CHEMICAL AND ISOTOPIC CONSTRAINTS ON SOURCE-WATERS AND CONNECTIVITY OF BASIN-FILL AQUIFERS IN THE SOUTHERN SAN LUIS BASIN, NEW MEXICO

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Abstract. — Selected wells and surface water sources in the Taos Valley have been sampled and analyzed for major anions and cations, trace metals, $^{87}Sr/^{86}Sr$, ^3H, δ^2H, and $\delta^{18}O$. $^{87}Sr/^{86}Sr$ varies from 0.7074 to 0.7156, indicating water-rock interaction with variable source rocks. Because these waters have relatively enriched $^{87}Sr/^{86}Sr$ it is likely that the Pennsylvanian carbonates and granitic basement rocks have contributed significantly to their Sr isotopic compositions. Tritium results indicate that recharge to the shallow aquifer occurs on a time scale of < 5 to 10 years, but that recharge to some deep alluvial wells and Agua Azul (Servilleta Formation) wells occurs on a time scale of > 50 years. Recharge into the mountain front fractured bedrock aquifers occurs on time scales ranging from < 5 to 10 years to > 50 years. δ^2H and $\delta^{18}O$ data suggest that some deep basin-fill aquifer wells have received older (Pleistocene) recharge, whereas other deep wells have received Holocene recharge. Some compartmentalization of the Tertiary aquifer system is indicated by these results. This aquifer compartmentalization is likely caused by intrabasin faults such as the Seco fault that exhibit significant offset.

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 (Fig. 1). 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).

METHODOLOGY

Samples were collected from test wells, exploratory and domestic wells and from surface water. Water samples were analyzed for major cations and anions, and trace metals. Three well-bore volumes were purged prior to sampling. Isotopic data, including tritium (^3H), deuterium (δ^2H), oxygen-18 ($\delta^{18}O$), and strontium ($^{87}Sr/^{86}Sr$) were obtained from selected wells to provide a preliminary evaluation of the timing of recharge to the different aquifers underlying the basin and to evaluate aquifer connectivity. Surface water samples were collected from locations near the Sangre de Cristo mountain front and analyzed for ^3H, δ^2H, and $\delta^{18}O$. Samples for Sr isotopic analyses were filtered through 0.2μm filter and acidified with ultraclean HCl. Strontium separation was done using standard cation exchange methodology. $^{87}Sr/^{86}Sr$ was analyzed by Plasma Ionization Multicollector Mass Spectrometry, using the ThermoFinnigan Neptune, at Woods Hole Oceanographic Institution (WHOI). Isotopic analysis for ^3H, δ^2H, and $\delta^{18}O$ were performed at the University of Waterloo Environmental Isotope Lab. Tritium analysis was by the liquid scintillation counting technique, with a detection limit of 0.6 ± 0.8 TU achieved by enriching water samples 15 times by electrolysis. Selected samples were enriched over 100 times to achieve a detection limit of 0.1 ± 0.1 TU. Deuterium analyses were performed on hydrogen gas produced from water reduced on hot Manganese. The precision for this technique is ± 2.0 per mille. $\delta^{18}O$ analysis utilized equilibration of CO^2 with water in a temperature controlled bath, automated extraction of CO^2 and analysis with an attached mass-spectrometer. The precision for this technique is ± 0.2 per mille.

DESCRIPTION OF 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; Drakos et al., 2004b, this volume). The lower Servilleta basalt flow and underlying Chamita Formation may act as a transition zone and/or boundary between the shallow and deep aquifers. 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; Drakos et al., 2004b, this volume). Ground water flow in the shallow aquifer is generally from northeast to southwest at a gradient of 0.02 (Drakos et al., 2004b, this volume, Fig. 5). 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). Stratigraphic nomenclature follows Galusha and Blick (1971) and Bauer et al. (1999). Ground water flow in the deep aquifer is generally from east to west at a gradient of 0.004 (Drakos et al., 2004b, this volume, Fig. 6).

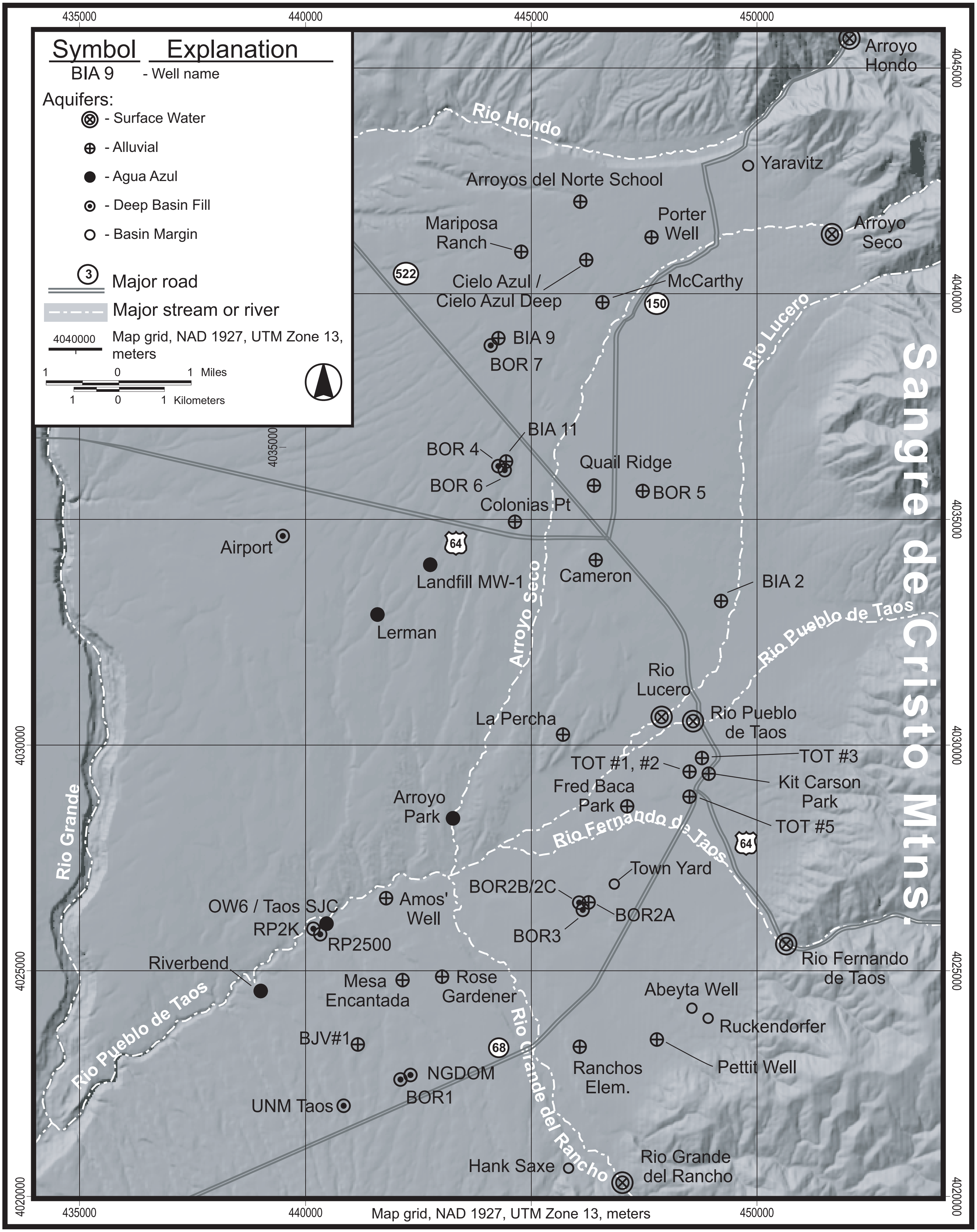

Figure 1. Site location map showing isotope sample locations.

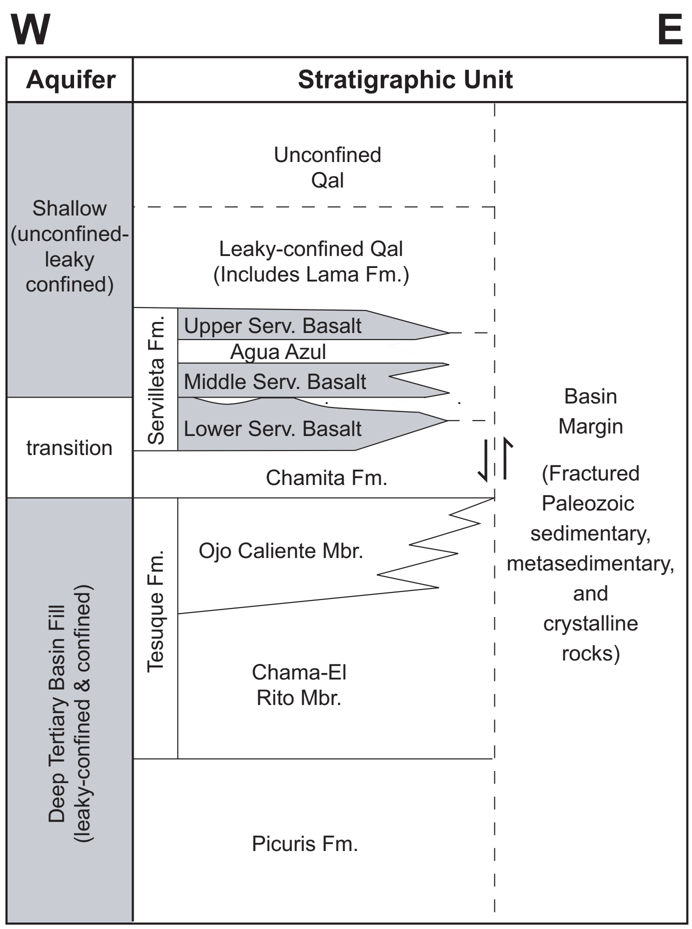

FIGURE 2. Taos Valley geohydrologic framework

GEOCHEMISTRY

General Geochemistry

Major cation and anion concentrations for Taos area wells are shown in Table 1 and Figure 3. Following standard criteria for ground water investigations, only samples that had a cation-anion balance of ± 5% or less were considered (Mazor, 1991, p. 70; Table 1). Most water samples plot in either of two separate groupings. Samples from wells completed in shallow alluvial, Agua Azul (Servilleta Formation), and deep alluvial facies of the shallow alluvial aquifer are typically calcium-bicarbonate waters, whereas samples from wells completed into the deep tertiary basin fill aquifer below the Servilleta Formation range from sodium bicarbonate to sodium sulfate waters (Fig. 3). These data could be interpreted either as cation exchange or as mixing within or between reservoirs. However, the strong coherency of the trends could be attributed to mixing. The range of total dissolved ion (TDI) concentrations of the two groups overlap; however, the alluvial waters are more variable (Alluvial TDI ranges from 73 to 708 parts per million (ppm) whereas deep aquifer TDI ranges from 195 to 310 ppm; Table 1). Several outliers are observed, including the deep leaky-confined alluvial wells BOR5 and Cielo Azul deep. BOR5 exhibits a sodium bicarbonate water chemistry that is similar to the water chemistry of wells completed into the Tertiary basin fill aquifers below the Servilleta Formation (Fig. 3). Well "Cielo Azul deep" water chemistry plots in an intermediate position between the low-sulfate members of the shallow and deep aquifers. The location of points for Cielo Azul shallow – Cielo Azul deep – BOR5 on the Piper diagram is suggestive of a mixing relationship between shallow and deep portions of the shallow alluvial aquifer in the northern Taos Valley. These data are consistent with the location of the area of downward vertical gradient (Drakos et al. 2004b, this volume, Fig. 5).

Isotopic Data

Tritium and stable isotope data have been collected from selected wells in the study area to evaluate basin recharge and aquifer interactions in the Taos Valley (Fig. 4). These data are used to evaluate the relative age of recharge into the different aquifers, to evaluate possible mixing between different aquifers, and to provide a preliminary evaluation of the connection between surface water and deep groundwater. Samples were collected between March 2002 and May 2003 (Table 2).

Tritium

Samples were collected for tritium analyses to assess the following: 1) the extent of recent recharge into the shallow alluvial aquifer system in the vicinity of the Town of Taos, 2) to obtain preliminary data on recharge into the Agua Azul aquifer, 3) to evaluate the timing of recharge into the Paleozoic limestone aquifer along the mountain front, 4) to determine if the deep Tertiary aquifers receive recent or older recharge, and; 5) to begin building a data base of tritium, $\delta^{18}O$ and $\delta^{2}H$ in surface water. Qualitative estimates of the mean groundwater residence time can be made based on tritium concentrations, expressed in tritium units (TU). According to Clark and Fritz (1997, p. 185), the following age estimates can be made for continental regions:

<0.8 TU	Submodern – recharged prior to 1952
0.8 to ~ 4 TU	Mixture between submodern and recent recharge
5 to 15 TU	Modern (< 5 to 10 yr)
15 to 30 TU	Some "bomb" ^{3}H present
> 30 TU	Considerable component of recharge from 1960's or 1970's
> 50 TU	Dominantly the 1960's recharge

Tritium results indicate that recharge to the shallow aquifer along the mountain front occurs on a time scale of < 5 to 10 years (Fig. 4; Table 2). Less than 5 to 10 year old recharge was observed in wells sampled up to 5 miles from the Sangre de Cristo mountain front, and may extend much further, as few wells were sampled at greater distances (Fig. 4; note wells with TU values of 4 to 13). However, alluvial wells BOR2A and BIA 9 each exhibited < 0.8 TU tritium, indicating > 50 year-old recharge (Fig. 4). The reason for the older recharge observed in BOR2A and BIA 9 is unclear, but is likely related to both local geologic control, and to anthropogenic factors. In the case of BIA 9, the older recharge may be related to the greater depth of BIA 9 (TD = 575 ft [175m]), relative to other alluvial wells sampled (TD of 330 ft [101 m] or

TABLE 1. Major cations and anions in selected wells, southern San Luis Basin. TDI = total dissolved ions. ND = none detected. All values in mg/l. Sample locations included in Appendix A.

Sample ID	Aquifer Facies	Na	K	Ca	Mg	Cl	HCO_3	CO_3	SO_4	F	TDI	Ion Balance (%)
McCarthy	Alluvial	25.8	ND	49.2	14	13	219	ND	27	0.34	348.3	2.1
Mesa Encantada	Alluvial	43.1	ND	129	13.8	10	334	ND	177	0.81	707.7	-0.2
BJV#1	Alluvial	20.2	2.7	77.6	10.9	27	151	16	82	0.77	388.2	1.8
Colonias Pt	Alluvial	19.8	1.17	40.1	10	5.1	195	ND	14.8	0.53	286.5	0.5
La Percha	Alluvial	12	0.8	22	4.7	2	95	ND	10	0.2	146.7	5.0
Cielo Azul Shallow	Alluvial	17.7	1.56	58.5	16.9	5.58	261	ND	19.8	0.39	381.4	2.5
BOR2A	Alluvial	25.5	1.54	50.9	9.2	6	210	ND	36	0.32	339.5	0.8
Cielo Azul Deep	Alluvial	23	1.1	14	1.5	2	86	ND	6	0.73	137.3	3.4
Mariposa Ranch	Alluvial	22.5	2.35	40.7	6.2	3.53	161	ND	30.5	0.25	267	2.8
BOR5	Alluvial	38.7	ND	1.5	ND	0.91	33.7	32.6	4.36	1.04	112.8	-1.5
BIA - 2	Alluvial	ND	1.6	18	3.7	0.9	62	ND	6	0.12	73	-3.1
BIA-11	Alluvial	6.1	1.6	32	6.1	2.1	91	19	20	0.15	149	4.1
Cameron	Alluvial	7.1	4.07	28.3	5.8	8	110	ND	11	ND	174.3	1.0
River Bend	Agua Azul	29	2.6	75.6	14.3	24	175	ND	106	0.56	427.1	4.1
Lerman	Agua Azul	16.3	1.1	19.2	1.2	4	87	ND	11	0.25	140.1	0.4
BOR7	Ojo Caliente	63.1	0.5	2.8	ND	9.21	53.3	20	45.4	0.73	195	2.0
BOR6 #1	Ojo Caliente	64.9	0.4	2	0.3	5.3	46.8	33.4	44.7	3.51	201.3	-3.1
BOR6 #2	Ojo Caliente	71.5	0.2	1.6	ND	8.65	61.3	24.5	53.9	3.43	225.1	-2.6
Airport	Ojo Caliente	79.4	1.4	11.2	ND	27	152	ND	38	0.66	309.7	-0.4
UNM/Taos	Chama-El Rito	68	0.4	2	0.2	11	102	8.2	32	4.87	228.7	-1.5
BOR2B	Chama-El Rito	69.5	0.44	5.3	0.2	7	98	29	30	0.8	240.2	-1.8
NGDOM	Chama-El Rito	68.3	0.27	2.2	0.2	17	101	16	34	0.31	239.3	-4.4
BOR2C	Chama-El Rito	100	0.24	1.9	ND	16	32	26	104	5.77	285.9	1.6
BOR3	Chama-El Rito	86	ND	2.3	ND	9	69	ND	100	7.54	273.8	-0.1
Town Yard	Basin Margin	120	1.25	10	1.17	11	201	ND	87.7	4.83	436.9	1.4
Ruckendorfer	Basin Margin	57.6	ND	48.3	16.3	8	268	ND	52	0.54	450.7	4.4

less), and to the absence of irrigation return flows in the vicinity. BOR2A was drilled through a relatively thick sequence of clay-rich sediments (possibly sag pond deposits along the Town Yard fault), which have apparently inhibited recent recharge at that location. The Town Yard fault could also inhibit recharge to BOR2A; however, pumping test data from BOR2B, BOR2C, and BOR3 (Drakos et al, 2004b, this volume) indicate that the Town Yard fault is likely not a barrier to horizontal flow.

The Agua Azul aquifer exhibited < 0.8 TU at Taos Landfill MW-1, and < 0.05 TU at the Arroyo Park well (Fig. 4). These data suggest that Agua Azul aquifer recharge occurs on a time scale of greater than 50 years. However, the Amos well, which (based on the driller's log) was drilled through a thin basalt flow, had a tritium value of 4.69 ± 0.33 TU. This indicates a source of modern recharge to the Amos well, possibly derived from percolation of acequia irrigation waters. The Amos well is either 1) not drilled into the Agua Azul aquifer and is receiving mountain front recharge, or 2) the Aqua Azul aquifer is in hydrologic communication with the Rio Pueblo de Taos in the vicinity of the Amos Well.

The mountain front fractured Paleozoic sedimentary rock aquifer was sampled at the Saxe and Abeyta wells (Fig. 4). Sample results from these two wells were near the method detection limit, ranging from 0.06 to 0.09 TU. These limited ^3H data indicate either: 1) greater than 50 year old recharge or, 2) possibly a mixture of older waters with a small component of water derived from recent recharge. In contrast, the Yaravitz well, completed in fractured crystalline rocks (amphibolite), exhibited a tritium value of 10.6 ± 0.9 TU, indicating modern recharge (Fig. 4; Table 2).

Surface water samples were collected in May 2003 from the major streams draining the Sangre de Cristo Mountains. With the exception of Arroyo Hondo, all samples were between 8 and 11 TU, indicating a modern source of water to these streams (Table 2). Arroyo Hondo exhibited 25.8 ± 1.8 TU, which may indicate some component of early 1960's recharge. This would suggest that the Arroyo Hondo is fed in part by groundwater discharge from a deeper and/or less permeable groundwater flow system within the mountains, and is consistent with the potentiometric surface map indicating the upper Rio Hondo is a gaining reach (Drakos et al., 2004b, this volume). Alternatively, these higher tritium values may be related to fractionation in the snow pack in the highest part of the Sangre de Cristo Mountains that was supplying the Arroyo Hondo during the May 2003 sampling event.

Limited sampling from wells completed into Tertiary sediments below the Servilleta Formation (RP2500, BOR7, and

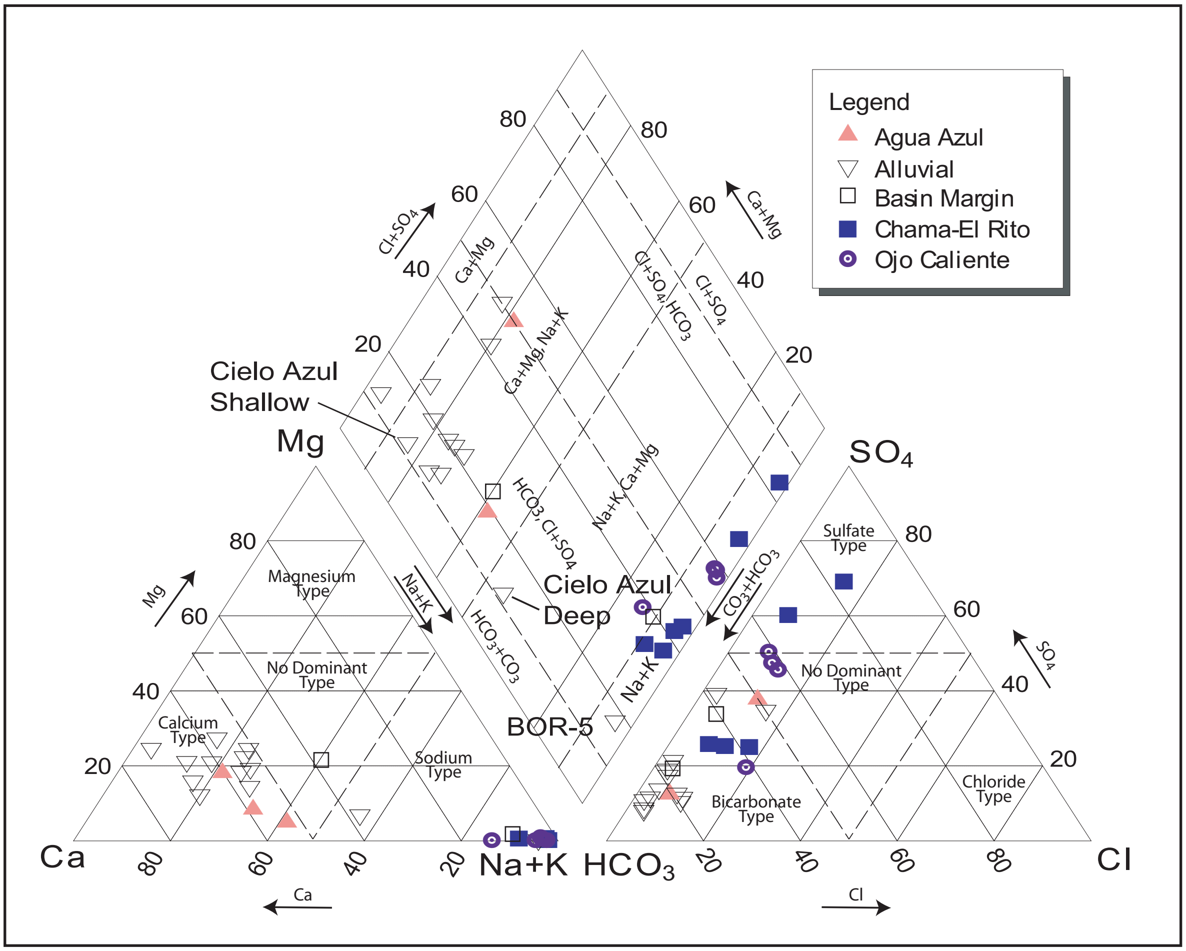

FIGURE 3. Piper diagram showing major cations and anions for Taos area wells

BOR2B) indicates that recharge occurs on a time scale of greater than 50 years (Table 2).

Oxygen and Hydrogen Isotopes

$^{18}O/^{16}O$ and $^{2}H/^{1}H$ were obtained on samples collected from wells and surface water locations chosen to cover a range of depths and geographic locations in the southern San Luis Basin (Fig. 1; Table 2). $\delta^{18}O$ and $\delta^{2}H$ data are compared to the global meteoric water line and to local meteoric water lines constructed from three sites in northern New Mexico (Fig. 5). Most shallow alluvial ground water samples and surface water samples plot along the Santa Fe and Valles Caldera meteoric water lines and lie above the global meteoric water line. BIA9 and BOR7 also lie along the local meteoric water lines, although BOR7 (the deepest well in the area) is completed to a depth of 2992 ft in Tertiary sediments below the Servilleta basalts. The results from BOR7 and deep alluvial well BIA9 indicate that Holocene precipitation recharges both the leaky-confined alluvial aquifer and the deep basin-fill aquifer in the northeast part of the study area.

Samples collected from three of four deep wells (BOR1 Deep, RP2500, BOR3), plot well below both local and global meteoric water lines, are strongly depleted in $\delta^{2}H$, and are slightly depleted in $\delta^{18}O$ relative to modern, meteoric water lines (Fig. 5). These data suggest older recharge under a different climatic regime than present. Water samples from BOR1 Deep, RP2500, and BOR3 plot in the "older recharge" field on Figure 5. The "older recharge" field represents late Pleistocene recharge, which is likely not part of an actively recharged flow system (Johnson et al., 2002). BOR2A also has low $\delta^{2}H$, and may be completed into an isolated water-producing zone within the "sag pond" deposits along the Town Yard fault. BOR2A may represent a mix of Pleistocene and Holocene/younger water, or it may represent a sample evaporated from Pleistocene water (P. Johnson, personnal communication, 2004). Some compartmentalization of the Tertiary aquifer system is indicated by these results, with RP2500, BOR3, and BOR1 completed into aquifers that are isolated from other aquifers in the basin.

Data from Agua Azul wells lacking tritium, fractured bedrock wells and shallow alluvial wells with tritium present, and BOR2B all plot near, though slightly below local meteoric water lines (Fig. 5). These limited data suggest that the waters in the Agua Azul aquifer are Holocene, although older than the minimum of 50 years indicated by tritium results. BOR2B, located < 70 ft (21 m) from BOR2A and drilled to a depth of 1400 ft (430 m) lies near the modern meteroric water line, indicating Holocene

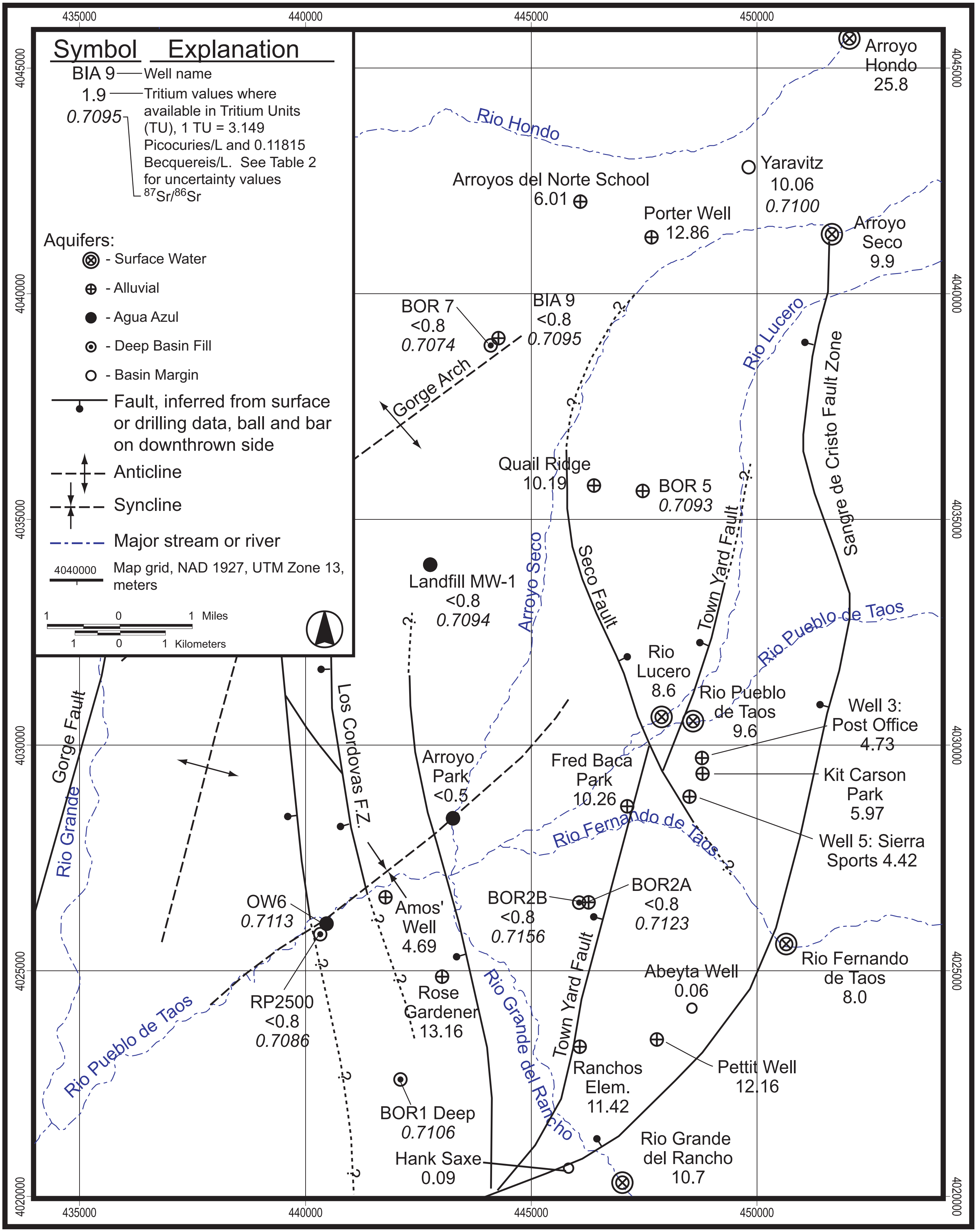

Figure 4. Selected wells sampled for isotope study showing tritium and $^{87/86}$Sr values.

TABLE 2. Isotope data from selected wells, southern San Luis Basin. Sample locations included in Appendix A.

SAMPLE SITE	Date Sampled	$\delta^{18}O$	$\delta^{2}H$	^{3}H (TU)	$^{87}Sr/^{86}Sr$	AQUIFER	TD (feet)
TOT #3	3/21/02			4.73+/-0.33		Qal	330
TOT #5	3/21/02	-13.7	-103.36	4.42+/-0.31		Qal	330
BOR 2A	5/8/02	-13.37	-110.86	<0.8 +/- 0.6	0.7123	Qal	291
Yaravitz	5/7/02	-14.06	-106.34	10.6 +/- 0.9	0.7100	pC basin margin	400
OW6	5/9/02	-13.01	-99.8		0.7113	Agua Azul (Ts)	146
Landfill MW-1	5/9/02	-13.68	-103.17	<0.8 +/- 0.6	0.7094	Agua Azul (Ts)	294
BOR2B	5/8/02	-13.75	-104.1	<0.8 +/- 0.6	0.7156	Ttce? (Tc?)	1480
BOR3	10/29/01	-14.9	-123			Ttce	2109
RP2500	5/1/02	-14.71	-119.28	<0.8 +/- 0.6	0.7086	Ttoc	2500
BOR1-Deep	5/9/02	-14.7	-115.83		0.7106	Ttce	2000
BOR 7	6/13/02	-14.95	-107	<0.8 +/- 0.5	0.7074	Ttoc?	2992
BIA 9	6/13/02	-13.22	-95	<0.8 +/- 0.5	0.7095	Qal above basalt	575
BOR 5	8/1/02				0.7093	Lama Fm	1763
Arroyo Park	12/13/02			<0.05 +/- 0.06		Agua Azul (Ts)	190
Kit Carson Park	12/12/02			5.97+/-0.41		Qal	270
Fred Baca Park	12/12/02			10.26+/-0.69		Qal	75
Ranchos Elem.	12/12/02			11.42+/-0.77		Qal?	140 ?
Pettit Well	12/13/02			12.16+/-0.81		Qal?	360 ?
Quail Ridge MW	12/17/02			10.19+/-0.69		Qal	75
Arroyos del Norte	12/17/02			6.01+/-0.4		Qal?	?
Amos' Well	12/17/02			4.69+/-0.33		Qal (or Agua Azul?)	122
Porter Well	12/19/02			12.86+/-0.86		Qal	220
Hank Saxe	12/19/02			0.09+/-0.06		P ss and ls	260
Rose Gardiner	12/19/02			13.16+/-0.88		Qal	135
Abeyta Well	12/23/02			0.06+/-0.06		Qal?	360
Arroyo Hondo	5/8/03	-13.71	-97.21	25.8+/-1.8		Surface water	
Arroyo Seco	5/8/03	-13.77	-99.84	9.9+/-0.7		Surface water	
Rio Lucero	5/8/03	-13.3	-95.6	8.6+/-0.7		Surface water	
RPdT	5/8/03	-14.1	-101.52	9.6+/-0.7		Surface water	
R. Fern. de Taos	5/8/03	-13.32	-98.18	8.0+/-0.6		Surface water	
R.G. del Rancho	5/8/03	-13.45	-96.5	10.7+/-0.8		Surface water	

Tritium is reported in Tritium Units. 1TU = 3.149 Picocuries/L or 0.11815 Becquerels/L.
The Sr isotopic analyses were determined at Woods Hole Oceanographic Institution on a Finnigan multi-collector ICPMS Neptune. $^{87}Sr/^{86}Sr$ ratios are normalized to $^{86}Sr/^{88}Sr$=0.1194 and corrected to $^{87}Sr/^{86}Sr$ =0.710240 for NBS987 standard.
$\delta^{18}O$ values are ± 0.2 per mille.
$\delta^{2}H$ values are ± 2.0 per mille.

recharge to the upper part of the deep Tertiary aquifer system underlying BOR2A. The scatter in these data also point out the limitations of this small data set.

Strontium Isotopes

$^{87}Sr/^{86}Sr$ was obtained for 10 samples collected from wells completed into the different aquifers and aquifer facies at a variety of geographic locations within the study area (Fig. 4, Table 2). This preliminary data set was acquired to determine if $^{87}Sr/^{86}Sr$ varies sufficiently in Taos area groundwater to be a useful analytical tool for evaluating water sources and water rock interaction. The Sr isotopic compositions of the waters show a large range (0.7074 to 0.7156). These waters isotopic compositions are enriched relative to the Taos volcanics (e.g. the $^{87}Sr/^{86}Sr$ in the Servilleta basalts ranges from 0.704 to 0.705; Dungan et al., 1986), have similar isotopic compositions as the Pennsylvanian age limestones 0.7081-0.7082 (assuming that they a value of $^{87}Sr/^{86}Sr$ similar to the global seawater value at that time; Veizer et al., 1999), and lower $^{87}Sr/^{86}Sr$ than the Proterozoic granitic and metamorphic rocks from this region (> 0.770; Brookins et al., 1985) (Table 2). This large range indicates water rock interaction with different source rocks, but because these waters have relatively enriched $^{87}Sr/^{86}Sr$ it is likely that the Pennsylvanian carbonates and granitic basement rocks have contributed significantly to their Sr isotopic compositions. For example, the sample with the highest $^{87}Sr/^{86}Sr$ ratio was from well BOR2B, located adjacent to and down gradient of the Town Yard fault (Fig. 4). BOR2B is completed into a coarse-grained section with abundant limestone gravel likely derived from the Pennsylvanian Alamitos Formation on the upthrown side of the Town Yard fault, and may receive recharge from the carbonate aquifer (Drakos et al., 2004a and b, this volume). While Pennsylvanian carbonates have high $^{87}Sr/^{86}Sr$, the much higher value for BOR2B (0.7156) requires water rock interaction with a source having even higher $^{87}Sr/^{86}Sr$, such as the Proterozoic granitic basement underlying the Alamitos Formation at relatively shallow depth on the upthrown side of the Town Yard fault.

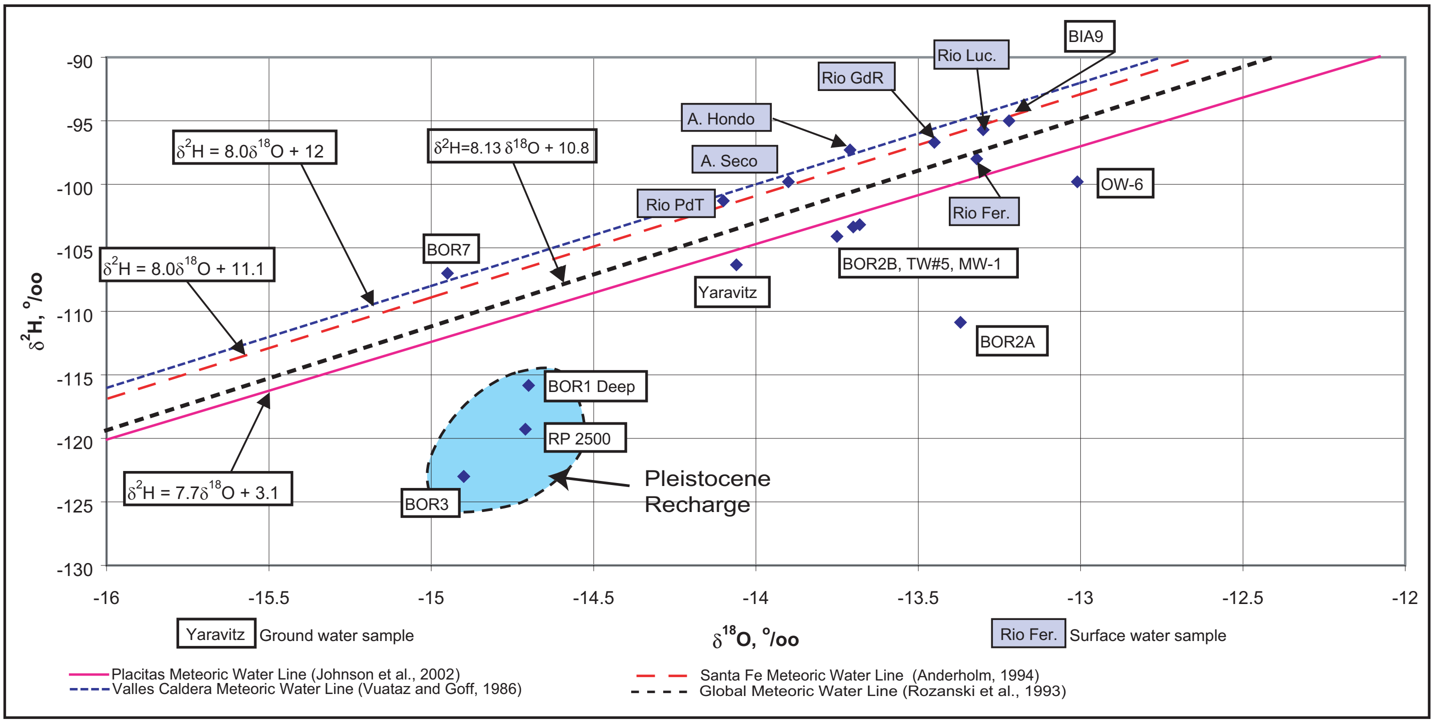

FIGURE 5. Plot of δ^{18}O-vs- δ^{2}H for selected wells and streams, southern San Luis Basin. Rio PdT = Rio Pueblo de Taos; A. Seco = Arroyo Seco; A. Hondo = Arroyo Hondo; Rio GdR - Rio Grande del Rancho; Rio Fer. = Rio Fernando de Taos; Rio Luc. = Rio Lucero

The Agua Azul aquifer, located stratigraphically between the Upper and Middle Servilleta basalt in the Servilleta Formation, does not exhibit a low ^{87}Sr/^{86}Sr signature as would be expected from waters interacting with basalt (Table 2, values of 0.7113 from OW6 and 0.7094 from Landfill MW1). The Agua Azul ^{87}Sr/^{86}Sr data therefore indicate that water is interacting primarily with the interbedded sediments, rather that the basalts. These data are consistent with aquifer testing data that indicate that the Servilleta basalts have low vertical hydraulic conductivity and may act to separate the shallow and deep aquifer systems in the southern San Luis Basin (Drakos et al., 2004b, this volume).

Trends in ^{87}Sr/^{86}Sr-versus-depth or ^{87}Sr/^{86}Sr-versus-cations or anions are not apparent from the data set collected thus far. However, the two deepest wells sampled, BOR7 and RP2500, completed into the Ojo Caliente Member of the Tesuque Formation, exhibited the lowest ^{87}Sr/^{86}Sr values of 0.7074 and 0.7086 measured in this study (Table 2). Two possible explanations for these relatively low ^{87}Sr/^{86}Sr values are: 1) the Ojo Caliente fine sand has a low ^{87}Sr/^{86}Sr value; or 2) waters recharging the deeper basin fill aquifer wells are interacting with predominantly non-granitic sediments and may be percolating slowly through the Servilleta basalts.

Drinking Water Quality

Water quality from both the shallow and deep aquifer systems is generally good, with the exception of high pH and arsenic observed in the deep aquifer, and high fluoride less frequently observed in wells completed into the deep aquifer. High fluoride has also been reported for some shallow wells in the Llano Quemado, Chamisal, Des Montes, and Ranchos de Taos areas (Garrabrant, 1993). High sulfur, iron, and fluoride concentrations are observed in some basin margin aquifer wells (Bauer et al., 1999; Drakos and Lazarus, 1998). In some cases, the source for arsenic in the deep aquifer may be related to mineralization along mountain front faults. Time series sampling for arsenic conducted during the BOR1 pumping test, showed that arsenic concentrations increase after an impermeable boundary is encountered (Fig. 6). These data suggest that higher-arsenic concentration water is associated with the Los Cordovas fault strand manifested as an impermeable boundary in the BOR1 test. However, a similar increase in arsenic concentration was not observed during time series sampling during the RP2500 pumping test (Drakos and Hodgins, unpubl. GGI report for the Town of Taos, 2001). This indicates that faults are not consistently associated with arsenic-enriched fluids; perhaps basin margin faults are more likely to be associated with mineralized/high-arsenic water.

DISCUSSION

Aquifer Compartmentalization

Several of the intrabasin faults act as hydrologic boundaries, and result in some compartmentalization of the deep basin-fill aquifer (Bensen, 2004; Drakos et al., 2004b, this volume; Rieter and Sandoval, 2004, this volume). The Seco fault acts as an impermeable boundary, and may act to separate a northeast deep-aquifer system that was recharged by Holocene precipitation from a southwest deep aquifer system that has been recharged by older, Pleistocene precipitation. Limited δ^{18}O and δ^{2}H data suggest that the deep aquifer in the southwestern part of the Taos Valley represents longer residence time and a more restricted flow system than does the deep aquifer in the northern and eastern part of the study area.

CONCLUSIONS

Tritium results indicate that recharge to the shallow aquifer occurs on a time scale of less than 5 to 10 years. However, recharge to some leaky-confined alluvial wells occurs on a time frame of > 50 years. Agua Azul aquifer recharge occurs on a time scale of > 50 years. Recharge into the mountain front fractured bedrock aquifers appears to occur on variable time scales ranging from < 5 to 10 years to > 50 years. δ^2H and $\delta^{18}O$ data indicate that BOR1 Deep, RP2500, and BOR3 are completed into older (Pleistocene) waters whereas BOR7 is completed into younger (Holocene) waters. Some compartmentalization of the Tertiary aquifer system is indicated by these results, with RP2500, BOR3, and BOR1 completed into areas that are isolated from other regions of the aquifer. $^{87}Sr/^{86}Sr$ ranges from 0.7074 to 0.7156, indicating water-rock interaction with variable source rocks. The highest $^{87}Sr/^{86}Sr$ value was from well BOR2B, located adjacent to and down-gradient of the Town Yard fault, and may indicate that water recharging the aquifer in the vicinity of BOR2B is interacting with granitic Proterozoic basement and the overlying Alamitos Formation at relatively shallow depth on the upthrown side of the Town Yard fault. Low $^{87}Sr/^{86}Sr$ values are associated with wells completed into the Ojo Caliente Member of the Tesuque Formation and/or deep wells. Agua Azul $^{87}Sr/^{86}Sr$ data indicate that water is interacting primarily with the interbedded sediments, rather than the basalts.

Groundwater samples from wells completed in shallow alluvial, Agua Azul, and deep alluvial facies of the shallow alluvial aquifer are typically calcium-bicarbonate waters, whereas samples from wells completed into the deep tertiary basin fill aquifer below the Servilleta Formation range from sodium-bicarbonate to sodium sulfate waters. Relatively enriched $^{87}Sr/^{86}Sr$ values indicate it is likely that the Pennsylvanian carbonates and granitic basement rocks have contributed significantly to Sr isotopic compositions in groundwater. Water quality from both the shallow and deep aquifer systems is generally good. Poor quality waters, with high pH and arsenic and, more rarely, high fluoride, were observed in some wells completed into the deep aquifers.

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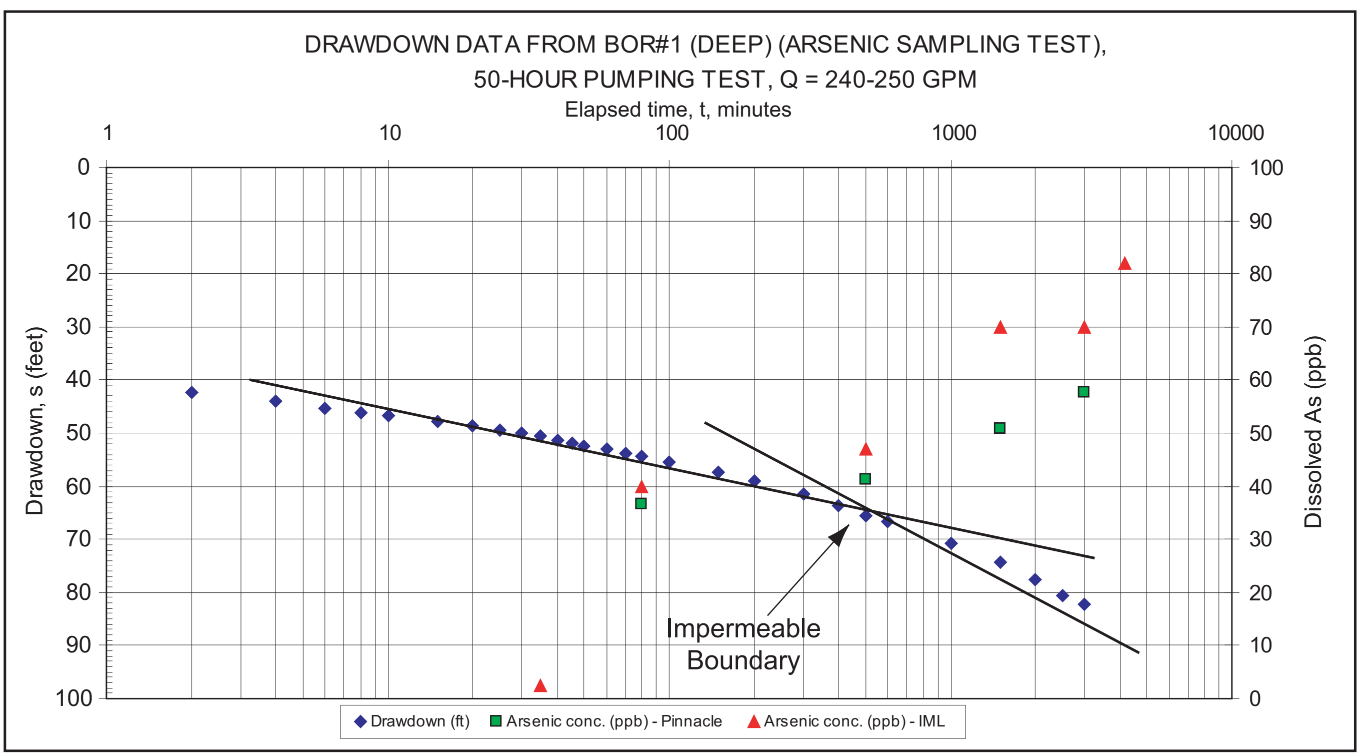

FIGURE 6. Arsenic concentrations and drawdown in BOR1 (deep)

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APPENDIX A - Locations for Taos Area Wells and Surface Water Samples

	UTM NAD 27, zone 13, m.			**UTM NAD 27, zone 13, m.**	
WELL NAME	Easting	Northing	WELL NAME	Easting	Northing
Abeyta Well	448752	4024118	Lerman	441824	4032655
Arroyo Hondo	452696	4046154	Mariposa Ranch	445180	4040820
Arroyo Park	443740	4028440	McCarthy	446307	4038831
Arroyo Seco	448745	4041260	Mesa Encantada	442346	4024531
Arroyos del Norte	446162	4042084	NGDOM	442290	4022740
BIA 11	444775	4035824	OW-6	449590	4033200
BIA 2	449600	4033180	Pettit Well	447925	4023423
BIA 9	444280	4038930	Porter	447769	4041305
BJV #1	441230	4023480	Quail Ridge MW	446472	4035777
BOR 1 Deep	442124	4022604	Ranchos Elem. Sch	446316	4023297
BOR 6 #1	444797	4035805	R. Fernando de Taos	450851	4025541
BOR 6 #2	444797	4035805	R.G. del Rancho	447172	4020228
BOR2A	446247	4026541	Rio Lucero	448028	4030617
BOR2B/2C	446240	4026553	R. Pueblo de Taos	448731	4030516
BOR3	446247	4026541	Riverbend	439120	4024530
BOR5	447345	4035906	Rose Gardener	443027	4024817
BOR7	444280	4038930	RP 2000 Deep	440380	4026000
Cameron	446529	4034294	RP 2500	440462	4026069
Cielo Azul	446420	4040260	Ruckendorfer	449460	4023920
Cielo Azul Deep	446400	4040250	TOT #3	448941	4029690
Colonias Point	444910	4034920	TOT #5	448631	4028835
Fred Baca Park	447225	4028617	Town Taos Airport	439480	4034760
Hank Saxe	440507	4020477	Town Yard	447060	4026680
Kit Carson Park	448900	4029260	UNM/Taos	441310	4022260
La Percha	445760	4030300	Yaravitz	449826	4042805
Landfill MW1	442758	4034011			