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 on six wells completed in the Ojo Alamo Sandstone with yields ranging from 35-180 gpm (190-981 m³/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 m³). The municipal water-treatment plant, located at the reservoir, treats and distributes an average of 1,600,000 gpd (6,055 m³/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).

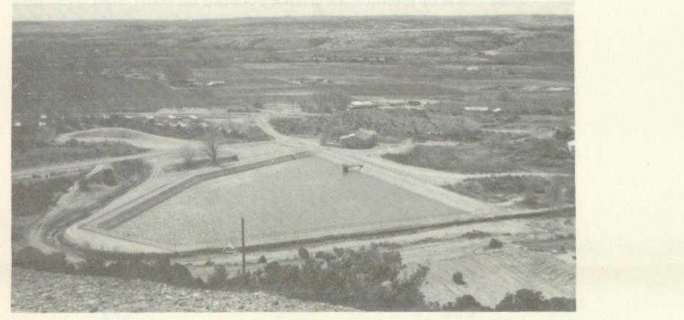

FIGURE 11—AZTEC MUNICIPAL RESERVOIR AND TREATMENT PLANT, SE¼ sec. 3, T. 30 N., R. 11 W.; view toward west; note irrigated agriculture in background.

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 m³/d), but the system stores only 8,000 gal (30 m³) (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 hm³) 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 residences 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 [illegible] 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 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	135.66	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	880
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 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	E	*	
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 ft²/d (feet squared per day); the metric equivalent is m²/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 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.

sample no.	source	Cations: % Ca	Cations: % Mg	Cations: % Na+K	Anions: % CO$_3$+HCO$_3$	Anions: % SO$_4$	Anions: % 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

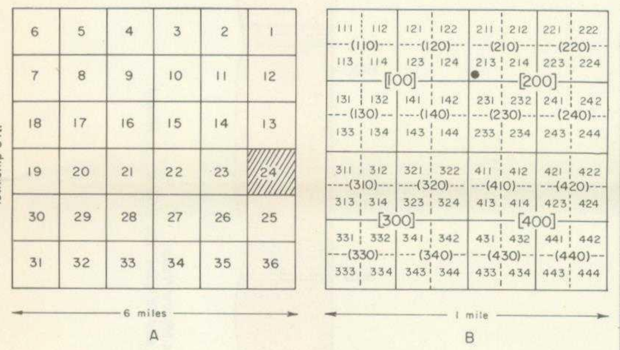


FIGURE 1—METHOD OF NUMBERING WELLS AND SPRINGS. A) Subdivision of a township into sections; B) Subdivision of a section into quarter-quarter-quarter section blocks; dot indicates location of a well numbered 5.10.24.213.

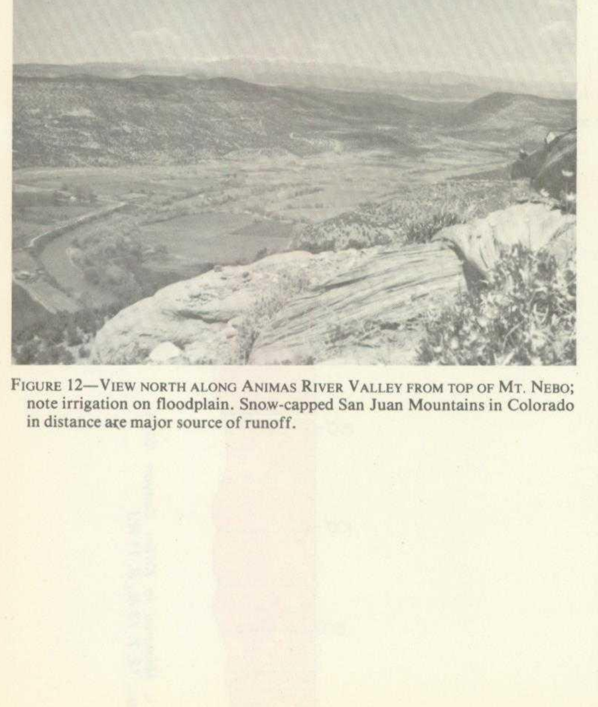
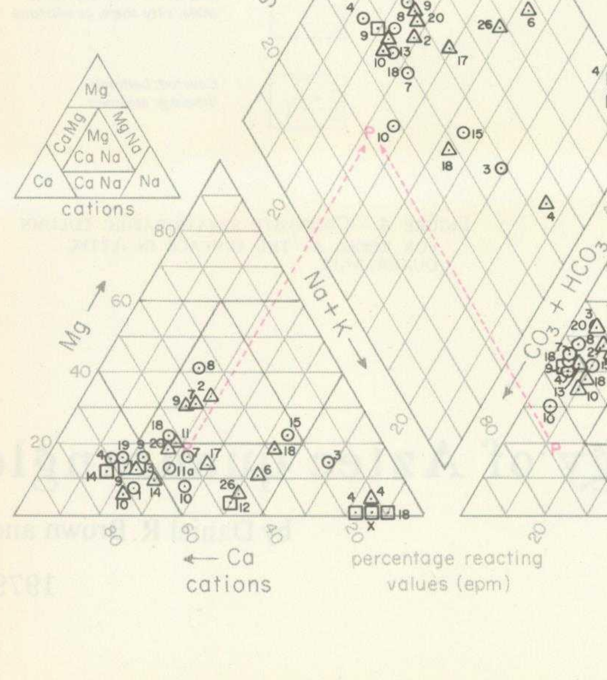


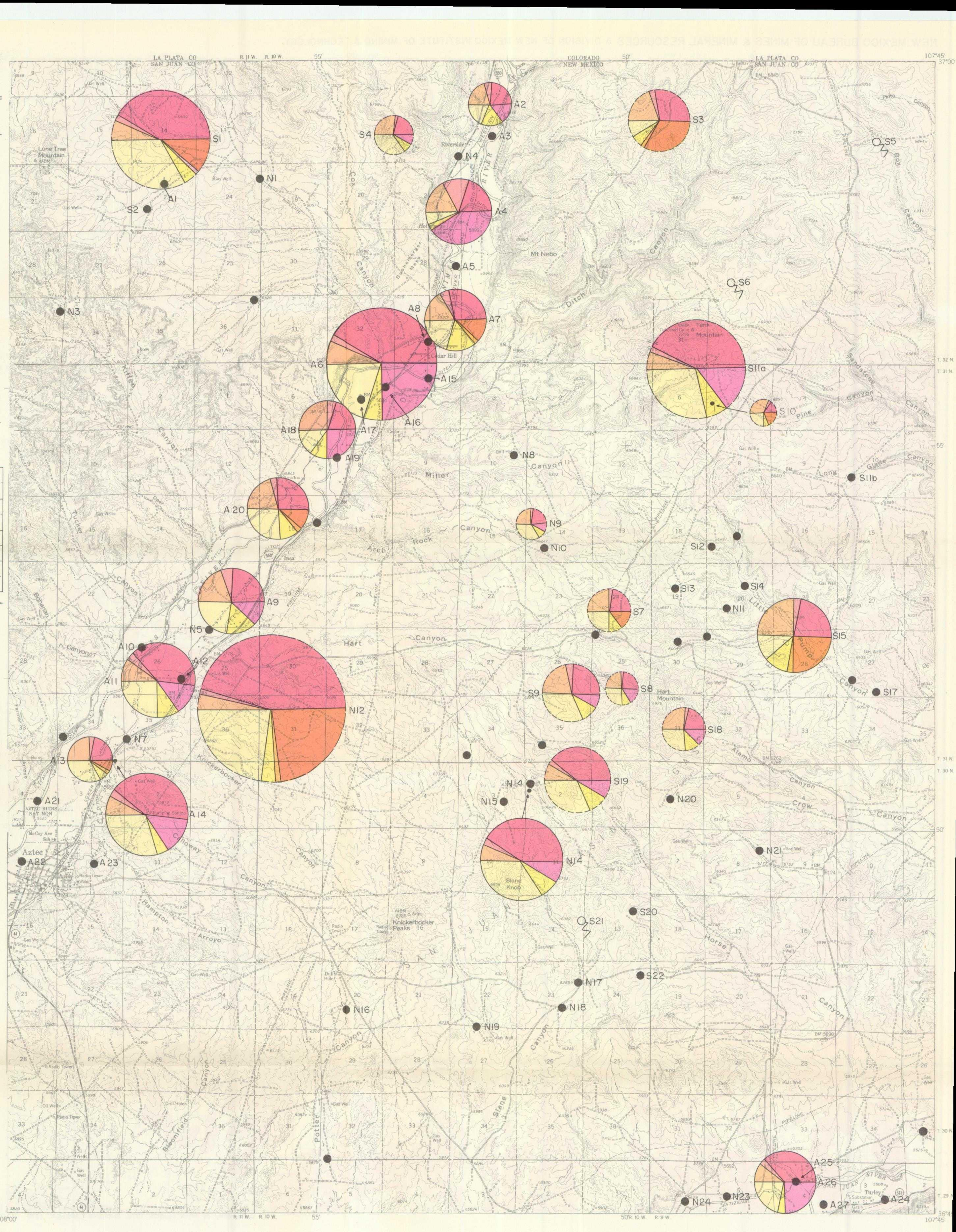
FIGURE 12—VIEW NORTH ALONG ANIMAS RIVER VALLEY FROM TOP OF MT. NEBO; note irrigation on floodplain. Snow-capped San Juan Mountains in Colorado in distance are major source of runoff.

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.

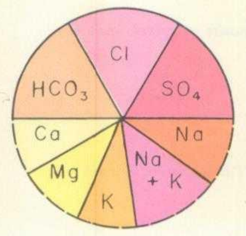
EXPLANATION

△ Alluvium (13)
○ San Jose Fm. (11)
□ Nacimiento Fm. (6)

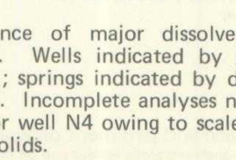




● Water well, not inventoried
A5● Water well, inventoried (table 1)
S6○ Spring, inventoried (table 2)



Abundance of major dissolved constituents in samples. Wells indicated by solid outline (see table 3); springs indicated by dashed outline (see table 4). Incomplete analyses not plotted; no plot given for well N4 owing to scale used for total dissolved solids.



Scale relating radii of circular diagrams to total dissolved solids concentration (ppm) in sample

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.