

# 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, <sup>87</sup>Sr/<sup>86</sup>Sr, <sup>3</sup>H, δ<sup>2</sup>H, and δ<sup>18</sup>O. <sup>87</sup>Sr/<sup>86</sup>Sr varies from 0.7074 to 0.7156, indicating water-rock interaction with variable source rocks. Because these waters have relatively enriched <sup>87</sup>Sr/<sup>86</sup>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<sup>2</sup>H and δ<sup>18</sup>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 (<sup>3</sup>H), deuterium (δ<sup>2</sup>H), oxygen-18 (δ<sup>18</sup>O), and strontium (<sup>87</sup>Sr/<sup>86</sup>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 <sup>3</sup>H, δ<sup>2</sup>H, and δ<sup>18</sup>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. <sup>87</sup>Sr/<sup>86</sup>Sr was analyzed by Plasma Ionization Multicollector Mass Spectrometry, using the ThermoFinnigan Neptune, at Woods Hole Oceanographic Institution (WHOI). Isotopic analysis for <sup>3</sup>H, δ<sup>2</sup>H, and δ<sup>18</sup>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. δ<sup>18</sup>O analysis utilized equilibration of CO<sup>2</sup> with water in a temperature controlled bath, automated extraction of CO<sup>2</sup> 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 volcanoclastic 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).

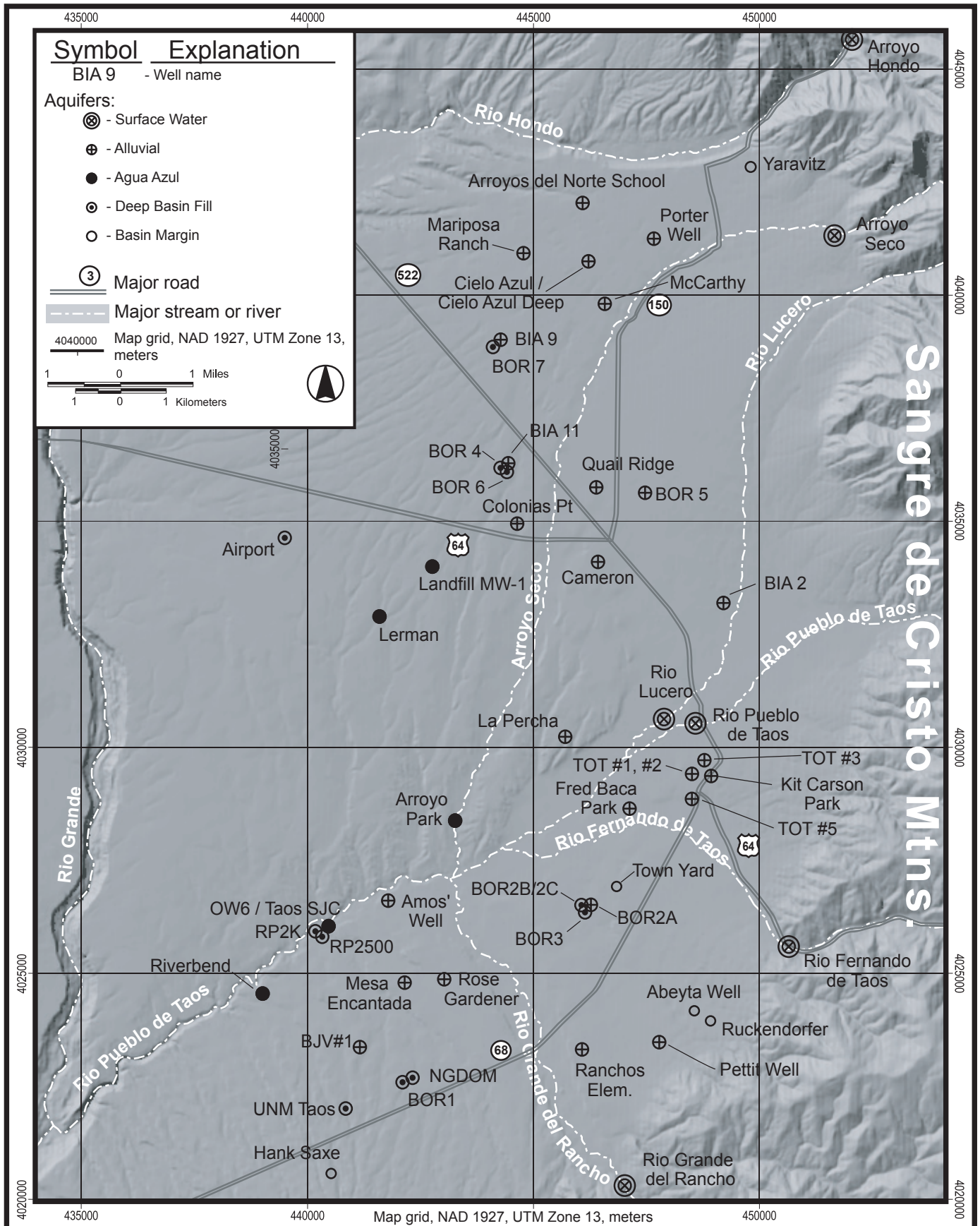


FIGURE 1. Site location map showing isotope sample locations.

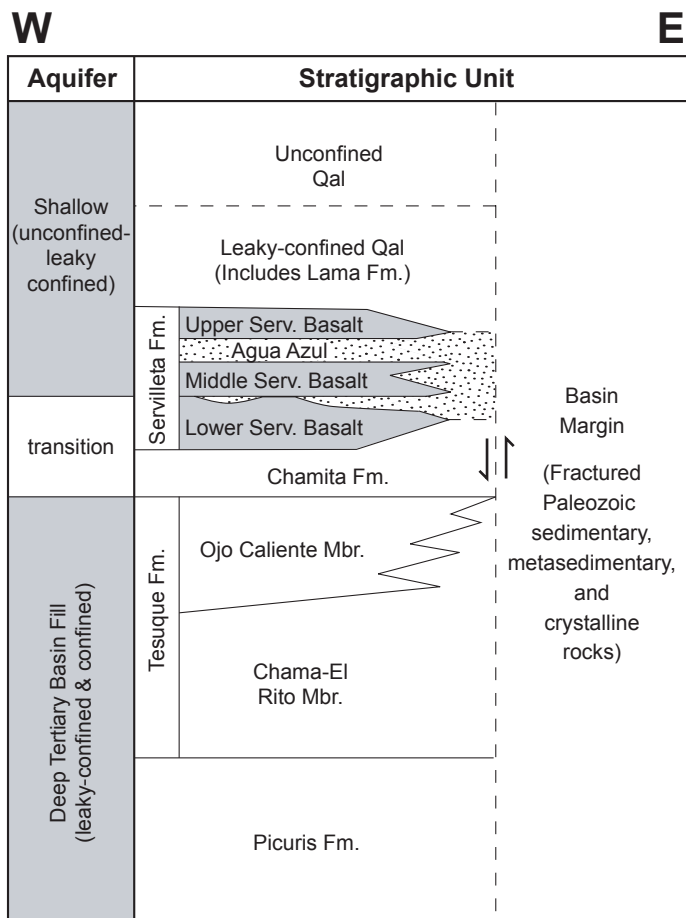


FIGURE 2. Taos Valley geohydrologic framework

**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, δ<sup>18</sup>O and δ<sup>2</sup>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” <sup>3</sup>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<br>Facies |      |      |      |      |      |                  |                 |                 |      |       | Ion         |
|--------------------|-------------------|------|------|------|------|------|------------------|-----------------|-----------------|------|-------|-------------|
|                    |                   | Na   | K    | Ca   | Mg   | Cl   | HCO <sub>3</sub> | CO <sub>3</sub> | SO <sub>4</sub> | F    | TDI   | 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  $4.69 \pm 0.33$  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 Agua 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 <sup>3</sup>H 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  $10.6 \pm 0.9$  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  $25.8 \pm 1.8$  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

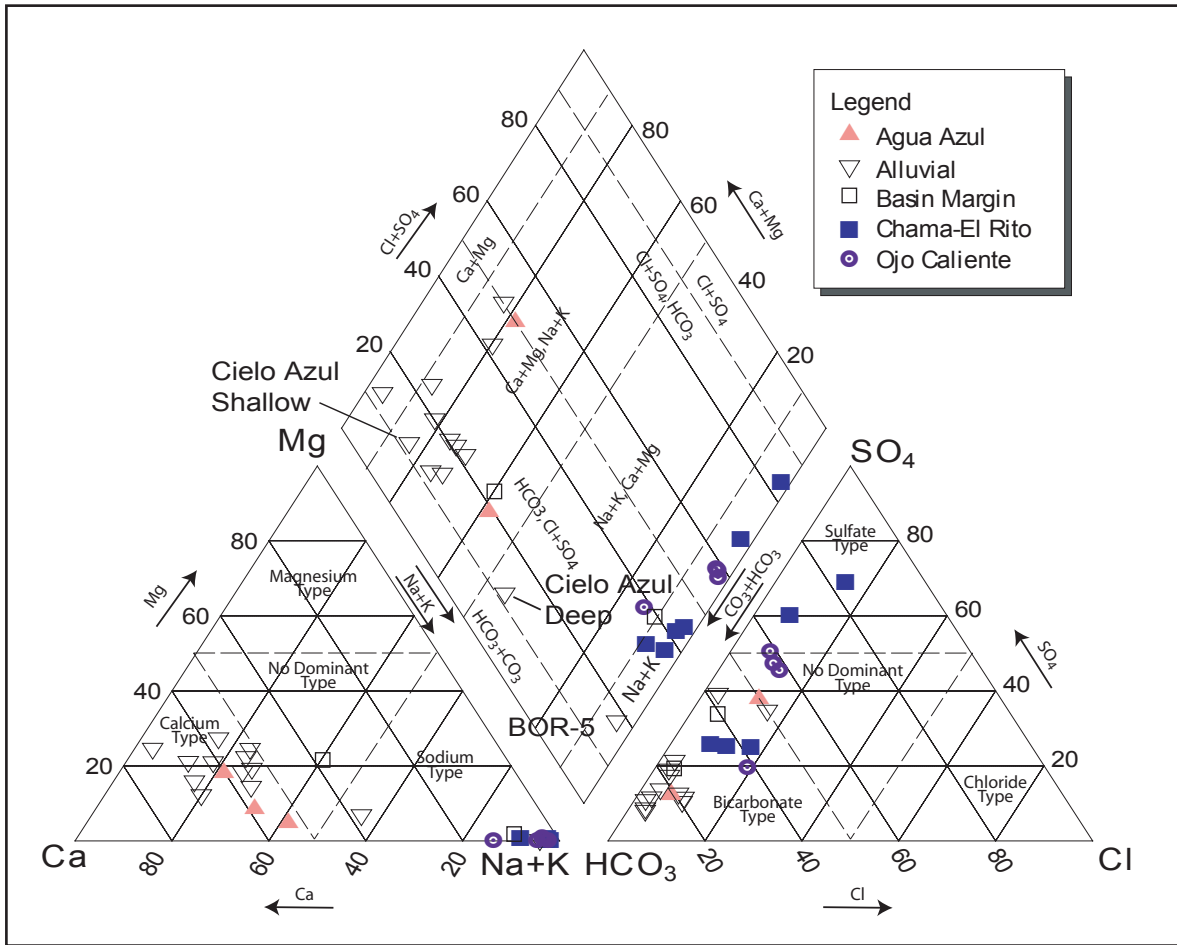


FIGURE 3. Piper diagram showing major cations and anions for Taos area wells

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

**Oxygen and Hydrogen Isotopes**

<sup>18</sup>O/<sup>16</sup>O and <sup>2</sup>H/<sup>1</sup>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).  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  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  $\delta^2\text{H}$ , and are slightly

depleted in  $\delta^{18}\text{O}$  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  $\delta^2\text{H}$ , 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, personal 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 meteoric water line, indicating Holocene

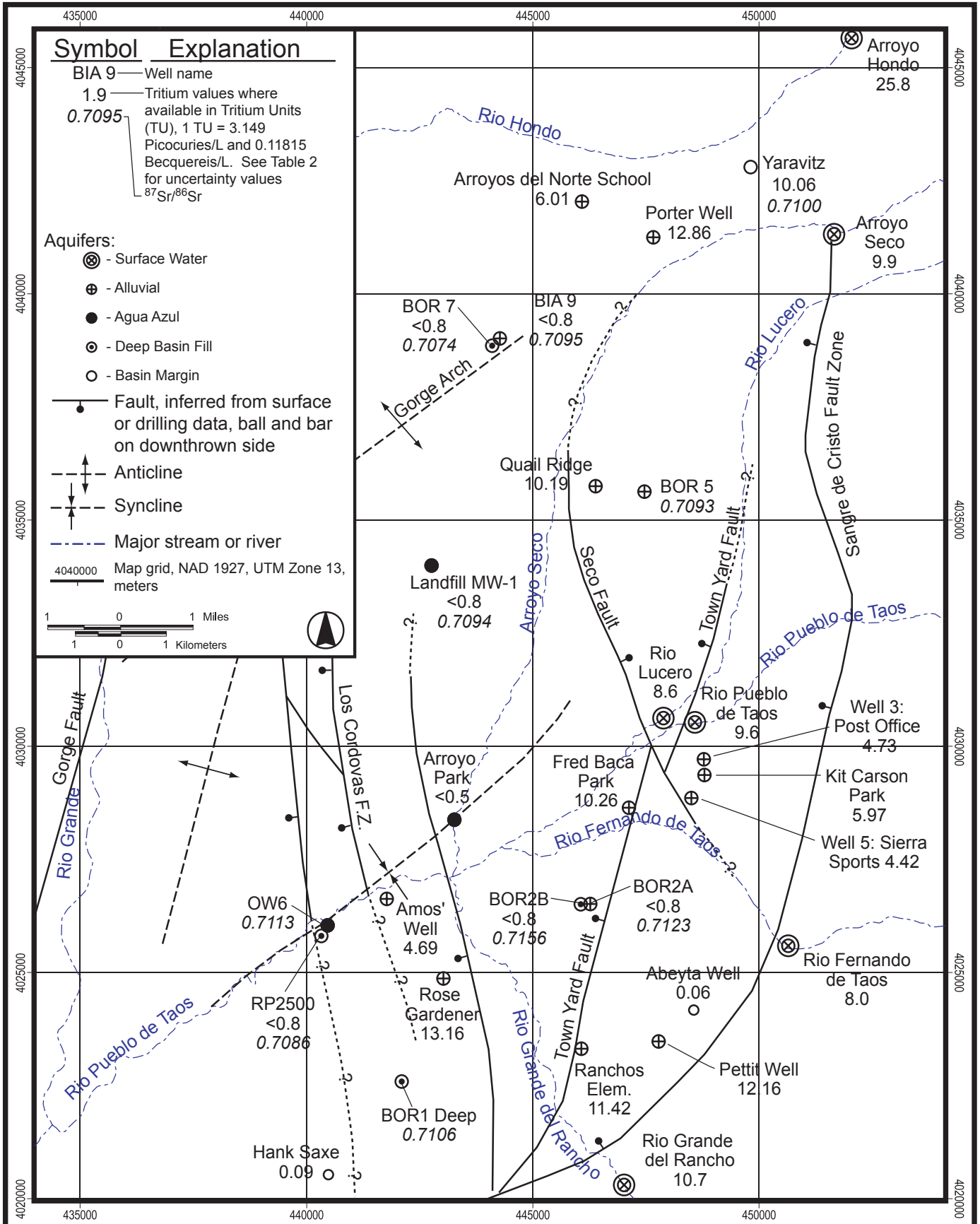


FIGURE 4. Selected wells sampled for isotope study showing tritium and <sup>87</sup>Sr/<sup>86</sup>Sr values

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

| SAMPLE SITE       | Date Sampled | $\delta^{18}\text{O}$ | $\delta^2\text{H}$ | $^3\text{H}$ (TU) | $^{87}\text{Sr}/^{86}\text{Sr}$ | 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.  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios are normalized to  $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$  and corrected to  $^{87}\text{Sr}/^{86}\text{Sr}=0.710240$  for NBS987 standard.

$\delta^{18}\text{O}$  values are  $\pm 0.2$  per mille.

$\delta^2\text{H}$  values are  $\pm 2.0$  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

$^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  similar to the global seawater value at that time; Veizer

et al., 1999), and lower  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$ , the much higher value for BOR2B (0.7156) requires water rock interaction with a source having even higher  $^{87}\text{Sr}/^{86}\text{Sr}$ , such as the Proterozoic granitic basement underlying the Alamitos Formation at relatively shallow depth on the upthrown side of the Town Yard fault.

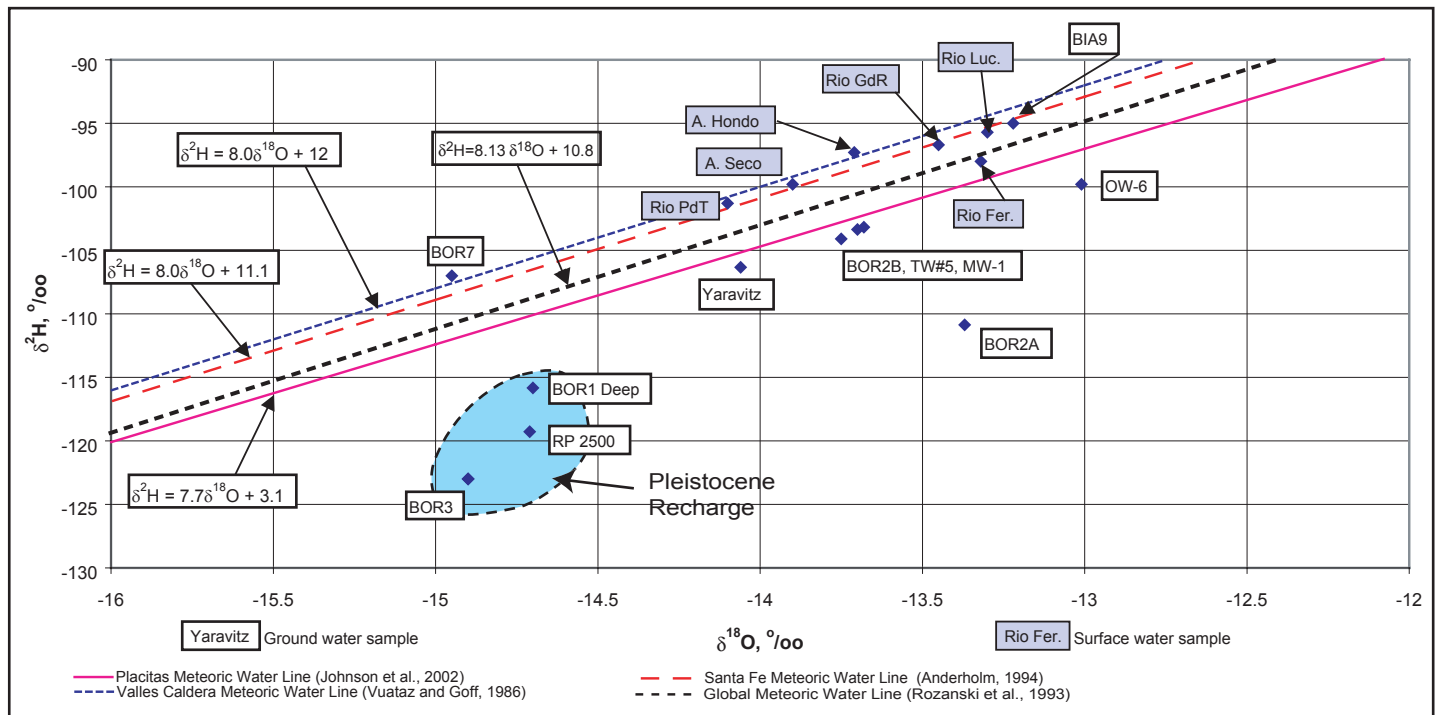


FIGURE 5. Plot of  $\delta^{18}\text{O}$ -vs-  $\delta^2\text{H}$  for selected wells and streams, southern San Luis Basin. Rio PdT = Rio Pueblo de Taos; A. Seco = Arroyo Seco; A. Hondo = Arroyo Hondo; Rio GdR - Rio Grande del Rancho; Rio Fer. = Rio Fernando de Taos; Rio Luc. = Rio Lucero

The Agua Azul aquifer, located stratigraphically between the Upper and Middle Servilleta basalt in the Servilleta Formation, does not exhibit a low  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  data therefore indicate that water is interacting primarily with the interbedded sediments, rather than 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  $^{87}\text{Sr}/^{86}\text{Sr}$ -versus-depth or  $^{87}\text{Sr}/^{86}\text{Sr}$ -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  $^{87}\text{Sr}/^{86}\text{Sr}$  values of 0.7074 and 0.7086 measured in this study (Table 2). Two possible explanations for these relatively low  $^{87}\text{Sr}/^{86}\text{Sr}$  values are: 1) the Ojo Caliente fine sand has a low  $^{87}\text{Sr}/^{86}\text{Sr}$  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 Que-

mado, Chamisal, Des Montes, and Ranchos de Taos areas (Garbrant, 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  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  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.  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  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.  $^{87}\text{Sr}/^{86}\text{Sr}$  ranges from 0.7074 to 0.7156, indicating water-rock interaction with variable source rocks. The highest  $^{87}\text{Sr}/^{86}\text{Sr}$  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 Alamos Formation at relatively shallow depth on the upthrown side of the Town Yard fault. Low  $^{87}\text{Sr}/^{86}\text{Sr}$  values are associated with wells completed into the Ojo Caliente Member of the Tesuque Formation and/or deep wells. Agua Azul  $^{87}\text{Sr}/^{86}\text{Sr}$  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  $^{87}\text{Sr}/^{86}\text{Sr}$  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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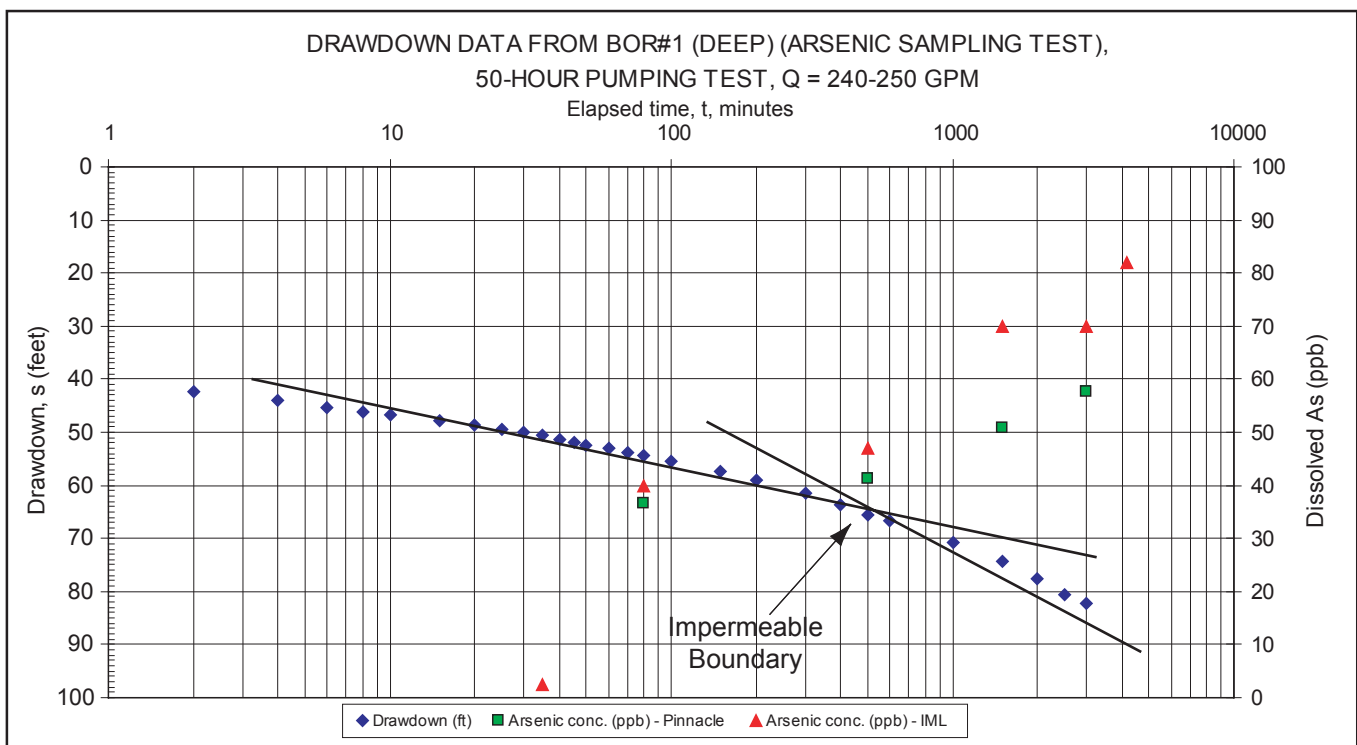


FIGURE 6. Arsenic concentrations and drawdown in BOR1 (deep)

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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  |                         |         |          |