Hydrogeologic Investigation of the Arroyo Hondo Area, Taos County, New Mexico

Final Technical Report
Prepared for Taos County

March 2009

Open-File Report 505

New Mexico Bureau of Geology and Mineral Resources

AQUIFER MAPPING PROGRAM

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Project Funding

The Healy Foundation, with Taos County acting as the fiscal agent.

The New Mexico Bureau of Geology & Mineral Resources.

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EXECUTIVE SUMMARY

The Arroyo Hondo ground water study reveals a complex, three-dimensional ground water system with multiple hydrostratigraphic units and aquifers. Distribution of the geologic and hydrostratigraphic units is presented through geologic maps and seven detailed cross sections that depict the distribution of geologic and hydrostratigraphic units, well data, surface water features, water levels, faults, and zones of fracturing and sediment layers in volcanic rocks. Cross sections are constructed both parallel and perpendicular to regional ground water flow and illustrate aquifers in the context of the geologic framework, the Rio Grande and the Rio Hondo, local acequias and other surface water features.

Ground water exists primarily within the Quaternary-Tertiary alluvial fan sediments known as the Blueberry Hill deposit, the Servilleta Formation basalts and interbedded sediments, the lower Tertiary Chamita Formation of the Santa Fe Group, and locally within the Cerro Negro dacite. A shallow alluvial aquifer in the Blueberry Hill alluvial fan deposit is limited to an area south of the Rio Hondo and east of the Airport fault. This aquifer is semi-perched on the Cerro Negro dacite, a massive, crystalline volcanic unit with relatively low regional permeability, and is recharged primarily through local irrigation return flow. A shallow perched aquifer also exists in the alluvial fan deposits north of the Rio Hondo, on the southwest flank of Cerro Negro. Here, perched ground water accumulates on the Cerro Negro dacite, recharges from Acequia de Atalaya, and discharges from the Medina spring, and possibly the lower Rio Hondo springs.

The Cerro Negro dacite contains localized, productive aquifers in fractured and rubble zones but generally appears to behave as a perching bed for shallow alluvial aquifers. Static water levels are highly variable, regionally inconsistent, and significantly lower than those measured in overlying perched or shallow alluvial aquifers. It is likely that fractured aquifers in the Cerro Negro dacite are highly compartmentalized, and have only limited or partial interconnection with adjacent aquifers.

The Servilleta Formation, named the deep volcanic-alluvial aquifer in this study, contains productive zones in thin basalts and sediments west of the Airport fault. A uniform hydraulic gradient between the Airport fault and the Rio Grande suggests that ground water moves easily between and through the interlayered basalts and sediments. This regional potentiometric surface grades westward to the elevation of cool springs that emerge in the Rio Grande gorge. Due to limited data and variable, regionally inconsistent water levels in deep wells east of the Airport fault, it is uncertain whether this deep aquifer system underlies the entire study area or if it includes the Cerro Negro dacite.

A transition zone between shallow and deep aquifers occurs at the Airport fault, which defines the western limits of the Cerro Negro dacite and the shallow alluvial aquifer. A vertical head differential of more than 300 feet exists across the Airport fault, which forms a high-permeability zone with a strong, local downward gradient. At the fault, shallow water levels rapidly merge with those in deep volcanic-alluvial wells on the west side of the fault, implying downward leakage from shallow to deep aquifers. Relatively young recharge ages in springs discharging in the Rio Grande gorge from the deep volcanic-alluvial aquifer suggest that shallow alluvial ground water merging

with the deep aquifer at the Airport fault transition zone comprises a significant portion of the ground water discharging at the springs.

The Rio Hondo is part of a stream-connected aquifer system with gaining, neutral and losing reaches controlled by the permeability of contiguous, underlying geologic units. The alluvial deposits along the Rio Hondo were probably above the water table under natural conditions, but now have locally perched or semi-perched aquifers due to the development of irrigation. In the Rio Hondo drainage, accretion of ground water from surface water and irrigation recharge is a critical factor controlling the extent of the shallow alluvial aquifer. Because of interconnections between the Rio Hondo, the Rio Grande and shallow and deep aquifers, depletions of ground water from these aquifers have the very real potential of contributing to surface water depletions in a matter of decades or less. Similarly, reductions in irrigation would have negative effects on ground water levels in the shallow alluvial aquifer.

I. INTRODUCTION

Background

Taos County is the northernmost county along the Rio Grande in New Mexico. As such, it plays an important role in the hydrologic condition of the Rio Grande and a critical role in the administration of water within the Rio Grande ground water basin. The population of Taos County has increased steadily since 1960, with rapid growth and home construction in the Arroyo Hondo region, including the neighborhoods of Arroyo Hondo, Hondo Mesa, and Stagecoach. Since 2000, Arroyo Hondo has experienced a population growth of 8.2 percent, to a population of about 2400 people in 2007. Most new development requires the installation of domestic water wells and septic tanks. Recently, there has been public concern about the vulnerability of shallow domestic wells to extended drought, and the potential future impacts of increased ground water pumping on domestic wells, down-gradient springs in the Rio Grande gorge, the Rio Hondo and Rio Grande, and acequias.

Because most shallow ground water in the Taos region ultimately flows to the Rio Grande, consumption of ground water eventually results in depletions to the river flow (Burck et al. 2004, Shomaker and Johnson 2005). Approximately 98 percent of all water withdrawn in the Taos region in 2000 was used for irrigation. However, 61 percent of that water was returned to streams, resulting in an average annual net depletion of approximately 40,000 acre-feet of water. As growth and development increase, accompanied by installation of more domestic wells, this net depletion is expected to increase.

The Taos Regional Water Plan (Daniel B. Stephens & Assoc., 2006), adopted by the New Mexico Interstate Stream Commission in July 2008, lists the following as key water issues facing the Taos region:

- Rio Grande Compact and availability of water rights
- Drought vulnerability
- Infrastructure needs
- Water quality
- Public education
- Protection of agriculture
- Protection of water rights
- Planning for growth
- Watershed protection
- Data gaps

The hydrogeologic data, interpretations and conceptual model of ground water flow presented here can aid in management of the water resources of the Arroyo Hondo area. This report is the most thorough assessment to date of the ground water system in the Arroyo Hondo area, and can support state, county, and local officials and private citizens who make decisions related to water resources.

Previous Work

Studies of the geology of the Taos region have been reported in a variety of formats. A set of geologic quadrangle maps has recently been produced by the New Mexico Bureau of Geology & Mineral Resources (http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.html), including recent maps of the Arroyo Hondo, Guadalupe Mountain, Taos, and Los Cordovas quadrangles (Fig. 1). A great variety of geologic and hydrogeologic topics are covered in the 2004 New Mexico Geological Society Guidebook (Brister et al., 2004), and by references therein. Grauch and Keller (2004) and Bankey et al. (2006) provided the latest interpretations of regional geophysical studies of the southern San Luis Basin.

Published literature on regional water resources includes a general water resource inventory of Taos County (Garrabrant, 1993), a surface water assessment of Taos County (Johnson, 1998), a summary of the ground water geology of Taos County (Benson, 2004), recent work related to the Taos Pueblo water rights settlement such as a regional ground water flow model (Burck et al., 2004), and the Taos County Regional Water Plan (Daniel B. Stephens and Assoc., 2006).

Our current understanding of the geology of the Arroyo Hondo area is based on the modern geologic quadrangle maps (Bauer and Kelson, 2001; Kelson and Bauer, 2003, 2006, and 2008), and many earlier studies of the Taos Plateau and southern Sangre de Cristo Mountains. This report provides the first comprehensive synthesis of geologic and geophysical data and subsurface geologic interpretations.

Modern investigations of the hydrogeology of the Arroyo Hondo region are few. Bauer et al. (1999) assessed the hydrogeology of the region south of Taos. Drakos et al. (2004a and 2004b) studied the hydrologic characteristics of the aquifers and the geochemistry of the surface water and ground water in the Taos region. Rawling (2005) performed a hydrogeologic investigation of the Arroyo Seco area, just east of our study area.

Purpose and Scope

The objective of this work was to characterize and interpret the three-dimensional geology and hydrogeology of the greater Arroyo Hondo area, as a westward extension of the hydrogeologic assessment of the Arroyo Seco area (Rawling, 2005). Our work shows the profound effect that geologic features have on the ground water system, and allows us to better understand the distribution of ground water and its flow patterns, and to evaluate the interactions of ground water and surface

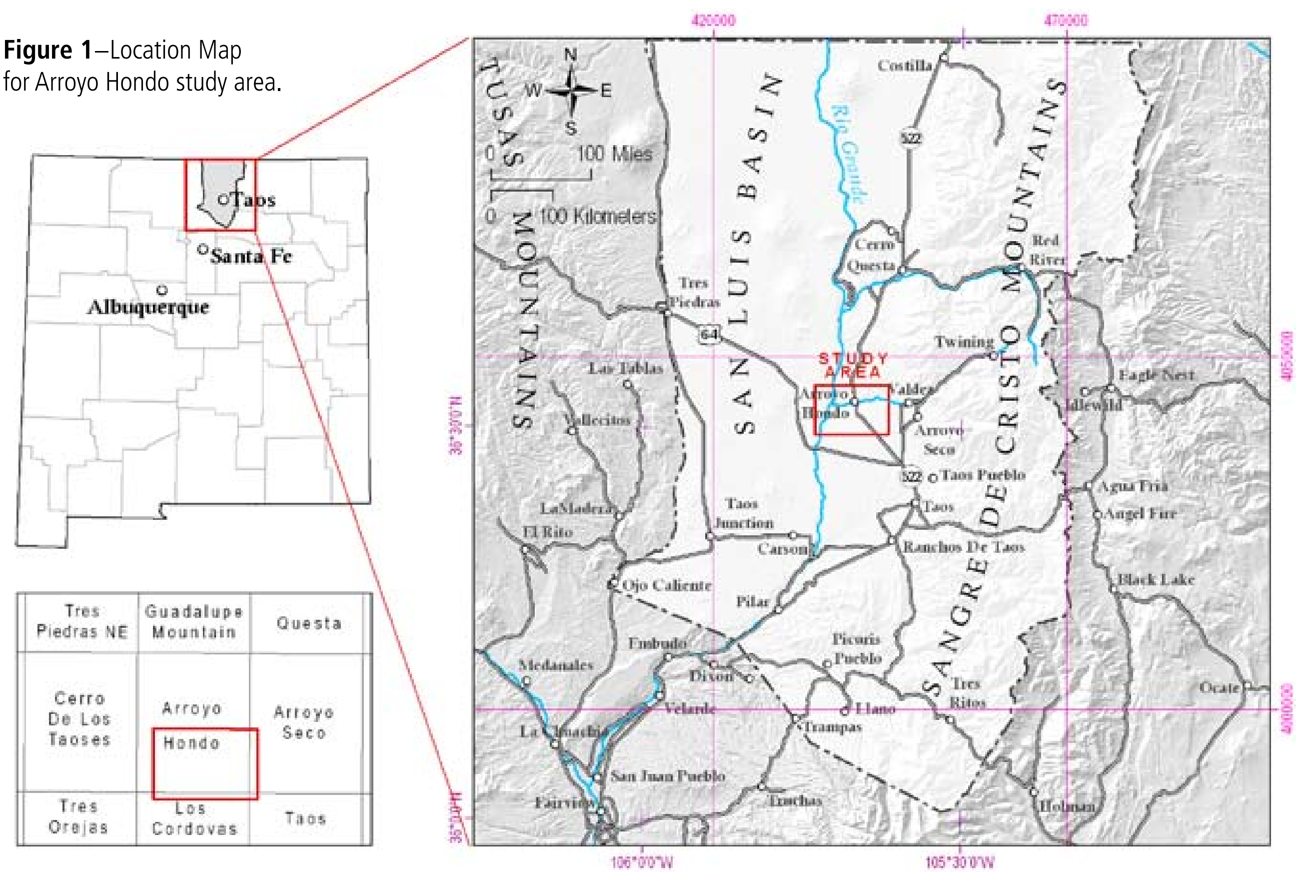


Figure 1–Location Map for Arroyo Hondo study area.

water. The study area focused on the region of high population growth along both sides of the lower Rio Hondo, and the Rio Grande gorge.

Because of the new digital geologic map of the Arroyo Hondo quadrangle (Kelson and Bauer, 2006), no new geologic mapping was needed for this study. Instead, the focus of this report was to compile existing hydrologic and geologic data, measure water levels from domestic wells, draw cross sections and hydrogeologic maps, interpret existing aeromagnetic data, and propose a conceptual model of ground water flow and geologic controls. This work was conducted by staff and contractors of the New Mexico Bureau of Geology & Mineral Resources (a division of New Mexico Tech) in Socorro, New Mexico between October 2005 and July 2007. The work was funded, in part, by Taos County through a grant from the Healy Foundation.

The report contains maps of the geology, aeromagnetic data, water well locations, surface drainages and acequias, hydrogeologic conditions and domains, and a regional potentiometric surface. It also contains tables of water levels, data compiled from water wells used in the investigation, copies of all the well records used in the study, and a summary of hydrogeologic units. These data were used to construct seven detailed geologic cross sections, which were combined with hydrologic information to develop a conceptual hydrogeologic model of the ground water flow system.

Description of Study Area

The village of Arroyo Hondo is located in the Rio Hondo valley, 10 miles northwest of Taos (Fig. 1). The study area (28 square miles) straddles the western half of the Rio Hondo drainage, and includes the Arroyo Hondo neighborhood, the western edges of the Arroyo Seco/Valdez and Lower Des Montes neighborhoods, the northern parts of the Hondo Mesa and Stagecoach neighborhoods and Taos Pueblo Tract B, and the Rio Grande gorge, including the east and west rims (Fig. 2).

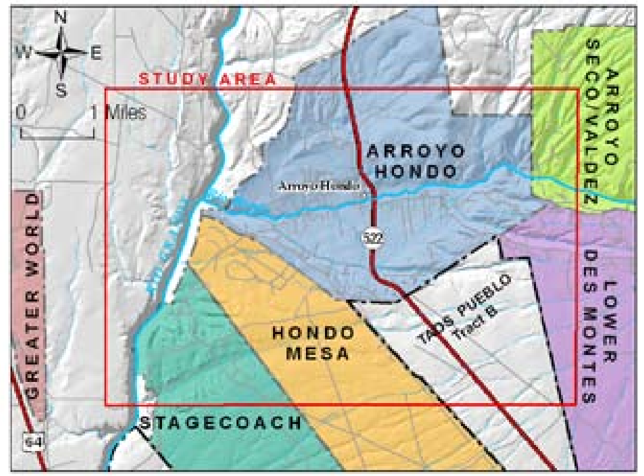
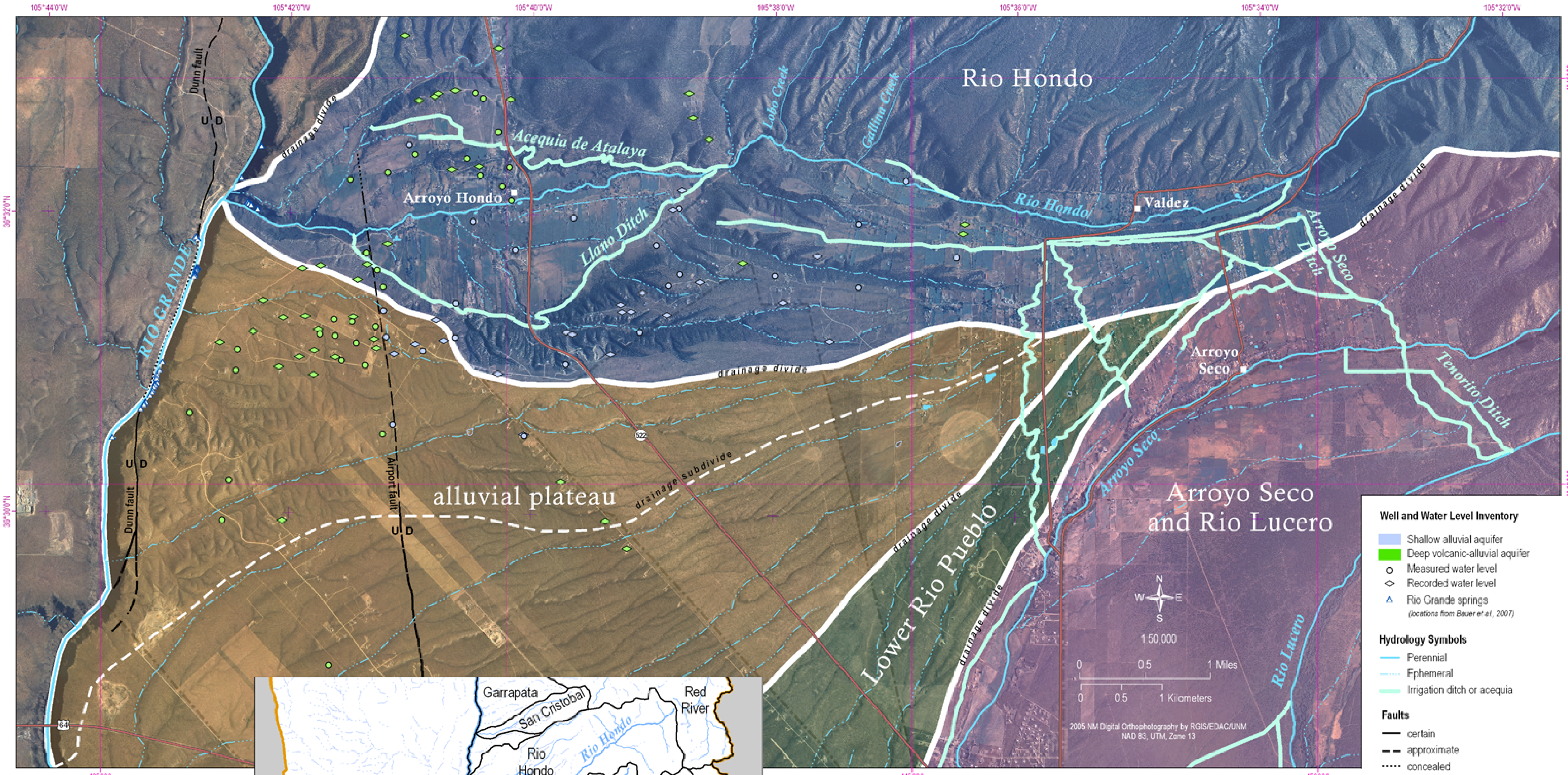


Figure 2–Taos County neighborhood association map with study area.

North of the Hondo valley is a topographically high Pliocene volcano known as Cerro Negro. Between Cerro Negro and the Rio Grande is a high, dissected landscape of sand and gravel deposits. South of the Hondo valley is Hondo Mesa, a relatively flat, high, sandy alluvial plateau. In the southwestern study area are the Stagecoach hills, a topographically high cluster of ridges and hills that represent an erosional remnant of an older alluvial plateau.

The Rio Hondo, one of three perennial Rio Grande tributaries in Taos County, drains 75 square miles including the northwest portion of Wheeler Peak and the southern Taos Mountains. Elevations in the drainage range from over 13,000 ft at Wheeler Peak to 6470 ft at the Rio Grande. As it flows west, its canyon steadily deepens to the confluence with the Rio Grande where it is incised about 400 feet. In the western part of the study area, the Rio Grande flows south through a deep, narrow canyon cut in basalts and gravels of the Taos Plateau volcanic field. (Fig. 3) Surface drainages south of the Hondo valley on Hondo Mesa and the alluvial plateau are poorly developed, disconnected from mountain recharge, and only carry runoff during local storm events. A dozen or more acequias divert surface water from the Rio Hondo, upper Arroyo Seco, and upper Rio Lucero to irrigate about 3000 acres in the Arroyo Hondo area (Johnson, 1998). Infiltration and percolation of



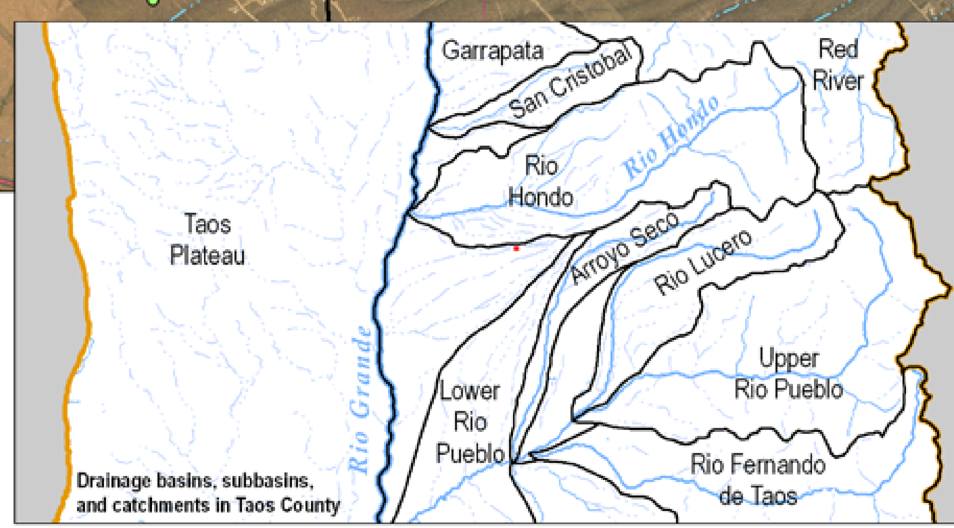


Figure 3–Surface water drainages and acequias in the Arroyo Hondo area.

surface water and acequia irrigation is believed to contribute significant recharge to shallow ground water aquifers (Burck et al., 2004). Important ditches in the Rio Hondo valley include the Llano Ditch and Acequia de Atalaya (Fig. 3).

Several sets of springs emerge from the eastern wall of the gorge, including cool springs upstream from the Dunn Bridge, a nearly continuous line of springs downstream from the bridge, and Manby Hot Springs (aka Stagecoach hot springs) two miles south of the bridge. A cluster of cool springs also emerges on the north side of the Rio Hondo, just east of the confluence (Figs. 3 and 4).

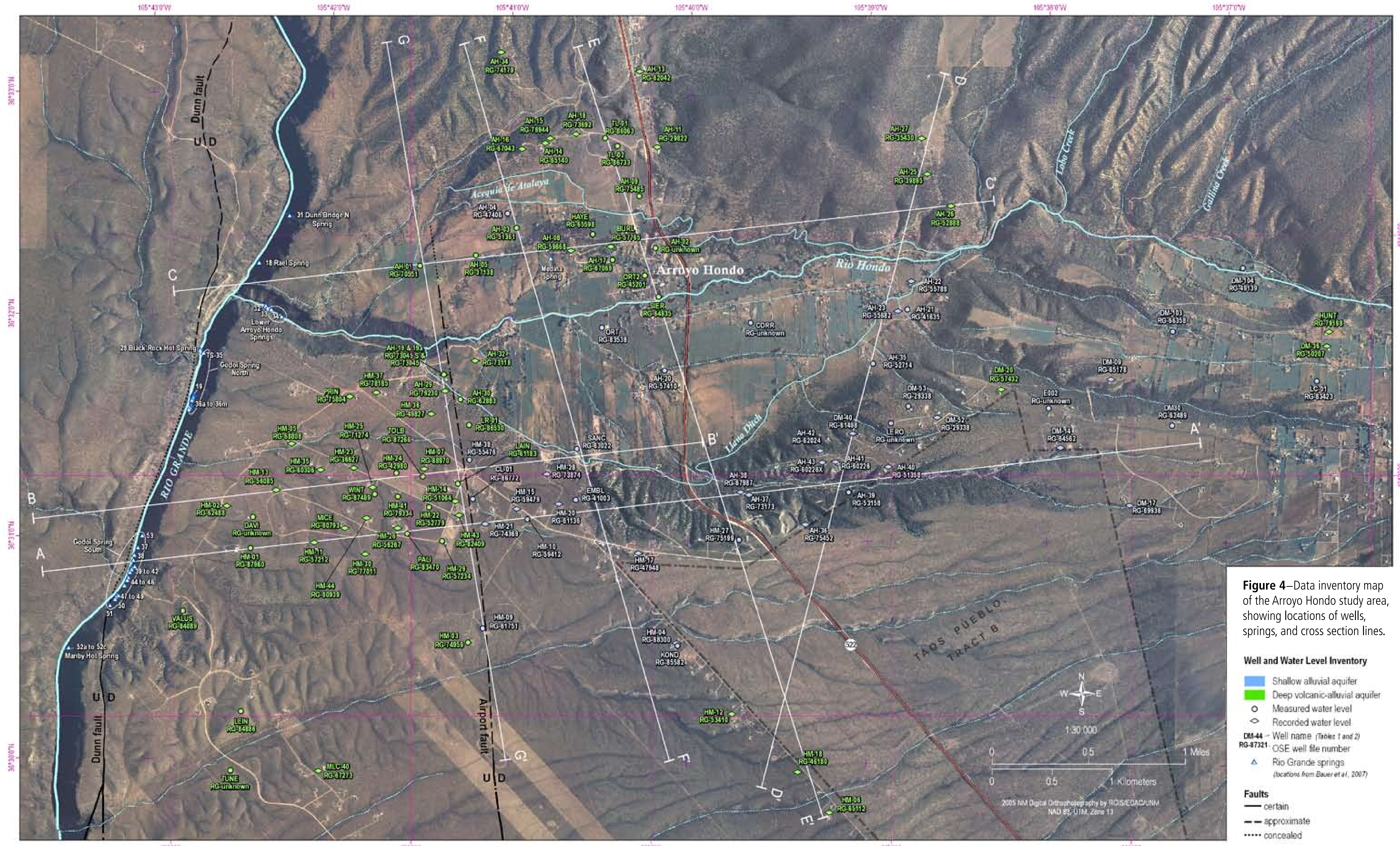


Figure 4—Data inventory map of the Arroyo Hondo study area, showing locations of wells, springs, and cross section lines.

II. METHODOLOGY

Water Levels

A major component of this study was measuring water levels in a representative population of domestic water wells in the Arroyo Hondo area. Between December 2005 and May 2006, water level measurements were made in 56 wells using a 500–foot steel tape for pump-equipped wells, and a 650–foot electric meter for clear wells. Measurements were made to a repeatable accuracy of 0.01 feet. In cases where a water level could not be reproduced with this accuracy, the water level from the New Mexico Office of the State Engineer (NMOSE) well record was used. The wells were field located with a handheld GPS device. In addition to the measured wells, 54 other water wells previously inventoried by the Taos Soil & Water Conservation District (TSWCD) during their Taos County water well inventory (Benson, 2004) are included with published well ID names and located with published coordinates. These wells were used to add subsurface geologic and hydrologic control. All well records were evaluated for quality control.

In all cases, well depth, water level, and screen interval were compiled from original OSE well records. Although the GPS locations recorded by TSWCD staff are considered to be accurate, the depth-to-water entries from well records are considered to be approximate. Elevations of wells and springs were calculated in ArcGIS using the 10–meter DEM coverage and GPS-derived coordinates. Well data are compiled in Table A1 (Appendix A), a well inventory map is shown in Figure 4, and original well records are attached in Appendix A.

***Measured versus Recorded Water Levels*–**Many of our measured water levels differed significantly from those recorded by drillers on NMOSE well records (Table A1). In the 48 wells that yielded precise water levels, the discrepancies with the recorded level ranged from -107 feet (measured level was lower than recorded level) to +143 feet (measured level was higher than recorded level). Water levels in 19 of the measured wells differed by more than 30 feet with those noted on the well record. Possible reasons for these discrepancies include seasonal variations in water levels, long-term water level changes reflecting the difference in recharge between wet and dry cycles, or inaccurate measurement or recording by the well driller. The latter may be due to measuring the water level before a static water level was reached in the newly drilled wells. There are no obvious geographic patterns in the variations between water levels measured in this study and those recorded by the well drillers.

***Water Level Contouring*–**ArcGIS software was used to plot the well locations and water level measurements. Ground water elevation contours were drawn by hand and then digitized. Inherent in the contouring of regional water level measurements are the assumptions that ground water flow is horizontal, the measurements are from a single aquifer, and that hydraulic head does not vary with depth. In general, these assumptions were not met by the regional water-level data from Arroyo Hondo. A significant potentiometric head difference of about 400 feet differentiates “shallow” and “deep” wells. Wells completed above and below this depth show significant differences in both hydrostratigraphic unit and ground water elevation. Because there appear to be two aquifer systems, we depict both a shallow water table surface and a deeper potentiometric surface that represent two separate aquifers.

Where there is hydrologic or geologic evidence of a connection between the shallow aquifer and the Rio Hondo, the water table contours cross the stream channel at upstream or downstream angles depending on whether evidence suggests the stream is gaining or losing, respectively. In two short reaches of the Rio Hondo, geologic and hydrologic evidence suggests that the stream is disconnected from the shallow alluvial aquifer and the water table contour is drawn perpendicular to the boundary.

It is important to note that water level elevations herein are from wells with screened intervals varying from tens to hundreds of feet, and are not point measurements of hydraulic head. The water level elevations therefore represent a vertical average of the hydraulic head over some aquifer interval rather than at a discrete point in the aquifer. With these facts, and the variation in data quality, in mind, the contours were controlled primarily by measured water levels rather than recorded and were not forced to fit every water level elevation. Contours are dashed where approximate and queried where inferred.

Geologic Map

The Arroyo Hondo geologic map used in this study (Kelson and Bauer, 2006) is part of a new digital, open-file 7.5–minute quadrangle map created in 2005 and 2006 through the New Mexico Bureau of Geology & Mineral Resources STATEMAP Program. The study area encompasses most of the southern half of the map. Although the map distinguishes between the Servilleta Formation basalts, the Cerro Negro dacites, and other Tertiary volcanic units, it does not show the individual flow units of the Servilleta Formation, nor does it differentiate other volcanic flows that are exposed in the Rio Grande gorge. Geologic map unit descriptions for the Arroyo Hondo study area are described in Appendix B.

Geologic Cross Sections

We created seven new hydrogeologic cross sections for this study. The locations of sections were chosen to optimize hydrogeologic insights while maximizing the number of measured wells that could be incorporated into the section lines. The topographic profiles were generated by ArcGIS software. All cross section lines are straight and vertically exaggerated by a factor of five to better illustrate hydrologic and geologic details. Wells located within about 500 ft of the lines were orthogonally projected onto the cross sections, and labeled as “Projected”.

On the cross sections, lithologic picks of volcanic rock versus sediment at each well were made using the lithologic logs on the NMOSE well records. The volcanic intervals were used as approximate guides for drawing the geologic units. In some cases, it was clear that the driller had generalized the minor lithologic variations encountered in the hole. No lithologic log differentiated between Servilleta Formation basalt and Cerro Negro dacite. The depictions of these two units on the cross sections are based on: 1) the geologic map (Kelson and Bauer, 2006); 2) drawings of the geology of the walls of the Rio Grande gorge (Peterson, 1981); 3) high-resolution aeromagnetic data that can help discern buried rock types and faults (T. Grauch, personal communication, 2006); and 4) an understanding of the volcanic and sedimentary systems and geologic processes of the area. On the three cross sections that cross the Rio Grande gorge, the geologic units shown in the gorge were adapted from the work of Peterson (1981).

The screened (perforated) intervals of the wells shown on the cross sections were retrieved from the well records. In nearly all cases, the static water level is above the top of the screen, although in a few wells the screen is either partially or entirely above the water level. One well (RG-46180) is apparently unscreened. Several measured wells are of unknown construction, as the well records are not available.

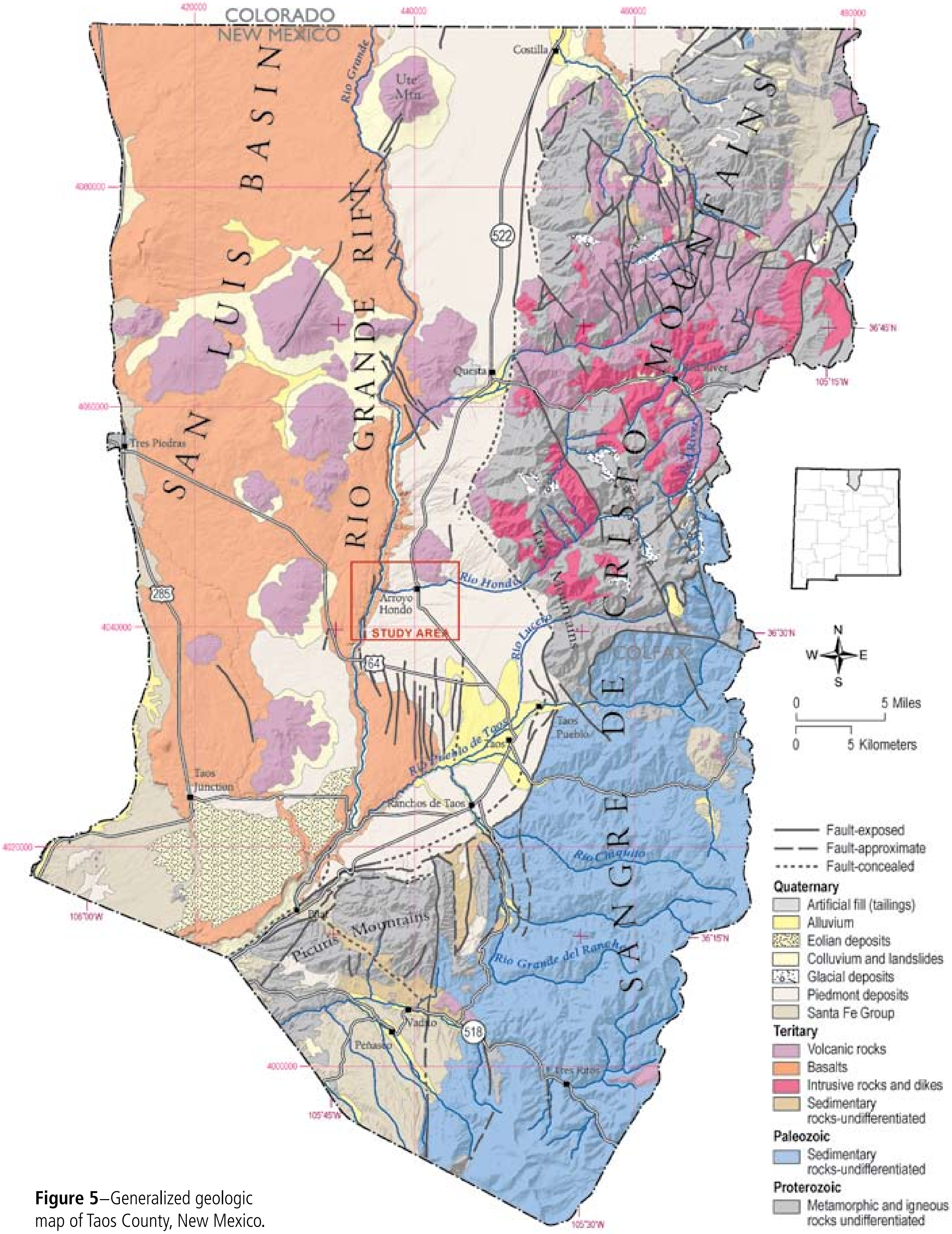


Figure 5–Generalized geologic map of Taos County, New Mexico.

III. GEOLOGIC SETTING

Regional Geology

The study area lies within the southern San Luis Basin, the northernmost basin of the Rio Grande rift (Fig. 1). The 150-mile-long San Luis Basin is bordered by the Sangre de Cristo Mountains on the east and the Tusas and San Juan Mountains on the west. The basin is roughly divided into two physiographic provinces, the broad San Luis Valley of southern Colorado and the narrow Taos Plateau of northern New Mexico. The divide between the two consists of a prominent zone of volcanoes stretching west from Questa (Fig. 5). At the southern end of the basin, near Taos, the rift is about 20 miles wide and filled with about a 3-mile-thick section of sediments and volcanic rocks.

Upon exiting the San Juan Mountains, the Rio Grande turns southward, transects the San Luis Basin, and flows southward through successive rift basins towards the Gulf of Mexico. The river itself did not excavate the rift. Rather, the river follows the topographically lowest part of the rift, carving several spectacular canyons along the way. Beginning in southern Colorado, the Rio Grande has cut a steep-walled canyon, known as the Rio Grande gorge, into the basalt cap rock. The gorge deepens southward to a maximum of 850 feet at the Wild Rivers Recreation Area near Questa, and then gradually shallows as the Rio Grande flows through the southern San Luis Basin and into the Española Basin.

Unlike the rift basins to the south, the San Luis Basin is relatively undissected. That is, the sedimentary material that fills the basin has not yet been extensively exposed by the action of rivers and streams. Instead, the Rio Grande and its major tributaries have cut deep, narrow canyons through the volcanic rocks that cap most of the Taos Plateau. The river canyons provide the only good exposures of the rocks in the basin, which in the Taos area consist of Tertiary volcanic rocks interbedded with poorly consolidated sand-gravel-clay deposits.

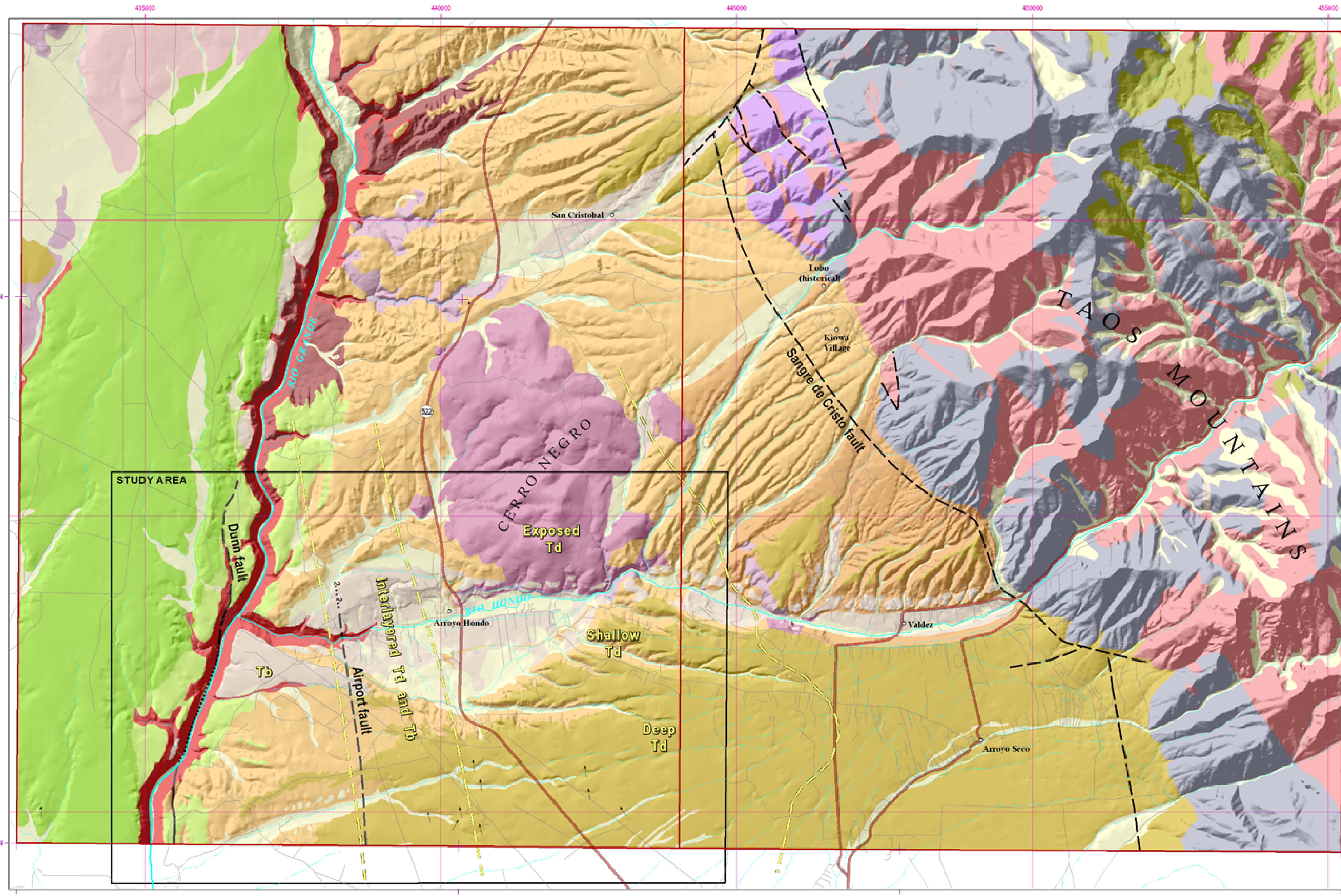
A single type of volcanic rock dominates the Taos Plateau landscape—the olivine tholeiite basalts of the Servilleta Formation. The gorge walls chiefly consist of thin, near-horizontal layers of this dark-gray, pahoehoe (ropy), vesicular (with small air pockets) lava. Much of the basalt was erupted from a cluster of low-relief shield volcanoes near Tres Piedras, traveling as thin, molten sheets for tens of miles before solidifying. Over 600 feet of basalt were locally stacked up during about 2 million years of episodic eruptions, between about 4.8 and 2.8 million years ago. These rocks can be seen from any location along the gorge, but are especially well exposed near the Rio Grande Gorge Bridge.

The second type of volcanic rock in the Arroyo Hondo area is found on the Cerro Negro volcano, a dacite lava dome (lava cone or volcanic dome) that was formed by eruptions of sticky lava that could only flow short distances before solidifying (Figs. 7 and 9). The lava piles over and around the vent, and commonly expands from within, forming steep-sided domes with lava rubble covering the surface. Domes can be active from decades to centuries. Most of the large volcanoes on the Taos Plateau are lava domes.

Although some of the sediment that fills the rift basin was deposited by the Rio Grande, most of the clay, silt, sand, gravel, and cobbles were eroded from the nearby mountains during the past 25 million years. The San Luis Basin is surrounded by alluvial fans that have slowly

Figure 6–Geologic map of the Arroyo Hondo and Arroyo Seco 7.5-minute quadrangles, showing the general distribution of rock units and surficial deposits in the Sangre de Cristo Mountains, the piedmont, and the Taos Plateau.

Arroyo Hondo map adapted from Kelson and Bauer (2006). Arroyo Seco map adapted from unpublished map compilation by G. Rawling.



Geologic Units

- Qal *Alluvium*
- Qt *Stream terrace deposits*
- Qfu *Alluvial fan deposits*
- Qtrg *Ancestral Rio Grande terrace deposits*
- Qtrg *Ancestral Rio Grande gravel*
- QTg *Old alluvium, Blueberry Hill alluvial fan deposit*
- QTsfu *Quaternary and Tertiary sedimentary rocks*
- Qm *Glacial deposits*
- Ta *Andesitic lava flows (Oligocene)*
- Tucem *UCEM dacite*
- Tb *Servilleta Formation, basalt (Pliocene)*
- Tg *Servilleta Formation, interbasalt gravel (Pliocene)*
- Ti *Igneous rocks*
- Td *Cerro Negro dacite ((late Miocene)*
- Xa *Proterozoic igneous and metamorphic rocks*

Faults

- Fault, certain
- Fault, approximate
- Fault, concealed

Approximate boundary between Tb and Td (based on aeromag in Fig.10)

Tres Piedras NE	Guadalupe Mountain	Questa	Red River
Cerro De Los Taoses	Arroyo Hondo	Arroyo Seco	Wheeler Peak
Tres Orejas	Los Cordovas	Taos	Pueblo Peak

N W E S

Scale 1:70,000
NAD 27, UTM, Zone 13

0 1 2 Miles

0 1 2 Kilometers

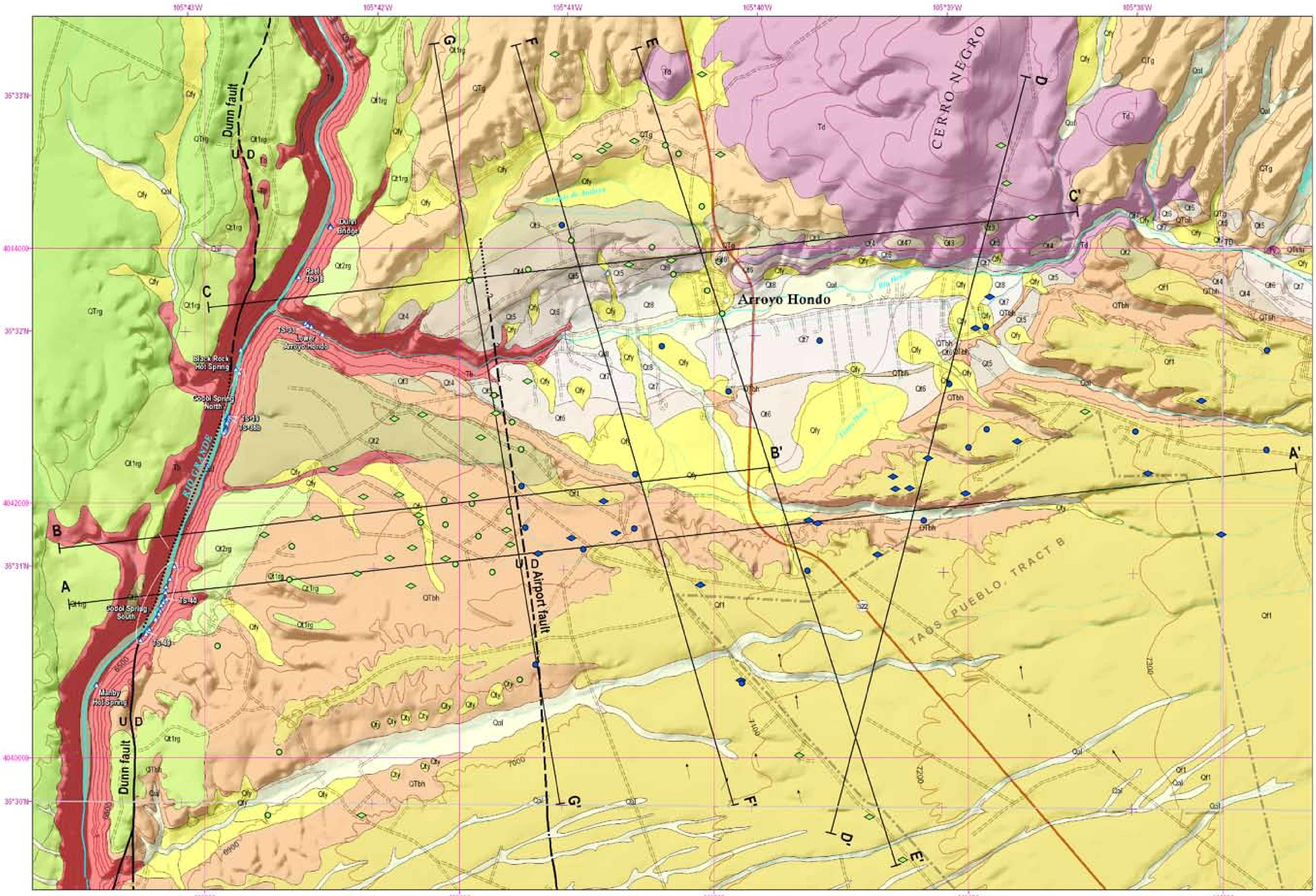


Figure 7–Geologic map of the Arroyo Hondo study area, Taos County, New Mexico. Locations of hydrogeologic cross sections are shown.

Adapted from the geologic map by Kelson and Bauer (2006).

Geologic Units

- Qal — *Alluvium*
- Qfy/Qty — *Young alluvial fan and stream terrace deposits*
- Qt8 — *Stream terrace deposits*
- Qt7 — *Stream terrace deposits*
- Qt6 — *Stream terrace deposits*
- Qt5 — *Stream terrace deposits*
- Qt4 — *Stream terrace deposits*
- Qt3 — *Stream terrace deposits*
- Qfu — *Undivided alluvial fan deposits*
- Qt2 — *Stream terrace deposits*
- Qt2rg — *Ancestral Rio Grande terrace deposits*
- Qf1 — *Alluvial fan deposits*
- Qt1rg — *Ancestral Rio Grande terrace deposits*
- QTrg — *Ancestral Rio Grande gravel*
- QTg — *Old alluvium*
- QTbh — *Blueberry Hill alluvial fan deposit*
- Tb — *Servilleta Formation, basalt*
- Tg — *Servilleta Formation, gravel*
- Td — *Cerro Negro dacite*

Map Symbols

- Contact, certain
- Contact, approximate
- Fault, certain
- Fault, approximate
- Fault, concealed
- Asymmetrical valley
- Cross section line

Well and Water Level Inventory

- Shallow alluvial aquifer
- Deep volcanic-alluvial aquifer
- Measured water level
- Recorded water level
- Rio Grande springs (locations from Bauer et al., 2007)

N W E S

1:30,000

0 0.25 0.5 Miles

0 0.25 0.5 Kilometers

CONTOUR INTERVAL 100 FEET
NAD 83, UTM, Zone 13

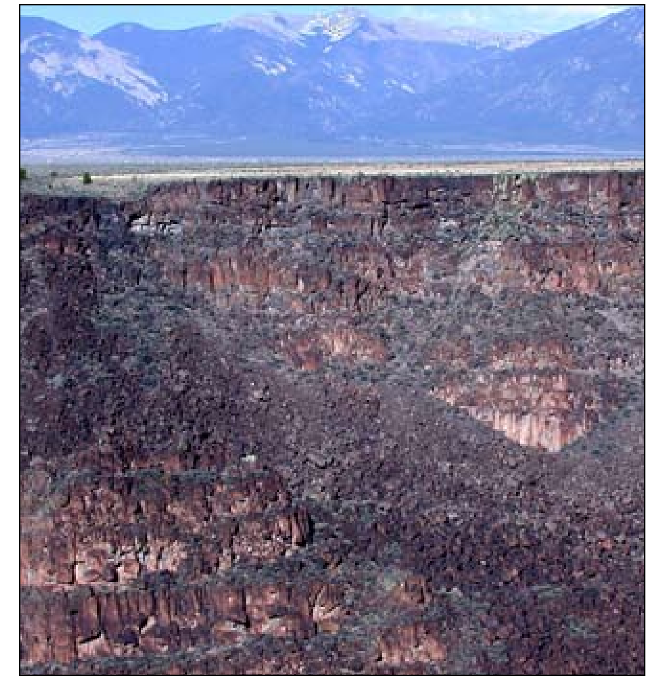


Figure 8–Photograph of typical highly fractured Servilleta Formation basalt flows in the Rio Grande gorge. View east to the Sangre de Cristo Mountains.

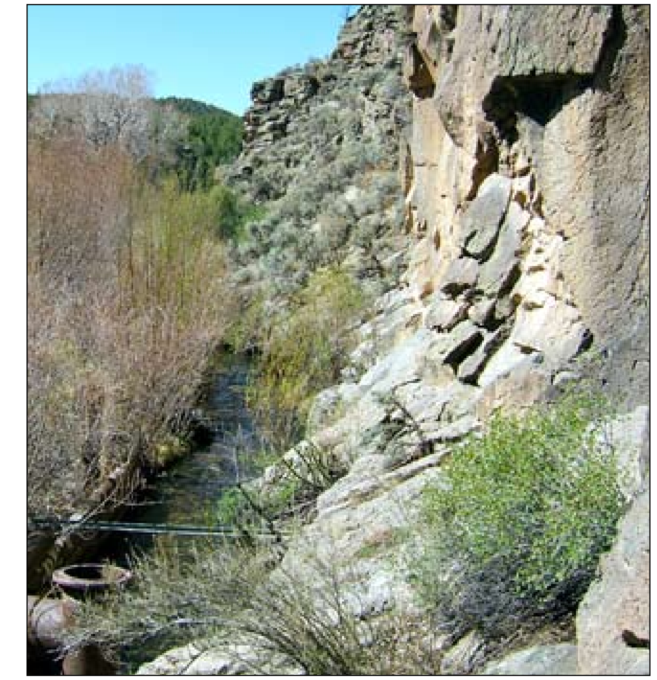


Figure 9–Photograph of a thin flow of dense Cerro Negro dacite, mantled by a fractured rubble zone, exposed along the Rio Hondo.

advanced from the mountains into the basin. An alluvial fan begins to form where a rapidly moving mountain stream flows out onto a relatively flat valley floor. As the stream loses velocity, the coarser sedimentary material is dropped by the stream. This material forms an "apron" that radiates out from the point where the mountain stream enters the valley.

Over time, each alluvial fan is buried under successively younger alluvium as the basin slowly sinks. In the Rio Grande rift, these rift-fill deposits are called the Santa Fe Group. Over much of the basin, we can only see the youngest basin fill at the surface. However, glimpses of Santa Fe Group sediments exist in the gorge, commonly as red or tan layers sandwiched between basalt or dacite lava flows in the gorge walls. The youngest of these alluvial fans and ancestral Rio Grande river deposits overlie the Servilleta basalts and locally comprise the area's shallow aquifers.

Geology of the Arroyo Hondo Area

Volcanic Rocks–The study area contains well-exposed Servilleta Formation in the Rio Grande gorge and in the western Rio Hondo canyon (Fig. 7). In the gorge, the basalts have been sub divided into four major flow units (Peterson, 1981). From oldest to youngest they are the lower Servilleta Basalt (Tb1 & Tb2), middle Servilleta Basalt (Tb3), and upper Servilleta Basalt (Tb4). All exposed basalts are extensively fractured, especially by columnar joints that tend to vertically penetrate entire basalt flows (Fig. 8). Many of the columnar fractures are open. Such basalt fracturing formed as each lava flow cooled, thus we expect the buried basalt units to also be extensively fractured, and therefore exceedingly permeable in the vertical dimension. In addition, the flow tops are typically characterized by highly vesicular ropy structures that create porous and permeable horizontal zones between flows. Over much of the Arroyo Hondo area, the top of the Servilleta Formation has been eroded so that the thickness of Tb4 is inconsistent. In addition, basalt flows, as well as the major flow units, are locally laterally discontinuous. The discontinuity, variable thickness, and monolithic nature of these basalts make them poor stratigraphic markers, which cannot be convincingly correlated in the subsurface using well data alone.

A second variety of basalt is exposed in the lower cliffs near the Rio Hondo and Rio Grande confluence. This "silicic alkali basalt" (Lipman and Mehnert, 1979) is a relatively rare eruptive product of the Taos Plateau volcanic field, and differs from the Servilleta Basalt by subtle variations in chemistry and mineralogy. The outcrop exposure of silicic alkali basalt in the study area is characterized by thick flows, brecciated aa margins (aa describes a more viscous lava flow whose surface is covered by thick, jumbled piles of loose, sharp blocks), and radial fracture patterns in the massive interiors of the flow lobes. The source vent for these flows is unknown, but must be nearby.

The Cerro Negro dacite volcano is composed of many, perhaps hundreds, of small lava flows, which have collectively built the volcanic edifice. The volcano certainly contains multiple vents, and is therefore enormously complex in three dimensions. Although each dacite flow is composed of relatively dense, fine-grained rock that generally lacks porosity, they do contain extensive fractures and rubble zones around their perimeters. Columnar joints are pervasive in thinner flows (Fig. 9). In addition, the dacite flows are generally mantled by extremely fractured rubble zones that formed as the lava cooled. Cerro Negro therefore contains a vast three-dimensional network of high porosity and permeability zones intermingled with dense, low- or zero-permeability zones. Based on lithologic data from well logs, we estimate that the entire complex of multiple dacite flows is typically several hundred feet thick, but ranges from over 1000 feet north of the Rio Hondo to a few hundred feet thick beneath Hondo Mesa. Preliminary interpretation of high-resolution aeromagnetic data (Fig. 10, T. Grauch, personal communication, 2006) and lithologic logs from well records indicate that the Cerro Negro volcano is partially buried by alluvial deposits such that the top of the dacite dips southward and westward under the study area, and the dacite flows are interlayered with Servilleta Formation basalts in the western half of the study area (Figs. 5 and 10). At least one Cerro Negro dacite flow is exposed in the Rio Grande gorge, just upstream from the Rio Hondo confluence.

Sedimentary Deposits–The sedimentary deposits in the study area can be roughly divided into three horizontal zones: 1) deep sedimentary deposits that are stratigraphically below the oldest Servilleta Formation basalt (i.e., older than about 5 million years); 2) intermediate-depth sediments that are interbedded with the Servilleta Formation basalt units (i.e., between about 5 and 2.8 million years); and 3) shallow sediments that rest above the Servilleta Formation basalts (i.e., younger than about 2.8 million years). In all three zones, the sedimentary layers contain extensive vertical and horizontal compositional and textural variations due to the complex depositional environment along the edge of an active rift basin (Fig. 11).

The characteristics of the deep sedimentary deposits are not well known, as they are not exposed in the basin, and only a few deep wells south of the study area have penetrated them. They probably belong to the lower Chamita and Tesuque Formations of the Santa Fe Group. These lower Santa Fe Group alluvial deposits are composed of well-consolidated layers of clay, silt, sand, gravel, and cobbles.

Some of the intrabasalt sediments are exposed in the Rio Grande gorge. In general, these deposits are layered alluvial fan and fluvial deposits that are dominated by clay, silt, sand, and pebble- to cobble-sized clasts of Tertiary volcanic and Proterozoic metamorphic rock. Typically, these deposits are altered to a brick red color where overlain by basalt flows (Fig. 12).

The shallow sedimentary deposits are well exposed over much of the study area. They range in age from the thick Quaternary-Tertiary Blueberry Hill alluvial fan deposit (QTbh), exposed south of the Rio Hondo canyon, and its northern equivalent (QTg), to the thinner alluvial fan

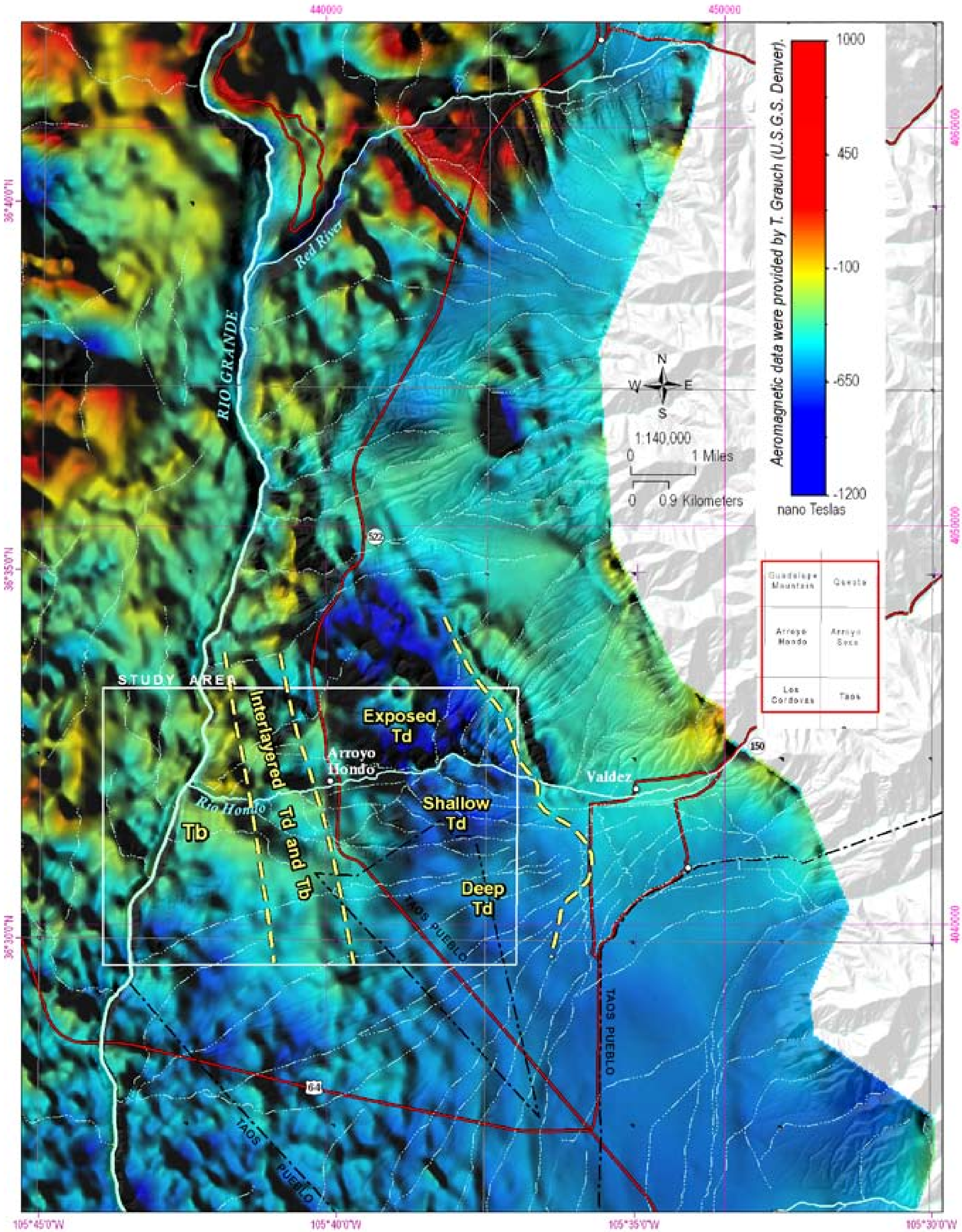


Figure 10—High-resolution aeromagnetic map of the Arroyo Hondo region. This map can be used to extract subsurface geologic information, such as buried faults, and the depth and extent of Servilleta Formation basalts (Tb) and Cerro Negro dacite (Td) flows.

(Qf1) and the numerous fluvial terrace deposits of the Rio Grande and Rio Hondo, and modern alluvium (Qal). Although the Quaternary deposits cover most of the map area (Fig. 7), collectively they comprise a thin mantle over the older deposits and volcanic units. Depending on local thickness, the permeability of the underlying unit, and the presence of local recharge, these young alluvial deposits can form important local aquifers, as in the case of the Blueberry Hill alluvial deposit near Arroyo Hondo.

Faults–Two mappable faults exist in the study area. The Dunn fault (Peterson, 1981; Dungan et al., 1984; Kelson and Bauer, 2006) is an east-dipping, east-down rift fault that parallels the Rio Grande gorge in the western study area. It exhibits about 115 feet of normal movement that appears to coincide in time with eruption of Servilleta Formation basalts and interlayered sediments, as Dungan et al. (1984) reported that the sedimentary interval between Tb2 and Tb3 is 56 feet thicker than the same interval west of the fault. In addition, the basalt flows east of the fault are all underlain by baked zones, indicating that the basalts covered wetlands or standing water. No such baked zones are found west of the fault. Where exposed west of the Dunn Bridge, the Dunn fault consists of a several-meter-wide brittle deformational zone that is characterized by brecciated basalt and fractured and altered sediments.

The second fault in the study area, the Airport fault, is not exposed, but is projected through the Hondo Mesa area from geologic mapping to the south (Kelson and Bauer, 2003) where it connects to a well-exposed segment of the Los Cordovas fault system. In the northern Los Cordovas and southernmost Arroyo Hondo quadrangles, the fault appears as a remarkably straight photolinear. Based on our interpretation of lithologic logs from well records, the Airport fault is an east-down normal rift fault that offsets basalts approximately 100 feet below Hondo Mesa (Fig. 13a, cross sections A–A' and B–B'). Similar to the Dunn fault, the Airport fault may be responsible for thickness changes of units across the fault and appears to cause significant westward thinning of the Blueberry Hill alluvial fan deposit (QTbh).

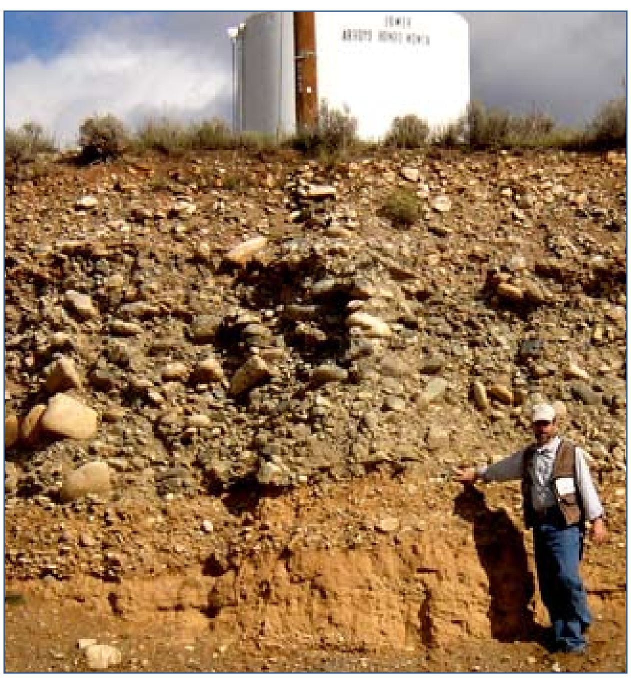


Figure 11–Photograph of exposure of typical Quaternary sedimentary deposits exposed in the Arroyo Hondo valley. Note the wide range of grain sizes and compositions of these layered units.

Figure 12–Photograph of the base of a Servilleta Formation basalt flow in the Rio Grande gorge. The underlying, orange-colored, silty sediments were baked by the molten lava flow.

IV. HYDROGEOLOGIC FRAMEWORK

Previous Work

No detailed hydrogeologic studies of the Arroyo Hondo area have been published. However, several previous workers in the Taos region have published hydrogeologic data and interpretations that we have found to be helpful. A comparative summary of data and aquifer descriptions from the various studies is presented in Table 1 (pg.26). A brief discussion of the major findings and interpretations from previous work is provided below.

Drakos et al. (2004a) developed a regionally significant geohydrologic framework for the Taos Valley. They identified two major aquifers in the Taos area, a shallow aquifer that includes the Servilleta Formation and younger alluvial deposits, and a deep aquifer of the Tertiary-age Santa Fe Group sedimentary units such as the Tesuque and Picuris Formations. The shallow aquifer was comprised of three geologic units:

1) Quaternary alluvium (Qal) and other surficial deposits (unconfined alluvium);
2) Older alluvium and the Blueberry Hill deposit and equivalent units (leaky-confined alluvium);
3) The Servilleta Formation upper and middle basalts and the intervening sediment (named the Agua Azul aquifer).

The Servilleta Formation lower basalt and underlying Chamita Formation (also known as Cieneguilla Formation) may be transitional between the shallow aquifer and the deep, leaky-confined and confined aquifer. In the Arroyo Seco area, they detected a downward vertical gradient in the shallow aquifer system. Based on a potentiometric map, they also noted that the upper Rio Hondo is a gaining stream, whereas the lower Rio Hondo is a losing reach. They reported that faults do not act as impermeable boundaries in the shallow alluvial aquifer, but may in the deep basin-fill aquifer.

Rawling (2005) investigated the Arroyo Seco area just to the east of our study area, using a detailed geologic map, geologic and hydrologic data from OSE well records, and measured water levels. He concluded the following:

1) Ground water flows generally westward, but flow paths are complicated by mountain-front faults, transmissivity variations, and interactions with streams.
2) The Sangre de Cristo fault has a noticeable affect on ground water flow patterns, producing both steep horizontal gradients and reversals in vertical gradients across the fault.
3) A region of downward flow exists at the western edge of the study area (eastern edge of Arroyo Hondo study area), where shallow ground water (in alluvium) moves vertically downward into buried volcanic rocks near the Gates of Valdez. This transition defines the edge of the Arroyo Seco shallow alluvial aquifer.
4) Buried volcanic rocks near the Gates of Valdez form a high transmissivity unit with a downward gradient. Based on geologic mapping presented in this report, these buried volcanic rocks correspond to the eastern edge of the Cerro Negro dacite complex that is exposed by incision of the Rio Hondo at the Gates of Valdez and on the flanks of Cerro Negro near Arroyo Hondo.
5) Ground water studies should depend on new water level measurements rather than those listed on well records.

Reiter and Sandoval (2004) reported on measured temperature logs from eight wells in the Taos Valley. Although none are in our study area, one well (BOR-7) is located less than two miles from the southeast corner of our area. They noted a very high temperature gradient near the water table surface indicating cool ground water flow, with possible upward flow from about 820 feet depth or a zone of warm, sub-horizontal flow at about 820 feet depth. They also found this well to be hydrogeologically disconnected from the nearby wells, and concluded that their data indicate that the hydrogeology of the Taos Plateau is complex, and may be divided into hydrogeologic cells by high-angle faults that act as both seals and pathways for ground water flow.

Benson (2004) produced a ground water map of Taos County from water levels and lithologic logs compiled from NMOSE well records. He proposed that a buried series of north-striking and east-striking faults compartmentalize the "water table" in the Stagecoach Hills/Hondo Mesa area. As we discuss below, our study confirms the complex character of the hydrogeologic system in the area, but we interpret the complexities as due to changes in permeability and transmissivity of multiple aquifers. Aeromagnetic data of Grauch (personal communication) provides no indication of buried faults in the study area. Furthermore, based on measured water levels, we find no evidence of the isolated ground water mounds and depressions that are shown on the Figure 4 water table map of Benson (2004), but do identify multiple aquifers with a large vertical head differential. He also noted that "recharge appears to tie directly to the Rio Hondo water level to the north", and that north of the Rio Hondo "the water table is about 200 feet above the adjacent Rio Hondo, and is probably recharged from high on Cerro Negro approximately ten miles northeast." Our cross sections contest this interpretation, as the measured water levels in the volcanic units north of the Rio Hondo are consistently more than 100 feet below the elevation of the river bed and regional ground water flow direction is to the west. Benson (2004) also reported on the results of major and trace element laboratory analyses of 100 well samples scattered throughout Taos County. He concluded that water quality is generally excellent, although many wells contain hard water, and some areas have elevated levels of some constituents. The wells that he sampled in our study area all appear to contain high-quality drinking water.

Drakos et al. (2004b) reported on the geochemistry and residence time of ground water in the Taos Valley. Although no samples were taken in our study area, they did sample several wells a few miles south and southeast of the Arroyo Hondo study area. They concluded that:

1) Residence time of ground water in the shallow aquifer ranges from less than 5 to about 10 years;
2) Recharge to some leaky-confined wells in alluvium takes more than 50 years;
3) Recharge to the Agua Azul aquifer (sediments between middle and upper Servilleta basalts) takes more than 50 years;
4) Isotopic data suggest that deep wells in basin-fill alluvium have received Pleistocene recharge (older than about 10,000 years), whereas others have received Holocene recharge;
5) Large intrabasin faults cause some compartmentalization of the Tertiary aquifer system.

Bauer et al. (2008) recently completed an inventory and preliminary geochemical investigation of springs in the Rio Grande gorge of Taos County. Forty three of the surveyed springs lie within the Arroyo Hondo study area (Fig. 4). The geologic setting and geochemistry of these springs, combined with well data, contribute to our conceptual hydrogeologic model. Nearly all of the cool springs emerge from near the base of the eastern gorge cliffs within about 50 vertical feet above the river. Where exposures of bedrock are sufficient, it appears that some of the springs emerge from the base of the basalt. The springs are generally small, and distributed in lines of springs and seeps. The largest measured discharge is 144 gal/min, although most springs flow at less than 15 gal/min. The principal clusters of springs in the Arroyo Hondo study area are summarized below.

1) North of the Rio Hondo confluence, the Dunn Bridge North spring zone consists of 20 springs and seeps that emerge from basalt debris at an elevation of approximately 6516 feet. The largest single discharge was measured at 144 gal/min in TS-31a, with a cumulative estimate of 239 gal/min for the zone. The springs are cool (59ºF, 15ºC), and TS-31a yielded a CFC age of 36 ± 2 years and a tritium concentration of 4.5 tritium units (TU) in 2004. The southernmost spring in the zone, the Rael Spring (TS-18, elevation 6460), yielded a tritium value of 4.0 TU in 2006. Based on geologic maps and cross sections, we interpret these springs to discharge from the lower silicic alkalic basalt (unit Tbsa).
2) The Lower Arroyo Hondo spring zone is located on the north bank of Rio Hondo near the confluence with the Rio Grande. The zone consists of a long seep zone plus two springs emerging from the base of the basalts at an elevation range of about 6500 to 6515 feet. The total estimated discharge is 53 gal/min, the water is cool (58ºF, 14ºC) and yielded a tritium concentration of 6.0 TU in 2004. Based on geologic maps and cross sections, we interpret these springs to discharge from the lower silicic alkalic basalt (unit Tbsa).
3) The Medina spring discharges from stream terrace deposits on the southern flank of Cerro Negro on the north side of the Arroyo Hondo valley at an elevation of approximately 6810 feet. No field parameters or discharge estimates are available, but anecdotal information describes the Medina spring as seasonal. Based on geologic maps and cross sections, we interpret the Medina spring to discharge from a perched aquifer that overlies the Cerro Negro dacite (unit Td) on the north side of the Rio Hondo.
4) The Godoi North spring zone is a cluster of many small springs and seeps located about 1000 meters downstream of the confluence that discharge from the base of the basalt. The zone has an estimated cumulative discharge of 122 gal/min, with the largest single spring discharging about 30 gal/min at an elevation of 6447 feet The springs are cool (63–67ºF, 17–19ºC), with field-measured dissolved oxygen from 6.5–8.2 mg/L, a CFC age of 53 ± 2 years, and a tritium concentration of 0.6 TU. Based on geologic maps and cross sections, we interpret the Godoi North spring zone to discharge either from the lower silicic alkalic basalt (unit Tbsa) or one of the Servilleta Formation basalt flows (unit Tb3).
5) The Godoi South spring zone is a line of springs nearly 1000 meters long, just upstream of Manby Hot Springs. The cumulative discharge was estimated at 112 gal/min, with the largest spring (TS-51) discharging about 30 gal/min at an elevation of 6467 feet. Temperatures range from cool (61ºF, 16ºC) in the north to warm (74ºF, 22ºC) near Manby Hot Springs. Field-measured dissolved oxygen ranged from 8 mg/L in the north to 5.6 mg/L in the south. Tritium concentrations from north and south samples were negligible in 2006. Based on dissolved oxygen and temperature trends, we interpret that cool water from the deep volcanic-alluvial aquifer in the Arroyo Hondo area is mixing with deep circulating geothermal water that ascends along the Dunn fault and feeds Manby Hot Springs. Based on geologic maps and cross sections, we interpret the Godoi South spring zone to discharge either from lower Servilleta Formation basalts (unit Tb2) or overlying sediments.
6) Black Rock hot spring is a small spring on the west side, with a measured discharge of 21 gal/min in 2002. The maximum temperature of the pool is about 101ºF (38ºC). To the south, Manby Hot Springs (aka Stagecoach hot springs) discharges over 100 gal/min of geothermal water (94º–100ºF, 34º–38ºC). Both springs are located near

the Dunn fault, which provides a vertical conduit for the ascent of deep geothermal ground water.

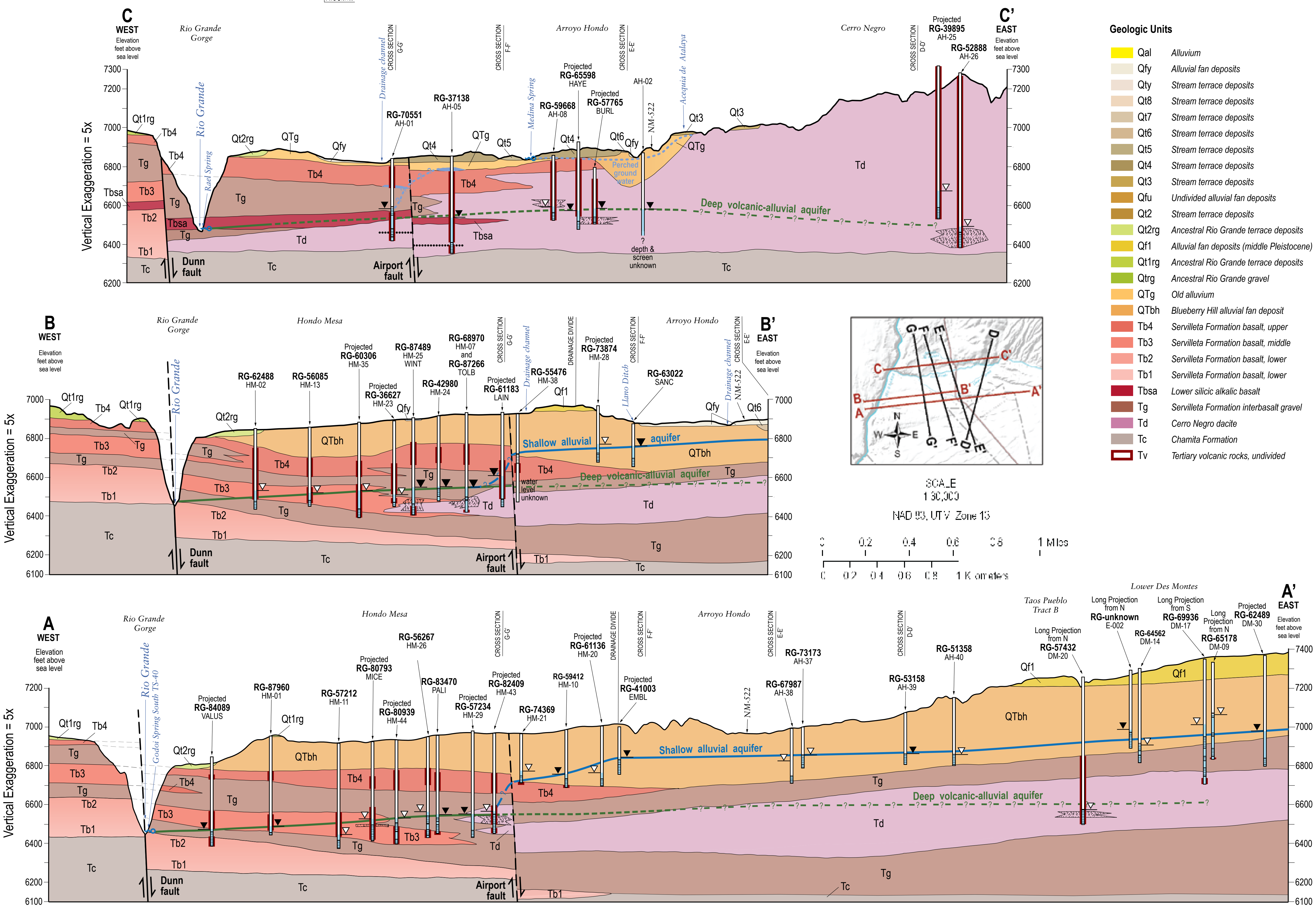
Ground Water Flow System

Hydrostratigraphic Units–Four major hydrostratigraphic units – geologic units with distinct hydrologic characteristics – exist in the Arroyo Hondo area. From geologically youngest to oldest (stratigraphically highest to lowest), these are: 1) modern floodplain and terrace deposits (geologic units Qt and Qal on figures 6, 7 and 13), Quaternary alluvial fan and Quaternary surficial deposits (Qf and Qal), the Blueberry Hill alluvial fan deposit (QTbh, south of the Rio Hondo) or its northern equivalent (QTg), and upper Tertiary alluvial fan deposits overlying volcanic rocks (Tg); 2) the complex of dacite flows and interlayered sediments belonging to the Cerro Negro volcano (Td); 3) Tertiary basalt flows of the Servilleta Formation and interlayered sediments belonging to the upper Chamita Formation (Tb and Tg); and 4) lower Santa Fe Group alluvial deposits belonging to the lower Tertiary Chamita and/or Tesuque Formations (Tc) that lie below the oldest Servilleta Formation basalt and the Cerro Negro dacite. Each of these hydrostratigraphic units appears to have distinct hydrological characteristics. Distribution of the geologic and hydrostratigraphic units is best understood through examination of the geologic maps (Figs. 6 and 7) and cross sections (Fig. 13).

Hydrogeologic Cross Sections–Many observations and interpretations of the Arroyo Hondo ground water flow system were made from an analysis of geologic cross sections, and well and water level data. Based on an analysis of 110 water well records (Fig. 4 and Table A1), the high-resolution aeromagnetic data (Fig. 10), and the geologic maps (Figs. 6 and 7), we constructed seven detailed cross sections through the study area (Figs. 13a and 13b) that depict the subsurface distribution of geologic and hydrostratigraphic units, well data, surface water features, water levels, faults, and zones of fracturing and sediment layers in volcanic rocks. East-west cross sections (A–A', B–B', C–C') are constructed generally parallel to regional ground water flow and extend from the eastern limit of the study area to the Rio Grande south of the Rio Hondo (A–A') and along the edge of the Cerro Negro volcano north of the Rio Hondo (C–C'). Cross section B–B' is constructed similar to A–A', but provides additional information on the nature of ground water flow in the vicinity of the Airport fault. North-south cross sections (D–D', E–E', F–F' and G–G') are constructed generally perpendicular to regional ground water flow and extend from north of the Rio Hondo on the southern flank of Cerro Negro to the southern edge of the study area in the center of the alluvial plateau (Hondo Mesa). These cross sections illustrate the subsurface distribution, location and extent of aquifers in the context of the geologic framework and the Rio Hondo, local acequias, and other surface water features, and provide insight regarding geologic controls on ground water flow.

Summary of Aquifers and Hydrostratigraphic Units

Regional ground water in the Arroyo Hondo area exists primarily within the Quaternary-Tertiary alluvial fan sediments known as the Blueberry Hill deposit, the Servilleta Formation basalts and interbedded sediments, the lower Santa Fe Group alluvial deposits, and locally within the Cerro Negro dacite. These hydrogeologic units are grouped into three separate aquifers on the basis of their hydrologic characteristics and distribution (Tables 1 and A1). Sufficient data exist to contour a water table surface for the shallow alluvial aquifer in the Quaternary-Tertiary Blueberry Hill deposit, and a potentiometric surface for the deeper volcanic-alluvial aquifer (Fig. 14). Ground water flow conditions in this complex aquifer system are discussed below.



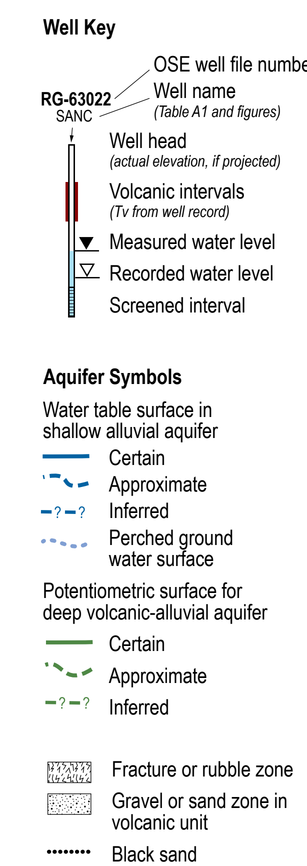


Figure 13a–Hydrogeologic cross sections through the Arroyo Hondo study area, showing approximate elevation of static water levels for shallow and deep wells. These cross sections are interpretations based on geologic mapping, water-level measurements, and drillers well records, and should not necessarily be used to site water wells. Cross section locations are shown on the geologic map (Figure 7) and the data inventory map (Figure 4).

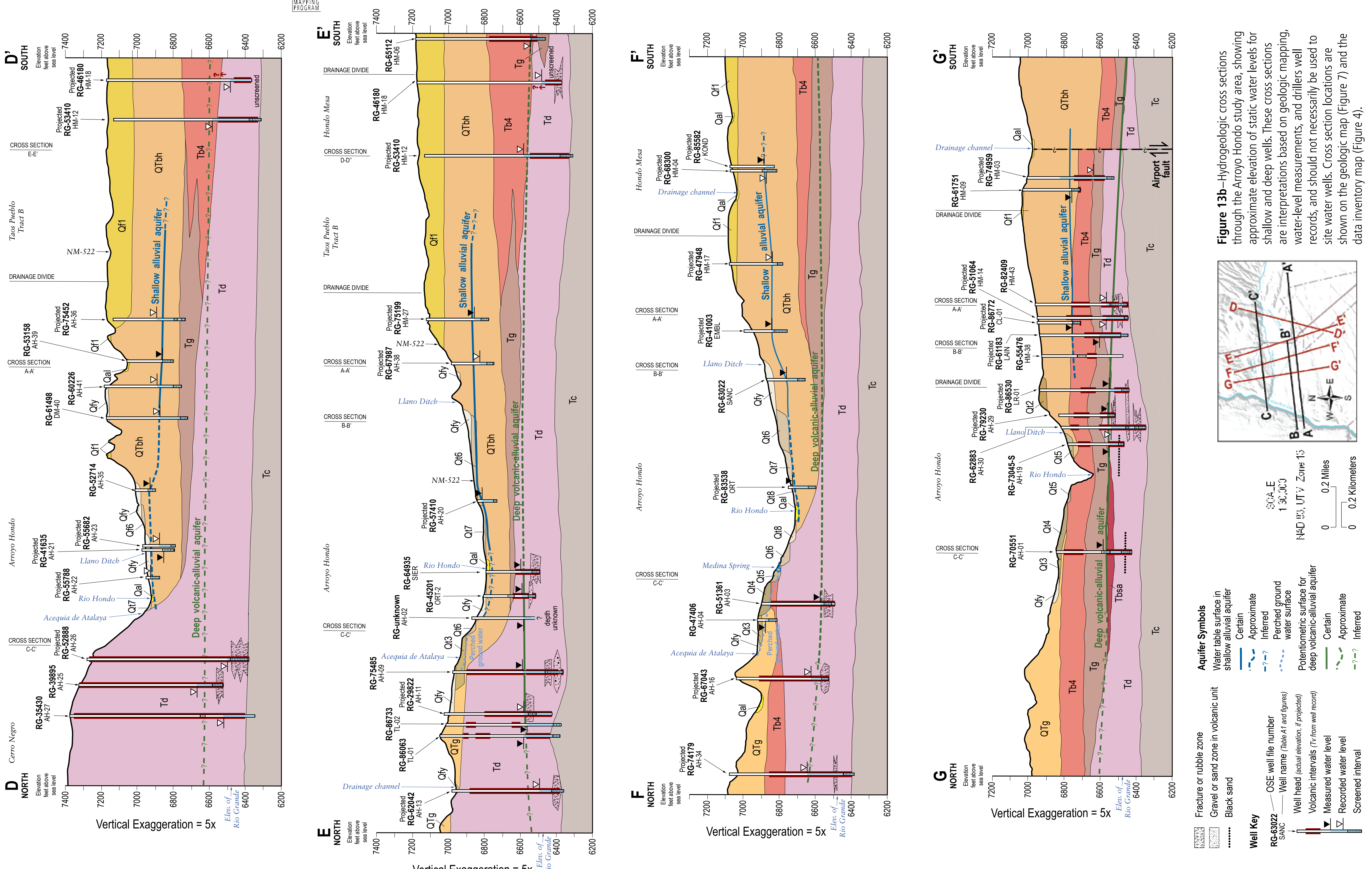


Figure 13b—Hydrogeologic cross sections through the Arroyo Hondo study area, showing approximate elevation of static water levels for shallow and deep wells. These cross sections are interpretations based on geologic mapping, water-level measurements, and drillers well records, and should not necessarily be used to site water wells. Cross section locations are shown on the geologic map (Figure 7) and the data inventory map (Figure 4).

Arroyo Hondo Shallow Alluvial Aquifer–Virtually all wells south of the Rio Hondo and east of the Airport fault are completed and screened in the Blueberry Hill alluvial fan deposit (QTbh) and contiguous upper Tertiary alluvial fan deposits of the upper Chamita Formation (Tg) that overlie Cerro Negro dacite flows. This saturated zone forms a distinct hydrostratigraphic unit, hydrologically separate from deeper water-bearing zones and aquifers in underlying volcanic (Td) and sedimentary (Tc) rocks, and is referred to as the Arroyo Hondo shallow alluvial aquifer. This aquifer is generally equivalent to the "shallow" aquifer of Drakos et al. (2004a).

Depth to ground water in the shallow alluvial aquifer varies from less than 20 to more than 300 feet. Shallow water levels are encountered in the Rio Hondo valley below the Llano Ditch and in wells near the active river channel. The greatest depth to ground water occurs on the alluvial plateau south of the Hondo valley and on the alluvial fans near the mountain front. Saturated thickness ranges from about 25 to 275 feet. Yields for wells in the Blueberry Hill alluvial deposit range from 15 to 30 gal/min (gpm), with an average of 19 gpm (Table 1). The aquifer is composed of semi-consolidated, poorly to moderately well sorted layers of clay, silt, sand, pebbles, and cobbles that are laterally heterogeneous. The hydraulic conductivity of 0.4 ft/day reported by Drakos et al. (2004a) (Table 1) is at the low end of the published range for clean sands and gravels, but is probably reasonable for a poorly sorted, clayey unit such as the Blueberry Hill deposit. In addition, in some areas where the Blueberry Hill deposit is well exposed, it is moderately well cemented and altered.

Ground water flow direction in the shallow alluvial aquifer is generally east to west. Static water levels in the aquifer define a shallowly west-dipping water table surface that ranges in elevation from 7200 feet at the eastern boundary to 6680 feet at its western extent near the Airport fault, for an average gradient of about 115 feet/mile or 0.02. The water table surface grades to the Rio Hondo, generally mimics topography, and is locally elevated in the vicinity of acequias and irrigated fields. The shallow alluvial aquifer does not exist in thin alluvial fan deposits north of the Rio Hondo or west of the Airport fault, and is evident in only a few wells south of the Rio Hondo drainage divide.

Near Arroyo Hondo, the shallow alluvial aquifer is a semi-perched aquifer. Accretion of ground water in the Blueberry Hill alluvial fan deposit is controlled by a combination of permeability differences between the alluvial sediments and underlying Cerro Negro dacite and the presence of active sources of recharge. The Cerro Negro dacite is a perching unit. Its distribution at shallow depths in the subsurface (Fig. 10) is contiguous with the shallow alluvial aquifer, and the Blueberry Hill alluvial deposit is only saturated where it overlies this massive, crystalline volcanic unit. Cerro Negro dacite is much less permeable than the Blueberry Hill deposit as a whole. Therefore, in areas where Blueberry Hill alluvial fan sediments are underlain directly by Cerro Negro dacite, conditions are generally favorable for accretion of ground water in the overlying alluvium. To the west, where Cerro Negro dacite is either overlain by Servilleta Formation basalts and interlayered sediments, or is truncated by or terminates against the Airport fault, saturation in the Blueberry Hill rapidly thins and disappears across a zone of downward leakage as ground water moves into the more permeable, underlying units (Fig. 13a, cross sections A–A' and B–B', and Fig. 14).

Spiegel and Couse (1969) were the first to recognize that the ancient stream-terrace deposits along the present streams were probably above the water table under natural conditions, but now have locally perched or semi-perched zones of saturation due to the development of irrigation. In the Rio Hondo drainage, the distribution of recharge from surface water and irrigation is a critical factor controlling the extent of the shallow alluvial aquifer. Channel infiltration through losing reaches of the Rio Hondo, leakage from local acequias, irrigation return, and infiltration of runoff through arroyo channels on the alluvial uplands are the primary sources of recharge to the shallow aquifer. No significant sources of

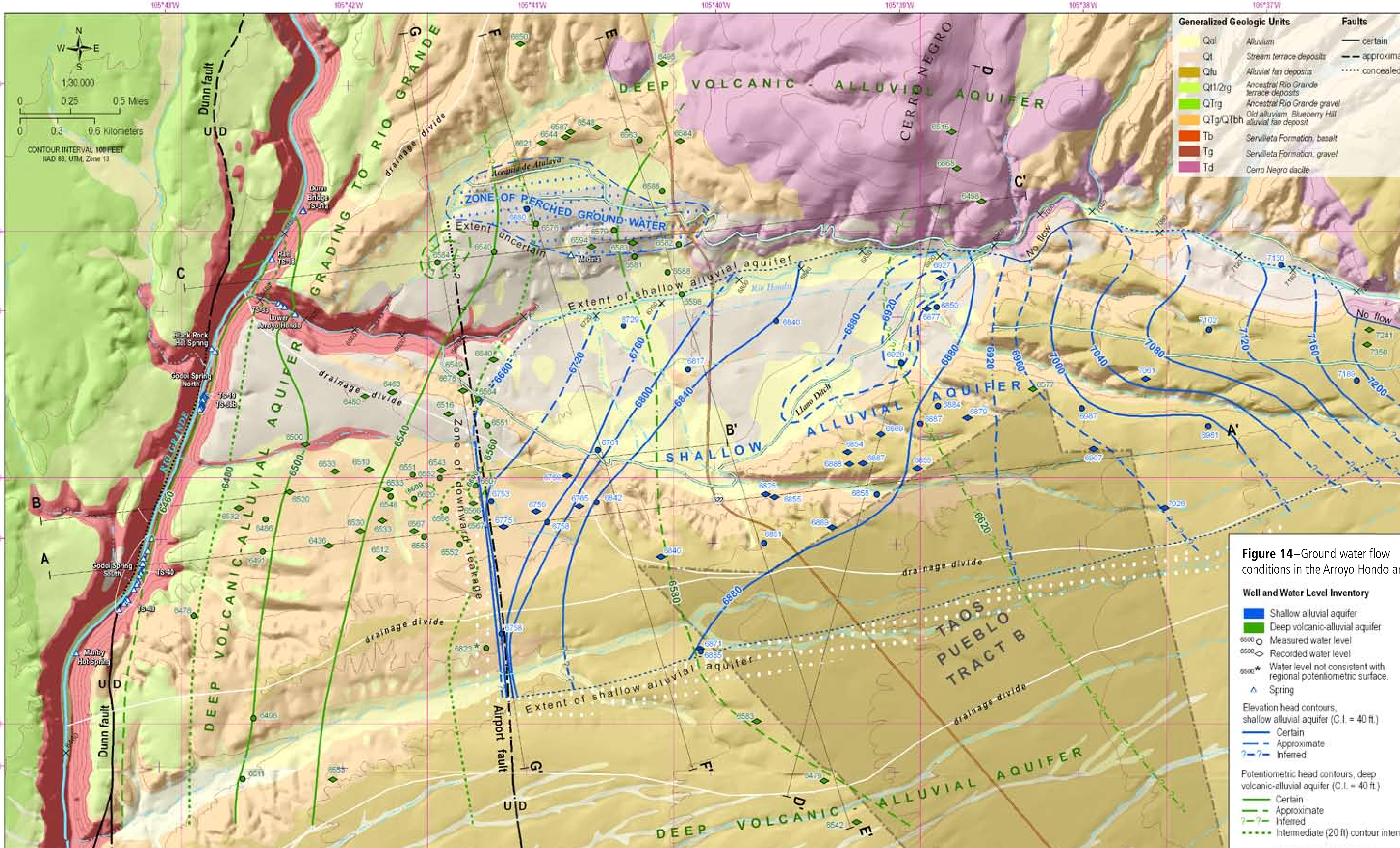


Figure 14–Ground water flow conditions in the Arroyo Hondo area.

Hydrogeologic Unit	Geologic Map Unit	Thickness in study area (ft)	This Study				Drakos et al. (2004) a				RG-87960 River View Acres well (Jenkins, 1980)	
			Aquifers	Hydraulic Conditions	Depth to Water (ft)	Average Yield (gpm)	Aquifers	Hydraulic Conditions	Transmissivity, T (ft^2/day)*	Hydraulic conductivity, K (ft/day)*	Transmissivity, T (ft^2/day)	Hydraulic conductivity, K (ft/day)
Quaternary deposits in Rio Hondo valley	Qal to Qf1	<80	Shallow alluvial aquifers	Unconfined alluvium			Shallow aquifer	Unconfined alluvium	580 – 1100	2.9 – 11		
Blueberry Hill deposit	QTbh, QTg	<600		Leaky perched aquifer	40 – 300	19		Leaky-confined alluvium	40	0.4		
Servilleta Fm basalt and sediments	Tb, Tg	<700	Deep volcanic-alluvial aquifers	Complex, leaky unconfined	330 – 470	24 (Tb) 17 (Tg)	"Agua Azul" aquifer Transition		280 – 1600	4.7 – 26.7	1250	96
Cerro Negro dacite	Td	<1000?		Unconfined fractured aquifer	215 – 385	25						
Chamita Fm	Tc	unknown	Deep Tertiary basin-fill aquifers	Semi-confined to confined?	450	10 to 100	Transition					
Ojo Caliente Mbr of Tesuque Fm	To (not on map)	unknown					Deep Tertiary basin-fill aquifer	Leaky-confined and confined	110 – 640	0.2 – 0.8		

**From select wells nearest Arroyo Hondo study area.*

Table 1–Summary of Hydrogeologic and Aquifer Units of Arroyo Hondo study area aquifer.

recharge exist on the alluvial plateau to the south, which is isolated from mountain runoff and has no acequias or irrigation. Arroyo channel infiltration may provide local, ephemeral recharge to the narrow strip of shallow aquifer that exists on the alluvial plateau (Figs. 3 and 14). Limited well data on the alluvial plateau, south of the Rio Hondo drainage divide, suggest that shallow alluvial ground water in the Blueberry Hill deposit disappears in a zone of downward flow as the Cerro Negro dacite dips to greater depths.

Shallow Perched Aquifer–A local zone of perched ground water exists in Quaternary-Tertiary alluvial fan deposits north of the Rio Hondo on the southwest flank of Cerro Negro (Fig. 14). Similar to the shallow alluvial aquifer in the Blueberry Hill alluvial deposit to the south, this perched ground water accumulates in older alluvial fan (QTg) and modern stream terrace (Qt) deposits by ponding on the surface of relatively impermeable Cerro Negro dacite flows. A static water level in shallow alluvial well AH-04 (cross section F–F'), located downslope of the Acequia de Atalaya, indicates a saturated thickness of 64 feet. The Medina spring (Fig. 4 and cross section F–F') represents the southernmost extent of this shallow perched aquifer. We interpret the Medina spring to discharge shallow, perched ground water that is recharged by leakage and irrigation return flow from the acequia. An elevated water level in well AH-01, a 420 ft well completed in volcanic and alluvial units north of the Rio Hondo and west of the Airport fault, may indicate that downward leakage from the shallow perched aquifer recharges deeper volcanic aquifers north of the Rio Hondo (Fig. 13a, cross section C–C'). The lower Rio Hondo spring zone, located down gradient of AH-01 on the north bank of the river, may reflect discharge from this local flow system. A tritium content of 6 TU in TS-33 (Bauer et al., 2008) indicates a surprisingly short residence time of 1 to 5 years for spring water, suggesting the springs are fed by a very local flow system and a recharge source in close proximity.

Cerro Negro Dacite–The Cerro Negro dacite, primarily a massive crystalline volcanic unit, contains localized, productive aquifers in fractured and rubble zones but generally appears to behave as a perching bed for shallow alluvial aquifers in overlying Quaternary and Tertiary alluvial fan deposits (QTbh, QTg, and upper Tg). Virtually all records for wells completed in the dacite indicate water-bearing strata to be fractured volcanic rock, decomposed 'basalt', or thin zones of black sand and gravel. Where wells encounter water in the Cerro Negro dacite, yields range from 10 to 50 gpm, with an average of 25 gpm (Table 1). The sediment intervals observed within the dacite rocks are interpreted to represent either local paleochannels or simply an eroded rubble zone at the surface or edge of a flow. With the exception of these volcanic sediment and fracture zones, the unit has extremely limited porosity and permeability. Most wells penetrate a substantial thickness of massive volcanic rock before encountering a water-bearing zone, and a few wells penetrate the entire thickness of the dacite unit before encountering water in underlying lower Tertiary sediments.

North of the Rio Hondo (east-west cross section C–C' and north-south cross sections), virtually all wells are completed in Cerro Negro dacite, most of these in fracture and rubble zones or intervals of sand or gravel. Static water levels (measured and recorded) in these wells are highly variable and are often regionally discontinuous, but are significantly lower than those measured in overlying perched or shallow alluvial aquifers. Hydrologic connection between isolated fractured aquifers within the Cerro Negro, and between the Cerro Negro aquifers and contiguous aquifers in Servilleta Formation basalts and sediments to the west and south, is unknown. Due to the geologic heterogeneity of the Cerro Negro dacite, it is likely that many of these fractured volcanic aquifers may exist in isolated, local compartments with limited interconnection and limited connection with adjacent aquifers (see section on **Geology of the Arroyo Hondo Area, *Volcanic Rocks***).

East of NM-522 and south of the Rio Hondo, in the eastern half of the study area, only three wells are completed in the Cerro Negro dacite (Td), and the static water levels appear to grade westward to the deep volcanic-alluvial aquifer beneath Hondo Mesa. Where Cerro Negro dacite and Servilleta Formation basalts and sediments are interlayered beneath Hondo Mesa (Figs. 6 and 10), these two geologic units may behave as a single hydrostratigraphic unit referred to as the deep volcanic-alluvial aquifer and discussed below.

Servilleta Formation and Deep Volcanic-Alluvial Aquifer–The Servilleta Formation constitutes a complex, three-dimensional aquifer system that is distinct from the shallow aquifer existing in Quaternary-Tertiary alluvial fan deposits. Wells completed in Servilleta Formation basalt flows (Tb, Tb1, Tb2, Tb3, Tb4) and interbedded sedimentary horizons (Tg) exist almost exclusively at or west of the Airport fault beneath western Hondo Mesa. Deep wells screened in some combination of sediments and volcanic rocks also exist south of the Rio Hondo drainage divide beneath southern Hondo Mesa, but at this location lithologic data are not sufficient to distinguish between interlayered Cerro Negro dacite and Servilleta basalts. For this study, this deep water-bearing zone is referred to as the deep volcanic-alluvial aquifer and is generally equivalent to the Agua Azul aquifer of Drakos et al. (2004a).

We infer that this deep aquifer system may underlie the entire study area, but limited data from deep wells in the central and eastern portions of the Arroyo Hondo area, and variable, regionally inconsistent water levels in the Cerro Negro dacite, make this inference somewhat speculative. Water level elevations in wells completed in the deep aquifer range from about 7300 feet in the east to 6480 feet in the west and are well below the elevation of the Rio Hondo. The potentiometric surface indicates that ground water flows east to west and grades to the elevation of cool springs that emerge at 6450 to 6470 feet in the Rio Grande gorge just above the river (Fig. 14). Tritium content and CFC (chlorofluorocarbon) recharge ages by Bauer et al. (2008) indicate a CFC recharge age of 36 ± 2 years and a tritium content of 4.54 TU (tritium units) for Dunn Bridge North spring (TS-31a) north of the Rio Hondo confluence, and 53 ± 2 years for Godoi North 2 spring (TS-36b) south of the Rio Hondo confluence.

The primary porosity and permeability of the basalts is very low, although the pahoehoe (ropy) flow tops provide some horizontal permeability. The secondary porosity and permeability supplied by the extensive network of open, vertical and sub-vertical fractures is large, although the storage capacity of basalts as a whole is probably low. The porosity of the interlayered sand- and gravel-dominated sediments is large, perhaps as high as 30 percent. The sediments can probably store significant amounts of water, but the flow may be restricted by interbedded clay intervals. We expect that ground water can move easily between layers of basalts and sediments within the Servilleta Formation. The uniform hydraulic gradient east of the Rio Grande, through Tb3 and adjacent Tg sediments, supports this interpretation. Records of wells completed in the deep volcanic-alluvial aquifer west of the Airport fault indicate that the basalts are the primary water-bearing strata in this aquifer (Fig 13a, cross sections A–A', B–B'). Wells completed in basalt intervals of the Servilleta Formation (Tb) have yields ranging from 17 to 30 gpm, with an average of 24 gpm, whereas yields from interlayered sediments (Tg) range from 4 to 30 gpm, with an average of 17 gpm. Yields from wells completed in both volcanic and sediment intervals reflect intermediate values of 10 to 25 gpm, with an average of 17 gpm (Table 1).

The only readily available report of a tested well in the Servilleta Formation is the River View Acres test well (RG-87960) as reported by Jenkins (1980). The 510 foot well was perforated at 500–510 feet in gravel of the Servilleta Formation. Its specific capacity after one hour of pumping at 9.2 gal/min was 2.6 gal/min/ft of drawdown. Transmissivity calculated from recovery data was 1250 ft^2/day and the estimated hydraulic conductivity is 96 ft/day (Table 1). The report concluded that the aquifer is highly permeable, and is capable of supplying the planned domestic wells for the subdivision.

Airport Fault Transition Zone–On Hondo Mesa, the southern cross sections (A–A' and B–B') delineate a narrow transition between shallow alluvial and deep volcanic-alluvial aquifers. This zone corresponds to a north-trending projection of the Airport fault and the western limit of thick Cerro Negro dacite flows in the subsurface. The Airport fault transition zone is a high-permeability zone associated with a strong downward gradient from the shallow alluvial aquifer to the deep volcanic-alluvial aquifer. Well depths east of the transition are shallow, ranging from 200 to 300 feet, and to the west are 400 to 550 feet. Across the transition, measured water levels in the shallow water-bearing zone drop as much as 200 feet, with reports of cascading water in wells. The hydraulic gradient increases dramatically from about 0.014 in the shallow aquifer zone to the east, to 0.3 in the transition zone at the fault, and back to 0.012 in the deep volcanic-alluvial aquifer to the west. Due to east-down displacement along the fault and the regional eastern dip of Servilleta Formation basalts and sediments, the Blueberry Hill deposit (QTbh) and the uppermost Servilleta Formation basalt (Tb4) are unsaturated west of the Airport fault. Thus the Airport fault transition zone defines the western extent of the shallow alluvial aquifer.

Throughout the study area, shallow alluvial wells have higher static water levels than those completed in the deep volcanic-alluvial aquifer, and in general, adjacent pairs of shallow and deep wells have measured water-level elevations differing by more than 300 feet in head. This vertical head differential defines a regional, vertically downward hydraulic gradient that implies downward leakage from the shallow alluvial aquifer to the deep volcanic-alluvial aquifer. Where the hydraulic gradient of the shallow aquifer steepens dramatically at the Airport fault, shallow water levels rapidly merge with the elevation head in deep volcanic-alluvial wells on the west side of the fault (cross sections A–A', B–B' and G–G'). Relatively young CFC recharge ages and significant tritium content in springs emerging in the Rio Grande gorge as discharge from the deep volcanic-alluvial aquifer suggest that shallow alluvial ground water merging with the deep aquifer at the Airport fault transition zone comprises a significant portion of the ground water discharging at the springs.

Lower Santa Fe Group Alluvial (Chamita) Aquifer–Ground water encountered in the lower Santa Fe Group alluvial deposits probably belongs to the deep alluvial aquifer that pervades the southern San Luis Basin. Little is known about the deep basin-fill (Chamita) aquifer, either regionally or within the Arroyo Hondo area. A few wells in the study area penetrate a full thickness of Cerro Negro dacite or Servilleta basalts (300 to 500 feet) and terminate in water-bearing sediments of the Chamita Formation. Reported yields from these wells vary from 10 to 100 gpm. At some localities that have either a thick unsaturated zone or non-water bearing zone of volcanic rocks and sediments, the Chamita aquifer constitutes the shallowest available ground water. Water levels in these wells are consistent with other wells in the deep volcanic-alluvial aquifer, and for this study, we make no distinction between the water-bearing zones at the top of the Chamita basin fill and those in overlying volcanic rocks.

Surface Water and Ground Water Interactions

The Rio Hondo is a small tributary to the Rio Grande, with peak annual flows of generally less than 300 cfs, and with major flood flows of only about 500 cfs. The Rio Hondo originates as ground water discharge in the Sangre de Cristo Mountains watershed, and as runoff from snowmelt and direct storm precipitation. Quaternary alluvium along the modern stream channel forms a narrow strip of saturated gravel that is probably less than about 20 feet thick in most areas. The alluvium probably has a similar permeability as the underlying Quaternary alluvial fan sediments. Beginning near the mountain front, acequia systems divert water for agriculture along both sides of the stream. As the diverted water passes along ditches, and is applied to fields, a portion infiltrates into the ground. This artificial recharge plays a significant role in sustaining the shallow alluvial aquifers, as indicated by ground water mounds and perched ground water beneath the three major acequias and ditches in the study area.

As noted by Spiegel and Couse (1969), the Rio Hondo is part of a stream-connected aquifer system and shallow wells in the upper Arroyo Hondo valley are hydraulically connected to the Rio Hondo. The ground water study by Rawling (2005) indicates that, from the mountain front near El Salto to the Gates of Valdez, the Rio Hondo is a gaining stream. At the Gates of Valdez, the limited water level data suggest that the stream is approximately neutral. Downstream from the Gates of Valdez, the stream-aquifer connection is strongly influenced by the complex geology of the Cerro Negro volcano and overlying basin-fill sediments. Where the stream channel incises into recent and Quaternary alluvial sediments, both the nearby water levels and local geology suggest the stream loses water to the adjacent shallow alluvial aquifer. Where the stream channel crosses massive, low permeability, Cerro Negro dacite flows, there is no geologic or hydrologic evidence of connection with the shallow alluvial aquifer and these reaches are designated "no flow" on Figure 14. At the western edge of the Arroyo Hondo agricultural valley, where the Rio Hondo has incised along the contact between Cerro Negro dacite and the Quaternary-Tertiary Blueberry Hill deposit, water levels suggest that the Rio Hondo briefly gains water from the shallow alluvial aquifer. But farther downstream where the channel cuts into Servilleta Formation basalt, regional leakage and dropping water levels in the shallow alluvial aquifer create a disconnect between stream and aquifer, leaving the Rio Hondo elevated above the regional ground water surface (Fig. 13b, cross section G–G').

Because of interconnections between the Rio Hondo, the Rio Grande and shallow and deep aquifers, depletions of ground water from these aquifers have the very real potential of contributing to surface water depletions in a matter of decades or less. Similarly, reductions in irrigation would have negative effects on ground water levels in the shallow alluvial aquifer.

V. SUMMARY AND CONCLUSIONS

The Arroyo Hondo ground water study reveals a complex, three-dimensional ground water system with multiple hydrostratigraphic units and aquifers. Distribution of the geologic and hydrostratigraphic units is presented through geologic maps (Figs. 6 and 7) and seven detailed cross sections (Figs. 13a & 13b) that depict the subsurface distribution of geologic and hydrostratigraphic units, well data, surface water features, water levels, faults, and zones of fracturing and sediment layers in volcanic rocks. Cross sections are constructed both parallel and perpendicular to regional ground water flow. These cross sections illustrate the subsurface distribution, location and extent of aquifers in the context of the geologic framework, the Rio Grande and the Rio Hondo, local acequias and other surface water features. The following summarizes the most salient conclusions of this study regarding regional hydrogeology and geologic controls on ground water flow.

1) Ground water exists primarily within the Quaternary-Tertiary alluvial fan sediments known as the Blueberry Hill deposit, the Servilleta Formation basalts and interbedded sediments, the lower Santa Fe Group alluvial deposits (Chamita Formation), and locally within the Cerro Negro dacite. These hydrogeologic units are grouped into three separate aquifers on the basis of their hydrologic characteristics and distribution.
2) A shallow alluvial aquifer in the Quaternary-Tertiary Blueberry Hill alluvial fan deposit is limited to an area south of the Rio Hondo and east of the Airport fault. This aquifer is semi-perched on the Cerro Negro dacite, a massive, crystalline volcanic unit with relatively low regional permeability, and is recharged primarily through local irrigation return flow.
3) A shallow perched aquifer exists in the Quaternary-Tertiary alluvial fan deposit north of the Rio Hondo on the southwest flank of Cerro Negro. Perched ground water accumulates on the Cerro Negro dacite, recharges from Acequia de Atalaya, and discharges from the Medina spring, and possibly the lower Rio Hondo springs.
4) The Cerro Negro dacite contains localized, productive aquifers in fractured and rubble zones but generally behaves as a perching unit for shallow alluvial and perched aquifers. Where wells encounter water in the dacite, yields can be as high as 50 gpm, with an average of 25 gpm. Static water levels are highly variable, regionally inconsistent, and significantly lower than those measured in overlying perched or shallow alluvial aquifers. It is likely that fractured aquifers in the Cerro Negro dacite are highly compartmentalized, and have only limited or partial interconnection with adjacent aquifers.
5) The Servilleta Formation, named the deep volcanic-alluvial aquifer in this study, contains productive zones in thin basalts and sediments west of the Airport fault. A uniform hydraulic gradient between the Airport fault and the Rio Grande suggests that ground water moves easily between and through the interlayered basalts and sediments. This potentiometric surface grades westward to the elevation of cool springs that emerge in the Rio Grande gorge. Tritium content and CFC (chlorofluorocarbon) recharge ages suggest a ground water residence time of 36 to 53 years. Due

to limited data and variable, regionally inconsistent water levels in deep wells east of the Airport fault, it is uncertain whether this deep aquifer system underlies the entire study area or if it includes the Cerro Negro dacite.

6) A transition zone between shallow and deep aquifers occurs at the Airport fault, which defines the western extent of the Cerro Negro dacite and the shallow alluvial aquifer. A vertical head differential of more than 300 feet defines a regional, vertically downward hydraulic gradient that implies downward leakage from shallow to deep aquifers. The Airport fault forms a high-permeability zone with a strong, local downward gradient, where shallow water levels east of the fault rapidly merge with those in deep volcanic-alluvial wells to the west. Relatively young recharge ages in springs discharging in the Rio Grande gorge from the deep volcanic-alluvial aquifer suggest that shallow alluvial ground water merging with the deep aquifer at the Airport fault transition zone comprises a significant portion of the ground water discharging at the springs.
7) The Rio Hondo is part of a stream-connected aquifer system with gaining, neutral and losing reaches controlled by the permeability of underlying geologic units contacting the stream channel. Shallow wells in alluvium of the upper Arroyo Hondo valley are hydraulically connected to the Rio Hondo. The alluvial deposits along the Rio Hondo were probably above the water table under natural conditions, but now have locally perched or semi-perched zones of saturation due to the development of irrigation. In the Rio Hondo drainage, accretion of ground water from surface water and irrigation recharge is a critical factor controlling the extent of the shallow alluvial aquifer.

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APPENDICES

APPENDIX A–NMOSE Well Records (electronic version only)
Table A1. Data Compiled for Water Wells

Table A1. Data Compiled for Water Wells and NMOSE Well Records

Well name	OSE record	UTM N (NAD83)	UTM E (NAD83)	Elevation from DEM	Depth of well (ft bls)	Drill record depth to water (ft bls)	Elevation recorded water level	Date drilled	Measured depth to water (ft bls)	WL Elevation	Date water level meas.	Recorded minus measured DTW (ft)	Depth to top screen	Depth to bottom screen	Depth to top screen 2	Depth to bottom screen 2	Elevation top of screen	Elevation bottom of screen	Driller	Comments	Water Bearing Formation +	Aquifer	Depth to top of first Tv	Depth to base of last Tv	Elevation of top of first Tv	Elevation of base of last Tv	Water bearing intervals	Aquifer description	Estimated yield (gpm)
DM-52 *	**RG-18489**	4042483	442383	7224	405	345	6879	1972	none				365	405			6859	6819	Dyer		QTbh/Tg	SAA					320-405	clay gravel	
AH-10 *	**RG-23113**	4044235	439943	6962	165	dry		1973	none				none	none					Siefkes	Dry hole.			37	165					0
DM-53	**RG-29338**	4042577	442145	7208	400	340	6868	1977	**323.9**	**6884**	3/13/06	16	382	398			6826	6810	Steinbaugh		QTbh	SAA					340-390	sand gravel, sand clay	>15
AH-11 *	**RG-29822**	4044735	440051	7024	510	440	6584	1989	none				460	510			6564	6514	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	230	510			460-510	fractured dacite	20
AH-27 *	**RG-35430**	4044807	442255	7375	1030	860	6515	1981	none				726	745			6649	6630	Red Top	Td/Tc contact at 975 ft	Td	DVAA	19	975	7356	6400	870-880 900-920	dacite	1, 9
HM-23 *	**RG-36627**	4042065	437525	6890	440	380	6510	1981	none				420	440			6470	6450	Cook	Screened in 5 ft basalt, 10 ft gravel; water bearing in gravel	Tb3, Tg	DVAA	220	425	6670	6465	400-425 425-435	basalt, gravel	20
AH-05	**RG-37138**	4043832	438542	6857	500	460	6397	1998	**317**	**6540**	3/13/06	143	450	500			6407	6357	McCann	Hole 'breathes' air moves in/out; driller reports drilling through "nothing for ~15 feet". Water bearing in shallow QTg and black sand in dacite	QTg, Td, Tds	DVAA	80	500	6777	6357	60-80, 450-460	coarse gravel, black sand	1, 20
AH-25 *	**RG-39895**	4044510	442299	7323	800	655	6668	1983	none				740	800			6583	6523	Cook	In Cerro Negro dacite.	Tdf	DVAA	0	800	7323	6523	760-800	fractured dacite	20
EMBL	**RG-41003**	4041798	439374	6998	242	160	6838	1984	**156.32**	**6842**	3/13/06	4	170	242			6828	6756	Fennell		QTbh	SAA					160-240	clay sand gravel	15
AH-21	**RG-41635**	4043382	442136	6975	180	125	6850	1984	**125**	**6850**	1/21/06	0	120	180			6855	6795	McCann		QTbh	SAA					125-160	sand gravel, clay sand	20
HM-24	**RG-42980**	4042022	437881	6916	440	360	6556	1985	**365.33**	**6551**	4/21/06	-5	380	420			6536	6496	Fennell		Tg	DVAA	160	240	6756	6676	360-440	sand gravel	20
ORT2	**RG-45201**	4043666	439950	6795	280	100	6695	1986	**206.58**	**6588**	4/6/06	-107	120	150	240	280	6675	6645	McCann	Well share; water bearing from black sand in dacite	Tds	DVAA	150	280	6645	6515	240-260	black sand in dacite	50
HM-18 *	**RG-46180**	4039535	441221	7169	805	690	6479	1997	none				none	none					Fennell	Redrill (record and log incomplete); water bearing in fractured 'basalt', possibly dacite	Td (Tb?)	DVAA		805		6364	760-805	fractured dacite or basalt	25
AH-04	**RG-47406**	4044181	438807	6919	103	45	6874	1987	**39**	**6880**	2/10/06	6	60	100			6859	6819	Fennell	Water bearing in shallow alluvium adjacent to acequia	QTg	Perched					45-100	gravel, clay gravel	5, 8
HM-17 *	**RG-47948**	4041355	439894	7080	300	240	6840	1987	none				270	300			6810	6780	Fennell		QTbh	SAA					240-300	sand gravel	20
DM-104	**RG-49139**	444931	4E+06	7159	65	26	7133	1988	**28.96**	**7130**	5/10/05	-3	43	59			7116	7100	Red Top										
HM-36 *	**RG-49827**	4042514	438169	6936	482	420	6516	1988	none				420	480			6516	6456	McCann	No Tb4 in lithologic log; water bearing in sand above Tb3 or Td	Tg	DVAA	430	482	6506	6454	425-430	coarse sand	25
DM-36	**RG-50207**	4043078	445630	7480	260	130	7350	1989	none		4/6/06		200	260			7280	7220	Fennell	Water bearing from fractured 'basalt' interpreted as dacite	Tdf	DVAA	130	260	7350	7220	180-260	fract'd dacite	20
HM-14 *	**RG-51064**	4041788	438371	6946	505	380	6566	1989	none				470	500			6476	6446	Fennell	Water bearing from fractured 'basalt'	Tdf	DVAA	160	505	6786	6441	460-500	fractured dacite	25
AH-40 *	**RG-51358**	4042075	441977	7205	405	350	6855	1989	none				350	400			6855	6805	McCann		QTbh	SAA					350-405	coarse sand, gravel sand	20-50
AH-03	**RG-51361**	4044061	438881	6903	410	290	6613	1999	**327**	**6576**	2/10/06	-37	360	440			6543	6463	Fennell	Data copied from OSE record by TSWCD (2002); screened and water bearing in fract'd 'basalt' interpreted as dacite.	Tdf	DVAA	55	410	6848	6493	327-400	fractured dacite	25
AH-35	**RG-52714**	4042932	441849	7011	115	70	6941	1990	**82**	**6929**	3/17/06	-12	75	115			6936	6896	McCann		QTbh	SAA					80-115	sand, clay gravel	25

Well name	OSE record	UTM N (NAD83)	UTM E (NAD83)	Eleva-tion from DEM	Depth of well (ft bls)	Drill record depth to water (ft bls)	Eleva-tion re-corded water level	Date drilled	Measured depth to water (ft bls)	WL Eleva-tion	Date water level meas.	Recorded minus measured DTW (ft)	Depth to top screen	Depth to bottom screen	Depth to top screen 2	Depth to bottom screen 2	Eleva-tion top of screen	Eleva-tion bottom of screen	Driller	Comments	Water Bearing Formation +	Aquifer	Depth to top of first Tv	Depth to base of last Tv	Eleva-tion of top of first Tv	Eleva-tion of base of last Tv	Water bearing intervals	Aquifer descrip-tion	Estima-ted yield (gpm)
HM-22	**RG-52779**	4041736	438151	6949	460	318	6631	1990	**382.62**	**6566**	5/5/06	-65	440	460			6509	6489	Cook	Water bearing in sand gravel below Tb4	Tg	DVAA	220	380	6729	6569	(320) 445-450	(basalt) sand gravel	15
AH-26 *	**RG-52888**	4044243	442499	7280	900	782	6498	1991	none				800	900			6480	6380	Cook	In Cerro Negro dacite; driller lost circulation and noted cavities.	Tdf	DVAA	16	900	7264	6380	800-900	fractured dacite	20
AH-39	**RG-53158**	4041861	441648	7068	270	210	6858	1991	**210**	**6858**	4/14/06	-0	210	270			6858	6798	McCann		QTbh	SAA					210-220 240-245	coarse sand	20, 20
HM-12 *	**RG-53410**	4040017	440671	7133	815	550	6583	1991	none				755	815			6378	6318	Thompson	Water bearing from volcanics and underlying gravel sand; WL rises into overlying Td or Tb	Tv, Tc	DVAA					760-820	volcanics, sand	10
HM-38 *	**RG-55476**	4042131	438489	6923	450			1994	none				200	250			6723	6673	Joe's	No recorded WL; well at Airport fault with water noted on top of Tb4 (cascading water?)	Tg	DVAA	250	300			250-251 300-310	gravel sand	<5
AH-23 *	**RG-55682**	4043371	442055	6969	180	92	6877	1992	none				160	180			6809	6789	Cook		QTbh	SAA					105-175	gravel, clay gravel	20
AH-22 *	**RG-55788**	4043619	442168	6952	80	25	6927	1993	none				40	80			6912	6872	Rodney's		QTbh	SAA	79	80	6873	6872	25-60	clay sand gravel	10
HM-13 *	**RG-56085**	4041882	436879	6857	410	337	6520	1992	none				380	410			6477	6447	Cook	Screened in 10ft basalt and 20ft gravel; water bearing from gravel in Tg.	Tb3, Tg	DVAA	160	390	6697	6467	380-410	basalt, gravel	20
HM-26 *	**RG-56267**	4041564	437891	6942	510	375	6567	1993	none				400	440	470	500	6542	6502	Fennell		Tg, Tb3f	DVAA	150	510	6792	6432	380-440, 470-500	sand gravel clay, fractured basalt	10, 10
HM-11 *	**RG-57212**	4041445	437195	6916	540	480	6436	1994	none				500	540			6416	6376	Fennell		Tg below Tb3	DVAA	360	480	6556	6436	480-540	sand gravel	25
HM-29	**RG-57234**	4041455	438261	6978	550	440	6538	1993	**425.65**	**6552**	5/5/06	14	510	550			6468	6428	Fennell		Tg	DVAA	100	400	6878	6578	500-550	sand gravel w/ clay	20
AH-20	**RG-57410**	4042874	440115	6841	107	30	6811	1993	**24**	**6817**	3/17/06	6	80	107			6761	6734	Fennell		QTbh	SAA					30-107	sand gravel clay	30
DM-20 *	**RG-57432**	4042717	442916	7257	760	680	6577	1994	none				680	760					Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	400	760			680-720	fractured dacite	25
BURL	**RG-57765**	4043794	439682	6795	288	190	6605	1993	**214**	**6581**	3/10/06	-24	258	288			6537	6507	Fennell	Water bearing from fractured 'basalt' interpreted as dacite	Tdf	DVAA	60	288	6735	6507	250-288	fractured dacite	25
HM-10	**RG-59412**	4041635	438973	6982	295	225	6757	1994	**224.11**	**6758**	5/5/06	1	250	290			6732	6692	Fennell		QTbh	SAA	295	300	6687	6682	225-290	sand gravel	20
HM-15 *	**RG-59479**	4041724	438881	6969	270	210	6759	1994	none				230	270			6739	6699	Fennell	Water bearing from shallow alluvium (240-270) east of Airport fault	QTbh	SAA					210-270	sand gravel clay	20
AH-08 *	**RG-59668**	4043872	439332	6864	340	270	6594	1995	none				300	340			6564	6524	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	30	340	6834	6524	300-340	fractured dacite	25
AH-41 *	**RG-60226**	4042116	441537	7182	425	295	6887	1994	none				380	420			6802	6762	Fennell		QTbh/Tg	SAA					290-400	sand gravel, sand clay gravel	25
AH-43 *	**RG-60226 X**	4042111	441425	7178	400	290	6888	1996	none				360	400			6818	6778	Fennell		QTbh/Tg	SAA					360-400	sand gravel	25
HM-35 *	**RG-60306**	4042050	437247	6883	490	350	6533	1994	none				450	490			6433	6393	Fennell	Basalt fractured from 440-490 ft	Tb3, Tb3f	DVAA	200	490	6683	6393	350-490	basalt, fractured basalt	25

Well name	OSE record	UTM N (NAD83)	UTM E (NAD83)	Eleva-tion from DEM	Depth of well (ft bls)	Drill record depth to water (ft bls)	Eleva-tion re-corded water level	Date drilled	Measured depth to water (ft bls)	WL Eleva-tion	Date water level meas.	Recorded minus measured DTW (ft)	Depth to top screen	Depth to bottom screen	Depth to top screen 2	Depth to bottom screen 2	Eleva-tion top of screen	Eleva-tion bottom of screen	Driller	Comments	Water Bearing Formation +	Aquifer	Depth to top of first Tv	Depth to base of last Tv	Eleva-tion of top of first Tv	Eleva-tion of base of last Tv	Water bearing intervals	Aquifer descrip-tion	Estima-ted yield (gpm)
HM-20 *	**RG-61136**	4041765	439231	6995	302	230	6765	1999	none				262	302			6733	6693	Fennell		QTbh	SAA					230-300	sand gravel	25
LAIN	**RG-61183**	4041932	438392	6936	490	339	6597	1995	**329.44**	**6607**	4/26/06	10	450	490			6486	6446	Fennell	Water bearing from Tg sediments below Tb4	Tg	DVAA	269	450	6667	6486	450-490	sand gravel	18
DM-40 *	**RG-61498**	4042351	441681	7169	480	300	6869	1995	none				410	450					Fennell		QTbh/Tg	SAA					300-450	sand gravel, sand clay gravel	18
HM-09	**RG-61751**	4040728	438599	7031	320	260	6771	1995	**272.99**	**6758**	4/6/06	-13	270	310			6761	6721	Thomas	30-ft of saturation in fan gravels on top of Tb4	QTbh	SAA	310	320	6721	6711	270-310	sand gravel	10
AH-42 *	**RG-62024**	4042207	441408	7142	420	288	6854	1995	none				340	360	380	420	6802	6722	Fennell		QTbh/Tg	SAA					340-360 380-420	sand gravel	20
AH-13 *	**RG-62042**	4045365	439906	6985	620	490	6495	1995	none				560	620			6425	6365	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	100	610	6885	6375	560-610	fractured dacite	30
HM-02	**RG-62488**	4041750	436468	6847	410	315	6532	1996	none		4/14/06		370	410			6477	6437	Fennell	WL not measured due to obstruction; drillers Depth-To-Water (6532ft) in Tb3.	Tg below Tb3	DVAA	100	360	6747	6487	360-410	sand gravel	30
DM-30	**RG-62489**	4042415	444341	7366	570	290	7090	1995	**385**	**6981**	4/13/05	-95	520	560			6846	6806	Fennell	Measured in 2005 by G. Rawling.	Tg	DVAA					385-560	sand gravel	18
AH-30 *	**RG-62883**	4042705	438287	6814	460	275	6539	1996	none				360	380	400	460	6454	6434	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	48	460	6766	6354	360-380 400-440	fractured dacite	7-10, 25
SANC	**RG-63022**	4042223	439384	6877	220	100	6777	1995	**115.70**	**6761**	4/14/06	-16	180	220			6697	6657	Fennell	Low WL in April; hi WL in Sept. Seasonal fluctuations with Llano Ditch?	QTbh	SAA					120-220	sand gravel sandy clay	15
DM-14 *	**RG-64562**	4042232	443409	7297	480	390	6907	1997	none				380	420	440	480	6917	6817	Fennell		QTbh/Tg	SAA					390-420 450-480	sand gravel	7, 8
SIER	**RG-64935**	4043487	440065	6788	300	210	6578	1997	**190.22**	**6598**	3/17/06	20	260	300			6528	6488	Fennell	Water bearing from fractured 'basalt' interpreted as dacite	Tdf	DVAA	60	300	6728	6488	240-300	fractured dacite	50
HM-06 *	**RG-65112**	4039197	441484	7182	720	640	6542	1997	none				640	720			6542	6462	Mahoney	Screened in 34' basalt (interpreted as possibly part dacite) and 46' gravel.	Tb4/Td, Tg	DVAA	247	674	6935	6508	640-720	basalt/ dacite sand gravel clay	12
AH-14 *	**RG-65140**	4044766	439119	7034	580	490	6544	1997	none				540	580			6494	6454	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	120	580	6914	6454	530-580	fractured dacite	30
DM-09 *	**RG-65178**	4042801	443831	7329	500	268	7061	1996	none				360	380	440	480	6969	6849	Fennell		QTbh/Tg	SAA	490	500			260-275 360-380 440-480	sand gravel	5, 10, 15
HAYE	**RG-65598**	4044007	439515	6929	450	350	6579	1998	**350.49**	**6579**	3/13/06	-0	410	450			6519	6479	Rodney's	Water bearing from alluvium beneath or interlayered with dacite	Tg	DVAA	85	385	6844	6544	385-450	clay sand gravel	15
DM-103	**RG-66358**	444346	4E+06	7343	280	200	7143	1997	**240.82**	**7102**	5/10/05	-41	220	280			7123	7063	Cisneros		QTbh	SAA							
AH-16 *	**RG-67043**	4044720	438927	7041	520	420	6621	1997	none				480	520			6561	6521	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	130	520	6911	6521	470-520	fractured dacite	30
AH-17 *	**RG-67069**	4043906	439666	6873	374	290	6583	1997	none				334	374			6539	6499	McCann	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	30	374	6843	6499	330-350 360-374	fractured dacite	30
MLC-40 *	**RG-67273**	4039546	437231	6993	560	440	6553	1997	none				500	560			6493	6433	Fennell	Water bearing in fractured 'basalt" or toe of dacite flow.	Tb3f?, Tdf?	DVAA	220	560	6773	6433	500-560	fractured dacite or basalt	30

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AH-38 *	**RG-67987**	4041864	440745	6985	237	160	6825	1997	none				197	237			6788	6748	Fennell		QTbh/Tg	SAA					160-240	sand gravel clay	30
HM-04 *	**RG-68300**	4040606	440212	7073	260	202	6871	1997	none				180	260			6893	6813	Vigil		QTbh	SAA					202-260	gravel sand	15-20
HM-05	**RG-68808**	4042267	437007	6850	455	350	6500	1998	none		5/8/06		405	455			6445	6395	Fennell	Water level unstable, UTM; water bearing from fractured basalt	Tb3f	DVAA	65	455	6785	6395	400-450	fractured basalt	25
HM-07 *	**RG-68970**	4042058	438112	6923	470	380	6543	1998	none				430	470			6493	6453	Fennell	Water bearing in fractured 'basalt' or westernmost dacite; water table in overlying Tg	Tg, Tb3/Td	DVAA	120	470	6803	6453	380-470	sand clay gravel, fractured volc	20
DM-17 *	**RG-69936**	4041751	443986	7346	640	320	7026	1998	none				400	460	560	600			Fennell	QTbh interpreted to approx 460 ft; Tg 460-610	QTbh, Tg	SAA	610	640			320-460 500-520 560-600	sand gravel clay, sand gravel	15, 30
AH-01	**RG-70551**	4043746	438079	6841	420	250	6591	1999	**257**	**6584**	4/14/06	-7	250	290	360	400	6591	6551	McCann	Perched water in 5-ft Tg sand; screened in lower Tg, Tbsa and Td/Tds; water bearing from black sand in dacite	Tg, Tbsa, Tds	DVAA	38	420	6803	6421	380-390	Tg sand, black sand in 'basalt'	5, 20
HM-25 *	**RG-71274**	4041903	437681	6903	475	370	6533	1999	none				435	475			6468	6428	Fennell	Water bearing in fractured basalt (Tb3), or toe of dacite flow	Tb3f (Tdf?)	DVAA	110	475	6793	6428	410-475	fractured basalt (dacite)	20
AH-19a	**RG-73045**	4042843	438276	6778	180	100	6678	1999	none				120	180			6658	6598	Fennell	A replacement well (RG-73045-S) was drilled nearby in 2003.	Tg, Tdf	DVAA	40	200	6738	6578	115-175 175-200	sand gravel fract'd dacite	15, 10
AH-19	**RG-73045 S**	4042843	438276	6778	315	230	6548	2003	**229**	**6549**	3/3/06	1	280	315			6498	6463	McCann	Replaced nearby 1999 well (RG-73045). Water bearing from black gravel in dacite (270-290 ft)	Tds	DVAA	60	315	6718	6463	230-290	rubble zone in dacite	20
AH-32 *	**RG-73118**	4042956	438536	6732	175	92	6640	2000	none				115	175			6617	6557	Vigil	Screened in 45ft gravel and 15ft basalt.	Tg, Tb4	DVAA	60	175	6672	6557	92-175	gravel, basalt	15-20
AH-37 *	**RG-73173**	4041841	440816	7005	218	150	6855	2001	none				150	218			6855	6787	Mahoney		QTbh	SAA					150-215	clay sand gravel	25
AH-18 *	**RG-73692**	4044844	439376	7008	525	460	6548	2000	none				480	520			6528	6488	Fennell	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	20	525	6988	6483	460-520	fractured dacite	25+
HM-28 *	**RG-73874**	4042014	439133	6969	290	200	6769	2000	none				250	290			6719	6679	Fennell		QTbh	SAA					240-290	sand gravel	20+
AH-34 *	**RG-74179**	4045524	438751	7080	695	430	6650	2000	none				630	690			6450	6390	McCann	Screened in 50ft 'basalt' and 10ft gravel; water bearing in fract'd basalt/dacite (20) and sand-gravel (100)	Td, Tdf, Tc	DVAA	220	680	6860	6400	430-695	dacite, fractured dacite, gravel	20, 100
HM-21 *	**RG-74369**	4041601	438618	6965	252	190	6775	2002	none				220	250			6745	6715	Fennell		QTbh	SAA	250	252	6715	6713	190-250	sand gravel	18
HM-03	**RG-74959**	4040611	438477	7005	480	370	6635	2001	**181.67**	**6823**	4/21/06	188	440	480			6565	6525	Fennell	Located on west side of Airport fault; WL doesn't reflect regional head	Tg below Tb3 or Td	DVAA	260	430	6745	6575	430-480	gravel clay	8
HM-27	**RG-75199**	4041466	440734	7119	343	245	6874	2001	**267.55**	**6851**	2/8/06	-23	303	343			6816	6776	Fennell	Well share.	QTbh	SAA					270-340	sand gravel	15
AH-36 *	**RG-75452**	4041594	441285	7136	403	247	6889	2001	none				343	363	383	403	6793	6773	Rodney's	Water bearing in sediments projected as Tg	Tg	DVAA					270-400	clay sand gravel	15

Well name	OSE record	UTM N (NAD83)	UTM E (NAD83)	Elevation from DEM	Depth of well (ft bls)	Drill record depth to water (ft bls)	Elevation recorded water level	Date drilled	Measured depth to water (ft bls)	WL Elevation	Date water level meas.	Recorded minus measured DTW (ft)	Depth to top screen	Depth to bottom screen	Depth to top screen 2	Depth to bottom screen 2	Elevation top of screen	Elevation bottom of screen	Driller	Comments	Water Bearing Formation +	Aquifer	Depth to top of first Tv	Depth to base of last Tv	Elevation of top of first Tv	Elevation of base of last Tv	Water bearing intervals	Aquifer description	Estimated yield (gpm)
AH-09	**RG-75485**	4044326	439905	6978	612	510	6468	2001	**390**	**6588**	3/17/06	120	512	612			6466	6366	Vigil	Screen in 60ft 'basalt' interpreted as dacite and 40ft gravel.	Td, Tdf, Tds	DVAA	80	612	6898	6366	510-612	fractured dacite, dacite, sand gravel	20-25
PRIN	**RG-75804**	4042660	437491	6900	520	420	6480	2001	none		4/14/06		440	520			6460	6380	Vigil	Water level rising (UTM); water bearing from fractured basalt.	Tb3f	DVAA	100	520	6800	6380	420-520	fractured basalt	15-20
AH-15 *	**RG-76944**	4044807	439161	7047	620	460	6587	2001	none				560	620			6487	6427	Joe's	Water bearing in fractured 'basalt', interpreted as dacite	Tdf	DVAA	210	620	6837	6427	530-620	fractured dacite	18
HM-30 *	**RG-77011**	4041348	437621	6962	555	450	6512	2002	none				500	555			6462	6407	Fennell	Deepened existing well from 460ft to 555ft; water bearing in sand gravel below Tb3.	Tg	DVAA	<460	500	<6502	6462	500-546	sand gravel	18+
HM-37 *	**RG-78185**	4042693	437712	6893	520	430	6463	2002	none				460	500			6433	6393	Joe's	Water bearing from gravels interlayered within undivided Tv (Tb or Td)	Tg	DVAA	200	520	6693	6373	450-500	gravel	18
HUNT	**RG-79198**	4043197	445648	7490	437	249	7241	2002	none		4/27		297	347			7193	7143	Rodney's	WL erratic, UTM; screen in gravel and basalt; water bearing from decomposed 'basalt' interpreted as dacite.	Tds	DVAA	65	347	7425	7143	249-340	volc gravel in dacite	12
AH-29	**RG-79230**	4042633	438414	6824	300	265	6559	2002	**260**	**6564**	3/17/06	5	280	300			6544	6524	McCann	Driller WL uncertain; water bearing from fractured 'basalt' interpreted as dacite	Tdf	DVAA	80	300	6744	6524	275-300	fractured dacite	50
HM-41	**RG-79334**	4041827	437893	6923	520	378	6545	2003	**303.20**	**6620**	3/3/06		420	440	480	520	6503	6483	Fennell	Screen in 20ft gravel and 40ft fractured 'basalt' or toe of dacite flow.	Tg, Tb3f?, Tdf?	DVAA	157	520	6766	6403	382-440 480-520	sand gravel, fractured basalt	8, 10
MICE	**RG-80793**	4041565	437452	6926	510	396	6530	2003	none		5/5/06		430	510			6496	6416	Vigil	Water level erratic (UTM)	Tb3, Tb3f	DVAA	180	510	6746	6416	396-510	basalt, fractured basalt	25-30
HM-44 *	**RG-80939**	4041648	437631	6926	530	393	6533	2004	none				420	460	510	530	6506	6466	Fennell	Screened in 16ft gravel and 44ft fractured basalt or toe of dacite flow.	Tg, Tdf?, Tb3f?	DVAA	152	530	6774	6396	393-436, 436-530	sand gravel, fractured basalt or dacite	10, 10
HM-43 *	**RG-82409**	4041672	438401	6959	510	392	6567	2004	none				410	510			6549	6449	Vigil	Screened in 80ft 'basalt' (40 ft fractured, possibly toe of dacite flow) and 20ft gravel.	Tdf, Tb3?, Tg	DVAA	200	510	6759	6449	392-510	basalt, fractured dacite, gravel	10-12
LC-01	**RG-83423**	4042786	445547	7474	380	276	7198	2006	**284.72**	**7189**	4/7/06	-9	270	330	350	380	7204	7144	Fennell		QTbh	SAA					285-380	sand clay gravel	5
PALI	**RG-83470**	4041517	437971	6959	506	387	6572	2004	**405.60**	**6553**	5/5/06	-19	426	446	466	506	6533	6513	Rodney's	Screened in 54 ft of Tg and 6 ft of Tb3	Tg	DVAA	195	506	6764	6453	387-500	clay sand gravel	12
ORT	**RG-83538**	4043230	439592	6749	150	20	6729	2004	**20.50**	**6729**	3/10/06	-1	110	150			6639	6599	McCann	Water bearing from gravel zones in alluvium	QTbh	SAA					21-145	sand gravel clay	20
VALUS	**RG-84089**	4040875	436101	6847	456	370	6477	2005	**368.62**	**6478**	4/14/06	1	386	456			6461	6391	Fennell	Screen in 24ft gravel and 46ft basalt.	Tg, Tb2	DVAA	90	456	6757	6391	375-410, 410-456	sand gravel, basalt	15+
LEIN	**RG-84886**	4040041	436585	6969	546	470	6499	2006	**470.51**	**6498**	2/20/06	-1	506	546			6463	6423	Fennell	Screened in 25ft basalt, fractured basalt, and 15ft interlayered gravel.	Tb3, Tb3f, Tg	DVAA	193	546	6776	6423	510-527 527-542	fractured basalt sand gravel	10, 10

Table A1. Data Compiled for Water Wells and NMOSE Well Records

Well name	OSE record	UTM N (NAD83)	UTM E (NAD83)	Elevation from DEM	Depth of well (ft bls)	Drill record depth to water (ft bls)	Elevation recorded water level	Date drilled	Measured depth to water (ft bls)	WL Elevation	Date water level meas.	Recorded minus measured DTW (ft)	Depth to top screen	Depth to bottom screen	Depth to top screen 2	Depth to bottom screen 2	Elevation top of screen	Elevation bottom of screen	Driller	Comments	Water Bearing Formation +	Aquifer	Depth to top of first Tv	Depth to base of last Tv	Elevation of top of first Tv	Elevation of base of last Tv	Water bearing intervals	Aquifer description	Estimated yield (gpm)
KOND	**RG-85582**	4040584	440221	7077	300	230	6847	2006	**191.81**	**6885**	5/4/06	38	260	300			6817	6777	Thomas		QTbh	SAA					240-300	gravel sand	15
E001	**RG-85614**	4037759	437814	7005	568	472	6533	2005	**470.31**	**6535**	12/20/05	2	528	568			6477	6437	Fennell	Screen in 10ft basalt and 30ft gravel; water bearing from fract'd Tb3 and Tg	Tb3f, Tg	DVAA	210	538	6795	6467	470-500 545-568	fractured basalt, sand gravel	10, 10
TL-01	**RG-86063**	4044808	439620	7037	660	490	6547	2006	**455.40**	**6582**	3/17/06	35	620	660			6417	6377	Sperry	Water bearing from gravels below Td; WL in Td	Tc	DVAA	120	600	6917	6437	600-660	sand gravel	10
LR-01	**RG-86530**	4042420	438487	6936	496	361	6575	2006	**385.23**	**6551**	3/23/06	-24	456	496			6480	6440	Fennell	Water bearing in f ractured 'basalt' interpreted as dacite	Tdf	DVAA	226	496	6710	6440	450-496	fractured dacite	20
TL-02	**RG-86733**	4044742	439722	7014	640	520	6494	2006	**450.69**	**6563**	3/17/06	69	600	640			6414	6374	Sperry	Water bearing from gravels below Td; WL in Td	Tc	DVAA	110	410	6904	6604	580-640	gravel sand	10
CL-01	**RG-86772**	4041806	438518	6946	237	191	6755	2006	**193**	**6753**	3/8/06	-2	197	237			6749	6709	Fennell		QTbh	SAA	236	237	6710	6709	193-236	sand gravel	3.5
TOLB	**RG-87266**	4041993	438100	6929	509	379	6550	2006	**377.14**	**6552**	5/19/06	2	429	449	469	500	6500	6480	Fennell	Water bearing from sand gravel and dacite or basalt	Tg over Td	DVAA	162	509	6767	6420	429-509	clay sand gravel, basalt	15+
WINT	**RG-87489**	4041845	437700	6906	500	357	6549	2006	**357.73**	**6548**	7/12/06	-1	440	500			6466	6406	Rodney's	Water bearing in Tg alluvium; screened in fractured Tb3	Tg, Tb3f	DVAA	125	500	6781	6406	357-500	clay sand gravel, frct'd basalt	15
HM-01	**RG-87960**	4041396	436665	6952	510	456	6496	1980	**460.70**	**6491**	3/24/06	-5	500	510			6452	6442		From Jenkins (1980), River View Acres test well report. Water level originally measured 6/12/80.	Tg, Tb3	DVAA	180	485	6772	6467	456-485 500-510	basalt, gravel	
AH-02	**unknown**	4043894	440039	6873					**291**	**6582**	4/21/06								McCann	No record; WL measured by NMBGMR; water bearing unit inferred from WL and regional geology	Td	DVAA							
CORR	**unknown**	4043272	440831	6854					**14**	**6840**	4/6/06									No record; WL measured by NMBGMR; water bearing formation inferred from WL and regional geology	QTbh	SAA							
DAVI	**unknown**	4041657	436686	6867					**381**	**6486**	5/5/06									No record; WL measured by NMBGMR; water bearing formation inferred from WL and regional geology.	Tb3, Tg	DVAA							
E002	**unknown**	4042559	443313	7293				2005	**306.19**	**6987**	12/20/05		320	380	420	440	6973	6913	McCann	No record; WL measured by NMBGMR; screen intervels from driller's memory; water bearing formation inferred from WL and regional geology.	QTbh/Tg	SAA							
LERO	**unknown**	4042436	442001	7198				2006	**311.40**	**6887**	2/7/06								McCann	No record; WL measured by NMBGMR; water bearing formation inferred from WL and regional geology	QTbh/Tg	SAA							
TUNE	**unknown**	4039547	436498	6900					**388.77**	**6511**	3/27/06									New well, no record; WL measured by NMBGMR; water bearing formations inferred from water level and regional geology.	Tb3, Tg	DVAA							

+ See unit descriptions for formation on Figure 13; additional designation for fractures (f), sediments in volcanics (s)

*** Location coordinates from Taos County Soil Water Conservation District well inventory (2002)**

APPENDIX B–Geologic Map Unit Descriptions

By Keith Kelson and Paul Bauer

SURFICIAL DEPOSITS

Qal **Stream channel and valley-floor alluvium, and active floodplains (Holocene)**–poorly to well-sorted, poorly sorted sand, pebbles, and boulders; clasts of granitic, metamorphic, volcanic, and sandstone rock types; clasts along Rio Hondo dominated by granitic rock types, quartzite and basalt; clasts along tributaries draining the western side of the Rio Grande are dominated by volcanic rock types.

Qfy Qty **Young alluvial fan and stream terrace deposits (latest Pleistocene to Holocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I calcium carbonate development.

Qt8 **Stream terrace deposits (Holocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I calcium carbonate development.

Qt7 **Stream terrace deposits (early to middle Holocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I calcium carbonate development.

Qt6 **Stream terrace deposits (latest Pleistocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I to II calcium carbonate development.

Qt5 **Stream terrace deposits (late Pleistocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage II to III calcium carbonate development.

Qt4 **Stream terrace deposits (middle to late Pleistocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III calcium carbonate development, argillic Bt soil horizons and 10YR to 7.5YR hues in Bt horizons.

Qt3 **Stream terrace deposits (middle to late Pleistocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III calcium carbonate development, argillic Bt soil horizons and 10YR to 7.5YR hues in Bt horizons.

Qfu **Undifferentiated alluvial fan deposits (middle to late Pleistocene)**–probably correlative with stream units Qt2 through Qt6; poorly sorted silt, sand, pebbles, and cobbles; not correlated to other fan units because of lack of well-defined age control, clear stratigraphic position, and distinct lithologic characteristics.

Qt2 **Stream terrace deposits (middle Pleistocene)**–poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III to IV calcium carbonate development; thick argillic Bt soil horizons, and 7.5YR to 10YR hues in soil Bt horizons; upper soil horizons locally affected by surface erosion.

Qt2rg **Stream terrace deposits flanking Rio Grande (middle Pleistocene)**–poorly sorted silt, sand, pebbles, and boulders; clasts primarily of granitic, metamorphic, intermediate volcanic, basalt, and sedimentary rocks; locally may contain clasts of Tertiary Amalia Tuff; associated soils have stage III to IV calcium carbonate development, thick argillic Bt soil horizons, and 7.5YR to 10YR hues in soil Bt horizons; upper soil horizons locally affected by surface erosion; may be mantled locally by eolian sand; possibly faulted along the Dunn fault.

Qf1 **Alluvial fan deposits (middle Pleistocene)**–poorly sorted silt, sand, and rare pebbles; clasts primarily of granitic, intermediate volcanic, basalt, and metamorphic rock types; stage III and IV calcium carbonate development where preserved, although soil horizons are commonly affected by surface erosion; ash probably within Qf1 deposits at locality on Ranchos de Taos quadrangle near Stakeout Road dated at 1.27 ± 0.02 Ma ($^{40}Ar/^{39}Ar$ method, W. McIntosh, personal communication, 1996); deposit is more than 5 m thick in northeastern part of quadrangle, and is thinner from northeast to southwest; differentiated from unit QTbh by larger clast size, less oxidation, poor sorting, absence of abundant manganese oxide staining, and clasts that are less weathered.

Qt1rg **Stream terrace deposits flanking Rio Grande (middle Pleistocene)**–poorly sorted silt, sand, pebbles, and boulders; clasts of basalt, quartzite, slate, schist, other metamorphic rock types, volcanic rock types, and (rarely) sandstone and limestone; locally may contain clasts of Tertiary Amalia Tuff; where preserved, associated relict soils have stage III to IV calcium carbonate development, thick argillic Bt soil horizons, and 7.5YR hues in soil Bt horizons; upper soil horizons commonly affected by surface erosion; may be mantled locally by eolian sand.

QTrg **Stream gravel deposited by ancestral Rio Grande (late Tertiary? to middle? Pleistocene)**–poorly sorted sand, pebbles, and cobbles; clasts of basalt, quartzite, slate, schist, other metamorphic rock types, and volcanic rock types; very rare Amalia Tuff clasts; associated with broad, highest terrace west of Rio Grande; upper soil horizons commonly affected by surface erosion; locally mantled by eolian sand.

QTg **Old alluvium (late Tertiary? to middle? Pleistocene)**–poorly sorted sand, pebbles, and cobbles; clasts of basalt, quartzite, slate, schist, other metamorphic rock types, and volcanic rock types; locally high percentage of angular to subangular quartzite pebbles and cobbles; may be correlative with Blueberry Hill deposit; present along piedmont between Sangre de Cristo range front and Rio Grande gorge north of Rio Hondo; contains ash layer in roadcut near Cerro Negro (UTM 439989, 4044603).

QTbh **Blueberry Hill deposit (late Tertiary? to middle Pleistocene)**–poorly sorted silt, sand and pebbles; commonly crossbedded, and stained with black manganese oxide and yellowish-orange iron oxide coatings; oxidized; clasts are weathered or grussified; contains distinct discontinuous sandy interbeds; clasts are granitic rock types, quartzite, metamorphic rock types, and volcanic rock types; commonly crudely imbricated; imbrication suggests westerly flow direction in area north of Taos Municipal Airport; based on exposures at southwestern end of Blueberry Hill, thickness exceeds 25 m; may be considerably more; deposit may interfinger with unit QTg and QTrg.

TERTIARY ROCKS

Tb **Servilleta Formation, basalt (Pliocene)**–Dark-gray, diktytaxitic olivine tholeiite that forms thin, fluid, widespread pahoehoe basalt flows of the Taos Plateau volcanic field. These flows commonly form columnar-jointed cliffs in the Rio Grande gorge. Tabular plagioclase and sparse olivine are the only phenocrysts. Individual flows, which are up to 12 m thick, are grouped into packages of from one to ten flows (Dungan et al., 1984). These packages are separated by sedimentary intervals. Five central volcanic vents to the north are sources for the Servilleta Formation (Lipman and Mehnert, 1979). $^{40}Ar/^{39}Ar$ ages from basalts exposed in the Rio Grande gorge range in age from 4.81 ± 0.03 Ma for the lowest basalt near the Rio Grande Gorge Bridge, to 3.12 ± 0.13 Ma for the highest basalt flow at the Rio Grande Gorge Bridge.

Tg **Servilleta Formation, interbasalt gravel (Pliocene)**–Sedimentary intervals between basalt flow members, as much as 180 m thick in northern part of quadrangle, as exposed in the Rio Grande and Rio San Cristobal gorges.

Td **Cerro Negro dacite (Pliocene)**–dark-gray to black, non-vesicular, two-pyroxene dacite flows that erupted from a variety of vents on and around Cerro Negro. Dacite flows are at least partly interlayered with Servilleta Formation basalt flows.

Tsf **Santa Fe Group, undivided (Pliocene to Miocene)**–In cross sections only. Consists primarily of rift-related, clastic sedimentary deposits of the Tesuque Formation that underlie the Servilleta Formation in the map area. Mixed conglomerate, sandstone, and mudrock were derived from the Sangre de Cristo Mountains and Tusas Mountains. Lacustrine deposits may exist locally. The eolian Ojo Caliente Sandstone Member (middle to late Miocene) may exist in the subsurface. Older volcaniclastic units equivalent to the Los Pinos Formation, Chama-El Rito Member of the Tesuque Formation, and Picuris Formation may exist in the subsurface. Thickness unknown.

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