.14.200	6,280	Tn(?)	S	*	once supported homestead
Thurston	N12	31.10.31.100	5,950	Tn	S	*	occurs in Jones Arroyo

HYDROGEOLOGIC PRINCIPLES

Hydrogeology is the science that applies geologic concepts and methods to the understanding of hydrologic phenomena. Hydrogeologists attempt to explain the role of the geologic framework in controlling the occurrence and quality of water resources.

The ultimate source of most surface and ground water is precipitation. In the arid Southwest, a small amount of the moisture from rain and snow runs off to major streams; much of it quickly soaks into the ground. Although the bulk of this moisture is soon returned to the atmosphere through evapotranspiration, some may move deeper and be stored as ground water.

Ground water occupies fractures or intergranular pores in saturated zones beneath the ground surface. All natural materials in the ground may be classed as one of the following:

> **aquifer**—readily stores and transmits ground water;
> **aquitard** (or aquiclude)—stores, but poorly transmits ground water;
> **aquifuge**—neither stores nor transmits ground water.

Thus, the search for ground water is the search for aquifers.

Ground water in aquifers may be unconfined or confined. **Unconfined ground water** is in direct contact with the atmosphere and so is not under pressure. Unconfined water stands in wells at the same level where encountered in drilling. The surface characterizing the top of unconfined ground water is the **water table.** A water table map may be prepared by contouring water levels in wells tapping the unconfined aquifer.

Confined ground water (or **artesian ground water**) is restricted to an aquifer by the presence of aquifuges or aquitards at least above the aquifer and possibly also below it. The upper confining layer prevents direct contact with the atmosphere. Confined or artesian ground water is under pressure and will rise above the level where it is encountered in drilling, although not necessarily to the ground surface. The level to which artesian water rises in tightly cased wells is the **potentiometric surface.** A potentiometric surface map for a given artesian aquifer may be prepared by contouring water levels in wells open only to that aquifer.

Recharge, the process by which ground water is replenished, may be direct (from the surface itself) or indirect (from the surface by means of other geologic units). Recharge may be natural or artificial (induced by man). **Discharge,** the process by which ground water is depleted, similarly may be direct or indirect, natural or artificial. In some areas neither recharge nor discharge occurs.

Ground water moves from areas of recharge to areas of discharge. Movement occurs in **flow systems** of various sizes—ranging from small, local, mountain-to-valley systems to large regional systems covering entire counties or even states. Flow is through connected fractures or intergranular pores. Only in areas of underground caverns does ground water flow in distinct channels; the idea that ground water generally occurs in underground rivers is misleading. Movement is slow, averaging less than 5 ft/day. Higher flow rates occur in fractured rock and coarse, clean (not muddy) gravel.

Unconfined water moves from areas of higher water table toward areas of lower water table under the influence of gravity; flow is perpendicular to water table contours. Confined water moves from areas of higher potentiometric surface towards areas of lower potentiometric surface owing to differences in potential energy; flow is perpendicular to equipotential contours.

Several terms have evolved for specific aquifer properties. **Porosity** is that percentage of the volume of an aquifer consisting of pores or openings. The quantity of water that will readily drain by gravity from the pores of an aquifer is its **specific yield.** Conversely, the amount of water that remains in an aquifer after drainage by gravity is its **specific retention.** Both are expressed as a decimal fraction or percent; together they equal porosity.

Permeability is the capacity of a porous material to transmit water. The volume of water moving between two points in an aquifer is generally proportional to the vertical drop between the two points divided by the distance between the points. This relationship, called **Darcy's Law,** may be expressed mathematically as:

$$\frac{Q}{A} = K \times \frac{(h_1 - h_2)}{L} \quad \text{or} \quad Q = KA \times \frac{(h_1 - h_2)}{L},$$

where Q is the volume of water discharged per unit time, A is the cross-sectional area of the discharge site, K is the coefficient of permeability (also called **hydraulic conductivity**), $(h_1 - h_2)$ is the difference in height (or **head**) between the two points, and L is the distance between the points; $\frac{(h_1 - h_2)}{L}$ is also referred to as the **hydraulic gradient.** To solve for permeability the equation may be rewritten as follows:

$$K = \frac{Q}{A} \times \frac{L}{(h_1 - h_2)}$$

Permeability is commonly expressed as gpd/sq ft (gallons per day per square foot). If gallons are converted to cubic ft, permeability may be expressed as ft/d or m/d (feet per day; meters per day).

The amount of water flowing through an aquifer depends on its thickness as well as its permeability. **Transmissivity** takes this fact into account and is determined by multiplying permeability by thickness. It is usually expressed as gpd/ft (gallons per day per foot—of thickness). If gallons are converted to cubic ft, transmissivity may be expressed as ft^2/d (feet squared per day); the metric equivalent is m^2/d (meters squared per day). Another measure of the performance of an aquifer is **specific capacity,** which is the yield per foot of **drawdown** (decline of the water table or potentiometric surface after pumping). Specific capacity is expressed as gpm/ft or lps/m (gallons per minute per foot or liters per second per meter—of drawdown). **Storativity** is a dimensionless measure of the volume of water produced from (or injected into) storage per unit surface area of aquifer per unit change in head. It may be computed by the following equation:

$$S = \frac{v}{A\,(h_1 - h_2)},$$

where S is the storativity, v is the volume of water released from (or put into) storage, A is the cross-sectional area of the aquifer prism, and $(h_1 - h_2)$ is the change in head.

In addition to quantity, the hydrogeologist is also concerned with **water quality.** The quality or chemical character of water determines its usefulness to man. Specific quality/use criteria include salinity, hardness, taste, odor, color, turbidity, biological purity, and pH. In nature, water rarely occurs in a pure state; water moving through the environment picks up many natural and manmade substances as dissolved constituents or suspended matter.

Dissolved constitutents come from 1) solution of minerals in the ground, 2) contact with industrial or municipal waste, 3) addition of agricultural waste and fertilizers, and 4) mixing with waters already charged with dissolved solids. This dissolved load determines salinity, hardness, and pH.

Dissolved-solids content is determined in the field by means of a **specific-conductance** meter. Although pure water conducts electricity very poorly and thus is highly resistive, the addition of dissolved material (which separates into charged **ions**) makes it conductive; the more material in solution the greater the conductance. The unit measurement of specific conductance is the mho (the inverse of ohm, the unit of resistance). Values of specific conductance are usually reported (in both the English and metric systems) in μmhos or **micromhos** (millionths of a mho).

In the laboratory, total dissolved-solids content is approximated by weighing the residue obtained after oven drying a water sample at 356° F (180° C) for 1 hour. Results may be presented as ppm (parts per million) or mg/l (milligrams per liter), which are numerically equivalent for concentrations less than 7,000 ppm.

Ground waters may be classified and compared on the basis of dissolved-solids contents. Many schemes have been suggested, but that used by the U.S. Geological Survey (Swenson, H. A., and Baldwin, H. L., 1965, A primer on water quality: U.S. Geological Survey Special Publication, 27 p.) is followed herein: less than 1,000 ppm = **fresh**; 1,000-3,000 ppm = **slightly saline**; 3,000-10,000 ppm = **moderately saline**; 10,000-35,000 ppm = **very saline**; more than 35,000 ppm = **brine.** To compare ground-water compositions, concentrations of major cations and anions (positively and negatively charged ions, respectively) are plotted on a trilinear diagram as percentages of epm's (equivalents per million). The epm value is calculated by dividing the ppm value by the equivalent weight of the ion of interest (equivalent weight = atomic weight ÷ chemical valence).

Suspended matter includes sediments flushed into wells and bacteria thriving in the aquatic environment. Suspended sediments determine turbidity, and bacteria determine biological purity. In combination with dissolved constituents, suspended matter contributes to the color, odor, and taste of water.

Water-quality standards have been defined for most water uses. The U.S. Public Health Service has adopted standards for drinking-water quality. Most of these standards consist of recommended limits; maximum allowable limits have been defined only where specific health hazards exist. A common measure of water potability is total dissolved-solids content. The Public Health Service recommends 500 ppm as a desirable limit for drinking water. Lacking suitable sources, many public water supplies exceed this limit by more than four times. Water-quality requirements for various industrial purposes have been established; similarly, the tolerance of various crops to specific dissolved constituents has been determined.

TABLE 3—CHEMICAL ANALYSES OF WATER FROM WELLS IN THE AZTEC QUADRANGLE. Well field numbers correspond to those in table 1; see fig. 9 for locations. Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, HCO_3 = bicarbonate, SO_4 = sulfate, Cl = chlorine. Concentrations of constituents given as equivalents per million; TDS = total dissolved solids, ppm = parts per million; μmhos = micromhos.

owner or well name	field no.	date	HCO_3	Cl	SO_4	Na	K	Mg	Ca	TDS (ppm)	specific conductance (μmhos)
B. Heizer	A2	8/75	2.25	0.48	2.54	1.61	0.00	1.85	2.01	308	550
N.M. Port of Entry	N4	3/75	0.41	115.66	0.44	95.70	0.17	0.72	19.46	6,754	12,700
F. Clark	A4	9/75	3.75	2.56	4.58	9.35	0.04	0.58	1.39	687	1,120
A. Flaherty	A6	8/75	4.25	1.11	25.44	15.77	0.07	3.17	12.21	1,923	2,600
C. Lanier	A7	9/75	3.00	0.85	4.89	2.18	0.19	2.78	4.02	528	943
M. Bishop	A9	8/75	2.59	0.72	3.04	1.57	0.04	1.97	3.00	694	650
F. Randalmon	A10	8/59	4.61	0.73	3.04	1.52	–	0.56	5.09	484	777
A. Hill	A11	8/75	2.25	0.64	9.26	3.09	0.02	2.47	5.99	759	950
G. Foster	A13	8/75	2.75	0.31	2.39	1.07	0.11	0.82	3.73	317	610
L. Likes	A14	8/75	2.51	0.68	12.70	4.22	0.03	1.40	9.73	1,021	1,320
Pan Am Petroleum	A17	4/59	6.00	1.61	7.77	5.83	–	2.23	7.34	1,104	–
J. Hollar	A18	9/75	4.51	0.71	3.44	4.57	0.05	1.73	2.62	508	820
E. Flaherty	A20	9/75	4.25	0.41	5.20	2.14	0.49	1.87	5.39	576	780
C. Van Dusen	A22	7/54	4.95	1.07	51.22	26.27		–	–	–	4,320
C. Curulo	A26	2/76	1.50	0.28	5.33	3.61	0.09	0.52	3.27	512	840
Little Pump	S15	2/76	5.24	0.68	4.64	5.22	0.28	2.14	2.84	643	1,205
Atlantic State #1	N14	11/75	1.75	0.34	11.26	2.00	0.07	1.86	9.46	1,004	1,523
EPNG, Knickerbocker #1	N18	3/72	0.20	0.60	75.00	65.00	–	1.10	8.80	5,204	–
EPNG, Knickerbocker #1	N18	10/74	2.00	1.00	54.00	46.00	–	1.00	10.00	1,921	–

TABLE 4—CHEMICAL ANALYSES OF WATER FROM SPRINGS IN THE AZTEC QUADRANGLE. Spring field numbers correspond to those in table 2; see fig. 9 for locations. Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, HCO_3 = bicarbonate, SO_4 = sulfate, Cl = chlorine. Concentrations of constituents given as equivalents per million; TDS = total dissolved solids, ppm = parts per million; μmhos = micromhos.

spring name	field no.	date	HCO_3	Cl	SO_4	Na	K	Mg	Ca	TDS (ppm)	specific conductance (μmhos)
Cave	S1	6/75	2.51	0.40	16.64	4.44	0.21	1.73	14.20	1,305	1,650
Cattail	S3	6/75	3.75	0.40	5.04	6.05	0.22	1.40	1.60	567	820
High Hopes	S4	8/75	2.00	0.17	1.46	0.42	0.05	0.62	2.60	208	350
Arch Rock	S7	6/75	2.25	0.17	1.97	1.34	0.00	0.86	2.26	256	390
Hart #1	S8	6/75	1.25	0.07	1.25	0.77	0.00	1.44	1.31	150	295
Hart #2	S9	6/75	3.25	0.65	3.89	1.50	0.05	1.32	4.61	454	700
Last Chance	S10	6/75	1.25	0.11	0.59	0.68	0.00	0.18	1.09	110	183
Hidden	S11a	6/75	2.75	0.60	19.73	6.96	0.08	3.17	13.61	1,528	1,800
Cottonwood	S18	6/75	2.25	0.17	1.87	1.04	0.03	0.99	2.30	249	450
Mud	S19	9/75	2.00	0.12	8.95	1.70	0.09	1.89	7.37	709	1,000
Garrison	N9	6/75	1.25	0.07	0.99	0.45	0.01	0.34	1.61	136	–
Thurston	N12	6/75	2.75	0.53	41.60	22.29	0.11	2.47	21.50	3,081	2,900

TABLE 5—CHEMICAL DATA USED IN PREPARATION OF TRILINEAR PLOT. Sample numbers are well and spring field numbers used in previous tables; see tables 3 and 4 for raw data, fig. 9 for locations, and fig. 10 for trilinear plot. W = sample from well, S = sample from spring.

		Cations			Anions		
sample no.	source	% Ca	% Mg	% Na+K	% CO_3+HCO_3	% SO_4	% Cl
A2	W	36.7	33.8	29.4	42.7	48.2	9.1
A4	W	12.2	5.1	82.7	34.4	42.1	23.5
A6	W	39.1	10.2	50.7	13.8	82.6	3.6
A7	W	43.8	30.3	25.8	34.3	55.9	9.7
A9	W	45.6	29.9	24.5	40.8	47.9	11.3
A10	W	70.9	7.8	21.2	55.0	36.3	8.7
A11	W	51.8	21.3	26.9	18.5	76.2	5.3
A13	W	65.1	14.3	20.6	50.5	43.9	5.7
A14	W	63.3	9.1	27.6	15.8	79.9	4.3
A17	W	47.7	14.5	37.9	39.0	50.5	10.5
A18	W	29.2	19.2	51.5	52.1	39.7	8.2
A20	W	54.5	18.9	26.6	43.1	52.7	4.2
A26	W	43.7	6.9	49.4	21.1	75.0	3.9
S1	S	69.0	8.4	22.6	12.8	85.1	2.0
S3	S	17.3	15.1	67.6	40.8	54.8	4.4
S4	S	70.5	16.8	12.7	55.1	40.2	4.7
S7	S	50.7	19.3	30.0	51.3	44.9	3.9
S8	S	37.2	40.9	21.9	48.6	48.6	2.7
S9	S	61.6	17.6	20.7	41.7	49.9	8.3
S10	S	55.9	9.2	34.9	64.1	30.3	5.6
S11a	S	57.1	13.3	29.6	11.9	85.6	2.6
S15	W	27.1	20.4	52.5	49.6	43.9	6.4
S18	S	52.8	22.7	24.5	52.4	43.6	4.0
S19	S	66.7	17.1	16.2	18.1	80.8	1.1
N4	W	16.8	.62	82.6	.35	.38	99.27
N9	S	66.8	14.1	19.1	54.1	42.9	3.03
N12	S	46.2	5.3	48.3	6.12	92.7	1.2
N14	W	70.6	13.9	15.5	13.1	84.3	2.5
N18	W	11.7	1.5	86.8	.26	98.9	.79
NX	W	17.5	1.8	80.7	3.5	94.7	1.8

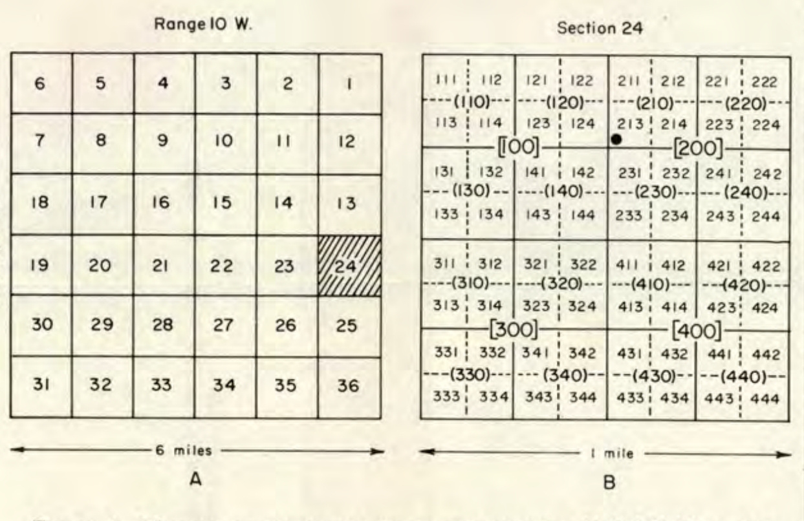
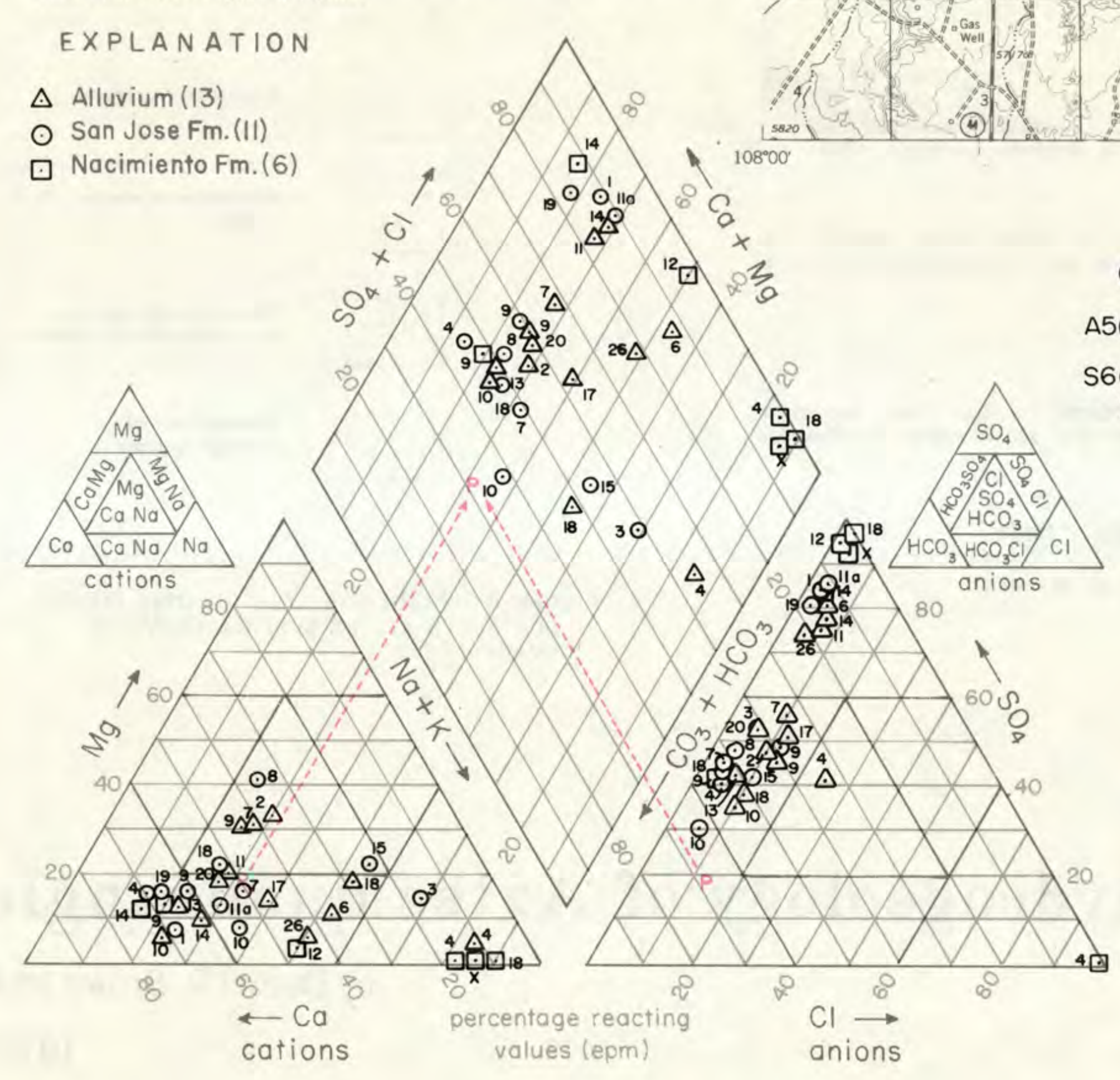


FIGURE 1—METHOD OF NUMBERING WELLS AND SPRINGS. A) Subdivision of a township into sections; B) Subdivision of a section into quarter-quarter-quarter section blocks; dot indicates location of a well numbered 5.10.24.213.

FIGURE 12—VIEW NORTH ALONG ANIMAS RIVER VALLEY FROM TOP OF MT. NEBO; note irrigation on floodplain. Snow-capped San Juan Mountains in Colorado in distance are major source of runoff.

FIGURE 10—TRILINEAR PLOT OF DISSOLVED SOLIDS IN GROUND WATERS OF AZTEC QUADRANGLE. See table 5 for data used; each analysis is indicated by 3 points, one in each of the 3 fields of the diagram; position of average potable water indicated by "P" (after Davis and DeWiest, 1967). Dashed lines show manner of plotting points in the diamond-shaped field. Numbers in parentheses indicate number of samples for aquifer.



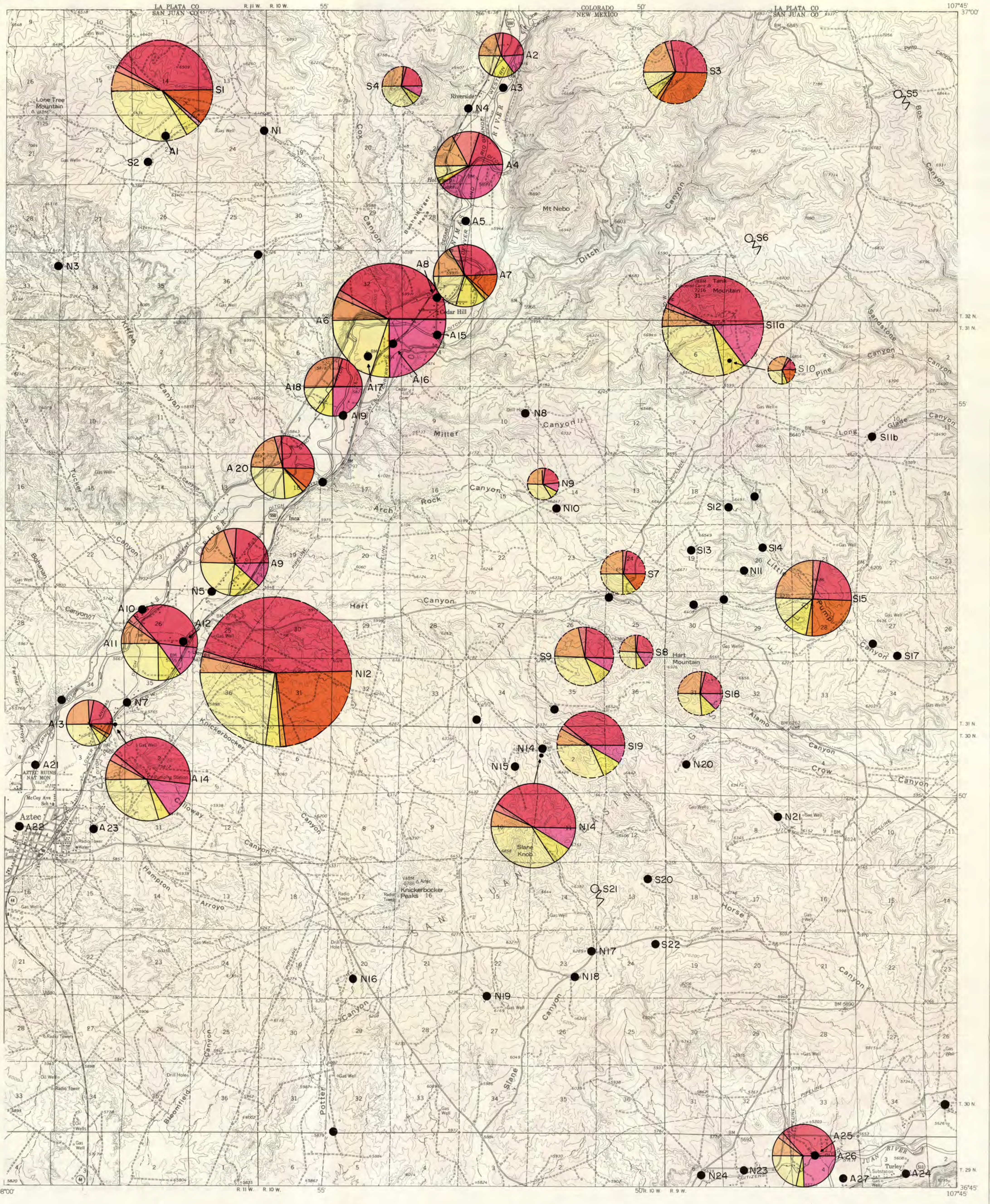


FIGURE 9—HYDROCHEMISTRY OF AZTEC QUADRANGLE.

Well and spring field numbers correspond to those in tables; A = alluvium is aquifer, S = San Jose Formation is aquifer, N = Nacimiento Formation is aquifer.

NMBGMR Map No. 13246