Geology and hydrogeology of the Arroyo Seco Area, Taos County, New Mexico
Final Technical Report

By

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I. INTRODUCTION AND SCOPE

This report describes the geology and hydrogeology of the southwestern Arroyo Seco quadrangle in Taos County, New Mexico. This area is approximately eight miles north of the Town of Taos and is undergoing extensive residential development. The New Mexico Office of the State Engineer (NMOSE) Hydrology Bureau has identified a need for more detailed hydrogeologic information (Peggy Johnson, NMBGMR, personal communication) to improve the NMOSE groundwater simulation model. To this end, I compiled existing geologic, hydrologic, and geophysical data, performed new geologic mapping, and measured water levels in 43 domestic wells. The synthesis of these data leads to an improved understanding of the distribution and flow patterns of groundwater in the area and the relation of groundwater to surface water, in addition to clarifying the geologic controls on the groundwater system.

The report includes a geologic map of the southwestern portion of the Arroyo Seco quadrangle, a subsurface bedrock map of the detailed study area, two geologic cross sections, two fence diagrams, and a water table elevation map. From these data and interpretations I derive a conceptual hydrogeologic model for the area and address how the groundwater system may respond to future development and/or drought.

II. GEOLOGY OF THE STUDY AREA

A. Geologic Mapping

The majority of the geologic map in this report (Map 1) is compiled from Lipman and Reed (1989) and Kelson (1986) and unpublished mapping of Proterozoic rocks by J.

Grambling. Geologic fieldwork was conducted in August 2004, and was largely reconnaissance and field checking of the two existing maps. Geologic contacts were locally refined, and additional orientation data were collected, with particular emphasis on joints in the crystalline rocks. Poor exposure precluded subdivision of the basin fill sediments east of the range front fault, but several excellent exposures were photographed and classified in terms of sedimentary facies Stereo pairs of aerial photographs were examined for delineation of surficial deposits south of the Rio Hondo valley and north of Gallina Creek to the northern edge of the quadrangle.

B. Regional Features

The dominant geologic features of the study area are the Sangre de Cristo Mountain uplift and the adjacent San Luis Basin, which is part of the Rio Grande rift. The study area lies on the northern margin of the Taos valley, which itself lies in the southeastern corner of the San Luis Basin. The San Luis Basin is one of the major basins of the Rio Grande rift, which has formed by extensional tectonic activity since the middle Tertiary period (~30 million years ago). It extends from central Colorado to Mexico and consists of a series of deep sedimentary basins filled with relatively young sediments and sedimentary rocks derived from flanking uplifts and axial rivers. The basins of the rift are typically flanked by mountain blocks uplifted along faults at the edge of the basins. In the Taos area, these are the Sangre de Cristo Mountains, which have been uplifted along the Sangre de Cristo fault. This major normal fault trends from southeast to northwest across the study area, but is buried by young sediments and is not exposed, except for one excellent exposure along the highway at the mouth of the Rio Hondo Canyon. Within the study area, the fault geometry ranges from essentially a single, large displacement strand north of the Rio Hondo mouth, to multiple buried strands and associated buried bedrock benches in the El Salto area. These are described in detail below.

For detailed discussions of the geology of the southern San Luis basin and adjacent mountains and exhaustive lists of relevant references, see Brister et al. (2004), and Bauer et al. (1999). In the following, I provide an overview of important features on the geologic map (Map 1) and subsurface structure map (Map 2), cross sections (Plates 1a and b), and fence diagrams (Plates 2a and b).

C. The Mountains

The Sangre de Cristo Mountains north of the latitude of Taos Pueblo are composed of Proterozoic quartz monzonite, felsic gneiss, amphibolite, quartzite, and minor quartz-mica schist. These rocks are intruded by Tertiary granite and granodiorite of the Lucero Peak and Rio Hondo plutons related to the Latir Peak volcanic field. Both the Proterozoic and Tertiary crystalline rocks are intruded by abundant, northeast-striking rhyolite and andesite dikes. North of the D. H. Lawrence Ranch and south of San Cristobal Canyon, the lower elevations of the range front are underlain by andesite lava flows and breccia intruded by quartz latite. These rocks are juxtaposed against the intrusive crystalline rocks to the east along a poorly exposed strand of the Sangre de Cristo fault that appears to die out to the south.

The bedrock in the mountains is extensively fractured. Within the Lucero Peak pluton and Proterozoic quartz monzonite above El Salto are numerous heavily fractured zones, small faults, and areas of silica-cemented breccia. The fractured zones are steeply west-dipping and roughly parallel to the range front, and are conspicuous as the relatively less deformed rock between them weathers in positive relief. These brittle features are probably Tertiary in age and subordinate to the Sangre de Cristo fault. The quartzite exposures at Cerrito Colorado and north of the D. H. Lawrence Ranch are pervasively shattered into decimeter-scale lozenges by multiple systematic joint sets, irregular fractures, and fractures along bedding planes.

The intensity and abundance of fracturing near the mountain front is well exposed in amphibolite outcrops at the mouth of the Rio Hondo Canyon. Three dominant joint sets with 5 to 20 cm spacing split the rock up in three dimensions. There are several small Tertiary faults in the outcrop that are roughly parallel to the steeply dipping joints and perhaps nucleated on them. These faults are 5 to 20 cm wide with well-developed chloritized gouge zones that include small knockers of amphibolite and shattered clasts of quartz vein fill. Edges of the faults are generally very sharp. The shallowly dipping joints are subparallel to the S1 compositional layering, or “pseudostratigraphy” in the amphibolite.

D. The Valley

In contrast to the fractured crystalline bedrock of the mountains, west of the mountain front, unlithified to poorly lithified Quaternary and late Tertiary sediments characterize the study area. These sediments have been variously referred to as the Chamita Formation, Lama formation, sediments of the Servilleta Formation, and undivided basin fill. Regardless of the name, the sediments encountered in wells and exposed in the Rio

Hondo Canyon range from as old as latest Miocene or earliest Pliocene to as young as possibly earliest Pleistocene in age. They are the uppermost part of the Santa Fe Group, which is the general term for the sediments and sedimentary rocks that filled the deep basin of the rift before drainage integration and the formation of the throughgoing Rio Grande. They were derived from the mountains to the east and were deposited by west-flowing streams and alluvial fans. In this report, these sediments will be referred to as Sante Fe Group sediments.

The Santa Fe Group sediments are overlain by fine-grained Blueberry Hill deposits and undivided Quaternary alluvial fan and stream terrace deposits. The Blueberry Hill deposits are exposed within the Taos quadrangle to the south of the study area. They are thought to be derived from the Rio Hondo, Arroyo Seco, and Rio Lucero drainages prior to the downcutting of the Rio Hondo, and are probably present in the Arroyo Seco area in the subsurface. In general, it is difficult to distinguish the youngest Santa Fe Group sediments from the overlying Quaternary fan and stream deposits in outcrop, and such distinctions could not be definitively made on well logs. On the geologic map, exposures in the south wall of the Rio Hondo canyon and to the north are referred to as Quaternary-Tertiary Santa Fe Group, undivided. This is an area that warrants more detailed stratigraphic study. The Blueberry Hill deposits and/or Quaternary fan and stream deposits overlap the Sangre de Cristo fault trace and onlap onto subsurface bedrock benches south of the Rio Hondo and west of Arroyo Seco (see Map 2).

South of the Rio Hondo, the Quaternary surficial deposits are relatively undissected, even along the Arroyo Seco drainage. North of the Rio Hondo, the piedmont is deeply dissected and Quaternary deposits exist only as thin, isolated terrace remnants on fingerlike mesas of Sante Fe Group sediments and on the broad surface north of the Gates of Valdez. Based on surface slope and elevation, the Q1 surface and deposit north of the Rio Hondo may have originally been continuous with the Qfy deposit south of the drainage.

E. Outcrop Descriptions of the Basin-fill Sediments

Several outcrops in, and north of, the Rio Hondo Valley were examined in detail to characterize the basin-fill sediments in the hopes of defining mappable subdivisions. Poor and noncontinuous outcrop precluded subdividing the basin fill, but the descriptions are useful as they illustrate the variations in clast composition, grain size, and sedimentary structures that typify the subsurface stratigraphy in the study area, and the types of geologic materials that comprise the aquifers tapped by local wells. I have assigned each distinctive set of deposits to a sedimentary facies representing the interpreted conditions of deposition.

1. **High gradient stream facies –** These deposits are abundantly exposed in several roadcuts along NM-230 where it descends the south wall of the Rio Hondo valley. These cobble to boulder gravels are poorly to moderately lithified and poorly to moderately well-bedded. Clast imbrication is very well-developed and indicates a westward transport direction. The deposits are dominantly matrix-supported, but locally are clast-supported. The matrix material is medium to coarse, tan to brown sand with abundant clay. This facies mainly differs from the alluvial fan channel deposits in having matrix-supported cobbles and boulders. It is interbedded with fine-grained stream channel facies and debris flow facies deposits.

2. **Fine-grained alluvial fan channel or stream channel facies –** The described outcrop is at UTM coordinates 447150 easting, 4043397 northing (NAD 27 datum). The approximately 6-m-high outcrop is composed of pale tan, very fine to fine sand in massive beds with internal laminations. Subtle, small crossbeds occur as pebble lags 3 to 10 cm thick. The pebbles are dominantly white to pale gray granitic igneous rock. This deposit is surprisingly clean and fine-grained considering its proximity to the mountain front. This facies appears common in the bluffs along the Hondo valley near the town of Valdez, beneath the Q6 terraces and their associated gravel deposits. This facies appears to become dominant downhill towards the valley bottom.

3. **Debris-flow facies** - The described outcrop is at UTM coordinates 446382 easting, 4045882 northing (NAD 27 datum). The deposit is composed of angular to subrounded cobbles and boulders up to one meter in size in a very poorly sorted clay-rich sandy matrix. As a whole, the deposit appears to be at the transition between clast-supported and matrix-supported. Subrounded cobbles of white to gray granitic rock are pervasively cracked and crumbling to grus. The metamorphic rock cobbles such as amphibolite are more angular and less weathered than the igneous rock cobbles. No bedding is apparent, other than a lens approximately 10 m across and 0.5 – 1 m thick composed of crudely bedded cobbles with no obvious imbrication. There are some interbedded reddish clay layers up to one meter thick with root molds.

4. **Mixed alluvial fan channel and debris flow facies** - The described outcrop is at UTM coordinates 446387 easting, 4043915 northing (NAD27 datum). The bottom half of the 4-m-high outcrop is a fining-upward sequence of pebbly to cobbly pink to tan clay-rich fine to very fine heterolithic sand. Pebble and cobble layers fine upwards and are 5 to 20 cm thick, with cobbles up to 10 cm in size. These may represent deposition in an alluvial fan channel during flood events. The top half of the outcrop is composed of sediments very similar to the debris flow facies described above.

Other smaller outcrops along the same road as facies 4 show the alluvial fan facies alone, and consist of clast-supported pebble-to-cobble conglomerate. These deposits are well bedded with a generally coarse sand matrix and clast imbrications yielding paleocurrents to the west. These alluvial fan facies deposits appear to be dominant in the area, with debris flows deposits second. Mixtures of these two facies dominate the higher bluffs north of Valdez, beneath the pediment surfaces and their deposits. It is estimated that they comprise at least one half of the sedimentary section, with facies 2 becoming dominant towards the valley floor of the Rio Hondo.

These types of poorly sorted, clay-rich gravel deposits typically have a wide range of hydraulic conductivities (the rate at which water will move through the deposit). The coarsest, most well-sorted, clast-supported members of these various deposits would likely make the best aquifers. The debris flow facies would be the lowest quality aquifer, due to pervasive clay layers. Generally, this seems to hold up when compared to the drillers logs of wells in the area, as most wells are screened in gravel or coarse sand and/or gravel intervals.

F. Subsurface Interpretations

Regionally, the abundant basalts on top of, and interbedded with, the Santa Fe Group sediments of the southern San Luis Basin are referred to as the Servilleta Formation. These are present throughout the subsurface south and west of the study area. Within the western part of the study area, numerous wells encounter igneous rocks around the Cerro Negro volcanic center. This small, 5 Ma dacite shield volcano (Read et al., 2004) just northwest of the study area is partly buried by onlapping sediments. It is well exposed in the narrow gorge of the Rio Hondo at the Gates of Valdez, where the rock is massive, dark gray to black, and extensively fractured. Wells DM-35, DM-21, and DM-38 penetrate through the basalt, and the remainder of the wells used to construct the basalt elevation contours either bottom in basalt or the drillers stopped upon encountering basalt, which may be either buried lava flows or sills (Map 2 and Plates 1 and 2). These may be derived from the Cerro Negro dacite volcano, or alternatively are outlying flows of the Servilleta Formation basalts. As compositional distinctions such as basalt or dacite cannot be reliably determined from the driller’s logs, I will refer to these rocks with the generic term “basalt” for the remainder of this report.

Buried bedrock benches exist along the mountain front in the El Salto area (Map 2 and Plates 1a and 2a). These were delineated with Wells ES-10, ES-15, ES-18, and the Yaravitz well, which all bottom in bedrock, either granite or amphibolite. Bedrock contours dip steeply but smoothly away from the El Salto mountain front immediately north of the Arroyo Seco drainage. The north-trending fault segment here must be buried west of ES-15, although smaller offset and/or breccia zones are likely closer to the mountain front (e.g., the "sand and gravel" zone in Well ES-10, which is probably a zone of brecciated basement rock, Plate 2a).

The northwest-trending segment of the El Salto mountain front must be a steep fault segment, as Well ES-23 is 500 feet deep and does not hit bedrock, yet it is very close to bedrock outcrops to the immediate north (Map 2). Offset is 500 feet or more. This also coincides with a 1000 to 3300 foot–deep buried discontinuity identified in preliminary aeromagnetic interpretations of the area (V. J. S.Grauch, U. S. Geological Survey, unpublished data) that is probably the range-front fault.

The Yaravitz well penetrates amphibolite at an elevation of 7594 feet, at a depth of 240 feet. The amphibolite is most likely a buried prong of bedrock that extends west from the mountain front, and south of the Rio Hondo valley. The existence of a prong is supported by the regional aeromagnetic map (Bankey et al., 2004) and analysis of unpublished aeromagnetic data by V. J. S. Grauch (U. S. Geological Survey). These interpretations identify a discontinuity at much greater depth (3300-6600 feet) than that along the fault segment adjacent to well ES-23.

My interpretation is that the aforementioned steep, large-offset, range-front fault changes to a more westerly orientation and bounds the south side of the bedrock prong penetrated by the Yaravitz well. Another strand trends northwest and is the fault exposed in the roadcut where Highway 150 descends into the Rio Hondo Canyon.

III. HYDROGEOLOGY

A. Hydrologic data and methods

Well data come from three sources. Water levels were measured in 43 domestic wells in the Arroyo Seco area from mid-April to mid-May, 2005 (Table 2). Many of these wells are included in the Taos Soil and Water Conservation District (TSWCD) inventory described below. The water levels were measured with a steel tape and the wells were located with a handheld GPS unit. During the time period of these measurements, streams, acequias, and most small surface drainages were flowing swiftly with runoff from a large winter snowpack in the Taos Range. Glorieta Geoscience, Inc. (GGI) provided locations, water level data, and selected chemistry and aquifer test data for 7 wells that they collected in the course of their consulting work (Table 3). Well locations and water elevations for these two data sets are considered to be reliable, although the GGI data are up to 10 years old. The remainder of the water level data are from the Taos Soil and Water Conservation District well inventory assembled by Tony Benson and students from UNM-Taos (Table 4). Although the wells in the inventory were accurately located with handheld GPS units, the water elevation data are from driller's well records and range greatly in accuracy.

Many of the water levels measured in this study differ greatly from water levels recorded on driller's logs, several by more than 100 feet (Table 2). Possible causes of these discrepancies include seasonal variations in water levels, long-term water level changes, or inaccurate water level measurements by the well driller. The latter may be due to recording the water level immediately upon drilling, before water levels equilibrated. There are no geographic patterns in the variations between the water levels measured in this study and those measured by the well drillers.

ArcGIS software was used to plot the well locations and water level measurements. Groundwater elevation contours were drawn by hand and then digitized. Several assumptions were made in creating the groundwater table map (Map 3). It is based largely on water levels in wells with screened intervals above 300 feet. This was taken to be the difference between “shallow” and “deep” wells, as wells completed above and below this depth generally show significant differences in groundwater elevation. I assumed that the shallow groundwater system, or shallow aquifer, is connected to flowing drainages and local groundwater and surface water flow patterns are parallel, so the water table contours cross streams at right angles. Always inherent in the contouring of water level measurements are the assumptions that groundwater flow is horizontal, the measurements are from a single aquifer, and that hydraulic head does not vary with depth. The contours on Map 3 terminate where these conditions appear to be violated, or where data points are sparse.

It is important to note that the water level elevations reported 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 the screened interval, and the resulting contoured surface is not strictly a potentiometric surface. With this fact, and the variation in data quality in mind, the contours were not forced to fit every well measurement. Contours are dashed where approximate and queried where speculative, and in two areas along the south rim of the Rio Hondo canyon two alternate contours are drawn.

B. Gaining and losing streams and groundwater recharge

The gaining or losing nature of streams and their interaction with the groundwater flow system can be determined from both groundwater contours and stream flow measurements. Groundwater elevation contours along the Arroyo Seco from the study of Drakos et al. (2004a) change from slightly gaining upstream (contours bend slightly upstream) of the namesake town to strongly losing (contours bend strongly downstream) downstream of the town. Drakos et al. (2004a) also performed streamflow measurements in January 2000 on the Arroyo Seco drainage, and these generally correlate with their groundwater contours, in that they indicate that the stream becomes losing where the groundwater contours start to bend strongly downstream. The groundwater contours in the present study show the same general pattern and degree of gaining and losing reaches – the stream becomes a losing reach in the vicinity of the town of Arroyo Seco (Map 3).

Losing streams recharge the subjacent groundwater system, and the small drainages undergoing transient flow from spring runoff during April and May 2005 were actively recharging groundwater. This can be seen in water levels in wells AS-101 and AS-102, which sit adjacent to, and north of, a small tributary drainage of Arroyo Seco creek just north of the town center. According to the homeowner, both wells are approximately the same depth, but AS-101 sits on a small hill to the north of AS-102 and the well head is 5 feet higher. However, the water level is 4 feet lower than in well AS-102, This indicates that the groundwater level is sloping away from the small drainage, and that a recharge mound exists under the drainage. It is likely that similar local recharge mounds develop under unlined flowing acequias. This recharge behavior of streams discharging from the mountain front has been documented previously in the southern Taos valley (Spiegel and Couse, 1969; Bauer et al., 1999, and references therein).

A January 2000 stream gauging study by Drakos et al. (2004a) showed the Rio Hondo to be a losing reach upstream of the Gates of Valdez and a gaining reach downstream. However, their groundwater elevation contours show the upstream portion to be a strongly gaining reach. They attributed the discrepancy to either: 1) the stream flow measurements not capturing all diversions from or additions to the reach during the measurement period; or 2) the groundwater measurements representing an averaged, longer-term set of conditions. During the present study, the Rio Hondo was flowing strongly and the groundwater elevation contours show it to be gaining upstream of the Gates of Valdez and losing or approximately neutral to the west (Map 3)

C. Groundwater flow patterns

The overall pattern of groundwater flow in the study area is from east to west, from the mountain block into the basin fill (Map 3, Plates 2a and b). However, the strongly curved groundwater elevation contours indicates that the details of the groundwater flows path are complex. There are limited data on the hydraulic properties of sediments penetrated by wells in the area (see section IIIG), and none that bear on the possible anisotropy of hydraulic properties. Assuming then that the water-bearing strata are isotropic, groundwater flow paths will be perpendicular to the elevation contours. The gaining and losing reaches of the streams are obvious, as groundwater flow paths will converge on gaining reaches (e.g., upstream Rio Hondo) and diverge from losing reaches (e.g., downstream Arroyo Seco).

Hydraulic gradients are variable as well, ranging from 0.02 in the lower reaches of the Arroyo Seco drainage, to 0.16 in the El Salto area, to a high of 0.18 north of the Yaravitz well. These variations in gradient yield insight into the nature of the water-bearing units, as they reflect variations in the transmissivity of the sediments, with lower gradients corresponding to higher transmissivities, and vice versa. Transmissivity is the product of aquifer thickness and hydraulic conductivity (the ease with which water moves through the material). High transmissivity indicates a thicker aquifer, or more permeable sediments such as gravel, or both, whereas low transmissivity corresponds to a thin aquifer, and/or less permeable material such as clay or relatively unfractured bedrock.

Gradients are fairly constant throughout the central portion of the map area and north of the Rio Hondo, probably reflecting relatively homogeneous aquifer properties. They become more variable and complex along the mountain front and in the vicinity of the Gates of Valdez – Des Montes area (Des Montes is a local name for the area surrounding and to the south of the Gates of Valdez). These areas are discussed in more detail below.

D. Gates of Valdez – Des Montes area: High transmissivity and downward flow

Drakos et al. (2004a) described an area of downward flow that extends from the Gates of Valdez-Des Montes to south of the area of the present study. The new water level data collected during this study replicate this downward gradient in the groundwater flow pattern (Map 3 and Plate 2a). It can be clearly seen by comparing water levels in adjacent shallow/deep well pairs. Examples of such pairs are Cielo Azul shallow and deep, DM-2 and DM-3 with the Arroyo Seco School well, and DM-102 with DM-21 (Tables 1 and 2). The deeper wells have water levels from 200 to more than 400 feet deeper. Immediately south of the Gates of Valdez, wells DM-36, DM-38, and DM-39 show a pattern of decreasing water level elevation with increasing screen depth (Map 3). All of these data indicate that the hydraulic head decreases with depth, indicating a vertically downward gradient and presumably downward flow.

Table 1 – Shallow and deep well pairs in the Des Montes area.

Well	Depth (ft)	Screen top (ft)	Screen bottom (ft)	Water level (ft)
Cielo Azul	353	?	?	7303
Cielo Azul Deep	850	720	840	7103
DM-2	280	240	280	7281
DM-3	320	240	320	7292
Arroyo Seco School	760	660	740	6820
DM-102	365	325	365	7206
DM-21	750	650	750	7049

Along the south rim of the Rio Hondo canyon east of the Gates of Valdez is a plateau in the groundwater surface, implying a high transmissivity zone. This forms a recharge mound immediately south of the river at the Gates, and immediately west of the Gates the groundwater level contours are straight as they cross the river. This suggests that the Rio Hondo changes from gaining to essentially neutral as it flows through the Gates of Valdez, i.e., the river is no longer gaining much water from the groundwater system.

Wells DM-36, DM-38, DM-39, VAL-103, and DM-101 largely define the high transmissivity zone, and have water levels that range over 100 feet. Unfortunately, only VAL-103 reflects a current measurement. Other water levels are from driller's records. DM-38 penetrates basalt and is screened in sand and gravel beneath the basalt at a depth of 300 to 340 feet. The top of this screen is approximately 50 feet beneath the river level immediately to the north in the canyon. The driller's record indicates a water elevation of 7249 feet, which is approximately 30 feet above the river level.

Well DM-36 is screened in fractured basalt at a depth of 200 to 260 feet, approximately at river level. Well DM-39 bottoms in basalt at 260 feet, and is screened in sand and gravel from 220 to 260 feet. This is also approximately at river level. Water levels in these two wells are similar, and slightly over 100 feet above the level of the Rio Hondo. It thus appears that the high transmissivity in this area is due to the combination of basalt and gravel layers, and not just fractured basalt alone (which would be expected to have high transmissivity). An estimated hydraulic conductivity for these highly permeable gravels and fractured basalt in this area is 100 to 1000 feet/day (Domenico and Schwartz, 1990).

The presence of a high transmissivity gravel layer is also implied by the warping of contours around well VAL-103, which is to the east of the subsurface basalt (Maps 2 and 3). This well is screened in sand and gravel and minor clay from 220 to 300 feet, approximately at the level of the river in the valley to the north. The water level in the well is at 7402 feet, about 80 feet above the river level. This defines a steep northward gradient to the river level, as shown in the contours.

Beyond about 0.5 km west of NM-230 in the west-central portion of the study area most wells are screened below 300 feet. From reports of homeowners in the area, many wells in a north-south strip in the vicinity of NM-230 and Lobo Road, which are screened at shallow depths, have gone dry in the past few years, and have had to be deepened or redrilled. The western edge of the groundwater elevation contours on Map 3 is interpreted to be the western edge of the "shallow aquifer" that is tapped by most wells from NM-230 east to the El Salto area. This shallow aquifer probably consists of multiple local unconfined or leaky-confined water-bearing strata, corresponding to the "upper aquifer" at 295-340 feet depth in the New Mariposa Ranch well (Glorieta Geoscience, 1995) and/or the "shallow aquifer" of 160 to 170 feet in the Arroyo Seco School well (Drakos, 1997). The "dieout" of this shallow aquifer at a point coincident with the area of downward gradients suggests that downward flow, probably through fractured basalt and/or permeable gravels is the dominant direction of groundwater movement in this portion of the aquifer.

E. El Salto area: Mountain front recharge and variable influence of faults

The basement prong beneath the Yaravitz well coincides with the steep hydraulic gradient along the south side of the mouth of Rio Hondo Canyon, perhaps indicating that the rock has relatively low transmissivity. Generally, crystalline rocks adjacent to major faults are highly fractured, as in the amphibolite outcrops upstream of the mouth of Hondo Canyon. However, the buried prong may contain subsidiary faults with chloritized gouge zones, which could act as low permeability-baffles and contribute to the high gradient.

To the south, in the El Salto area, there are significant changes in the vertical distribution of hydraulic head with geographic location that are probably related to the range-front faults. The log of Well ES-10 records granite at 260 feet, sand and gravel from 460 to 480, and then granite to the total depth. The sand and gravel interval is interpreted as most likely being crushed rock in a fault zone in the granite. This well is screened below 400 feet, entirely in bedrock and (inferred) faulted rock. Well ES-15 bottoms in granite at 250 feet, with multiple screens from 60 to 250 feet, so the water level reflects an integrated hydraulic head value over this interval. The similarity of water levels in these two wells (within 20 feet) indicates that there is little variation of head with depth between the interval 60-250 feet and greater than 400 feet. From this it is inferred that the fractured rock aquifer system within the Taos Range mountain block to the east discharges to the unconsolidated sediment aquifer system west of the mountain front along approximately horizontal flow paths that are not appreciably altered at the sediment-bedrock contact.

West of the inferred buried fault near well ES-15, wells ES-4 and ES-24 have screens shallower than 100 feet and greater than 240 feet, respectively. These wells also have water levels within 20 feet of each other, again indicating little change of head with depth and subhorizontal flow. Thus it appears that this segment of the buried north-south range-front fault is not greatly affecting the groundwater flow paths.

In contrast to these well pairs, along the northwest-strking fault segment, wells ES-21 and ES-130 have significantly lower water levels than those in the surrounding area, which otherwise increase fairly uniformly towards the mountain front. ES-21 is screened at 340-380 feet and ES-23, ~ 330 feet to the northeast is screened at 435-495 feet. The water level in ES-23 is approximately 300 feet higher than in ES-21, even though it is screened 50 feet deeper. A log for well ES-130 is not available, but the water level is approximately the same as ES-21 and a neighbor reported that it was approximately the same depth as ES-21. These data indicate an upward hydraulic gradient in the vicinity of the three wells, as opposed to the roughly horizontal flow out of the mountain block to the southeast.

Neither ES-21, -23, or -130 penetrated bedrock; geologic logs for all three show only sand and gravel. They are located in the "corner" formed by the inferred, buried, steeply dipping range front faults, which are influencing the hydraulic gradient in the area. Possible explanations are:

1) The shallow levels of the range-front fault near these wells are highly impermeable, perhaps due to cementation or development of clay-rich fault gouge. Therefore, groundwater exiting the mountain block crosses the fault at depth, resulting in an upward hydraulic gradient in the basin-fill sediments immediately west of the fault zone, or:

2) The fault itself is acting as a conduit, channeling water from depth to shallower levels. The adjacent intersection of fault strands is likely an area of intense bedrock fracturing, which would favor conduit behavior.

F. Rangefront north of the Rio Hondo Canyon

North of the Rio Hondo Canyon the steeply-dipping range-front fault is buried beneath the drainage that runs north from the Hacienda del Valdez condominium complex (Map 2). The location of the fault is constrained by well VAL-102, which penetrates bedrock at a depth of 200 feet, and well DM-44, which bottoms in sand and gravel at 670 feet depth (Plate 2b). The bottom 40 feet of well VAL-102 are described as sand and gravel in the well log, but are likely brecciated rock in a fault zone. The log for well DM-44 records an interval of granite from 590 to 620 feet, which may be a bedrock sliver related to the range-front fault. To the south, the Hacienda well penetrates quartzite at 43 feet and bottoms in amphibolite at 702 feet. The elevation of the quartzite in the well is about 40 feet above the level of the Rio Hondo at the mountain front.

Although there is little change in ground elevation between VAL-102 and DM-44, there is a drop in water levels of almost 600 feet between the two wells. VAL-102 is screened from 300 to 400 feet depth in granite, whereas the screen on DM-44 is over 200 feet deeper. This change in water levels implies a downward gradient between the two wells, and across the fault. The water level in DM-44 is from a driller's record and may not be accurate. The owners of DM-44 reported very small yields and deepened the well to 870 feet in 1989, although no data are available on the geology at depth, new screens, or water levels. Even if the reported water level in DM-44 is off by hundreds of feet, there would still be a large decline in water levels between this well and VAL-102, and thus across the range front fault from bedrock into basin-fill sediments. This is in contrast to the apparent upward gradient adjacent to the range front fault in the vicinity of wells ES-23 and ES-21. These differences are likely due to the combined effects of fault zone structure and permeability contrasts between fractured bedrock on one side of the fault and heterolithic basin fill sediments on the other side, but the relative importance of these two factors cannot be determined from the present data.

G. Hydraulic properties of the basin fill aquifers

Several estimate of hydraulic properties of the basin-fill sediments in the study area have been made by Glorieta Geoscience, Inc. (GGI), in the course of their groundwater consulting work in the northern Taos Valley. GGI drilled and tested the New Mariposa Ranch Well, DM-15 (NMOSE record # RG-62458; Glorieta Geoscience, 1995). The well is 800 feet deep with screens from 520 to 725 feet. Basalt was encountered from a depth of 756 feet to the bottom of the well. GGI measured a static water depth of 582 feet on 9/14/95. The water bearing strata are sandy gravel from 590 to 660 feet and gravel from 680 to 720 feet, and water also possibly comes from the fractured basalt. This “deep aquifer” is separated from the “shallow aquifer” at 295 to 340 feet by a presumed leaky confining bed consisting of cemented sandy gravel. GGI performed a 48-hour aquifer test, and from water level recovery curves they calculated transmissivity values that range from 520 to 550 $feet^2$/ day. Assuming an average saturated thickness of 110 feet, they then calculated hydraulic conductivity to be 4.9 feet/day

GGI drilled and tested the Cielo Azul, (DM-41, NMOSE record # RG-65614; Drakos, 1995) and Cielo Azul Deep (DM-43, NMOSE record # RG-70152; Glorieta Geoscience, 1998) wells. Two intervals of water-bearing strata were identified in the 352-foot deep Cielo Azul well, the upper in sand from 120 to 140 feet depth, and the lower in coarse sand from 310 to 330 feet depth. This lower zone is probably equivalent to the upper water bearing zone, or “shallow aquifer” in the Mariposa Ranch well, described above. GGI measured the depth to water in the lower aquifer at 136 feet. They performed a 48-hour aquifer test and from water level recovery curves calculated a transmissivity value of 390 $feet^2$/ day. They assumed a saturated thickness of 40 feet representing the two water-bearing zones, and from this derived a hydraulic conductivity value of 9.2 feet/day.

The Cielo Azul Deep well is 850 feet deep and is approximately 40 feet from the Cielo Azul well. This well is screened from 720 to 840 feet and is sealed off from the two higher water bearing levels described in the Cielo Azul well. The depth to water was 340 feet on 10/22/98. Presumably, this well is tapping the same aquifer as the Mariposa Ranch well. A 48-hour aquifer test was performed and transmissivity was calculated to be from 34.5 to 45.9 $feet^2$/day. During the test, no drawdown was observed in the adjacent, shallower Cielo Azul well. Hydraulic conductivity was calculated to be 0.4 feet/day, using an assumed saturated thickness of 100 feet representing the screened interval of the well.

Water levels in all of the tested wells recovered fully over the span of a few days to two weeks. The estimated hydraulic conductivity values are at the low end of published values for clean sands and gravels (Domenico and Schwartz, 1990), but all are reasonable for the deposits, considering they are likely moderately to poorly sorted mixes of gravel, sand and clay (see section IIE). The aquifers in the study area appear to be relatively homogeneous – the estimated conductivity values vary over slightly more than an order of magnitude, from 0.4 feet/day, to 9.2 feet/day. These values are in accord with the range in hydraulic gradients observed in the study area, which vary over approximately one order of magnitude (0.02 to 0.18).

IV. DISCUSSION

A. Declining water levels and recharge

According to local residents, in the western portion of the study area, several wells completed in the shallow aquifer (wells approximately 300 feet deep or less) have gone dry within the past five years, requiring redrilling or deepening. This is in the general region of downward gradient between the shallow and deeper aquifers, along and west of NM-230. Downward leakage from the shallow to deep aquifer may be part of the reason for the aquifer depletion. However, during the Cielo Azul Deep well aquifer test, no drawdown was noted in the adjacent shallow well in response to pumping in the deep well. For at least the time scale of that test (48 hours), the shallow and deep aquifers do not appear to be in good hydraulic communication (i.e., they are separated by an effective aquitard), and/or not enough vertical flow was induced to cause drawdown in the shallow aquifer. It is likely that the long term rate of downward leakage is low enough that it is not entirely responsible for the water level declines in the shallow aquifer.

A more likely cause of the declining water levels is reduced recharge to the aquifer due to drought within the last ten years. Drakos et al. (2004b) collected tritium data from three wells in the study area ranging from 200 to 760 feet deep. These data show that recharge to the shallow and deep portions of the groundwater system in the study area occurs on a time scale of < 5 to 10 years: i.e., the water is “modern” and has been in the aquifer less than 10 years. Consequently, it is likely that shallow domestic wells will respond to drought-induced variations in recharge to the aquifers. That there has been significant drought in the past ten years is clearly shown in Figures 1 through 3.

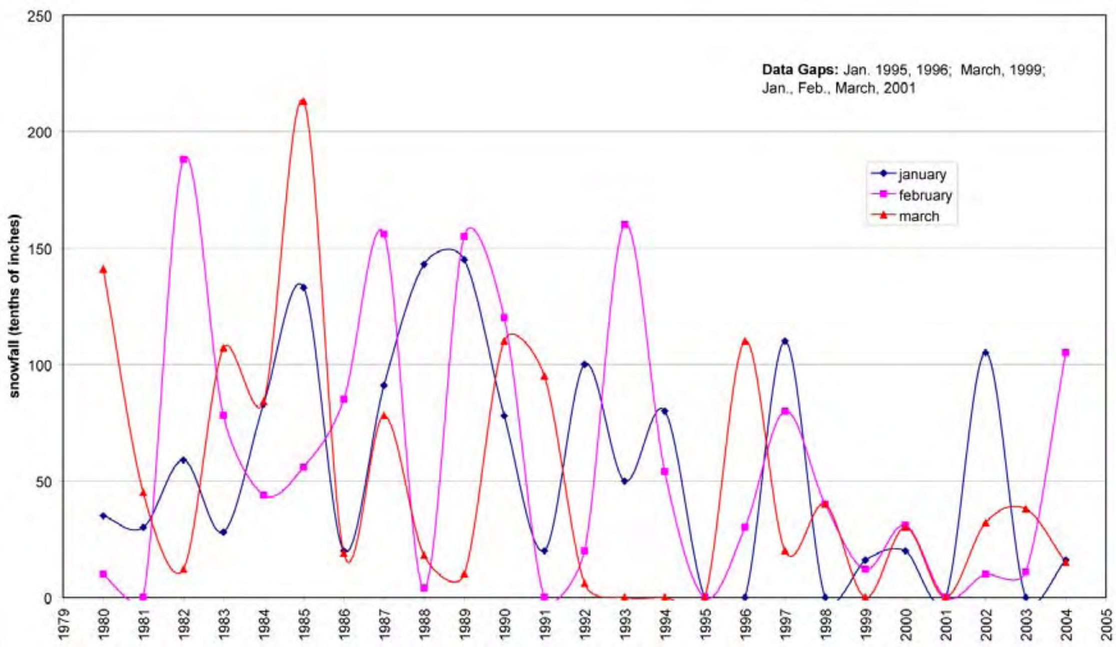

Figure 1. Snowfall data for Taos, NM, 1980 – 2004.

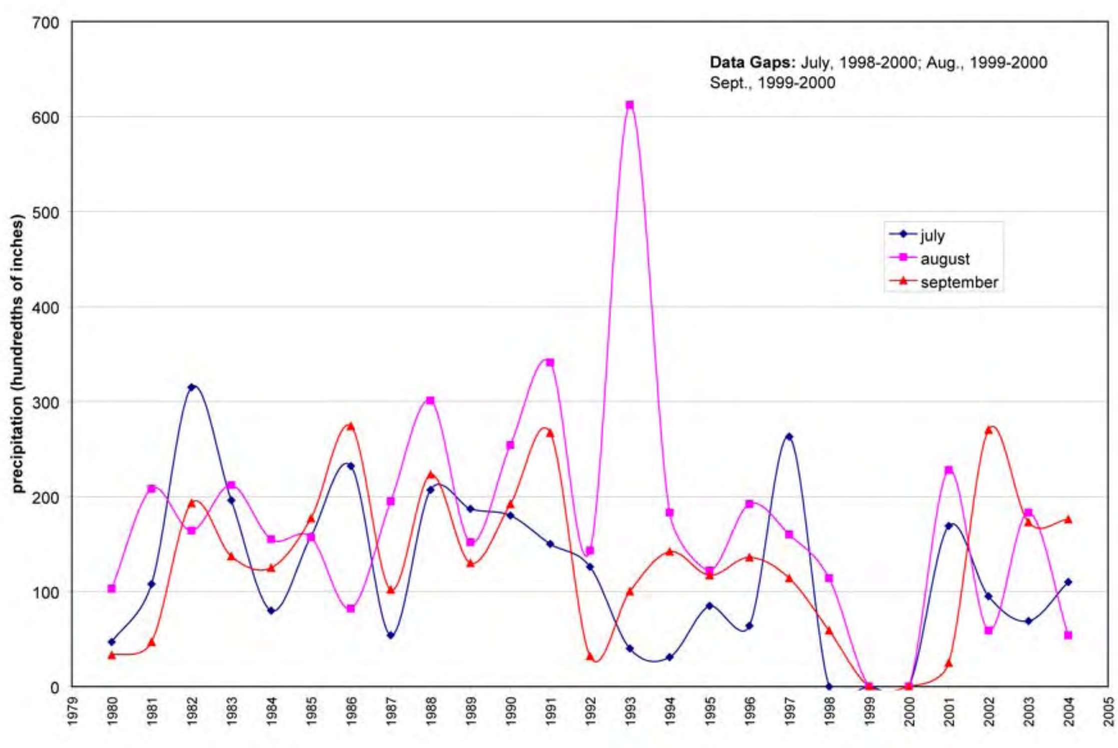

Figure 2. Monsoon season precipitation for Taos, NM, 1980 – 2004.

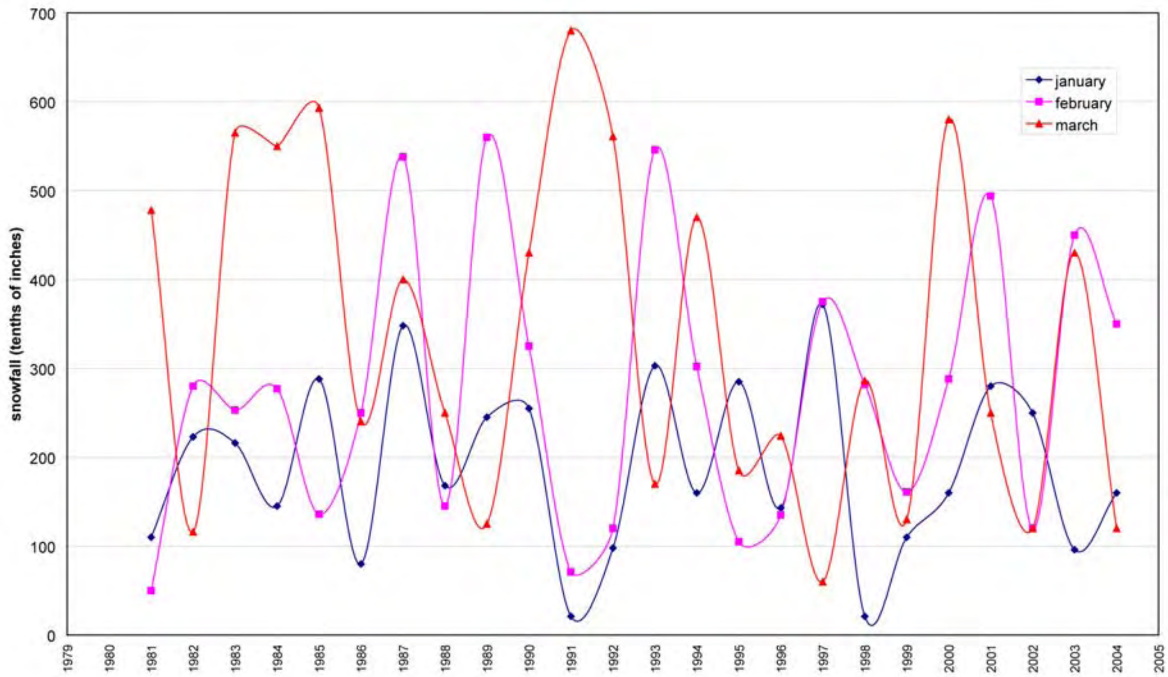

Figure 3. Snowfall data for Red River, NM. 1980 – 2004.

The effect of declining snowfall in the mountains above the study area, represented by the Red River snowfall data, is particularly significant, as it is responsible for the reduced peaks in stream flow in the Rio Hondo and Rio Lucero during the late spring runoff period, which is generally the months of April, May and June (Figures 4 and 5). As noted in Section IIIB, the Arroyo Seco and small tributary drainages in the vicinity of the town of Arroyo Seco contribute recharge to the shallow groundwater system during the spring runoff period. Declining winter snowpacks due to reduced snowfall directly affect the volume of runoff and thus recharge.

To date, the deeper wells in the western portion of the study area, such as the Arroyo Seco School well and the Mariposa Ranch well, have not shown water level declines. However, the isotopic data suggest that the deeper aquifer also could be negatively

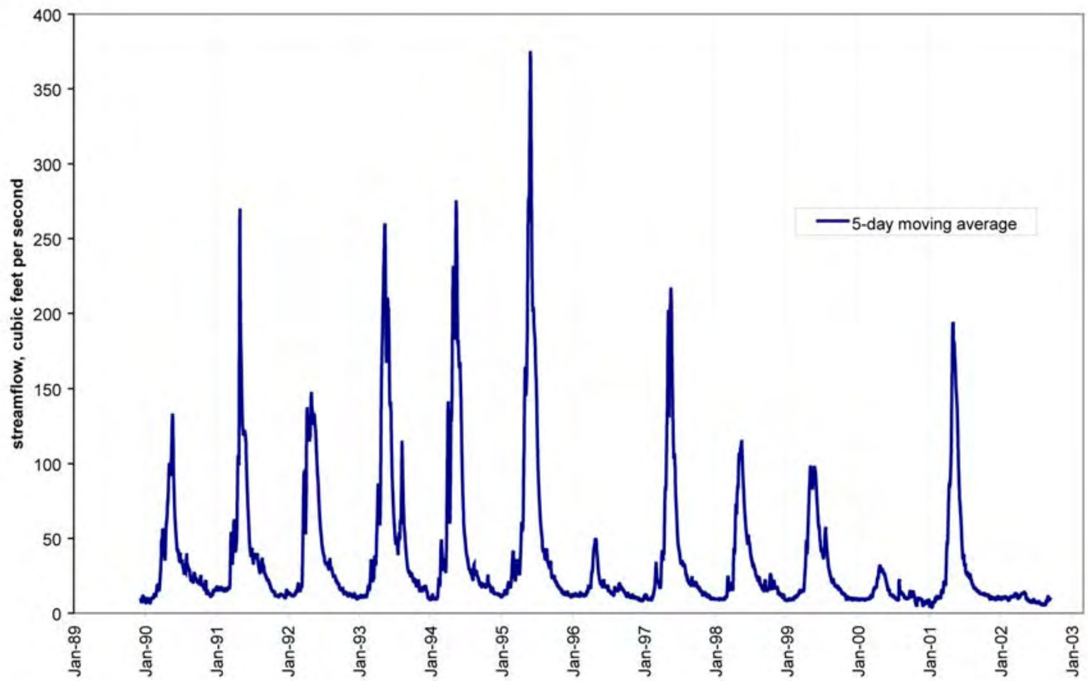

Figure 4. Daily streamflow data for the Rio Hondo at the Valdez gauge, 1990 – 2002.

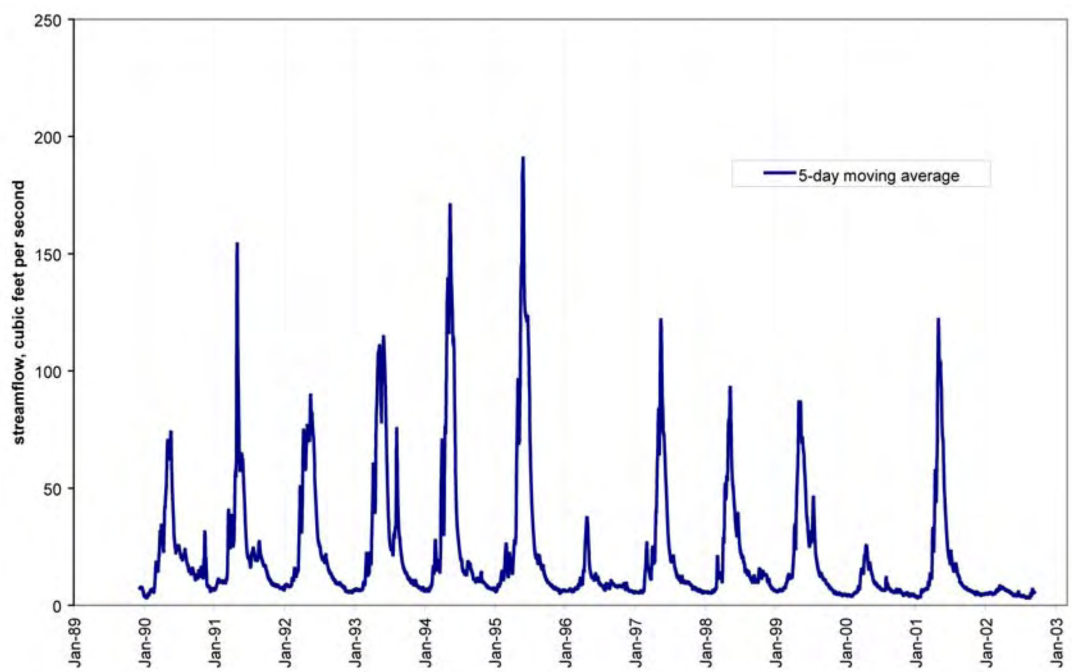

Figure 5. Daily streamflow data for the Rio Lucero, 1990 – 2002.

affected by reduced recharge if drought conditions continue into the future. Conversely, several years of abundant moisture should reverse the trend of declining water levels and drying wells, with the important caveat that excessive exploitation of the aquifer may negate any gains in groundwater storage from increased precipitation. Overall, the young groundwater ages imply that at least until the recent drought, the aquifer was receiving abundant recharge.

B. Groundwater travel times

It is worthwhile to compare the groundwater ages from tritium collected by GGI with estimates of groundwater travel times by hydrologic means. To illustrate, the length of the study area from the mountain front to the town of Arroyo Seco is roughly 11,000 feet, with an average hydraulic gradient of .055 across this distance. The range of calculated hydraulic conductivities from aquifer tests is 0.4 feet/day to 9.2 feet/day. Assuming an effective porosity of aquifer materials of 15%, travel times for groundwater to move this distance are on the order of 300 to 10000 years. This calculation assumes that all of the groundwater is being recharged only at the mountain front. As it has been shown that groundwater is recharged along the Arroyo Seco and subsidiary drainages by surface water, these travel times are upper bounds, and are probably significant overestimates. True travel times are less, as shown by the tritium data.

Nevertheless, the above calculation shows that the hydrologic properties, water level measurements, and isotopic data are all consistent. Additionally, it suggests that the hydrologic properties measured by GGI are reasonable values for aquifer materials throughout the study area.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The main conclusions of this study are as follows:

1. Groundwater flows generally from east to west through the study area, but the details of the flow paths are complex, and are affected by faults along the mountain front, variations in aquifer transmissivity, and recharge from and discharge to streams.

2. The Sangre de Cristo fault is composed of several interlinked fault strands, and the hydrologic properties of the fault vary from north to south. These variations have a noticeable affect on the groundwater flow patterns, resulting in upward, downward, and horizontal groundwater flow paths near and across the fault.

3. The region of downward flow at the western edge of the study area approximately coincides with the termination of the shallow aquifer, which is probably losing some water downward.

4. The buried basalt and dacite and associated gravel layers (?) in the vicinity of the Gates of Valdez comprise a high transmissivity unit with a downward gradient, and strongly influence the local groundwater flow pattern.

5. Tritium isotopic data, water level measurements adjacent to streams, and estimated groundwater travel times are consistent and indicate that recharge occurs to the aquifers during peak flows. The recent drying of wells tapping the shallow aquifer in the western portion of the study area is probably due to decreased recharge resulting from drought over the past ten years. Similar groundwater ages in the shallow and deep aquifers suggest that the deep aquifer could eventually be impacted by continued drought.

6. The large variation between water levels recorded on driller's records and those measured in this study calls into question the suitability of relying on these records for groundwater studies. It is recommended that future work in this area incorporate new water level measurements.

Further data collection in the study area would better delineate some of the more poorly constrained groundwater contours and more firmly establish the geologic controls on groundwater flow. Areas where more water level measurements would be useful include:

1. The high-transmissivity area around the Gates of Valdez;

2. North of the Rio Hondo, where there are only four new measurements;

3. Along the mountain front north of the El Salto area, both north and south of the Rio Hondo, to characterize the bedrock-sediment interface and the influence of the Sangre de Cristo fault;

Although the hydraulic properties determined by GGI appear to be representative of the aquifer sediments in general, aquifer tests in the El Salto area and north of the Rio Hondo would be useful to determine the spatial variability of the aquifers. Finally, continued monitoring of a subset of the wells in this study, both shallow and deep, would be necessary to document changes in water levels over time. This would allow the relative impacts of variations in recharge and increased residential use on groundwater storage and water levels to be determined.

VI. ACKNOWLEDGMENTS

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APPENDIX I. DESCRIPTIONS OF GEOLOGIC MAP UNITS

Note: LR indicates description from or adapted from Lipman and Reed (1989).

Quaternary Surficial Deposits

QHa, Q8 - Arroyo alluvium, undivided (Holocene to Historic) – Units are equivalent. Gravel and poorly to moderately sorted fine- to coarse-grained sand in active drainages. Bar and swale topography is well developed. Soils are very weakly developed.

Qc – Colluvium (Pleistocene to Holocene) - Poorly lithified and stratified bouldery to sandy colluvium that obscures underlying bedrock. Exists in steep drainages within the Sange de Cristo Mountains.

Ql – Landslide deposits (Pleistocene to Holocene) - Lobate accumulations of poorly sorted soil and rock debris on slopes marked by hummocky topography and downslope-facing scarps. Derived from bedrock and glacial deposits, and includes small earthflow, block-slump, and block-slide deposits (LR).

Qaf - Alluvial fans – (Pleistocene to Holocene) – moderately to poorly sorted clay, silt, sand and gravel in low relief fans at the mouths of small tributary drainages.

Qty – Young stream terrace deposits – (Pleistocene to Holocene) – Poorly sorted silt, sand, pebbles, and boulders in low terraces along the Rio Lucero. Equivalent to unit Qt6 of Kelson (1986). (Unit description adapted from Bauer et al. (2001))

Qt6, 7 – Fluvial terraces - (late (?) Pleistocene) – Strath terrace treads along the Rio Hondo valley eroded on older Santa Fe Group sediments. Thin deposits composed of veneers of sand and gravel.

Q6 – Undifferentiated alluvial fan and/or valley side-slope surface – (late (?) Pleistocene) – Deposits mantling older Santa Fe Group sediments. Composed of sand and gravel up to a few meters thick.

Qsct – Stream terrace deposits along San Cristobal Creek - (middle to early (?) Pleistocene) - Poorly sorted silt, sand, pebbles, and boulders in low terraces along San Cristobal Creek. Appear to be higher in elevation and more stabilized by vegetation than similar deposits along the Rio Lucero. Surface commonly disturbed by development.

Qt5, 4 – Fluvial terraces - (middle (?) Pleistocene) – Strath terrace treads along the Rio Hondo valley eroded on older Santa Fe Group sediments. Thin deposits composed of veneers of sand and gravel.

Q4, 3 – Undifferentiated alluvial fan and/or valley side-slope surfaces – (middle to early (?) Pleistocene) – Deposits mantling older Santa Fe Group sediments. Composed of sand and gravel up to a few meters thick.

Qt2 – Fluvial terraces - (middle to early (?) Pleistocene) – Strath terrace treads along the Rio Hondo valley eroded on older Santa Fe Group sediments. Thin deposits composed of veneers of sand and gravel.

Q2 – Undifferentiated alluvial fan and/or valley side-slope surface – (middle to early (?) Pleistocene) – Deposits mantling older Santa Fe Group sediments. Composed of sand and gravel up to a few meters thick.

Q1,Qfy – Highest extensive geomorphic surface and associated piedmont deposits (early Pleistocene) – Units are probably equivalent. Deposits mantle older Santa Fe

Group sediments. Composed of sand and gravel probably up to several meters thick south of the Rio Hondo.

Qfo – Older piedmont and fan deposits (earliest (?) Pleistocene) – Dissected piedmont and alluvial fan deposits along mountain front in the El Salto area. Field relations with Qtsfu are uncertain.

Quaternary and Tertiary Sedimentary Rocks

QTsfu – undivided Santa Fe Group sediments – (late Tertiary to Pleistocene (?)) – Well-stratified clay, sand, and gravel deposited by streams and in alluvial fans. Probably includes Blueberry Hill deposits of (Bauer et al., 2001). See sections IID and E for more detailed description.

Tertiary Igneous Rocks

Td – Cerro Negro dacite – (late Miocene) – Dark gray to black, extensively fractured two-pyroxene dacite flows and/or shallow intrusions. Age is 5.7 Ma (McIntosh et al., 2004).

Tgy – Lucero Peak Pluton – (Miocene) - White to pale pink, medium- to coarse-grained, equigranular granite to quartz monzonite.

Tg - Biotite granite – (Oligocene) – Granitic roof phase of the Rio Hondo pluton emplaced in the Questa caldera at about 26 Ma, during volcanism and caldera formation. Medium-grained and equigranular, with sparse aplite and no hornblende (LR).

Tgd – Rio Hondo Pluton (Oligocene) – White to pale grayish-orange, medium- to fine-grained, massive to locally foliated granodiorite. White to pale orange, aphanitic-porphyritic border facies has quartz phenocrysts and local breccia. Has potassium feldspar phenocrysts up to 4 cm in size. Generally forms rounded outcrops with abundant grus.

Ta – Andesitic lava flows – (Oligocene) – Purplish-gray to gray, aphanitic to porphyritic andesite lava flows and flow breccias, with minor interbedded volcaniclastic sediments. Phenocrysts include plagioclase and hornblende.

Tqi – Latite and quartz latite – (Miocene and Oligocene) - Light tan to gray latite and quartz latite, often stained rust brown, with 15-30% phenocrysts of sanidine, pyroxene and/or hornblende, sparse quartz, and altered cubes of pyrite. Plagioclase phenocrysts to several centimeters in length are present. Occurs as dikes up to 20 m wide and elongate intrusive masses north of the Lawrence Ranch.

Trp – Porphyritic rhyolite - (Miocene and Oligocene) - White to light tan to light gray porphyritic rhyolite typically containing 5-20% phenocrysts of quartz, sandine, and sparse plagioclase and biotite. Occurs as dikes 1-10 m wide and local irregular and shallow intrusions (LR). Generally only observed as float.

Tri – Aphanitic rhyolite –(Miocene and Oligocene) – Aphanitic to sparsely porphyritic rhyolite, otherwise similar to Trp.

Tapi – Porphyritic andesite and dacite – (Miocene and Oligocene) – Fine-grained dark gray aphanitic and porphyritic andesite and minor basalt. Where present, phenocrysts include hornblende, plagioclase, biotite, and little or no quartz or sanidine.

Tqk – Potassium feldspar quartz latite – (Miocene and Oligocene) – Coarsely porphyritic, light-gray quartz latite containing potassium feldspar phenocrysts as long as 5 cm (LR).

Trt - Amalia Tuff - (Oligocene) – Pinkish-red, welded rhyolite tuff with fiamme to 5 cm in length. Contains abundant phenocrysts of quartz and sanidine, and volcanic lithic fragments.

Tt – Tuff of Tetilla Peak – (Oligocene) – Quartz-rich, light-colored, weakly welded, rhyolitic ash-flow tuff containing abundant small volcanic fragments. Contains 10-30% phenocrysts of quartz, sanidine, plagioclase and sparse chloritized biotite. Lithic fragments mostly andesite and quartz-bearing rhyolite (LR).

Proterozoic Igneous and Metamorphic Rocks

Xd – Diabase – (early Paleozoic or late Proterozoic(?)) – Nonfoliated, dark gray-green, medium- to fine-grained rocks with well preserved ophitic texture (LR).

Xqc – Quartz monzonite of Columbine Creek (early Proterozoic) - White to gray to pale tan, moderately to strongly foliated quartz monzonite. Recrystallized to sugary textured, non foliated rock near Tertiary plutons. Age is 1730 Ma (Lipman and Reed, 1989).

Xq – Quartzite (early Proterozoic) - White to gray, massive, vitreous quartzite with crossbeds defined by heavy mineral concentrations. Pervasively fractured into decimeter-scale, angular lozenges by joints, irregular fractures, and bedding.

Xms - Biotite muscovite schist and gneiss – (early Proterozoic) – Medium- to coarse-grained, thinly layered to massive, lustrous quartz mica schist and gneiss. Commonly contains sillimanite. Locally contains garnet, andalusite and cordierite (LR).

Xfg – Felsic gneiss (early Proterozoic) - Pale gray to orange-brown, micaceous, weakly to moderately foliated, quartzofeldspathic gneiss locally grading to micaceous quartzite. Commonly interlayered with amphibolite and amphibole gneiss.

Xa – Amphibolite (early Proterozoic) - Thinly layered to massive, fine- to coarse-grained, medium green to dark green to black amphibolite and amphibole gneiss. Locally contains calc-silicate gneiss, biotite-hornblende gneiss, felsic gneiss, and muscovite biotite schist (LR).

Table 2 – Well data collected in this study (notes are at end of tables).

Well ID	OSE RG #[1]	UTM E[2]	UTM N	Elevation[3]	Depth[4]	Driller's dtw[5]	Measured dtw[6]	Date[7]	Water level	Screen top	Screen bottom	Bas/bedr[8] depth	Bas/bedr elevation
AS-1	68469	448438	4041199	7585	140	35	35.24	4/27/05	7550	100	140	-	-
AS-2	76172	447720	4042620	7631	350	0	192.98	4/28/05	7438	250	350	-	-
AS-4	69159	447402	4041580	7562	380	250	108.00	4/27/05	7454	340	380	-	-
AS-101	36895	448764	4041427	7617	50	10	15.59	4/28/05	7601	20	50	-	-
AS-102	?	448799	4041347	7612	?	?	6.81	4/28/05	7605	?	?	-	-
AS-103	57621	448872	4042064	7671	180	175	51.14	5/10/05	7619	130	170	-	-
DM-2	70886	446084	4042178	7466	280	131	185.01	4/13/05	7281	240	280	-	-
DM-3	72426	446183	4042263	7488	320	208	195.83	4/13/05	7292	240	320	-	-
DM-5	63664	446428	4043504	7371	184	68	96.45	5/12/05	7277	75	180	180	7193
DM-13	64878	447941	4040687	7523	105	20	*gps only*	-	7503	65	105	-	-
DM-21	59384	445809	4041642	7461	750	350	411.15	4/28/05	7049	650	750	675	6785
DM-24	20046	449435	4042394	7739	500	175	26.81	5/11/05	7713	169	408	-	-
DM-30	62489	444391	4042210	7365	570	290	385.40	4/13/05	6980	520	560	-	-
DM-34	68172	446935	4041361	7528	343	193	165.30	4/27/05	7362	183	343	-	-
DM-101	?	447382	4042496	7602	?	?	190.79	4/28/05	7411	?	?	-	-
DM-102	59384	445820	4041621	7461	365	190	255.00	4/28/05	7206	325	365	-	-
DM-103	66358	444395	4042993	7343	280	200	240.82	5/10/05	7102	220	280	-	-
DM-104	49139	444980	4043522	7159	65	26	28.96	5/10/05	7130	43	59	-	-
DM-105	74965	446764	4038728	7356	180	40	41.73	5/11/05	7314	100	180	-	-
DM-106	69994	446264	4040798	7470	420	290	252.04	5/11/05	7218	340	420	-	-
ES-1	68698	450417	4042057	7869	140	70	52.93	4/13/05	7813	100	140	-	-
ES-2	76245	451087	4042173	8001	426	28	53.20	4/12/05	7955	?	?	-	-
ES-3	64387	451472	4042125	8126	99	44	70.09	4/12/05	8057	48	99	-	-
ES-4	68777	450974	4042075	7964	100	50	4.98	4/27/05	7959	60	100	-	-
ES-5	58385	449973	4042257	7815	187	65	59.63	4/27/05	7755	100	140	-	-
ES-6	68531	450820	4042229	7969	650	138	143.95	5/10/05	7827	140	650	-	-

Table 2 (cont.) – Well data collected in this study.

Well ID	OSE RG #	UTM E	UTM N	Elevation	Depth	Driller's dtw	Measured dtw	Date	Water level	Screen top	Screen bottom	Bas/bedr depth	Bas/bedr elevation
ES-9	67222	451920	4041921	8241	100	37	32.64	4/27/05	8209	60	100	-	-
ES-10	72994	451632	4042523	8193	520	197	157.51	4/12/05	8068	420	520	-	-
ES-15	54271	451569	4041871	8126	250	60	13.18	4/13/05	8084	60	250	-	-
ES-18	55519	451925	4041381	8154	?	10	2.95	4/12/05	8153	22	220	-	-
ES-21	55147	450743	4042571	8055	?	284	313.63	4/13/05	7731	340	380	-	-
ES-23	63288	450866	4042749	8135	?	370	95.00	4/12/05	8051	435	495	-	-
ES-24	65789	451091	4042463	8095	?	180	179.32	4/12/05	7941	240	335	-	-
ES-126	?	451360	4041984	8077	?	?	16.74	4/12/05	8060	?	?	-	-
ES-127	?	451348	4041984	8070	?	?	3.49	4/12/05	8067	?	?	-	-
ES-128	?	451576	4041538	8049	?	?	0.45	4/12/05	8049	?	?	-	-
ES-129	?	451731	4042625	8291	?	?	246.34	4/12/05	8045	?	?	-	-
ES-130	60367	450692	4042590	8045	?	?	299.41	4/27/05	7746	?	?	-	-
ES-131	81280	450039	4042169	7812	145	46	64.25	4/27/05	7747	105	145	-	-
ES-132	31148?	449521	4042721	7779	150	90	51.72	5/11/05	7728	?	?	-	-
ES-seep	-	451943	4041685	8220	-	-	-	-	8220	-	-	-	-
VAL-7	53728	446598	4044438	7525	210	160	138.49	5/11/05	7386	180	210	-	-
VAL-101	62335	448745	4042841	7713	320	290	*gps only*	-	7423	260	335	-	-
VAL-102	68392	449462	4044674	7975	400	360	66.36	5/10/05	7909	300	400	-	-
VAL-103	74051	446770	4042772	7572	300	175	170.00	5/11/05	7402	220	300	-	-
VAL-104	74109	447095	4043589	7455	280	184	165.40	5/11/05	7290	200	280	-	-

Table 3 – Well data collected by Glorieta Geoscience, Inc., and used in this study.

Well	OSE RG #	UTM E	UTM N	Elevation	Depth	Driller's dtw	Measured dtw	Date	Water level	Screen top	Screen bottom	Bas/bedr depth	Bas/bedr elevation	Comment
Arroyo Seco Plaza	74081	448950	4041175	7613	740	60	?	?	7553	320	720	-	-	AS-5
Arroyo Seco School	66075	446162	4042084	7480	760	658	658.70	8/12/97	6820	660	740	800	6678	DM-1
Cielo Azul	65614	446420	4040260	7441	353	128	137.48	7/30/96	7303	?	?	-	-	DM-41
Cielo Azul Deep	70152	446400	4040250	7444	850	347	340.74	10/22/98	7103	720	840	-	-	DM-43
New Mariposa Ranch	62458	444890	4041950	7411	800	585	582.00	9/14/95	6829	520	725	756	6655	DM-15
Old Mariposa Ranch	?	445180	4040820	7405	~ 700	289	295.00	7/24/95	7110	?	?	-	-	DM-18
Yaravitz	52455	449826	4042805	7834	400	0	95.40	10/31/91	7738	270	400	-	-	-
Hacienda	?	449688	4043734	7660	702	80	?	?	7580	141	641	-	-	OSE data

Table 4 – Well data used in this study collected by Taos Soil and Water Conservation District.

Well	OSE RG #	UTM E	UTM N	Elevation	Depth	Driller's dtw	Water Level	Screen top	Screen bottom
DM-6	63898	446518	4041554	7503	300	130	7373	260	300
DM-7	67500	446457	4041657	7508	360	220	7288	260	360
DM-16	75035	444290	4041545	7359	760	480	6879	580	740
DM-23	73517	444823	4042687	7410	490	438	6972	440	490
DM-29	75913	444790	4042187	7394	960	870	6523	880	960
DM-36	50207	445683	4042875	7484	260	130	7354	200	260
DM-38	?	445736	4043034	7487	340	238	7249	300	340
DM-39	60926	446045	4042801	7516	260	180	7336	220	260
DM-42	71432	446291	4040386	7451	302	190	7261	262	302
DM-44	46375	448904	4044372	7961	870	620	7341	640	670
DM-45	?	446346	4044594	7638	310	250	7388	?	?
ES-20	?	451150	4041750	7979	320	205	7774	220	320
VAL-1	63016	447946	4043521	7538	232	195	7343	170	230
VAL-2	69159	447953	4043806	7394	380	250	7144	340	380
VAL-3	61611	448416	4044163	7895	693	410	7485	645	688
VAL-8	52512	448050	4043275	7444	35	15	7429	15	35
VAL-10	?	448500	4043300	7480	95	48	7432	?	?

[1] Identification number assigned to well by the NM Office of the State Engineer (OSE). All wells are in the Rio Grande hydrologic basin.
[2] Universal Transverse Mercator coordinates, NAD27 datum, in meters. Wells were located with a handheld GPS unit, with an accuracy of ± 8 meters or better.
[3] Elevations and depths of all wells are in feet. Elevations of well heads were derived from a 10-meter digital elevation model, based on the GPS location.
[4] Depth of well.
[5] Depth to water (dtw) as recorded by the well driller in OSE records.
[6] Depths to water in this study were measured with a graduated steel tape.
[7] Date of water level measurement.
[8] Bas/bedr = basalt or bedrock, depending on which was encountered in well.

PLATE 1A

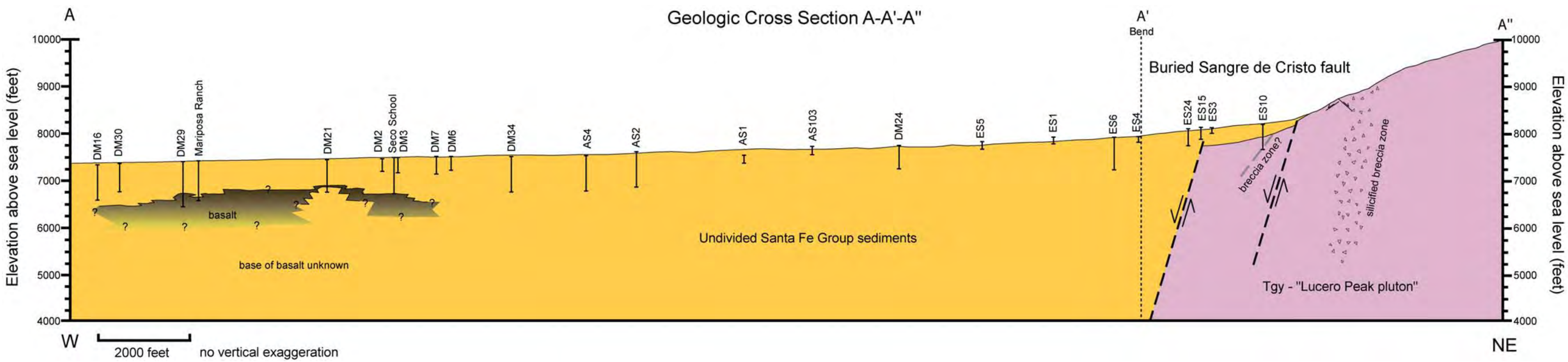

Geologic Cross Section A-A'-A''
A
A'
Bend
A''
Buried Sangre de Cristo fault
Elevation above sea level (feet)
10000
9000
8000
7000
6000
5000
4000
DM16
DM30
DM29
Mariposa Ranch
DM21
DM2
Seco School
DM3
DM7
DM6
DM34
AS4
AS2
AS1
AS103
DM24
ES5
ES1
ES6
ES4
ES24
ES15
ES3
ES10
basalt
base of basalt unknown
Undivided Santa Fe Group sediments
breccia zone?
silicified breccia zone
Tgy - "Lucero Peak pluton"
W
NE
2000 feet
no vertical exaggeration

PLATE 1B

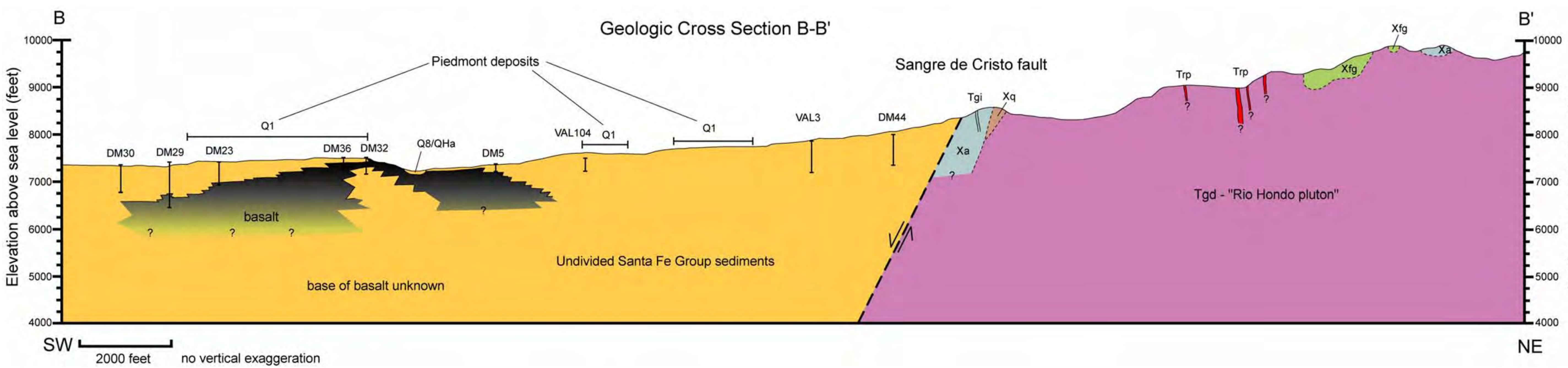

B
B'
Geologic Cross Section B-B'
10000
9000
8000
7000
6000
5000
4000
Elevation above sea level (feet)
Piedmont deposits
Sangre de Cristo fault
Q1
Q1
Q1
DM30
DM29
DM23
DM36
DM32
Q8/QHa
DM5
VAL104
VAL3
DM44
Tgi
Xq
Xa
Trp
Trp
Xfg
Xfg
Xa
basalt
?
Undivided Santa Fe Group sediments
base of basalt unknown
Tgd - "Rio Hondo pluton"
SW
2000 feet
no vertical exaggeration
NE

PLATE 2A

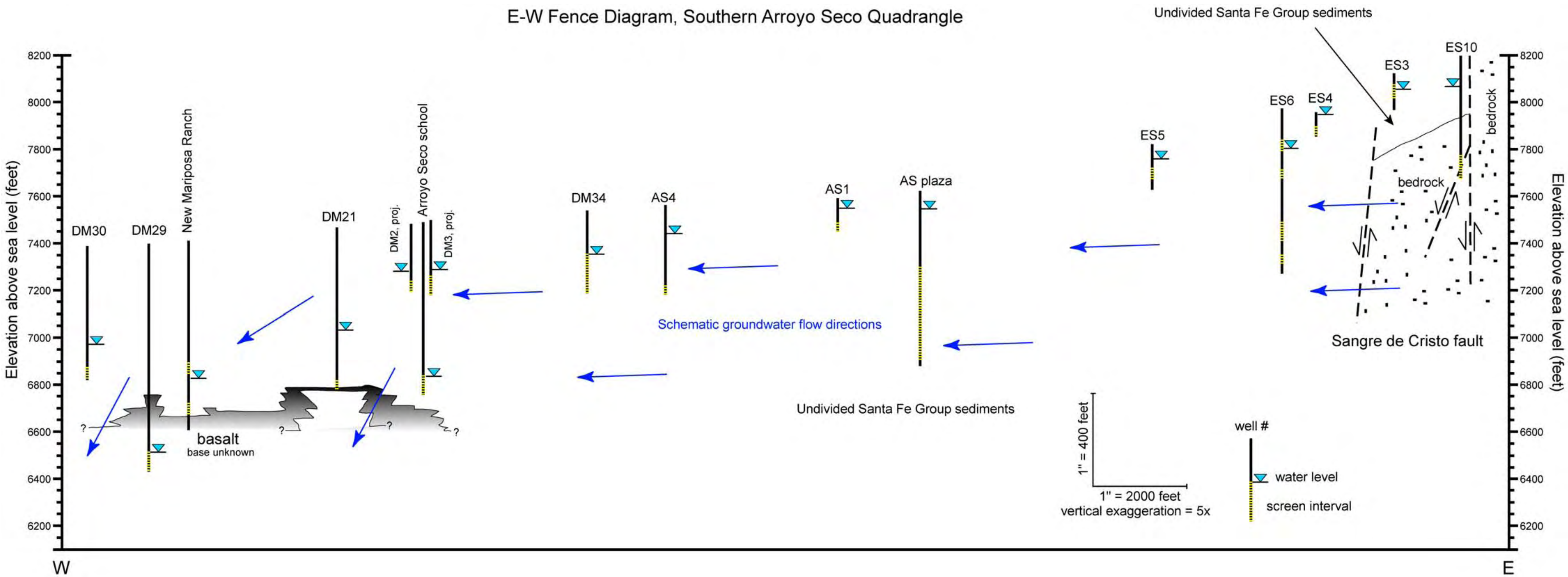


Plate 2a East to west fence diagram. Line of fence connects the wells shown (see Map 3); distances between wells are true distances, not projections. Tops of wells are at the ground surface. Examination of driller's logs revealed no continuous, stratigraphic horizons in the Santa Fe Group sediments that could be correlated. Groundwater flow directions are based on water level contours shown on Map 3.

PLATE 2B

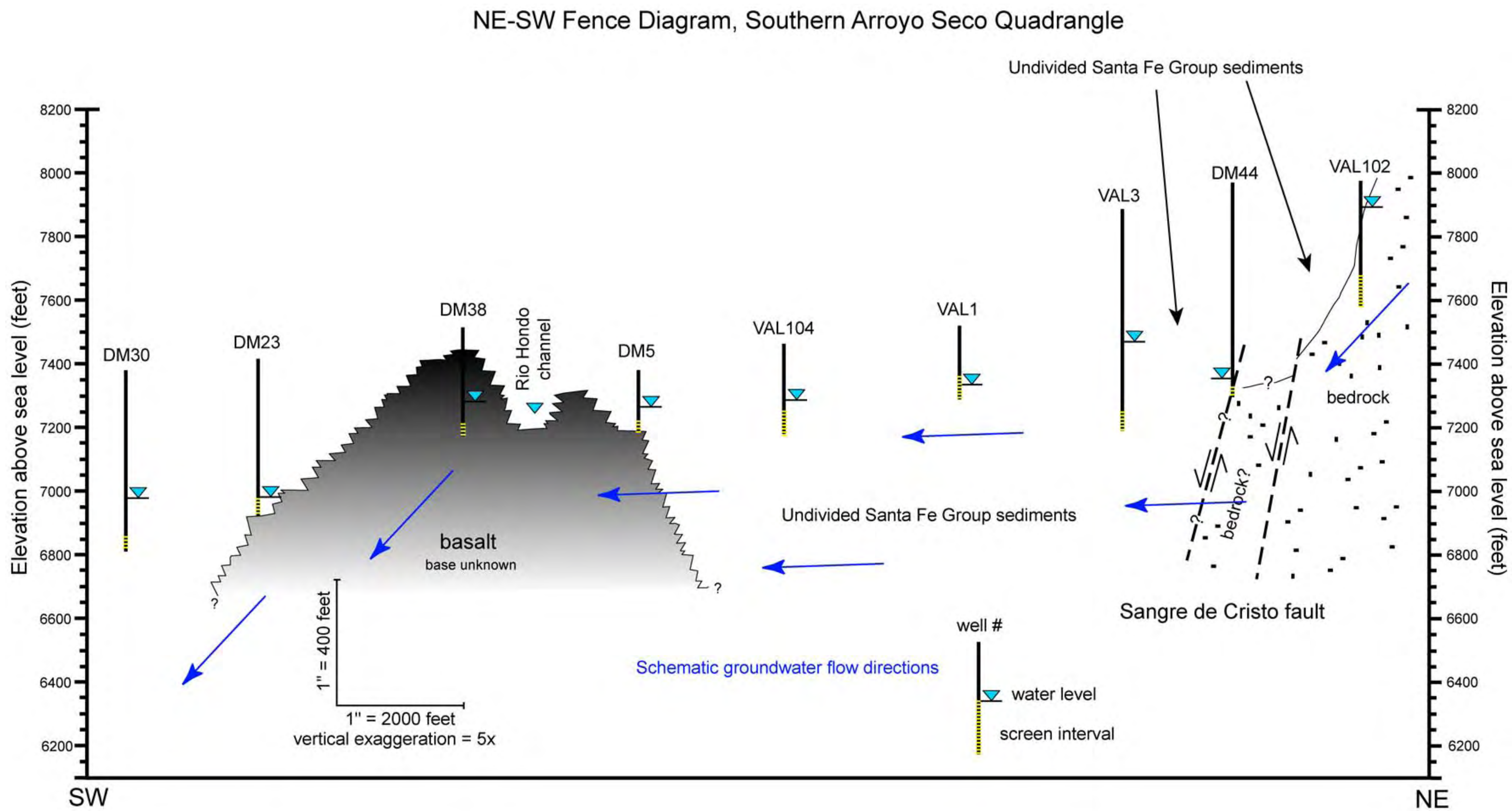
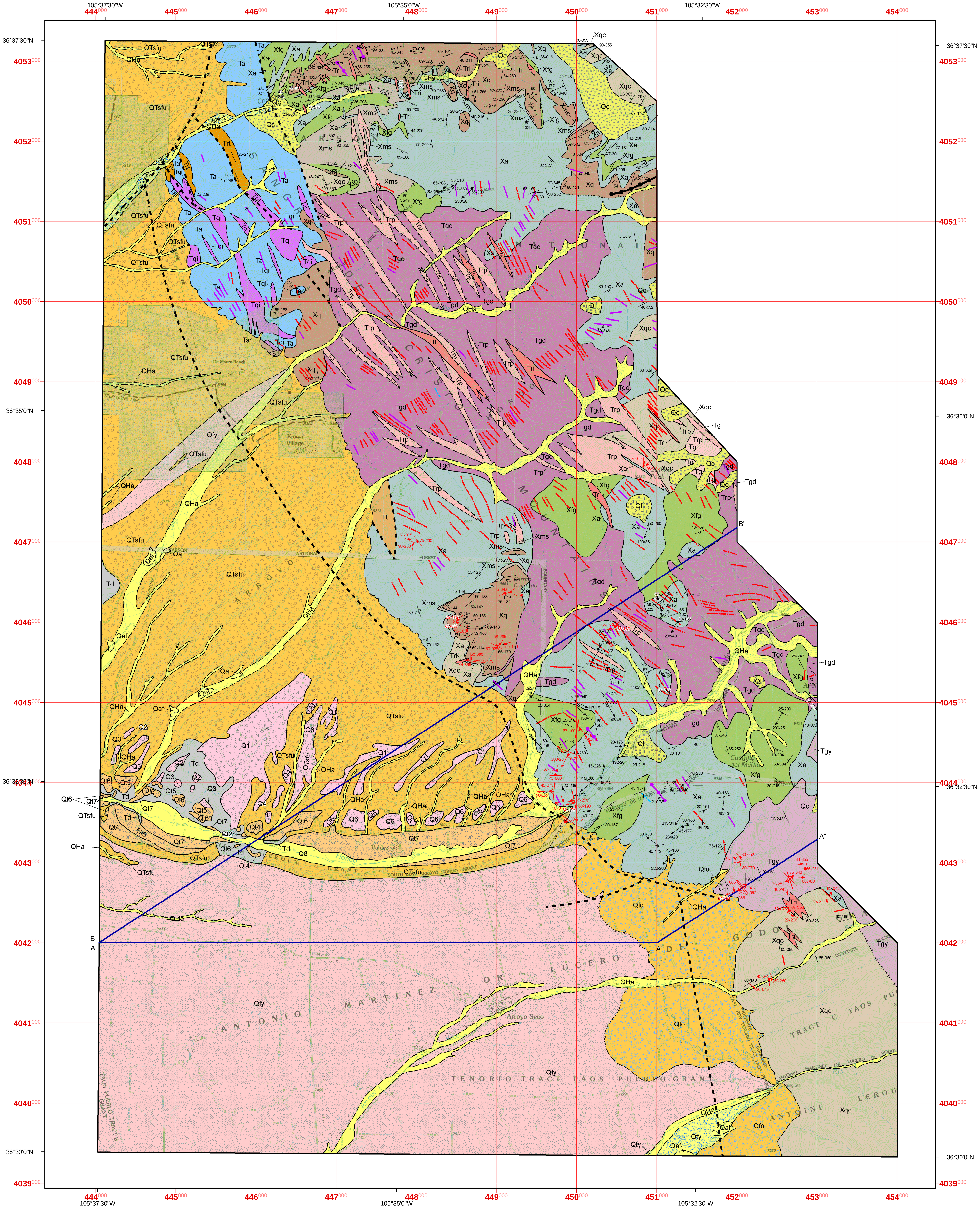


Plate 2b Northeast to southwest fence diagram. Line of fence connects the wells shown (see Map 3); distances between wells are true distances, not projections. Tops of wells are at the ground surface. Examination of driller's logs revealed no continuous, stratigraphic horizons in the Santa Fe Group sediments that could be correlated. Groundwater flow directions are based on water level contours shown on Map 3.



Explanation of symbols

Point measurements

- upright bedding
- overturned bedding
- bedding, top unknown
- S2 foliation
- compositional layering
- mineral lineation
- fault plane
- slickenline
- joint

Geologic contacts

- certain, exposed
- certain, approximately located
- inferred, approximately located
- uncertain, approximately located

Dikes

- Tqi
- Tri
- Trp
- Tapi
- Tqk
- Xd
- fault - approximately located
- line of cross section

Geologic Units

(see Appendix 1 for descriptions)

QHa, Q8, Qc, Ql, Qaf, Qty, Qt7, Qt6, Q6, Qsct, Qt5, Qt4, Q4, Q3, Qt2, Q2, Q1, Qfy, Qfo, QTsfu, Td, Tgy, Tg, Tgd, Ta, Tqi, Tri, Trp, Trt, Tt, Xqc, Xq, Xms, Xfg, Xa

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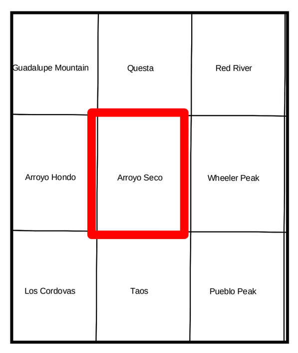
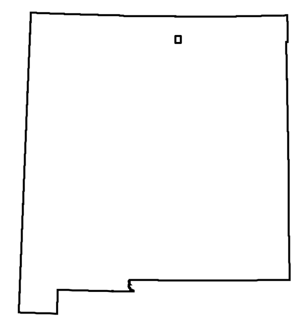
or contact:
NMBGMR Publications -- [505] 835-5410
NMBGMR Geologic Information Center -- [505] 835-5145





Magnetic Declination
July, 2005
9º 39' East
At Map Center

Base from U.S.Geological Survey 1984, from photographs taken 1976 and field checked in 1976.
Map edited in 1984
1927 North American datum, UTM projection -- zone 13N
1000- meter Universal Transverse Mercator grid, zone 13, shown in red

COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

Map 1 - Geologic Map of a portion of the Arroyo Seco 7.5 - minute Quadrangle
by
Geoffrey C. Rawling

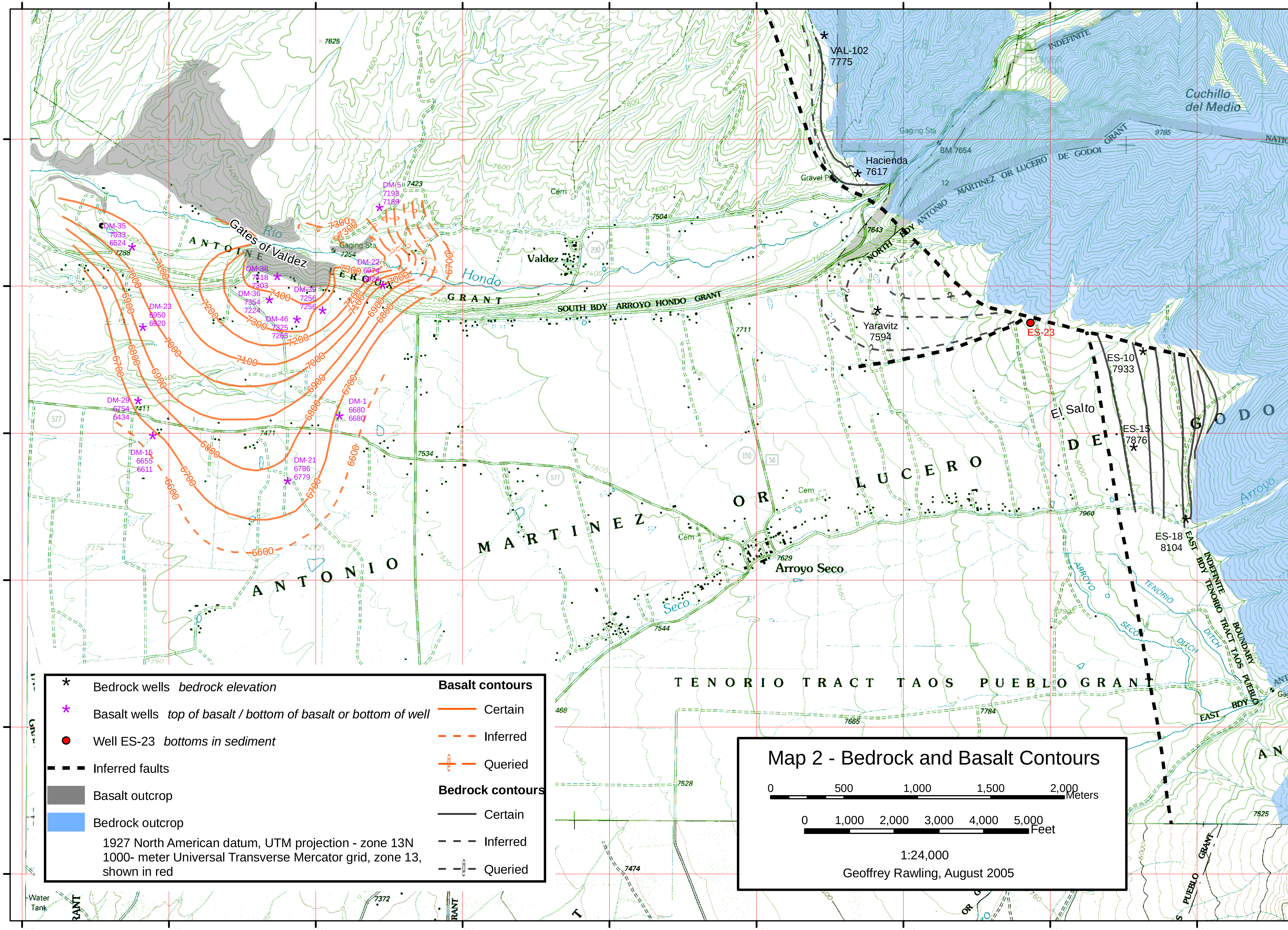
July 2005

1:24,000

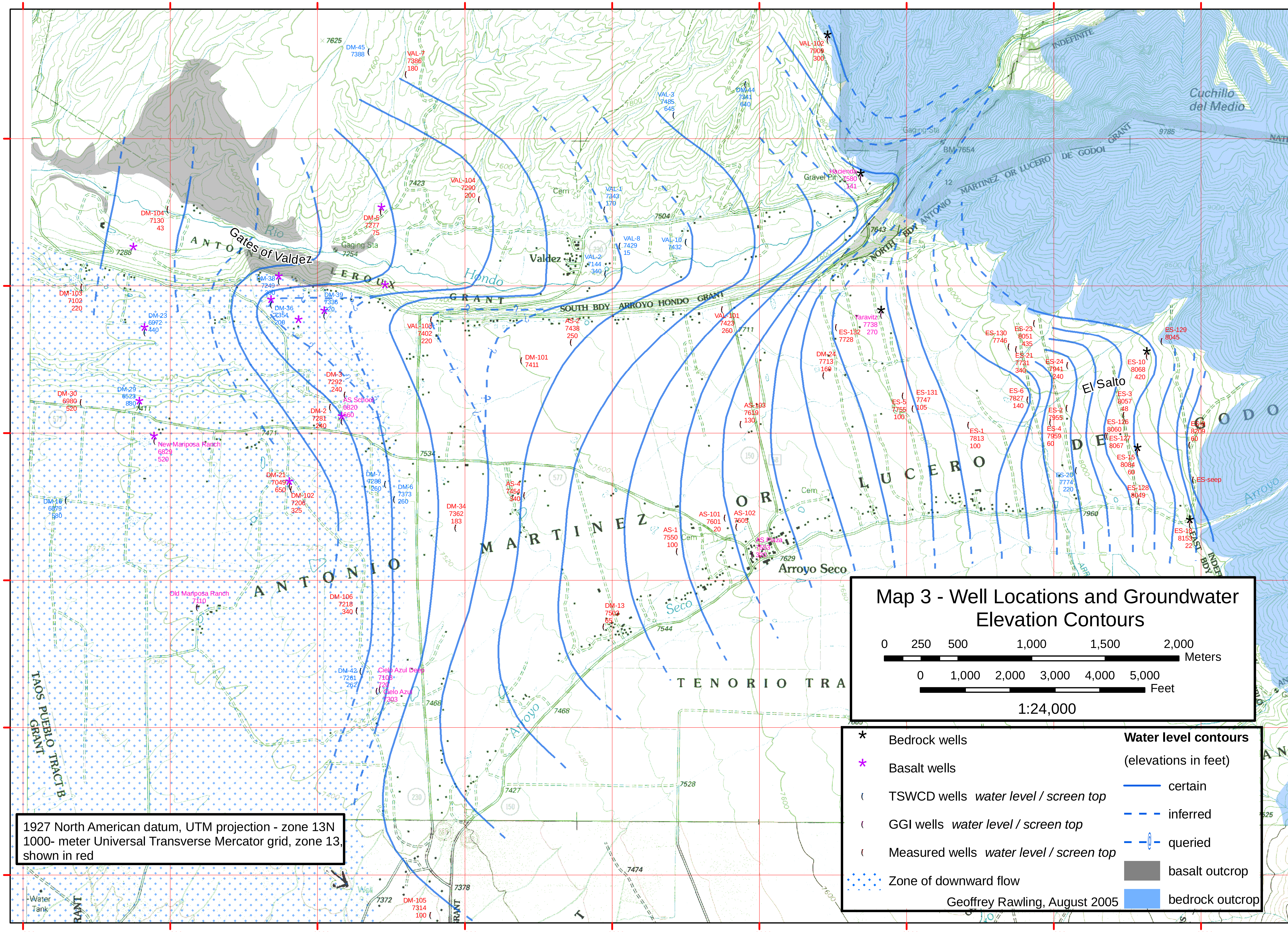
0 0.25 0.5 1 1.5 2 Miles

0 0.25 0.5 1 1.5 2 Kilometers

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



Map 2 - Bedrock and Basalt Contours
0 500 1,000 1,500 2,000 Meters
0 1,000 2,000 3,000 4,000 5,000 Feet
1:24,000
Geoffrey Rawling, August 2005
Bedrock wells bedrock elevation
Basalt wells top of basalt / bottom of basalt or bottom of well
Well ES-23 bottoms in sediment
Inferred faults
Basalt outcrop
Bedrock outcrop
1927 North American datum, UTM projection - zone 13N
1000- meter Universal Transverse Mercator grid, zone 13, shown in red
Basalt contours
Certain
Inferred
Queried
Bedrock contours
Certain
Inferred
Queried
VAL-102 7775
Hacienda 7617
Yaravitz 7594
ES-23
ES-10 7933
ES-15 7876
ES-18 8104
DM-5 7193 7189
DM-35 7033 6524
DM-38 7318 7303
DM-36 7354 7224
DM-39 7256 7256
DM-22 6974
DM-46 7325 7265
DM-23 6950 6920
DM-29 6754 6434
DM-1 6680 6680
DM-15 6655 6611
DM-21 6786 6779
Gates of Valdez
Rio Hondo
Valdez
Arroyo Seco
El Salto
Cuchillo del Medio
ANTONIO MARTINEZ OR LUCERO DE GODOI GRANT
SOUTH BDY ARROYO HONDO GRANT
TENORIO TRACT TAOS PUEBLO GRANT
444000 445000 446000 447000 448000 449000 450000 451000 452000
4044000 4043000 4042000 4041000 4040000 4039000



Map 3 - Well Locations and Groundwater Elevation Contours
0 250 500 1,000 1,500 2,000 Meters
0 1,000 2,000 3,000 4,000 5,000 Feet
1:24,000
Bedrock wells
Basalt wells
TSWCD wells water level / screen top
GGI wells water level / screen top
Measured wells water level / screen top
Zone of downward flow
Geoffrey Rawling, August 2005
Water level contours
(elevations in feet)
certain
inferred
queried
basalt outcrop
bedrock outcrop
1927 North American datum, UTM projection - zone 13N
1000- meter Universal Transverse Mercator grid, zone 13, shown in red
Gates of Valdez
Valdez
Arroyo Seco
El Salto
Cuchillo del Medio
Hondo
TAOS PUEBLO TRACT B GRANT
ANTONIO LEROUX GRANT
ANTONIO MARTINEZ OR LUCERO DE GODOI GRANT
SOUTH BDY ARROYO HONDO GRANT
TENORIO TRA
Old Mariposa Ranch
New Mariposa Ranch
Cielo Azul Deep
Cielo Azul
Hacienda
Taravitz
AS School
Gravel Pit
Gaging Sta
Water Tank
444000
445000
446000
447000
448000
449000
450000
451000
452000
4044000
4043000
4042000
4041000
4040000
4039000