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HYDROGEOLOGY OF SOUTHEAST SUNSHINE VALLEY, NEW MEXICO

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Abstract—In order to demonstrate water availability for subdivision approval, a site specific study was conducted for a location in the southeast Sunshine Valley. An exploratory well proved the existence of an exceptionally coarse-grained clastic aquifer, with tested hydraulic conductivity values of 70 to 83 feet per day. The results are compared with hydrologic studies in basin margin settings of Taos Valley, and provide regional and site specific data on the hydrogeology of the southern San Luis Valley. Analogous hydrogeologic characteristics may be found in alluvial fan deposits of streams debouching along the Sangre de Cristo mountain front.

INTRODUCTION

As part of a water availability study, the hydrogeology of a small (13-lot) subdivision site in the southeast Sunshine Valley was investigated with a test well, aquifer pump testing, water quality analysis, and modeling of water level drawdown. The study was made in conformance with Taos County and New Mexico Office of the State Engineer (NMOSE) requirements to insure the water supply and assess the potential effects on nearby water users over a 50-year time frame.

REGIONAL GEOLOGIC SETTING

Sunshine Valley is the southernmost part of the San Luis Valley, extending about 20 miles from the Colorado state line to the town of Questa in Taos County, New Mexico (Fig. 1). The valley is about five to ten miles wide and extends from the Rio Grande Gorge eastward to the Sangre de Cristo mountain front. The valley is bordered to the west by the extensive lava-capped Taos Plateau, which in turn is bordered on its west by the Tusas Mountains. Sunshine Valley lies in the Costilla Plains physiographic subdivision of Taos County (Garrabrant, 1993), and occupies about 125 square miles. The neighboring Taos Plateau occupies an additional 700 square miles and includes the volcanic prominence of Ute Mountain, a pleasingly symmetrical volcanic feature on the northwest boundary of Sunshine Valley. The valley is floored with alluvial deposits throughout its extent, but is progressively narrowed to the south by numerous volcanic features including Cerro de la Olla, Cerro Chiflo, and Cerro Guadalupe near the town of Questa, where Sunshine Valley has its southern boundary.

Sunshine Valley occupies the eastern edge of the San Luis Basin, created by the extensional tectonics of the Rio Grande rift and infilled with sediments and lava flows. Strata in the valley generally dip eastward towards the Sangre de Cristo Mountains, where the basin abruptly ends at a major, active normal fault. Holocene fault scarps are visible just southeast of the town of Costilla on this segment of the Sangre de Cristo fault zone (Machette and Personius, 1984, p.8).

Beneath the Servilleta Basalts, and interbedded with them, are thousands of feet of sedimentary basin-fill deposits of the Santa Fe Group. In Taos Valley, located 20 miles south of Sunshine Valley (Fig. 1), source areas for these 700-foot thick, Tertiary-age basalts include vents and volcanoes located mostly west of the Rio Grande, so the basalts thin towards the east and eventually pinch out near the mountain front and in irregular intervening areas. Thick sections of alluvium at the margins of the Sangre de Cristo Mountains are composed of alluvial fan and stream deposits that interfinger westward with finer-grained basin-floor and lacustrine strata (Bauer et al., 1999). The situation is analogous in Sunshine Valley, where Cerro Guadalupe, Cerro Chiflo, and Ute Mountain were ancient vent areas for the basalts that flowed eastwards. In the eastern side of Sunshine Valley, alluvial fan, stream, and lacustrine deposits form a thick wedge of alluvium under the piedmont at the foot of the mountain (Winograd, 1959). Detailed maps of the attitude and elevation of the basalt flows in Sunshine Valley show that they dip eastward and interfinger with alluvial fan and lakebed (or playa) deposits, the latter possibly related to ancient Lake Alamosa in the northern San Luis Basin (Machette et al., 2007). The extent of suspected lacustrine deposits was defined by Winograd (1959) based on deep test holes by the Army Corps of Engineers as part of a damsite study near the modern-day Wild and Scenic Rivers section of the Rio Grande Gorge (Winograd, 1985).

A regional geologic cross-section through the central Sunshine Valley (Figs. 2 and 3) shows the thick basin fill sediments on the east side of the basin terminating abruptly against the fault along the Sangre de Cristo Mountains uplift. Volcanic rocks at depth are overlain by fluviolacustrine deposits that pinch out eastward towards the site, replaced by coarse clastics from alluvial fans shed by the mountain block. The volcanic rocks rise to the surface towards the west, capping the broad Taos Plateau with lava beds. Very similar stratigraphic and structural relationships are found along the southeastern margin of the Taos Valley, where Servilleta Basalts on the Taos Plateau feather out towards the basin margin and are replaced by a thick alluvium wedge on the basin margins (Bauer et al., 1999). On a regional scale, the relationship can be thought of as a normal-faulted half-graben, where coarse clastic, marginal fanglomerates interfinger with east-tilted basin-floor sediments and volcanic rocks.

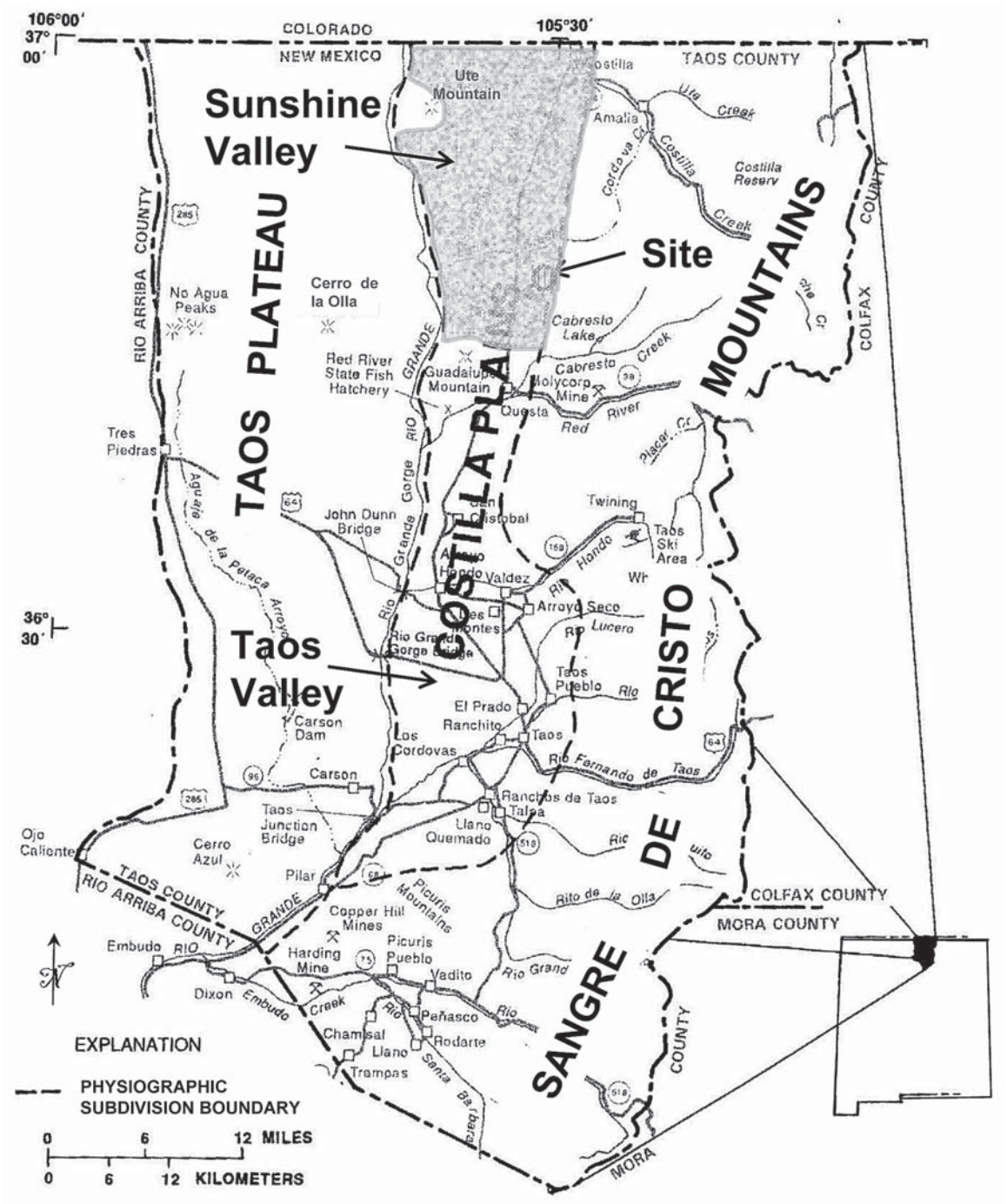


FIGURE 1. Location map (from Garrabrant, 1993) showing Sunshine Valley and location of detailed project area ("site").

REGIONAL HYDROLOGY

A component of groundwater is recharged in Sunshine Valley by direct infiltration of rainfall and snowmelt. Areal recharge over broad areas accumulates to create an important source of groundwater inflow from the Taos Plateau. Burck et al. (2004) created a regional groundwater model of Taos Valley that used an areally distributed recharge over the land surface of about 4% of the annual precipitation, or about 0.5 inches per year. The total recharge may therefore be about 25,000 AFA (acre-feet per annum) over the 825 square miles of the northern Taos Plateau and Sunshine Valley.

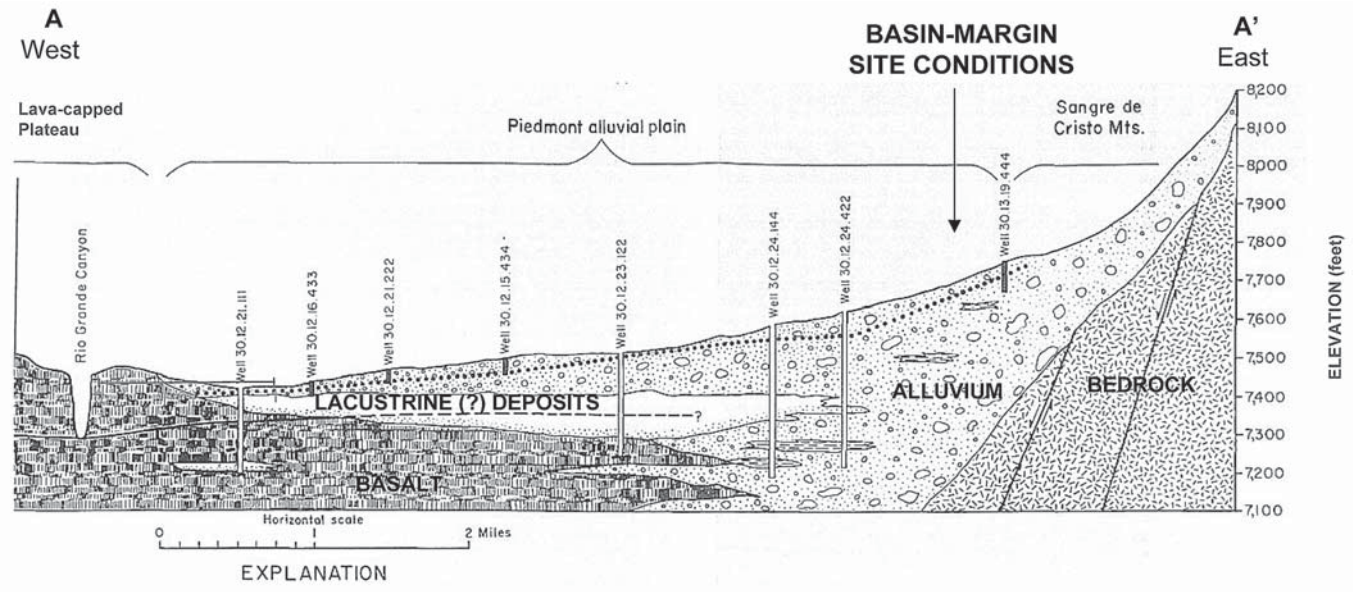


FIGURE 2. Regional geologic cross-section A-A' runs through the southeastern part of Sunshine Valley (modified from Winograd, 1959); location shown in Figure 3. Lacustrine (?) deposits are unpatterned; deep water table is represented by the dashed, queried line, and shallow water table by dotted line.

Groundwater also enters the aquifer systems via stream infiltration at the base of the Tusas and Sangre de Cristo Mountains. Steep mountain canyons debouch onto the broad alluvial aprons along the eastern edge of Sunshine Valley, spanning about 20 miles from the state line to Questa. These include several perennial streams (Costilla Creek, Latir Creek, Rito del Medio, Rito Primero, and Cañada Pinabete). Infiltration of surface water flows from Red River and Cabresto Creek also contributes to local recharge in the southernmost part of Sunshine Valley. In the Burck et al. (2004) regional model, mountain-front recharge (defined as the combination of stream infiltration and aquifer subflow) represents about 11% of the total annual precipitation in the mountainous areas around the basin. This compares well with estimates from other parts of the southwest US with similar elevations of 7% to 15% of the annual precipitation being recharged along the mountain front areas (Avon and Durbin, 1994). The Sangre de Cristo Mountains east of Sunshine Valley drain about 350 square miles and have an average precipitation of 24 inches, so at 11% the watershed yield would be about 49,000 AFA.

From the Colorado state line to the vicinity of Red River, the Rio Grande gains a total of about 70,000 AFA (Winograd, 1959). This water is derived as inflow from Colorado, mountain-front recharge along the Sangre de Cristos and Tusas Mountains, and direct recharge from the land surface, increasing streamflow by "groundwater accretion" to the Rio Grande. About one-quarter of this amount, or 20,000 AFA, is reportedly sourced within the Sunshine Valley (Garrabrant, 1993). Narrowing of the alluvium in the southern end of Sunshine Valley is caused by numerous volcanic features in the Questa area, likely limiting underflow and causing an upwelling of groundwater, which in turn increases streamflow. Based on detailed water-level mapping, Benson (2004) indicates that fractured volcanic rocks near Cerro Guadalupe may have relatively high permeability.

Outflow from the basin includes discharge to the Rio Grande, some component of underflow southward towards Taos Valley, and groundwater pumpage. Historically there have been agricultural wells in Sunshine Valley, with pumpage totaling 3,500 AFA in 1955 but decreasing to about 300 AFA by 1985 (Garrabrant, 1993). Numerous private domestic wells also use the groundwater resource in the area.

Depth to water in Sunshine Valley ranges from tens to hundreds of feet. Fracture zones within the basalt flows, and layers of sedimentary rocks between the flows, generally provide good amounts of groundwater to area wells, with yields as high as 3,000 gpm (gallons per minute). Perched alluvial aquifers were noted by Winograd (1959) in Sunshine Valley, often resulting in cascading water in wells open to both alluvium and basalt. The regional geologic cross-section (Fig. 2) shows both a perched and regional water table at the basin margin, reflecting a downward vertical gradient characteristic of recharge areas (Winograd, 1985; Bauer et al., 1999; Burck et al., 2004). Figure 3 is a regional water table map which shows groundwater contours converging towards the Rio Grande, confirming that the river is strongly gaining in this reach.

In the shallow alluvium aquifer of Taos Valley, reported values of the hydraulic conductivity (K) range from 0.1 to 22 ft/day (feet per day), with both confined and unconfined aquifer conditions present (Drakos et al., 2004). Storativity (S) is reported to range from 10^{-2} to 10^{-4}. The Burck et al. (2004) regional model used storage coefficient values of 15% (0.15), and T (transmissivity) values of 150 to 1,500 ft^2/day for shallow aquifers in Taos Valley. Table 1 summarizes pump test data for 4 wells in basin-margin alluvium of the southern Taos Valley, at locations where basalts were absent. These aquifer tests resulted in T values of 317 to 2,625 ft^2/day, and corresponding K values of 5.3 to 26.3 ft/day. These aquifer parameter values provide background for basin-

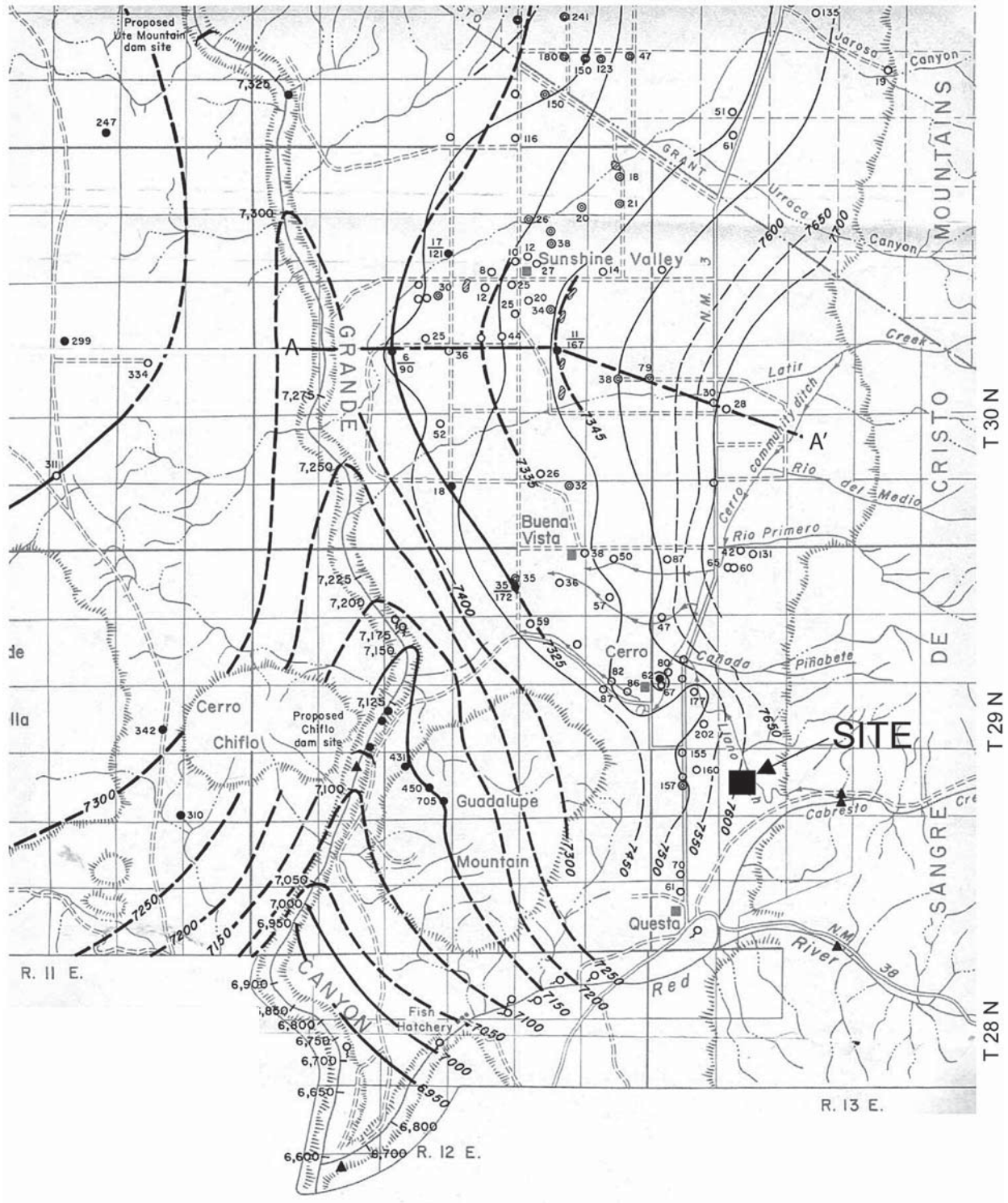


FIGURE 3. Regional water table map of southern Sunshine valley (modified from Winograd, 1959).

TABLE 1. Aquifer test summary for Basin-margin wells, southern San Luis Valley, New Mexico

NMOSE No.	Location (PLS)						TD	DTW	b	T (ft^2/day)	K (ft/day)	References
RG 90428 *	29N	13E	20	4	4	3	400	343.3	56.7	4,717	83.2	Darr, 2008a
RG 90552	25N	12E	26	4	4	3	262	75.5	60	812	13.5	Darr, 2008b
RG 87080	24N	12E	2	1	3	2	460	246.6	60	317	5.3	Darr, 2006a
RG 88208	25N	12E	35	3	4	4	400	168.7	100	572	5.7	Darr, 2006b
RG 88306	25N	12E	35	4	3	3	400	177.3	100	2,625	26.3	Darr, 2006c

Explanation:
NMOSE No. is the well registration number from New Mexico Office of the State Engineer.
***** Note that RG90428 is the test well in Sunshine Valley; other wells are in Taos Valley basin margin.
Location (PLS) are projected Township, Range, Section, and 160/40/10-acre Quarter coordinates.
TD is the Total Depth of the well, in feet.
DTW is the static Depth to Water, in feet.
b is the saturated, screened thickness of the well, in feet.
T (ft^2/day) is the transmissivity calculated from the recovery curve, in square feet per day.
K (ft/day) is the calculated hydraulic conductivity, in feet per day.

References:
Darr, 2006a, unpubl. consultant report for "Ocotillo" Subdivision, Taos County, New Mexico
Darr, 2006b, unpubl. consultant report for “Taos Mountain Vista” Subdivision, Taos County, New Mexico
Darr, 2006c, unpubl. consultant report for “Chaparral” Subdivision, Taos County, New Mexico
Darr, 2008a, unpubl. consultant report for "Cabins in the Pines” Subdivision, Taos County, New Mexico
Darr, 2008b, unpubl consultant report for "Los Llanos” Subdivision, Taos County, New Mexico

margin aquifer parameters in the San Luis Valley, and also provide a basis for comparison to the site-specific study presented below for the southeast basin margin of the Sunshine Valley.

DETAILED SITE STUDY

The site studied in detail is located northeast of the town of Questa, on the valley margin near Cabresto Creek. Well data near the study area were examined for rock type, water levels, completion details, estimated yield, and other information. The coordinates for each well location were cross-referenced with a digital terrain model based on 1:24,000 USGS topographic maps to arrive at land surface elevations. This information was combined with the reported depth to water from NMOSE (2008) to generate water table elevations, as shown in Table 2. The average total depth of these wells is 225 feet, and the average depth to water is 150 feet; therefore, the average water column in these wells is 75 feet. This information was then used to create a local water table map, shown in Figure 4. The water table map confirms that the flow direction is towards the west, with the water table elevation falling from 7,600 to 7,500 feet near the study area, in general agreement with the regional water table map (Fig. 3). Figure 4 also shows areas of high groundwater elevation near Cabresto Creek and the Llano Ditch.

A new test well was drilled to provide site-specific data on subsurface conditions. The test well (RG-90428 in Table 1) was drilled to a depth of 420 feet. Analysis of the well cuttings showed that the upper 120 feet of the section was composed of clay and clay-rich conglomerate, correlating to valley floor alluvium. Coarser sedimentary units were encountered below, with a thick section of sands, gravels and conglomerates to 420 feet. These sediments were particularly coarse-grained due to the proximity of the mountain front, with a notable absence of clay in the cuttings. The screened zone of the test well was placed in an 80-foot section of gravel at the bottom portion of the well, from 320 to 400 feet below land surface. The static water level was measured at 343.1 feet and the well yield was reportedly 25 to 30 gpm. The well is therefore screened across the water table, with a saturated screened thickness of 57 feet and a water column of 77 feet.

An aquifer test was conducted to gather site-specific aquifer parameter data. The test well was pumped for a period of 23.8 hours at an average rate of 29.4 gpm (Fig. 5). During the pumping period the maximum drawdown was 1.65 feet, indicating a specific capacity (SC) of 17.8 gpm/foot for the local aquifer in this area. Using empirical relationships between SC and T (Driscoll, 1986, p. 1021), an approximate T value of 4,764 ft^2/day is derived. Additional analyses of the pumping and recovery data using Jacob’s straight-line approximation of the Theis solution indicate a T value of 3,991 to 4,717 ft^2/day for the pumping and recovery phases, respectively. These values agree with the estimated T from the SC relationship, and establish consistent estimates for the site-specific aquifer T value. Dividing by the saturated screened thickness of 57 feet, the estimated value for K is 70 to 83 ft/day. Both the T and K values confirm that the local aquifer is exceptionally productive, exceeding regional averages and estimates from other aquifer tests in the basin-fill aquifer at basin margin settings (Table 1).

A hydrogeologic cross section (Fig. 6) was prepared for the site and surrounding areas, based on lithologic analysis of cuttings from the test well and descriptions from drillers logs in nearby wells. The section suggests that there are two distinct groundwater tables, shallow (perched) and deep (regional). The deep aquifer is tapped by the test well and by most of the other nearby wells. There is evidence of a shallow, perched aquifer near Cabresto Creek, which likely continues southwest along areas near Cabresto Creek, based on indications of recharge in that area on the water table map (Fig. 4). The presence of a shallow aquifer perched on fine-grained, basin-floor sediments of probable lacustrine or playa origin is consistent with the regional hydrogeologic setting of Sunshine Valley (Winograd, 1959, 1985). The cross-

TABLE 2. Water level data.

NMOSE No.	Location (PLS)						TD	DTW	LSE	UTM (E,N)		PSE
RG 40650	29N	13E	17	2	2	3	250	120	8146	449042	4067813	8026
RG 67791	29N	13E	17	2	2	2	485	290	8191	449223	4067955	7901
RG 70126	29N	13E	17	2	4		395	260	8207	449166	4067705	7947
RG 58493	29N	13E	17	4	2	3	218	100	8159	449049	4067081	8059
RG 02584	29N	13E	18	1	1	4	191	147	7623	446338	4067730	7476
RG 11986	29N	13E	18	1	1		150	100	7620	446303	4067831	7520
RG 64228	29N	13E	18	1	2	2	135	100	7671	446861	4067990	7571
RG 83723	29N	13E	18	1	2	2	230	111	7667	446823	4068003	7556
RG 37094	29N	13E	18	2			220	160	7726	447364	4067699	7566
RG 60996	29N	13E	18	2	2		110	105	7758	447564	4067904	7653
RG 12002	29N	13E	18	3			225	160	7643	446503	4066891	7483
RG 16758	29N	13E	18	3	4		200	140	7653	446633	4066644	7513
RG 18764	29N	13E	18	3	3	1	180	120	7631	446189	4066663	7511
RG 30872	29N	13E	18	3	1		200	140	7626	446253	4067128	7486
RG 43235	29N	13E	18	3	1		160	105	7627	446275	4067103	7522
RG 50215	29N	13E	18	3	1		178	103	7625	446230	4067106	7522
RG 11209	29N	13E	18	4	3		206	145	7687	447158	4066679	7542
RG 11796	29N	13E	18	4	4	3	200	148	7709	447412	4066511	7561
RG 34282	29N	13E	18	4	2	1	200	120	7720	447386	4067182	7600
RG 34382	29N	13E	18	4	2	1	200	120	7728	447415	4067163	7608
RG 37095	29N	13E	18	4			220	140	7719	447421	4066821	7579
RG 82689	29N	13E	18	4	3	4	300	200	7686	447165	4066479	7486
RG 74660	29N	13E	19	1	4	4	200	135	7660	446714	4065787	7525
RG 14128	29N	13E	19	2			210	160	7689	447304	4066071	7529
RG 14682	29N	13E	19	2	3		250	170	7671	447068	4065902	7501
RG 62930	29N	13E	19	2	3	1	200	165	7665	446944	4065894	7500
RG 13710	29N	13E	19	4	3	4	200	150	7666	447218	4064879	7516
RG 60711	29N	13E	19	4	2		220	160	7691	447451	4065530	7531
RG 69575	29N	13E	19	4	3	1	200	143	7667	446926	4065216	7524
RG 72860	29N	13E	20	1	2	4	435	350	7879	448402	4066100	7529
RG 74365	29N	13E	20	1	3	3	240	195	7718	447737	4065709	7523
RG 80209	29N	13E	20	1	4	3	380	308	7788	448164	4065712	7480
RG 84830	29N	13E	20	1	2	3	550	325	7825	448203	4066103	7500
RG 85096	29N	13E	20	1	2	3	490	289	7829	448228	4066080	7540
RG 69303	29N	13E	20	2	3	2	470	410	7974	448752	4066058	7564
RG 73667	29N	13E	20	2	3	3	310	252	7913	448621	4065778	7661
RG 86570	29N	13E	20	3	3	1	445	262	7698	447759	4065097	7436
RG 86583	29N	13E	20	3	3	2	445	252	7713	447945	4065097	7461
RG 42013	29N	13E	20	4	4	4	80	30	7737	449156	4064886	7707
RG 42588	29N	13E	20	4			110	50	7878	448853	4065257	7828
RG 63025	29N	13E	20	4	4	1	380	290	7801	449046	4064983	7511
RG 10479	29N	13E	21	4	4		150	27	7899	450618	4065170	7872
RG 06917	29N	13E	29	1			62	20	7651	448111	4064305	7631
RG 10359	29N	13E	29	1	2		136	98	7715	448294	4064598	7617
RG 11980	29N	13E	29	1	2	4	180	120	7653	448390	4064497	7533
RG 59893	29N	13E	29	1	4	2	55	14	7620	448376	4064262	7606
RG 00148	29N	13E	29	3	3	3	65	18	7511	447735	4063253	7493
RG 06478	29N	13E	30	1	4		198	98	7641	446648	4064210	7543
RG 10732	29N	13E	30	1			210	127	7644	446385	4064470	7517
RG 12762	29N	13E	30	1	4		200	128	7647	446679	4064174	7519
RG 68295	29N	13E	30	1	3	4	215	122	7641	446415	4064096	7519
RG 09762	29N	13E	30	3	3	3	52	10	7597	446147	4063281	7587
RG 10641	29N	13E	30	4	4		500	223	7603	447278	4063559	7380
RG 12578	29N	13E	30	4	2	1	100	44	7642	447316	4063951	7598
RG 67473	29N	13E	30	4	2	1	123	60	7641	447351	4063925	7581
RG 79327	29N	13E	30	4	2	1	210	150	7638	447299	4063916	7488

EXPLANATION: **NMOSE No.** is the well registration number from New Mexico Office of the State Engineer.
LOCATION (PLS) references the state cadastral system (township, range, section, quarters).
TD is the Total Depth of the well, in feet, as listed in OSE database.
DTW is the Depth to Water, in feet, as listed in OSE database.
UTM (E,N) are eastings and northings (meters), Projection UTM zone 13N NAD83.
LSE AND PSE are land surface elevation and potentiometric surface elevation. (NAVD88).

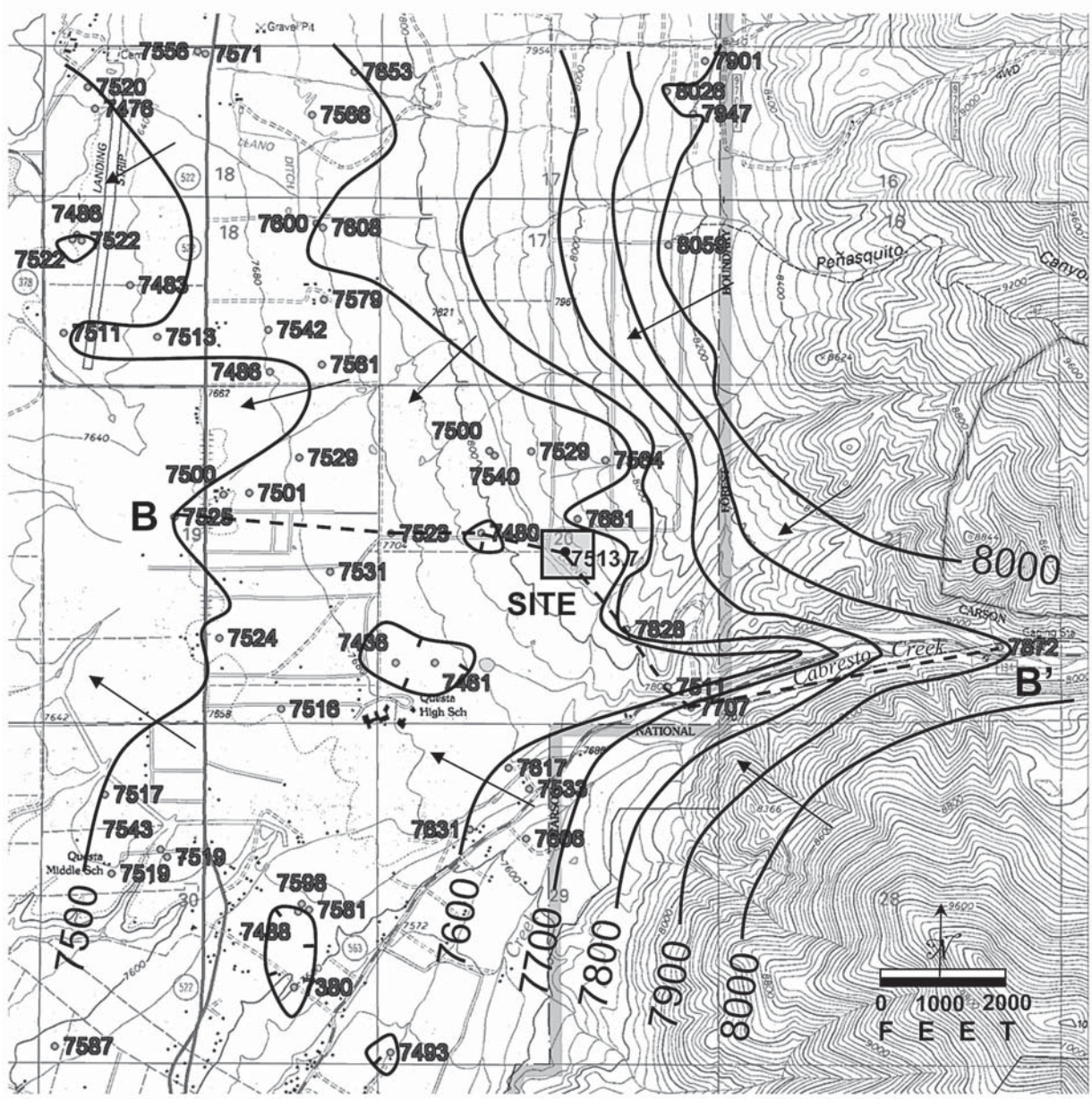


FIGURE 4. Water level map for detailed project area in southeast Sunshine Valley (base from USGS 1:24,000 topographic maps). Data points show water level elevation in feet above mean sea level (Table 2). Contour interval 100 feet, hachuring indicates localized water-table depressions, arrows indicate direction of groundwater flow. Location of cross-section B-B' (Figure 6) is shown as a dashed line.

section also shows the location of the basin-bounding fault and illustrates the lack of basalt interbeds in this area, characteristic of alluvium deposits on the east margin of the basin.

The TH96S analytical model (NMOSE, 1994) uses the Theis equation to estimate the effects of future groundwater withdrawals from the study area, and allows for a standardized analysis of groundwater withdrawals and pumping effects. For the proposed subdivision, withdrawals were estimated at 0.5 AFA per lot or a total of 6.5 AFA for thirteen lots. The model was set up to include a no-flow boundary at the trace of the Sangre de Cristo Fault, located 1,870 feet east of the site, with no recharge to simplify the solution and to provide a conservative (worst-case) scenario. Three model runs were prepared to represent: (1) effects of the pump test to insure the model accurately simulated the short-term aquifer response; (2) long-term effects of the subdivision withdrawal on water levels in nearby existing wells; and, (3) drawdown on the proposed subdivision well, including the combined effects from other nearby pumping wells. For each model run, the

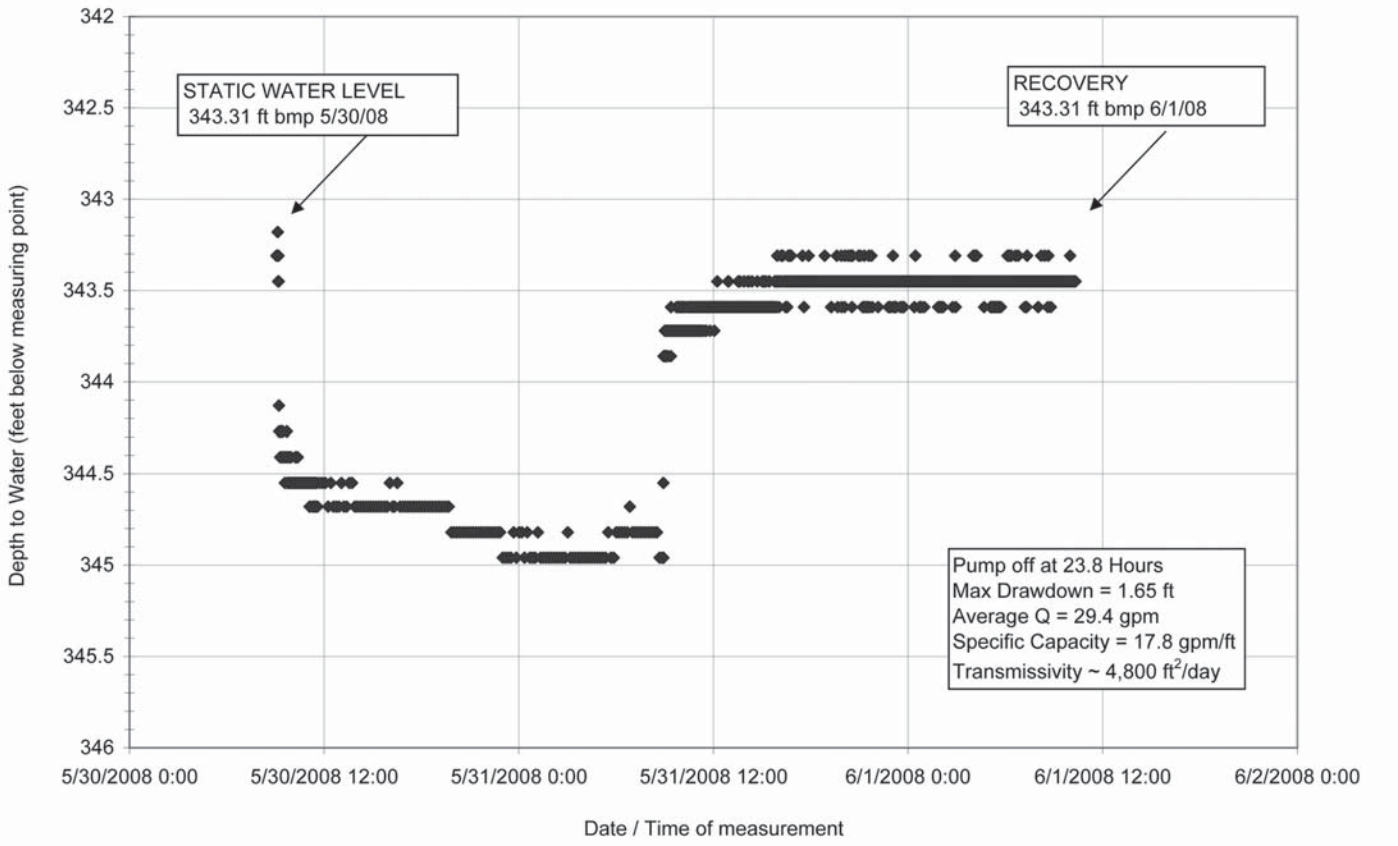


FIGURE 5. Summary plot of aquifer test for well at the detailed project study area (RG-90428), showing water level drawdown and recovery. Data were collected with a pressure transducer accurate to 0.13 inch; therefore, small water level fluctuations cause apparent overlapping of points and scatter on the graph.

lowest (most conservative) site-specific T value of 3,991 ft²/day was used from the pumping-phase data. An S value of 0.10 was used, which is lower (more conservative) than the regional model value of 0.15 (Burck et al., 2004).

The short-term pump test simulation resulted in a predicted drawdown of 1.44 feet after 24 hours, which agreed with the observed drawdown of 1.65 feet. The second model scenario resulted in 50-year drawdown on nearby wells of less than 1 foot, which is negligible considering that the average water column in these wells is 75 feet. The third model scenario considered effects of nearby pumping wells on the proposed subdivision supply wells, and resulted in a projected drawdown of about 2.3 feet. Adding an additional 20% safety factor per Taos County regulations, the 50-year effect on the 77-foot water column of the supply well is about 4%, which is minimal and within acceptable drawdown limits set forth in New Mexico Office of the State Engineer guidelines (Morrison, 2006).

Finally, water quality sampling and laboratory analyses were performed for the on-site test well. The results showed that the water is of excellent quality for drinking water purposes for the tested primary (health-related) and secondary (aesthetic) standards. This is consistent with the observation that most wells near the study area have TDS (total dissolved solids) concentrations of less than 500 mg/L (milligrams per liter), which is an indication of relatively fresh waters near recharge areas.

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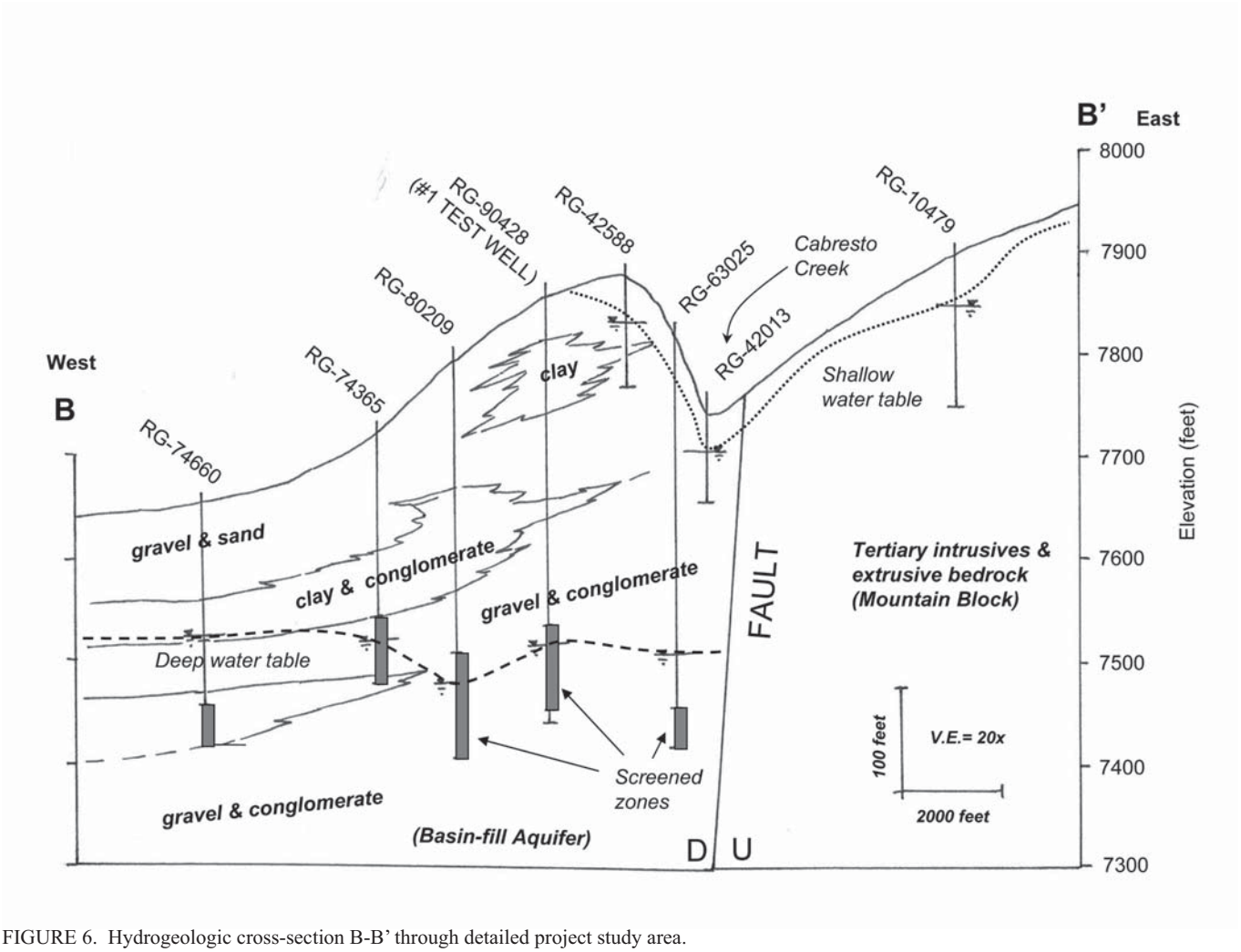


FIGURE 6. Hydrogeologic cross-section B-B' through detailed project study area.

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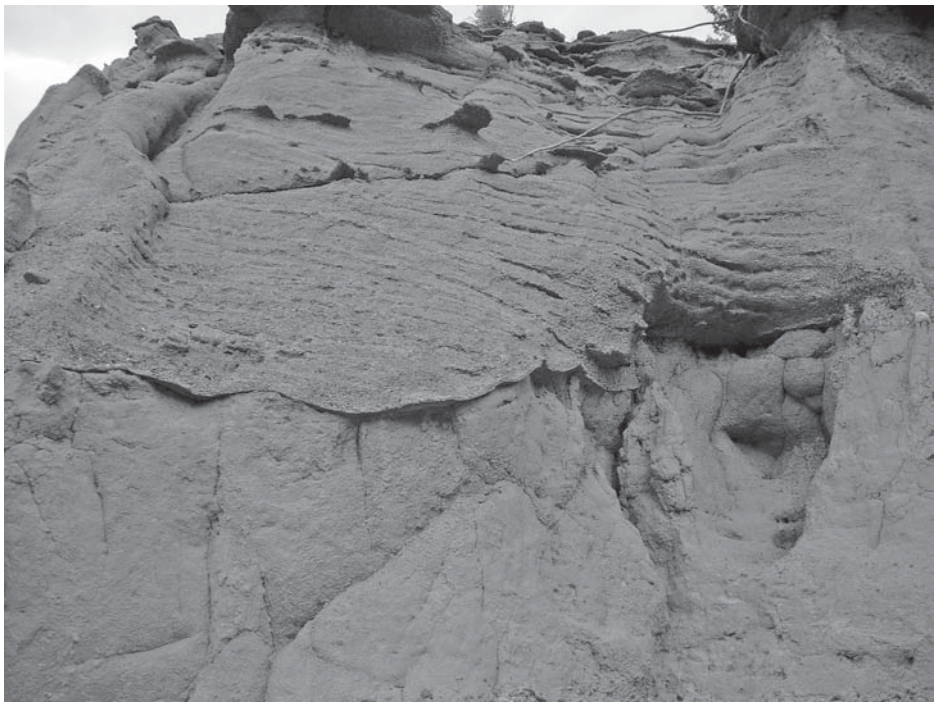
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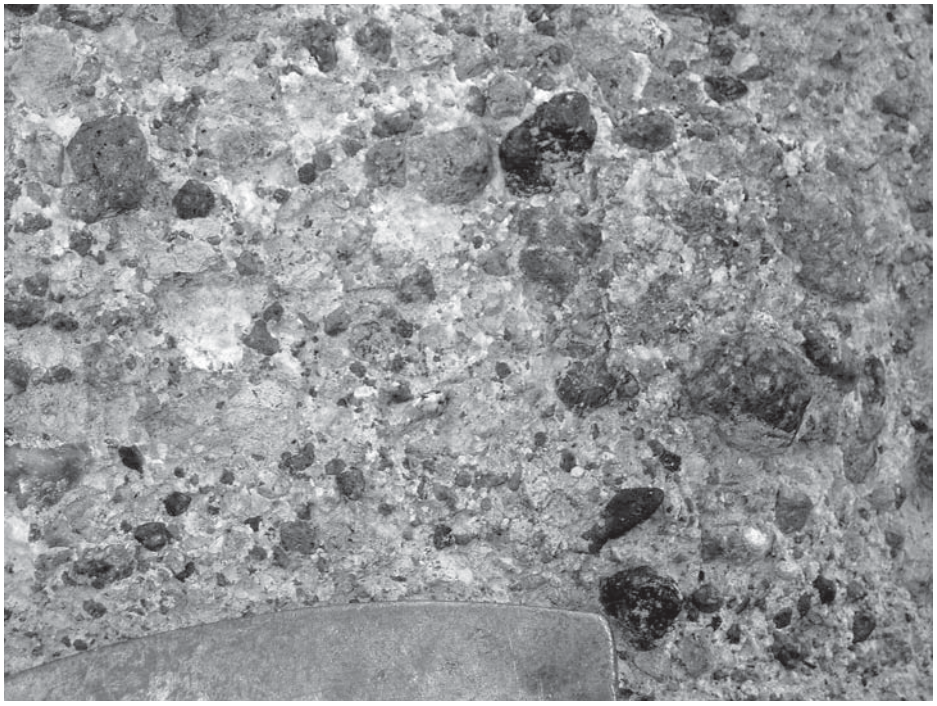
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Top photo: Planar cross-bedding of a gravelly sandstone of the Chama-El Rito Member (Tesuque Formation) near Dixon. In the finer-grained strata above this location, a partial skeleton of the horse Protohippus? was discovered. Lower photo: Clasts in Chama-El Rito Member channel-fills near Dixon contain abundant porphyritic dacitic clasts similar to those in the Duranes Member of the Tesuque Formation to the west. Other clast types include: 7-15% welded tuffs and rhyolite, 1-5% quartzite, 1-5% green sedimentary rocks of probably Pennsylvanian-Permian age, and trace to 3% orange granitoids. Top of rock hammer at bottom of photo.