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HYDROLOGIC CHARACTERISTICS OF BASIN-FILL AQUIFERS IN THE SOUTHERN SAN LUIS BASIN, NEW MEXICO

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ABSTRACT.—The Town of Taos and Taos Pueblo conducted a joint deep drilling program to evaluate the productivity and water quality of the Tertiary basin-fill aquifer system underlying the Servilleta Formation. Testing results from a series of municipal, exploratory, subdivision, and domestic wells are also used to characterize hydrologic properties (T, K, K', and S), and the effect of faults on groundwater flow in shallow and deep basin fill aquifers. The shallow unconfined to leaky-confined alluvial aquifer includes alluvial deposits and the underlying Servilleta Formation (Agua Azul aquifer facies). The deep leaky-confined to confined aquifer includes Tertiary age rift-fill sediments below the Servilleta Formation and is subdivided into the Chama-El Rito and Ojo Caliente aquifer facies. Although faults typically do not act as impermeable boundaries in the shallow alluvial aquifer and groundwater flow in the shallow aquifer is not significantly affected by faults, the Seco fault and several of the Los Cordovas faults act as impermeable boundaries in the deep basin fill aquifer. However, other Los Cordovas faults apparently do not affect groundwater flow in the deep aquifer, suggesting variable cementation along fault planes at depth. The Town Yard fault appears to be a zone of enhanced permeability in the shallow alluvial aquifer, and does not act as an impermeable boundary in the deep basin fill aquifer. Intrabasin faults such as the Seco fault that exhibit significant offset likely cause some compartmentalization of the deep aquifer system.

INTRODUCTION

The Town of Taos, Taos Pueblo, and adjacent communities are situated primarily within the Rio Pueblo de Taos and Rio Hondo drainage basins. The Rio Pueblo de Taos basin includes the following streams from north to south; Arroyo Seco, Rio Lucero, Rio Pueblo de Taos, Rio Fernando de Taos, and Rio Grande del Rancho (Figs. 1 and 3). Northern tributaries to Rio Pueblo de Taos drain Precambrian granite and gneiss, and Tertiary granite, whereas southern tributaries drain Paleozoic sandstone, shale, and limestone (Kelson and Wells, 1989). The area of this study includes the region between the Sangre de Cristo mountain front on the east and the Rio Grande on the west, the Rio Hondo on the north and the Rio Grande-Rio Pueblo de Taos confluence on the south (Fig. 1).

The majority of the historic water supply for municipal, domestic, livestock, and sanitary purposes for the Town of Taos, Taos Pueblo, and adjacent communities has been derived from the

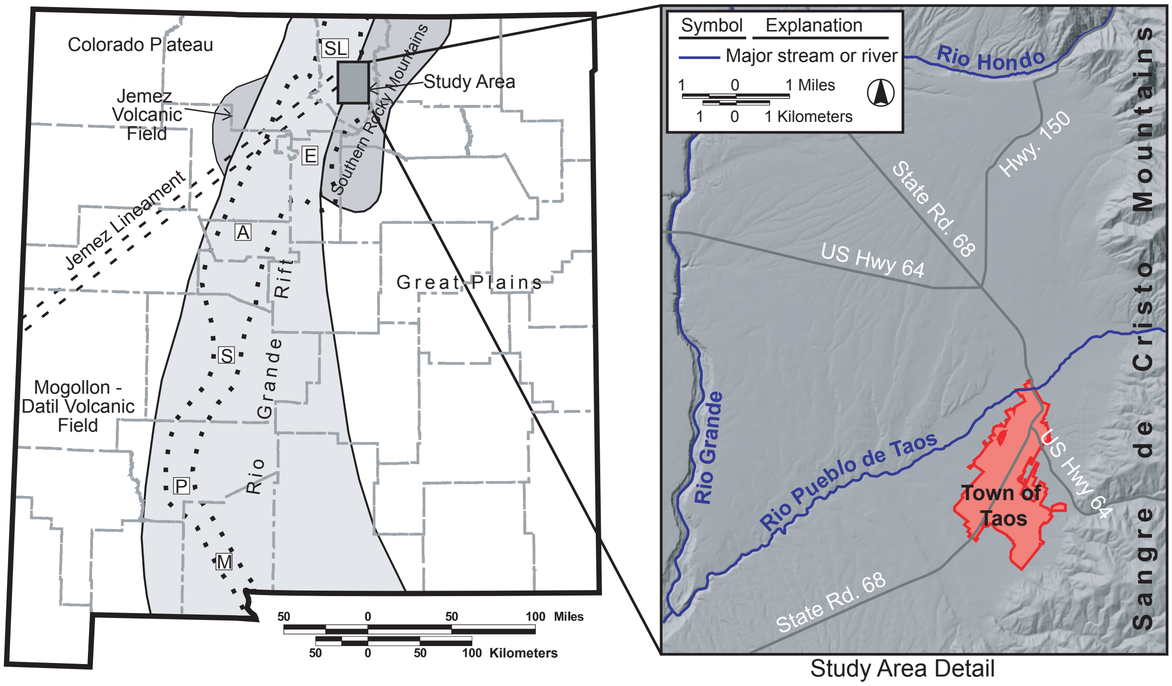

FIGURE 1. Location map – schematic map of New Mexico showing study area and the approximate limits of various physiographic provinces and geographic features. Major basins in the Rio Grande rift from north to south are: SL=San Luis, E = Española, A = Albuquerque, S = Socorro, P = Palomas, M = Mimbres. (state map modified from Sanford et al., 1995 and Keller and Cather, 1994).

shallow stream-connected alluvial aquifer system. In an effort to minimize stream depletion effects resulting from new groundwater development, the Town of Taos and Taos Pueblo, with funding from the U.S. Bureau of Reclamation (BOR), conducted a deep drilling program to evaluate the productivity and water quality of the Tertiary basin-fill aquifer system underlying the Servilleta Formation. The results of this drilling program, in conjunction with data collected from shallow basin fill and alluvial wells and additional deep exploratory wells, allow for a preliminary evaluation of aquifer characteristics, vertical connectivity of the shallow and deep aquifer systems, and the effect of faults on groundwater flow in the basin-fill aquifer system.

METHODOLOGY

A series of exploratory wells were drilled and tested during the deep drilling program and previous investigations to characterize the basin fill aquifer system. Data from 45 pumping tests are used to determine aquifer characteristics and boundary effects, in particular to determine the effect (if any) of faults on groundwater flow. Well nests and nested piezometers were installed in several locations and pumping tests were configured to: 1) measure transmissivity (T) and storage coefficient (S); 2) evaluate downward or upward leakage between aquifers induced by pumping stresses, and; 3) where possible, to calculate vertical hydraulic conductivity (K’). Water-level data collected from wells in the different aquifers using electronic sounders, steel tapes, and transducers are used to construct potentiometric surface maps of the aquifers and are used to determine upward or downward vertical gradients at point locations.

STRATIGRAPHIC UNITS

From oldest to youngest, the units underlying the basin discussed in this study are: 1) Pennsylvanian Alamitos Formation, 2) Tertiary Picuris Formation, 3) Tertiary Santa Fe Group, 4) Tertiary Servilleta Formation, and 5) Quaternary Alluvium. Galusha and Blick (1971) subdivided the Santa Fe Group into the Tesuque Formation and the overlying Chamita Formation. The Tesuque Formation is further subdivided into the Chama-El Rito Member and the overlying Ojo Caliente Sandstone Member (Fig. 2; Galusha and Blick, 1971). Although extending this Santa Fe Group stratigraphic nomenclature into the southern San Luis Basin may be problematic, it is used as an initial framework for this investigation.

DESCRIPTION OF THE SHALLOW AQUIFER SYSTEM

Two major aquifer systems are identified in the Taos area: 1) A shallow aquifer that includes the Servilleta Formation and overlying alluvial deposits and, 2) A deeper aquifer associated with Tertiary age rift-fill sediments (Fig. 2). The lower Servilleta basalt and underlying Chamita Formation may act as a transition zone and/or boundary between the shallow and deep aquifers, although there are not currently enough data points in this interval to definitively support or refute this hypothesis.

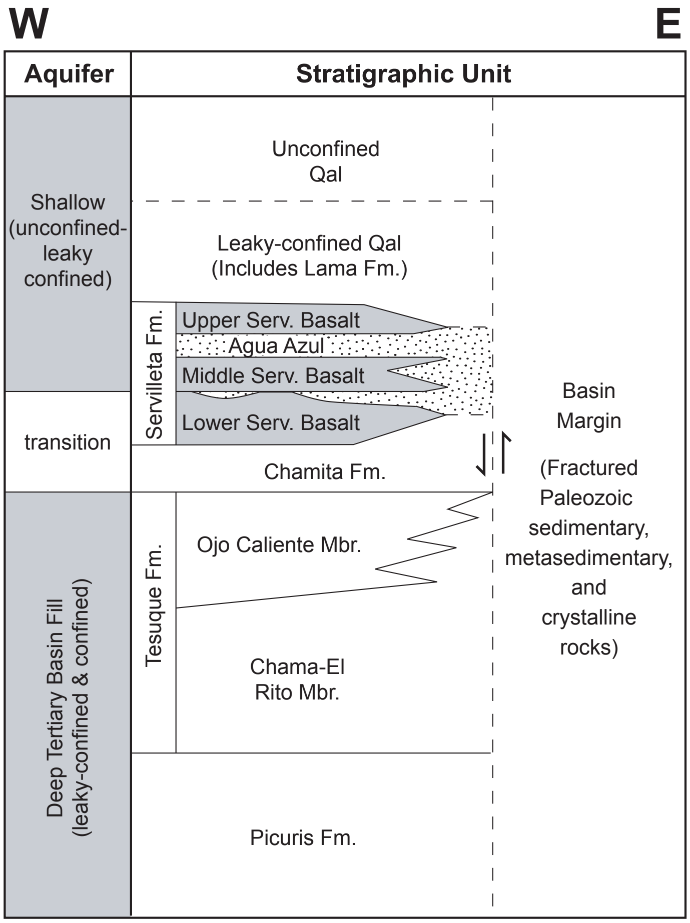

FIGURE 2. Taos Valley geohydrologic framework

The shallow aquifer system generally includes unconsolidated alluvial fan and axial-fluvial deposits overlying and interbedded with the Servilleta basalt flows. The shallow aquifer is subdivided on the basis of lithology and pumping test analyses into: 1) unconfined alluvium; 2) leaky-confined alluvium, and; 3) the Servilleta Formation (Fig. 2). Several wells in the study area are completed into shallow aquifers in fractured Paleozoic sedimentary formations and fractured Precambrian crystalline rocks along the Sangre de Cristo mountain front. These aquifers discharge to alluvium and/or the Servilleta Formation and are therefore part of the shallow alluvial-aquifer flow system. The shallow alluvial aquifer has a maximum thickness of 1500 ft (457 m) or more in the graben formed by the down-to-the-west Town Yard fault and the down-to-the-east Seco fault (Drakos et al., this volume), and pinches out in the western part of the study area where the alluvium is unsaturated at the Taos Airport domestic well (Fig. 4).

Hydrologic Characteristics of the Shallow Aquifer

Aquifer testing data are available for the shallow aquifer from 32 pumping tests at locations throughout the study area (Fig. 4; Table 1). Pumping tests were run for times ranging from 350 to 12,960 minutes (min) at discharge (Q) ranging from 18 to 440 gallons per minute (gpm) (Table 1).

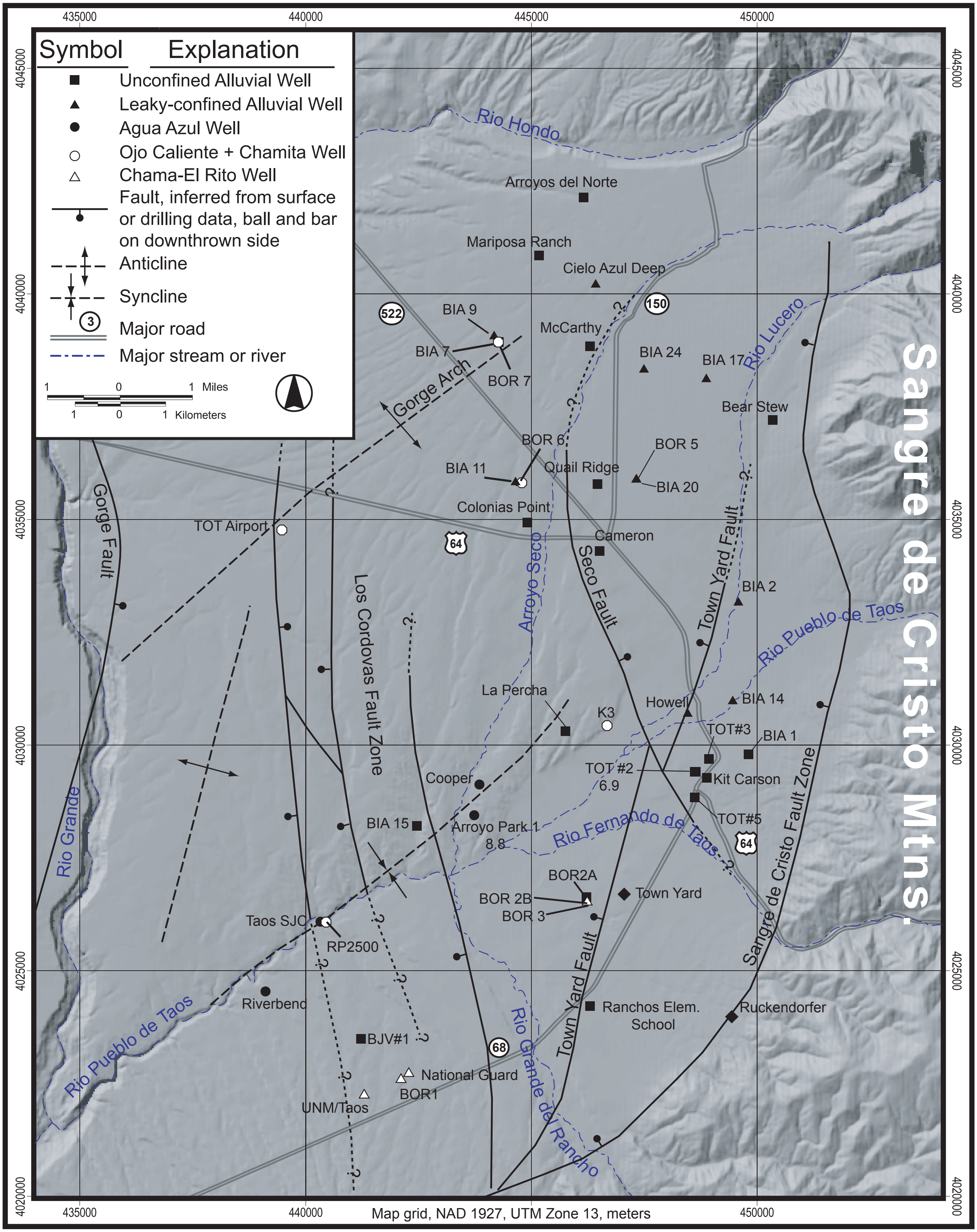

FIGURE 3. Map of study area with pumping test well locations

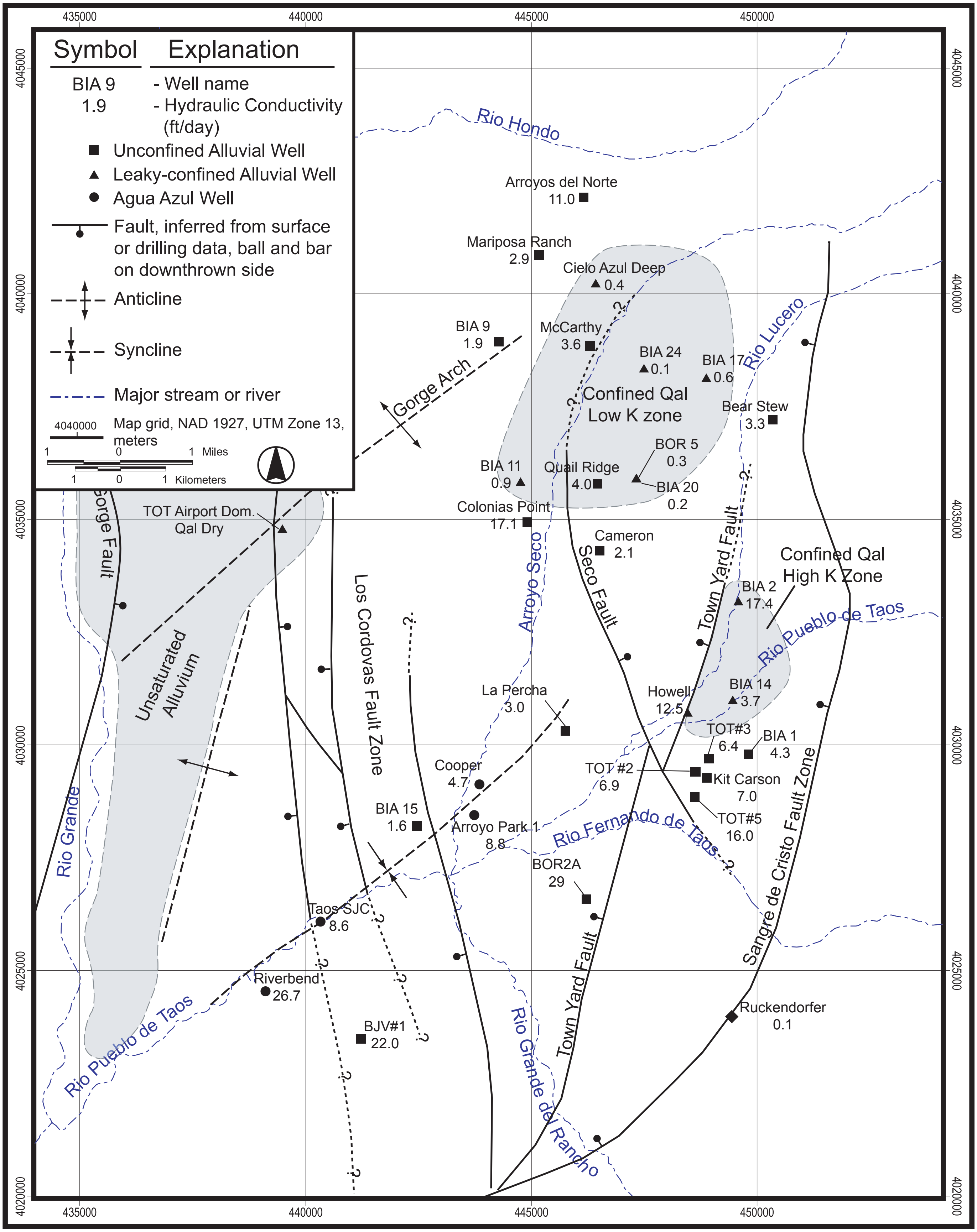

FIGURE 4. Map of shallow aquifer wells with K values from pumping tests

Unconfined alluvium

Pumping tests on 18 unconfined alluvial wells exhibit hydraulic conductivity (K) values ranging from 1.8 to 22 ft/day (mean = 6.8 ft/day, ± (1σ) 5.9 ft/day). No clear pattern is observed in geographic distribution of K in the unconfined alluvial aquifer (Fig. 4). The K value calculated at a given location is likely controlled by local facies changes (e.g. better sorted axial fluvial deposits yield higher K values than less well sorted overbank or fan deposits) and well design (e.g. whether the well was drilled and screened to sufficient depth to encounter a productive zone). Pumping tests were not run long enough to observe delayed yield and allow for a calculation of specific yield (S_y), but storativity (S) ranged from 10^{-4} to 10^{-2}. Possible recharge boundaries were observed in the TOT#3 and TOT#1 tests, and, although data are somewhat ambiguous, an impermeable boundary may be indicated in the BJV#1 test (Table 1). The possible recharge boundary observed in the TOT#3 and TOT#1 tests is likely a result of leakage into the shallow aquifer from the nearby Rio Pueblo de Taos and Rio Lucero.

Leaky-confined alluvium

Pumping tests on nine leaky-confined alluvial wells exhibit K values ranging from 0.1 to 17.4 ft/day, and fall into two distinct populations and geographic groupings. Low-K (mean K = 0.4 ft/day) northern wells correspond to older Blueberry Hill mudflow or weathered fan deposits underlying the large Rio Hondo alluvial fan at the northern portion of the study area. High-K (mean K = 11.4 ft/day) values observed in southern wells correspond to young (?), less-weathered deposits underlying the small Rio Pueblo de Taos fan (Fig. 4). The Howell well and BIA 2 (Buffalo Pasture) wells, which both exhibit high K values of 12 to 17 ft/day, lie along the northern trace (approximately located) of the Town Yard fault (Fig. 4). This segment of the fault may be a high-permeability zone or may be coincident with high-permeability Rio Lucero and/or ancestral Rio Hondo or Rio Pueblo de Taos channel fill deposits. The Town Yard fault may have been a control on stream channel location during aggradation of paleo-Rio Pueblo de Taos or paleo-Rio Hondo deposits. The Town Yard fault projects into the present day Rio Lucero drainage, and the "Seco fault" projects into the Arroyo Seco drainage (Fig. 4).

Servilleta Formation (Agua Azul aquifer)

Aquifer testing data are available for the Servilleta Formation from five pumping tests (Fig. 4, Table 2). All wells tested are completed into the "Agua Azul" aquifer between the upper and middle basalt flow members and are located along the Rio Pueblo de Taos and Arroyo Seco drainages (Fig. 4). Pumping test duration ranged from 2,880 to 5,760 min at Q ranging from 8 to 120 gpm (Table 2). Agua Azul wells exhibit K ranging from 4.7 to 26.7 ft/day (mean K = 12.0 ± 8.6 ft/day). Because the five wells tested in the "Agua Azul" aquifer are relatively close to one another (Fig. 4), determining the geographic distribution of K is not possible. Storativity values range around 10^{-4}.

TABLE 1. Aquifer testing data from unconfined and confined/leaky confined alluvial wells, southern San Luis basin. DTW = depth to water; Q = discharge; T = transmissivity; b = aquifer thickness; K = hydraulic conductivity. Well locations included in Appendix A.

Well Name	TD (ft)	Static DTW (ft)	Test length (min)	Q (gpm)	T (ft^2/day)	b (ft)	K (ft/day)	Storage coefficient	Boundaries observed	Source	Comments
Unconfined alluvium											
Colonias Point	127	55	2880	36	1,200	70	17.1	n.a.	none	GGI	well pumped at maximum Q of existing pump
Quail Ridge	150	45	2880	22	400	100	4.0	1.2×10^{-2}	none	GGI	calculations from obs. well data, r = 35 ft
TOT #1	182	43	400	125	830	140	5.9	5.2×10^{-4}	none/	GGI	calculations from obs. well data, r = 50 ft
McCarthy	193	84	2880	18	400	110	3.6	n.a.	none	GGI	
TOT #2	204	42	355	205	760	110	6.9	8.6×10^{-4}	none	GGI	calculations from obs. well data, r = 50 ft
BIA 15	225	116	1600	41	150	95	1.6	2.5×10^{-2}	none	BIA	observation well data, r = 21 ft
BJV#1	240	158	5760	68	1,980	90	22.0	1.0×10^{-3}	none/ imperm?	GGI	Theis curve is very poor fit; obs well data suggest impermeable boundary
Kit Carson	270	64	480	100	1,400	200	7.0	n.a.	none	GGI	
BOR 2A	291	61	250	45	230	80	2.9	n.a.	none	GGI	
TOT #3	312	60	350	180	960	150	6.4	n.a.	none/	GGI	T calculated from obs. well data, r = 18 ft
TOT#5	330	14	1720	370	3,700	230	16.1	n.a.	none	GGI	
Bear Stew	339	46	1300	33	968	290	3.3	n.a.	recharge?	BIA	
Cameron	350	107	2880	50	500	240	2.1	n.a.	none	GGI	
La Percha	360	105	2880	69	700	235	3.0	n.a.	none	GGI	
BIA 1	400	92	1440	180	825	190	4.3	n.a.	none	BIA	T = avg of Pump & Rec semilog plots
BIA 9	575	470	1400	18.5	230	120	1.9	3.0×10^{-4}	none	BIA	T calculated from obs. well data, r = 23.1 ft
Mariposa Ranch	781	585	2880	31-49	580	200	2.9	n.a.	none	GGI	well dev. during pumping; T from rec data
Arroyos del Norte	800	659	2880	55	1,100	100	11.0	n.a.	none	GGI	
Confined or leaky-confined alluvium											
Southern wells											
Howell	500	13	12960	440	5,000	400	12.5	6.3×10^{-3}	leaky/recharge	GGI	T and S calculated from obs. well data, r = 485 ft; k' = 0.2 ft/day
BIA 14	613	-1	2800	70	810	220	3.7	n.a.	none	BIA	
BIA 2	700	18	1440	300	5,700	440	17.4	6×10^{-3}	leaky/recharge	BIA	S calculated from obs. well data, r = 47 ft
Northern wells											
BIA 17	470	86	1440	19	230	385	0.6	n.a.	leaky/recharge	BIA	
BIA 11	760	100	2800	70	310	330	0.9	1×10^{-3}	none	BIA	S calculated from obs. well data (30'screen), r = 147 ft;
Cielo Azul deep	850	339	2880	20	40	100	0.4	n.a.	none	BIA	no drawdown observed in adjacent shallow well during test
BIA 24/ Grumpy	1000	177	944	25	32	400	0.1	n.a.	none	BIA	Blueberry Hill Fm?
BIA 20/ West	1018	111	1120	50	120	600	0.2	n.a.	none	BIA	Blueberry Hill Fm?
BOR 5	1763	265	5760	40	110	400	0.3	n.a.	none	BIA	Blueberry Hill Fm?

Groundwater Flow Direction in the Shallow Aquifer System

A composite alluvial and Agua Azul (Servilleta) potentiometric surface map representing the shallow alluvial aquifer was constructed from water levels measured to the nearest 0.01 ft from wells that could be assigned to a specific aquifer. In the northeast part of the study area, a downward vertical gradient was observed in the alluvial aquifer, with up to 200+ ft (60+ m) head difference in adjacent wells (e.g. well nests Cielo Azul shallow and deep, BIA20/BOR5, Mariposa shallow/deep; Fig. 5). Where strong downward vertical gradients are observed, the shallower water level was used for construction of the potentiometric surface map. Water levels from Agua Azul wells were included with the alluvial well data, because the Agua Azul aquifer interfingers with the alluvium near the mountain front and in the southern part of the study area, and water levels in the Agua Azul are similar to those measured in the unconfined alluvium.

In addition to groundwater elevations measured in wells throughout the study area, streambed elevation data are incorporated into the construction of the potentiometric surface map. Streambed elevations were determined from USGS 7.5’ quadrangles and added as elevation control points to the base map. Equipotential lines are contoured so that groundwater elevation is less than or approximately equal to streambed elevation. Equipotential lines lie consistently lower than streambed elevation along the lower Rio Pueblo de Taos and the Arroyo Seco, indicating a disconnection between surface water and groundwater in those areas.

Groundwater flow direction in the composite Alluvial plus Aqua Azul (Servilleta) aquifer system is from northeast to southwest and east to west (Fig. 5). A broad groundwater trough is observed north of Rio Pueblo de Taos and west of Rio Lucero (Fig. 5). At its northern end the trough axis projects into the Rio Hondo drainage (Fig. 5), and the trough lies along the eastern side of the large Rio Hondo fan north of Rio Pueblo de Taos. This trough may correspond to an area of high-permeability fluvial deposits associated with the ancestral Rio Hondo, and is coincident with a structural low (Lipman, 1978, p. 42) or Rio Pueblo de Taos syncline of Machette and Personius (1984) and Dungan et al. (1984), suggesting a structural control on the location of the ancestral Rio Hondo drainage. However, the location of the river has been restricted to near its present course since stream incision occurred in response to rapid cutting of the Rio Grande gorge ca. 0.6 to 0.3 Ma ago (Wells et al.,1987; Kelson and Wells, 1987). Since that time, the Rio Hondo has been an entrenched stream flowing very close to its present location (Kelson and Wells, 1987, Kelson and Wells, 1989). Other high transmissivity zones associated with axial stream deposits have been identified along the Rio Grande del Rancho (within the Miranda graben) and along the Rio Fernando (Spiegel and Couse, 1969; Bauer et al., 1999). A groundwater high is observed in the vicinity of the lower Arroyo Seco drainage on the west side of the Town of Taos, corresponding to the area between the Gorge arch and the Rio Pueblo de Taos syncline (Fig. 5). The composite Alluvial plus Servilleta aquifer system becomes unsaturated in the western part of the study area, indicating this upper aquifer is discharging to surface water where it is stream connected and/or leaking into the deeper basin-fill aquifer. The steepening gradient in the vicinity of the Los Cordovas faults suggests that the faults are an area of downward leakage through which the shallow aquifer may be recharging the deep aquifer system.

Equipotential lines are deflected downstream along most of the Arroyo Seco and the upper Rio Lucero, indicating that these are losing streams west of the mountain front (Fig. 5). Based on equipotential lines, the upper Rio Hondo is a gaining reach, whereas the lower Rio Hondo is a losing reach. Equipotential lines are generally deflected upstream along the Rio Pueblo de Taos, lower Rio Lucero, and Rio Fernando de Taos, indicating that these streams are gaining reaches (Fig. 5).

In January and June 2000, personnel from the BIA, GGI, and the BOR measured flows in Taos valley rivers (Rio Hondo, Arroyo Seco, Rio Lucero, Rio Fernando de Taos, Rio Pueblo de Taos, Rio Grande del Rancho). Flows were measured in January and June to determine seasonal variations in stream loss or gain. Acequia diversions from and return flows to each river were also measured and accounted for in the flow data to allow for a determination of gaining or losing reaches (see Smith, 2001 and 2002, unpubl. BOR reports, for results of this study). Figure 5 summarizes the results of the January, 2001 stream gaging, showing losing, gaining, and no net change reaches of the major stream systems. In general, results of stream gaging correlate well with gaining and losing reaches derived from construction of the potentiometric surface map described above. However, two significant differences are observed between the gaging data and the potentiometric surface map: 1) gaging data show the upper reaches of the Rio Hondo as losing reaches, while the equipotential lines suggest it is a gaining reach, and 2) gaging data indicate the upper reach of the Rio Lucero is gaining, while the potentiometric surface map suggests it is a losing reach (Fig. 5). These differences may be a result of the groundwater elevation representing long-term

TABLE 2. Aquifer testing data from Servilleta Formation sediments and fractured basalt (Agua Azul) wells, southern San Luis Basin. Well locations included in Appendix A.

Well Name	TD (ft)	Static DTW (ft)	Test length (min)	Q (gpm)	T (ft^2/day)	b (ft)	K (ft/day)	Storage coefficient	Boundaries observed	Source	Comments
Cooper	180	96	2880	31	280	60	4.7	n.a.	none	GGI	
Arroyo Park	262	105	2880	48	530	60	8.8	5.3×10^{-4}	none	GGI	S calc from obs well, r = 2000 ft
Taos SJC	180	29	5760	120	430	50	8.6	2.5×10^{-4}	none	GGI	calculations from observatin well data, r = 25 ft;k' = 0.02 ft/day
Barranca del Pueblo		233	2880	7.5-12	670	60	11.2	n.a.	none	RE/SPEC	b is unknown; 60 ft used as default aquifer thickness
Riverbend	215	121	2880	54	1,600	60	26.7	8.5×10^{-5}	none	GGI	

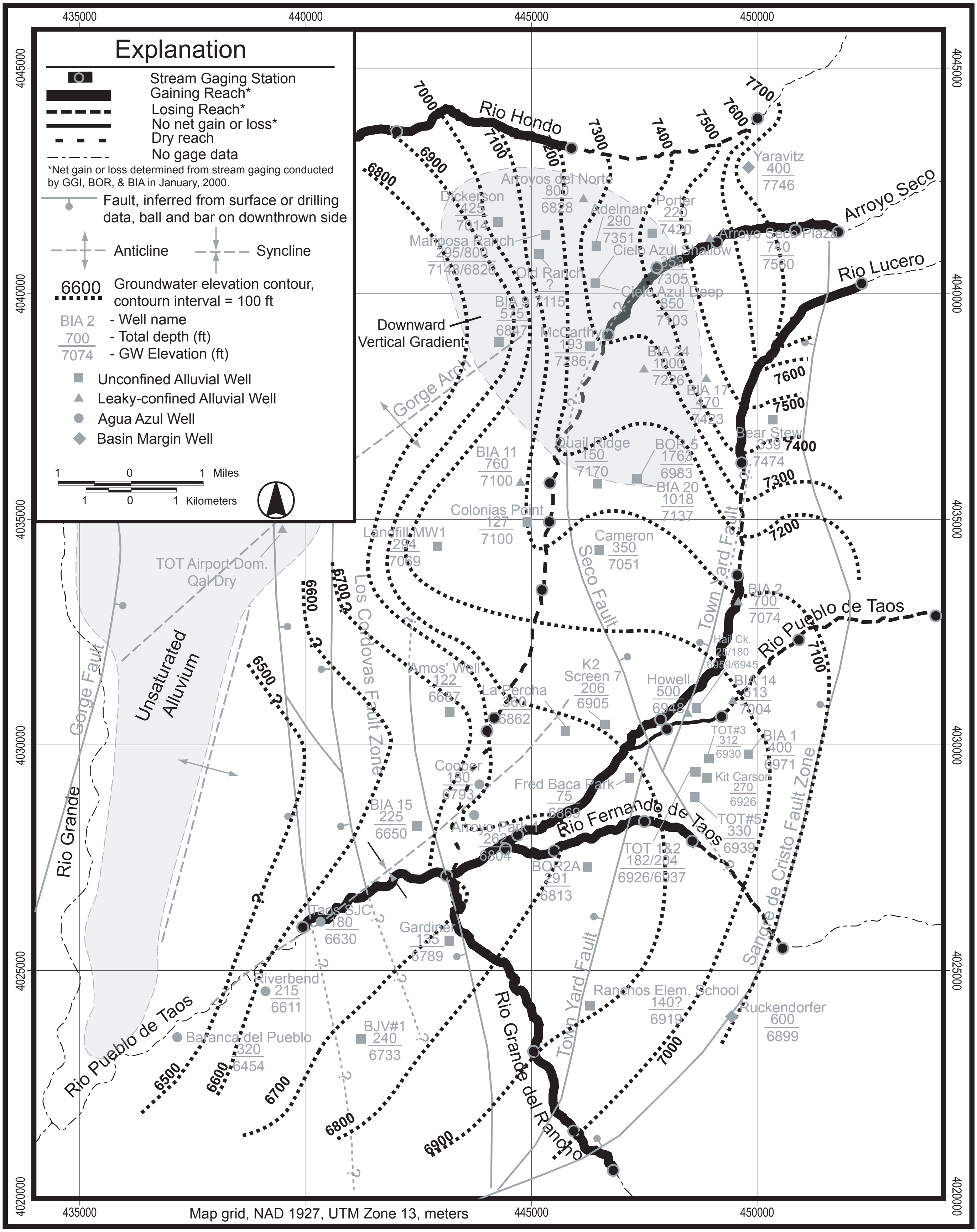

FIGURE 5. Shallow aquifer potentiometric surface map, gaining and losing stream reaches

conditions, while the gaging data are a snapshot of conditions at a particular time. It is also possible that some surface diversions from, or additions to, the rivers may not have been accounted for or may have been variable during the gaging study.

Effect of Faults on the Shallow Aquifer

Unconfined and leaky-confined alluvium

Twenty-seven pumping tests have been conducted on alluvial wells, nine of which were conducted on wells completed into the leaky-confined alluvial aquifer facies, and five of which were additional tests conducted on Agua Azul (Servilleta) wells. Of these tests, data from only one well near the southern portion of the study area (BJV#1) suggest impermeable boundary effects (Table 1). Pumping test data from numerous other wells located in close proximity (< approximately 0.5 mi or 0.8 km) to faults do not show impermeable boundary effects (Fig. 4; Table 1). As examples, the Howell, BIA2, and possibly Bear Stew wells are located along the Town Yard Fault; Quail Ridge, Cameron, and TOT#5 are located along the Seco fault; and BIA 15 is located near one of the Los Cordovas faults. Data from the BJV#1 test is suggestive of an impermeable boundary, which may correspond to a southern extension of the western Los Cordovas fault (Fig. 3). The down-to-the-west Los Cordovas fault would likely juxtapose a thick clay against the underlying relatively thin water-producing sandy gravel described in the BJV#1 well log (Lazarus, unpubl. GGI report for BJV properties, 1989). In contrast, data from three wells located along the northern segment of the Town Yard fault (Howell, BIA 2, and Bear Stew wells) indicate leakage or recharge boundaries, suggesting that the northern segment of the Town Yard fault may be a zone of enhanced permeability. Alternatively, as discussed above, the northern Town Yard fault may be coincident with an area of deposition of high-permeability axial channel deposits.

Based on the well density used to construct the potentiometric surface map and the 100-ft contour interval utilized, equipotential lines in the unconfined and leaky-confined alluvial aquifers are not strongly affected by the major faults in the basin (Fig. 5). This is consistent with the aquifer testing data, which indicate that, except in rare cases, intrabasin faults do not act as barriers to groundwater flow in the shallow alluvial aquifer. In some cases, such as the northern segment of the Town Yard fault, intrabasin faults may act as zones of enhanced permeability in the alluvium.

Servilleta Formation (Agua Azul aquifer facies)

Neither recharge nor impermeable boundaries were observed in any of the five tests for which data are available (Table 2). This is an unexpected result, given the relatively thin producing interval (50-60 ft thick [15-20 m]) aquifer and the proximity of Agua Azul wells to several of the Los Cordovas faults, in particular the proximity of the Taos SJC well to the western Los Cordovas fault strand (Fig. 4).

Aquifer Anisotropy/Vertical Hydraulic Conductivity

Alluvium

Data on vertical hydraulic conductivity (K’) and aquifer anisotropy are available from one location in the shallow aquifer system. The Howell well pumping test configuration included observation wells completed in both the deep leaky-confined and shallow stream-connected unconfined alluvial aquifers (Hail Creek shallow/deep; Fig. 5). Based on the Hantush-Jacob (1955) leaky-confined aquifer solution, a K’ of 0.2 ft/day was calculated. Based on the Howell well pumping test, horizontal K is approximately 60 times vertical K.

Servilleta Formation (Agua Azul)

Data on K’ and aquifer anisotropy are available from one location in the Servilleta Formation. The Taos SJC well pumping test configuration included observation wells completed in both the Agua Azul and the overlying shallow stream-connected unconfined alluvial aquifer (GGI, unpubl. consulting report to the Town of Taos, 1997). Based on the Hantush-Jacob (1955) leaky-confined aquifer solution, a K’ of 0.02 ft/day through the USB was calculated. Horizontal K is approximately 430 times vertical K at that location.

DEEP TERTIARY BASIN FILL AQUIFER

The deep Tertiary basin fill aquifer includes generally weakly to moderately cemented eolian, alluvial fan, fluvial, and volcaniclastic deposits that underlie the Servilleta Formation. The deep Tertiary basin fill aquifer includes the Chamita Formation, the Ojo Caliente Sandstone Member of Tesuque Formation, the Chama-El Rito Member of Tesuque Formation, and the Lower Picuris Formation (Fig. 2). Pumping test data are available for the Ojo Caliente Sandstone Member of Tesuque Formation, the Chama-El Rito Member of Tesuque Formation, but are not available from wells completed solely in the Chamita or Picuris Formation.

The Tertiary basin fill aquifer exhibits confined or leaky-confined characteristics in the central and eastern part of the study area, but is likely unconfined in the western part of the study area along the Rio Grande. A deep fractured crystalline rock aquifer at or near the Sangre de Cristo mountain front may discharge to the deep basin fill aquifer system, but no wells are known to be completed into this zone. The Chamita Formation and the overlying Servilleta Formation, while not extensively studied, may represent a transition zone between the shallow and deep aquifer systems (Fig. 2). The deep aquifer is, where investigated thus far, greater than 2000 ft thick. However, the Taos graben, within which the study area lies, has a depth of approximately 5 km (16,000 ft) (Cordell, 1978; Bauer and Kelson, this volume), so further investigations may show the deep aquifer to be significantly thicker than is presently known.

Hydrologic Characteristics of the Deep Aquifer

Ojo Caliente Sandstone Member of Tesuque Formation

Aquifer testing data are available from five wells completed entirely or predominantly in the Ojo Caliente Sandstone Member of the Tesuque Formation (Fig. 6). Three of the tests were multiple-well pumping tests (Table 3). Wells completed into the Ojo Caliente range in depth from 1720 to 2991 ft (524 to 912 m; Table 3), and exhibit pressure head (height of water column above the screened interval in a well) ranging from 500 ft (150 m) in the Airport well to greater than 1700 ft (500 m) in BOR7. Pumping test durations ranged from 1,361 to 11,965 min at Q ranging from 57 to 400 gpm (Table 3). Ojo Caliente wells exhibit K ranging from 0.2 to 0.8 ft/day (mean K = 0.4 ± 0.25 ft/day). Hydraulic conductivity in the Ojo Caliente is relatively consistent throughout the area and does not show variability relative to geographic location (Fig. 6). S values range from 1×10^{-3} to 2×10^{-2} (Table 3).

Chama-El Rito Member of Tesuque Formation

Aquifer testing data are available from five wells completed entirely or predominantly into the Chama-El Rito Member of the Tesuque Formation, three of which are multiple-well tests (Fig. 6; Table 4). Wells completed into the Chama-El Rito Member range from 1200 ft (365 m) to 2109 ft (643 m) in depth (Table 4), and exhibit pressure head ranging from 590 ft (180 m) at UNM/Taos to greater than 1300 ft (400 m) (BOR3). Pumping tests were run for times ranging from 2,737 to 15,840 min at Q ranging from 60 to 500 gpm (Table 4). Chama-El Rito wells exhibit K ranging from 0.6 to 3.4 ft/day (mean K = 1.8 ± 1.0 ft/day). Aquifer testing data for the Chama-El Rito Member are only available for the southern part of the study area so the geographic distribution of K throughout the basin is unknown. An S of 5×10^{-4} was calculated from the BOR3/BOR2 pumping test. All Chama-El Rito wells exhibited a confined or leaky-confined response during pumping tests. These data, in conjunction with the large pressure head observed in Chama-El Rito wells, indicates that the portion of the Chama-El Rito Member investigated thus far is a confined or leaky-confined aquifer.

Groundwater Flow Direction in the Deep Tertiary Aquifer System

Water level data from deep wells in the basin were used to construct a preliminary potentiometric surface map of the deep basin fill aquifer. These limited data suggest that groundwater flow direction in the deep aquifer is generally from east to west, at a relatively shallow gradient of approximately 0.004 ft/ft (Fig. 6). The shallow alluvial aquifer system has a much steeper gradient (measured north of and parallel to the Rio Pueblo de Taos) of approximately 0.02 ft/ft. Although the head in the shallow aquifer system is much higher in the eastern part of the study area along the Sangre de Cristo mountain front, the potentiometric surfaces in the shallow and deep aquifers project toward one another in the western part of the study area. Head in the shallow alluvial aquifer is approximately from 100 to 200 ft higher than the head in the deep aquifer just east of where the shallow aquifer becomes unsaturated, suggesting the shallow aquifer discharges to the deep aquifer system in this general area.

Vertical gradients in the deep aquifer are observed at several well nests in the study area. Downward gradients are observed in the deep basin fill aquifer at well nests BOR4/BOR6, BOR7/BIA9, BOR1/NGDOM, and BOR2/BOR3, whereas upward gradients are observed at RP2500/RP2000 and K2/K3. Both well nests with upward gradients (BOR2/BOR3 and K2/K3) are located along the approximate trace of the Rio Pueblo de Taos syncline (Fig. 6; Lipman, 1978). These data suggest recharge to the deep aquifer at or near the basin margin migrates downdip within the syncline resulting in an upward pressure head along the fold axis.

Effect of Faults on Groundwater Flow

Ojo Caliente Sandstone Member of Tesuque Formation

Impermeable boundary effects were observed in K2/K3, RP 2500/RP2000, and BOR6/BOR4 pumping tests (Table 3). K3/K2 and BOR6/BOR4 are located within approximately 0.5 mi (0.8 km) of the Seco Fault (Fig. 6). The Servilleta Formation is offset approximately 950 ft across the down-to-the-east Seco fault (Drakos et al, 2001). The Seco fault is interpreted as the

TABLE 3. Aquifer testing data from wells completed in Ojo Caliente Sandstone Member of Tesuque Formation, southern San Luis Basin. Well locations included in Appendix A.

Well Name	TD (ft)	Static DTW (ft)	Test length (min)	Q (gpm)	T (ft^2/day)	b (ft)	K (ft/day)	Storage coefficient	Boundaries observed	Source	Comments
K3 - K2	1796	271	10,000	400	200 (early) 90 (late)	960	0.2	1×10^{-3} to 2×10^{-2}	impermeable	BIA	calculations from obs well, r = 65 ft; no drawdown observed in overlying aquifer
RP2500/ RP2000	2500	152	11,965	400	250 (early) 60 (late)	1,200	0.2	1.4×10^{-3}	impermeable	GGI	calculations from obs well, r = 95 ft; no drawdown observed in overlying aquifer
Airport	1720	500	2,760	57	250	685	0.4	n.a.	none	GGI	well developed during test; T is suspect
BOR6/ BOR4	2020	610	10,059	365	640	810	0.8	7×10^{-3}	impermeable	BIA	T and S calc from BOR4 late obs well late time data; r = 103 ft
BOR7	2991	732	1,361	70	110	480	0.2	n.a.	none	BIA	

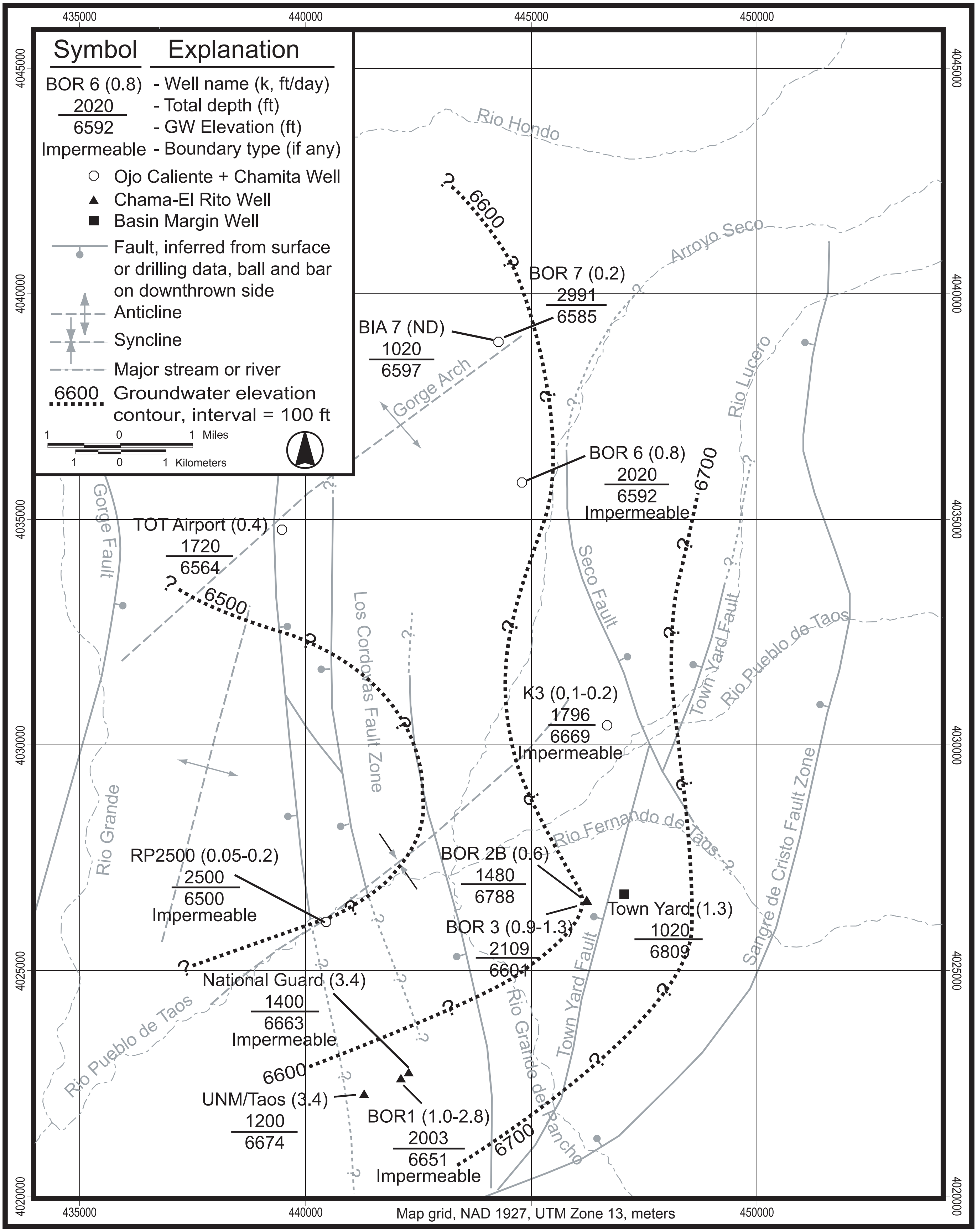

FIGURE 6. Potentiometric surface map and K values for deep basin-fill aquifer

TABLE 4. Aquifer testing data from wells completed in Chama-El Rito Member of Tesuque Formation, southern San Luis Basin. Well locations included in Appendix A.

Well Name	TD (ft)	Static DTW (ft)	Test length (min)	Q (gpm)	T (ft^2/day)	b (ft)	K (ft/day)	Storage coefficient	Boundaries observed	Source	Comments
UNM/Taos	1200	310	2737	60	670	200	3.4			GGI	possibly Chamita Fm?
NGDOM	1400	266	5,760	140	760	400	1.9	n.a.	impermeable	GGI	ddn observed in adjacent deep well (BOR1); no ddn in shallow completion
BOR1	2003	281	5,760	240	1400 (early) 520 (late)	510	1.9	n.a.	impermeable	GGI	early-time k = 2.8 ft/day; late time k = 1.0 ft/day; drawdown observed in adjacent shallow well (NGDOM)
BOR2B	1480	83	2,880	67	280	480	0.6	n.a.	none	GGI	no ddn in overlying or underlying aquifers
BOR3	2109	274	15,840	500	710 (early) 450 (late)	530	1.1	5×10^{-4}	none/possible facies change	GGI	early-time k = 1.3 ft/day; late time k = 0.9 ft/day; no drawdown observed in overlying aquifers

impermeable boundary observed in the K3 and BOR6 pumping tests. RP2500 is located between two of the Los Cordovas faults; one or both of which likely act as impermeable boundaries. As discussed above, similar impermeable boundary effects were not observed in the 180-ft deep Taos SJC well, located adjacent to RP2500. These data suggest that either 1) the Los Cordovas fault(s) near RP2500 exhibit much greater offset with depth, or 2) that impermeable boundary effects are offset by leakage into the shallow aquifer, but are not offset by leakage at depth. The Ojo Caliente has an apparent thickness of > 1200 ft (370 m) at RP2500 (Drakos and Hodgins, unpubl. GGI report for the Town of Taos, 2001), so either the fault plane is a very low-permeability zone, or offset at depth is significant.

Impermeable boundary effects were not observed in the Airport well and BOR7 pumping tests. Both tests were run for much shorter duration (less than 3000 min) at lower discharge than were the three Ojo Caliente tests discussed above (10,000 min or more; Table 3). The BOR7 test was likely not run long enough to observe the Seco fault as a possible boundary; however, from the very close proximity of the Airport well to the western Los Cordovas fault (Fig. 6) it is likely that the cone of depression would have intersected the fault plane during the pumping test. One possible explanation for the absence of an impermeable boundary is that offset on the western Los Cordovas fault is dying out to the north, and Ojo Caliente sediments are juxtaposed against one another across the fault.

Chama-El Rito Member of Tesuque Formation

Impermeable boundary effects were observed in one pumping test conducted in the Chama-El Rito Member of the Tesuque Formation (BOR1/NGDOM pumping tests; Table 4). The impermeable boundary observed in the BOR1/NGDOM pumping tests is likely the southern extension of one of the Los Cordovas faults. The possibility that the Los Cordovas faults extend south of the Rio Pueblo de Taos is suggested by Bauer and Kelson (this volume). Impermeable boundary effects are not observed in the UNM/Taos pumping test, suggesting that the impermeable boundary observed in the BOR1/NGDOM pumping tests are related to faults in the eastern rather than the western portion of the Los Cordovas fault zone (Fig. 6). The southern extension of the trace of the eastern Los Cordovas fault shown in Figures 4-6 is coincident with a fault interpreted from geophysical data from Reynolds (unpubl. consulting report to BIA, 1989).

A series of pumping tests were conducted on the BOR2/BOR3 well nest, located in relatively close proximity to the Town Yard fault (Fig. 6). Test data from BOR2B and BOR2C indicate that the Town Yard fault does not act as an impermeable boundary at this location. Test data from BOR3 were indicative of a weak negative boundary, suggesting a facies change from coarser-grained to finer-grained deposits at some distance from the well (Drakos, Hodgins, Lazarus, and Riesterer, unpubl. GGI report for the Town of Taos, 2002). The Town Yard fault may act as a recharge zone, where the buried Paleozoic sedimentary rock aquifer is in hydrologic communication with rift-filling sediments.

Aquifer Compartmentalization

Several of the intrabasin faults act as hydrologic boundaries, and result in some compartmentalization of the deep basin-fill aquifer. The Seco fault acts as an impermeable boundary, and may act to separate a northeast deeper aquifer system that has been recharged by modern to Holocene precipitation separated from a southwest deep aquifer system that has been recharged by older, possibly Pleistocene precipitation (Drakos et al., this volume). Data from high-precision temperature logs also indicates compartmentalization of the deep basin fill aquifer (Reiter and Sandoval, this volume). Some Los Cordovas fault splays act as impermeable boundaries (e.g. the eastern Los Cordovas fault near BOR1 and one or both of Los Cordovas faults near RP2500), whereas other faults do not appear to affect groundwater flow in the deep aquifer (e.g. the western Los Cordovas fault near the Airport well and near UNM/Taos). This may indicate variable cementation along the fault plane and/or variable offset along Los Cordovas fault strands.

Aquifer Anisotropy/Vertical Hydraulic Conductivity

Ojo Caliente Sandstone Member of Tesuque Formation

The RP2500/RP2000 and K3/K2 pumping test configurations included observation wells completed in both the Ojo Caliente and the overlying Agua Azul (Servilleta) aquifers. Drawdown was not observed in the overlying Agua Azul aquifer during 400 gpm, 10,000 to 12,000 min pumping tests. Without additional piezometers in the Chamita Formation sediments that overlie the Ojo Caliente, and with the presence of strong negative boundary effects observed in the pumping test data, K' in the Ojo Caliente-Chamita Formation aquifer system cannot be evaluated. During the time frame of the pumping tests, no connection was observed between the shallow (Agua Azul) and deep (Ojo Caliente) aquifers.

Chama-El Rito Member of Tesuque Formation

The BOR1/NGDOM and BOR2/BOR3 pumping test configurations included observation wells completed in both the producing interval and water-bearing zones in the overlying Tertiary deposits and shallow alluvial aquifers. Drawdown was not observed in the overlying shallow alluvium during any of the five tests conducted on BOR1, NGDOM, BOR2B, BOR2C, or BOR3 (Table 4). Hydrologic communication was observed between BOR1 and NGDOM during pumping tests on each well, indicating leakage between different producing intervals within the Chama-El Rito aquifer at that location. However, it is notable that no drawdown was observed in BOR2B (bottom of screened interval = 1480 ft) during the 15,840 min (11 day), 500 gpm pumping test on BOR3 (top of screened interval = 1604 ft). BOR3/BOR2 test data indicate that clay beds with very low K' are present within the Chama-El Rito Member at some locations. These preliminary data do not allow for a direct calculation of K' but show that K' likely varies significantly throughout the Chama-El Rito aquifer system. During the time frame of the pumping tests, no connection was observed between the Agua Azul or shallow alluvial aquifers and the Chama-El Rito aquifer.

BASIN MARGIN AQUIFER

Hydrologic Characteristics of the Basin Margin Aquifer

Wells completed into fractured sedimentary and crystalline rock aquifers, while not utilized extensively for municipal use, are utilized for individual domestic and small community water systems. Where fractured, these aquifers are productive but likely are limited in areal extent and are subject to dewatering of the fracture system. In the southern part of the study area, the basin margin aquifer has a moderate to high gradient of 0.1 to 0.7 ft/ft to the northwest (Bauer et al., 1999). Water table elevation contours from Bauer et al. (1999, Plate 1) indicate that the basin margin aquifer discharges to the shallow basin fill aquifer.

Limited aquifer testing data are available from three wells completed into fractured Paleozoic sedimentary rocks or fractured crystalline rocks, two of which are located in basin margin settings (Figure 5; Table 5). Well depths range from 400 to 1200 ft (120 to 365 m) in depth, and include the Town Yard well, drilled into the Paleozoic Alamitos Formation underlying the Tertiary sediments in the southeast part of the study area (Fig. 4, Table 5). Pumping tests were run for times ranging from 435 to 2880 min at Q ranging from 8 to 48 gpm (Table 5). Based on these limited test results, the fractured sedimentary rock and crystalline rock aquifers exhibit hydraulic conductivity (K) ranging from 0.1 to 2.8 ft/day. Data on S are not available. Head in the Ruckendorfer and Yaravitz wells is at a similar elevation to the head in the shallow alluvial aquifer (Fig. 5), indicating that these basin margin wells are discharging to the shallow alluvial aquifer

CONCLUSIONS

Two major aquifer systems are present in the Taos area. The shallow aquifer includes the Servilleta Formation and overlying alluvial deposits. The deeper aquifer includes Tertiary age rift-fill sediments below the Servilleta Formation. The shallow aquifer system includes unconsolidated alluvial fan and axial fluvial deposits overlying and interbedded with and including the Servilleta basalts and is subdivided into: 1) unconfined alluvium; 2) leaky-confined alluvium, and; 3) the Servilleta Formation. The deep Tertiary basin-fill aquifer includes the Chamita Formation, the Ojo Caliente Sandstone Member of the Tesuque Formation, the Chama-El Rito Member of the Tesuque Formation, and the Picuris Formation.

Hydraulic conductivity in the shallow unconfined alluvial aquifer ranges from 6.8 ± 5.9 ft/day for the unconfined alluvial facies to 12.0 ± 8.6 ft/day for the Agua Azul aquifer facies. The deep leaky-confined alluvial wells exhibit K values ranging from 0.1 to 17.4 ft/day, and fall into two distinct populations and geographic groupings. The low-K (mean K = 0.4 ft/day) deep aquifer facies corresponds to older Blueberry Hill mudflows or weathered fan deposits underlying the large Rio Hondo alluvial fan in the northern portion of the study area. The high-K (mean K = 11.4 ft/day) deep alluvial aquifer facies corresponds to young (?), less-weathered deposits underlying the small Rio Pueblo de Taos fan. A K' of 0.2 ft/day was calculated from a single test in the alluvial aquifer, and a K' of 0.02 ft/day through the USB was calculated from a single Agua Azul test. Storativity of the alluvial aquifer ranges from 10^{-4} to 10^{-2}.

The deep basin-fill aquifer system is subdivided into the Chama-El Rito and Ojo Caliente facies. Ojo Caliente wells exhibit K of 0.4 ± 0.25 ft/day. S values for Ojo Caliente wells

TABLE 5. Aquifer testing data from basin margin wells, southern San Luis Basin. Well locations included in Appendix A.

Well Name	TD (ft)	Static DTW (ft)	Test length (min)	Q (gpm)	ft2/day	b (ft)	T (ft^2/day)	Storage coefficient	Boundaries observed	Source	Comments
Yaravitz	400	93	2880	31	310	110	2.8	n.a.	none	GGI	fractured amphibolite/granite along fault
Town Yard	1020	115	435	48	400	300	1.3	n.a.	none	GGI	open hole test; preliminary data for Pz
Ruckendorfer	600	391	2880	8	20	170	0.1	n.a.	impermeable?	GGI	poor curve match; Pz sandstone aquifer

range from 10^{-3} to 10^{-2}. Chama-El Rito wells exhibit a K of 1.8 ± 1.0 ft/day. An S of 5×10^{-4} was calculated from the BOR3/BOR2 pumping test.

Faults typically do not act as impermeable boundaries in the shallow alluvial aquifer. However, the Seco fault and several of the Los Cordovas faults act as impermeable boundaries in deep basin-fill aquifer. The Town Yard fault is a zone of enhanced permeability or is coincident with a high-permeability zone in the shallow alluvial aquifer, and does not act as an impermeable boundary in the deep basin fill aquifer. Intrabasin faults with significant offset, such as the Seco fault, result in compartmentalization of the aquifer.

Groundwater flow direction in the composite Alluvial plus Servilleta aquifer system is from northeast to southwest and from east to west at 0.02 ft/ft. A broad groundwater trough is observed whose axis is north of Rio Pueblo de Taos and west of Rio Lucero This trough may correspond to an area of high-permeability fluvial deposits associated with the ancestral Rio Hondo, whose course was controlled by the Rio Pueblo de Taos syncline. An area exhibiting a downward vertical gradient in the shallow aquifer is observed between the Rio Hondo and Rio Lucero in the northern part of the study area. The limited available data suggest that groundwater flow direction in the deep aquifer is generally from east to west, at a relatively shallow gradient of approximately 0.004 ft/ft. Downward gradients are observed in the deep basin-fill aquifer except at the Rio Pueblo de Taos syncline, where upward gradients are observed at RP2500/RP2000 and K2/K3.

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APPENDIX A

WELL LOCATIONS FOR TAOS AREA WELLS CITED IN THIS STUDY

	UTM NAD 27, zone 13, m.	
WELL NAME	Easting	Northing
Abeyta Well	448752	4024118
Arroyo Hondo	452696	4046154
Arroyo Park	443740	4028440
Arroyo Seco	448745	4041260
Arroyos del Norte	446162	4042084
Baranca del Pueblo	437160	4023520
Bear Stew	450352	4037199
BIA 11	444775	4035824
BIA 13	448320	4034830
BIA 13	449820	4029780
BIA 14	449470	4030990
BIA 15	442470	4028200
BIA 17	448890	4038130
BIA 2	449600	4033180
BIA 20	447335	4035901
BIA 24	447500	4038340
BIA 9	444280	4038930
BJV #1	441230	4023480
BOR 1	442124	4022604
BOR 4 Deep	444766	4035805
BOR 6 #1	444797	4035805
BOR 6 #2	444797	4035805
BOR2A	446247	4026541
BOR2B/2C	446240	4026553
BOR3	446247	4026541
BOR5	447345	4035906
BOR7	444280	4038930
Cameron	446529	4034294
Cielo Azul	446420	4040260
Cielo Azul Deep	446400	4040250
Colonias Point	444910	4034920
Cooper	443860	4029120
Fred Baca Park	447225	4028617
Hank Saxe	440507	4020477
Howell	448470	4030712
K2 - K3	446688	4030429
Kit Carson	448900	4029260
La Percha	445760	4030300
Landfill MW1	442758	4034011
Lerman	441824	4032655
Mariposa Ranch	445180	4040820
McCarthy	446307	4038831
Mesa Encantada	442346	4024531
NGDOM	442290	4022740
OW-6	449590	4033200
Pettit Well	447925	4023423
Porter	447769	4041305
Quail Ridge	446472	4035777
Ranchos Elem. Sch	446316	4023297
R. Fernando de Taos	450851	4025541
R.G. del Rancho	447172	4020228
Rio Lucero	448028	4030617
R. Pueblo de Taos	448731	4030516
Riverbend	439120	4024530
Rose Gardiner	443027	4024817
RP 2000 Deep	440380	4026000
RP 2500	440462	4026069
Ruckendorfer	449460	4023920
Taos SJC	440340	4026080
TOT #1	448626	4029394
TOT #2	448648	4029400
TOT #3	448941	4029690
TOT #5	448631	4028835
Town Taos Airport	439480	4034760
Town Yard	447060	4026680
UNM/Taos	441310	4022260
Vista del Valle	443681	4023916
Yaravitz	449826	4042805