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SUBSURFACE MAPPING AND HYDROLOGIC CHARACTERISTICS OF BISHOP'S LODGE MEMBER OF THE TESUQUE FORMATION

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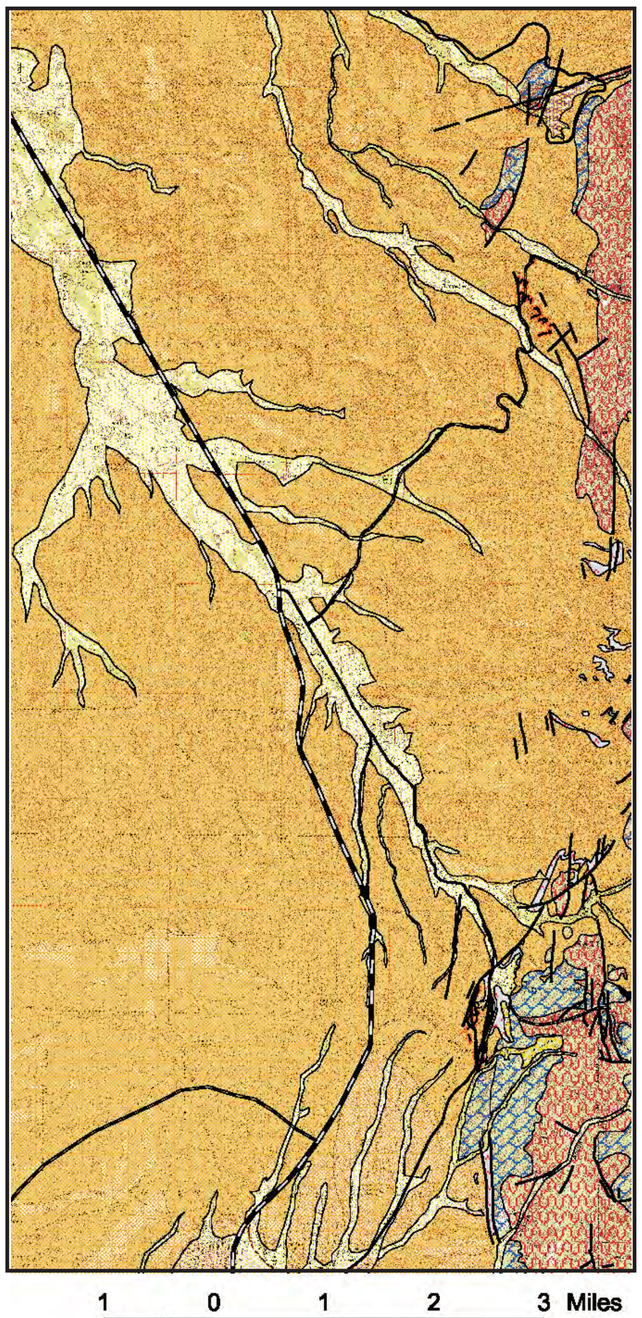
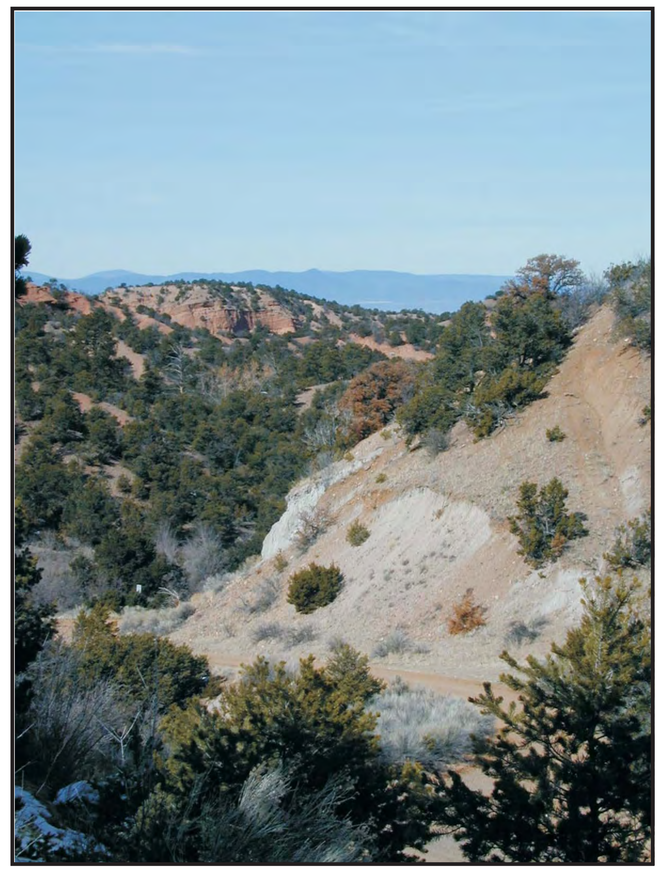


ABSTRACT

The Bishop's Lodge Member (BLM) of the Tesuque Formation crops out along the Sangre de Cristo Mountain front northeast of the Santa Fe area. Several domestic water wells in the Tesuque area have encountered the BLM at depths ranging from ground surface to 730 feet. The BLM interfingers with the Nambé Member of the Tesuque Fm (Read et al., 1999) and together comprise the basal Tesuque Fm. Encountering the BLM in these boreholes vertically constrains the basal portion of the Tesuque Aquifer system along the Sangre de Cristo Mountain front near the Village of Tesuque. In outcrop, the BLM consists of white and gray tuffaceous mudstone, sandstone, and pebble to cobble conglomerate. The portion of the BLM encountered in well borings is predominantly tuffaceous mudstone interfingered with Nambé Member arkosic sand, silt and clay. The BLM is generally a poor aquifer because it is composed of low-permeability, fine-grained volcaniclastic sediments. These low permeability sediments also create a confining layer resulting in artesian flow in some wells that penetrate into the underlying, more permeable, sediments.

Olivine basalt of the Nambé Member of the Tesuque Fm was encountered in a 980-feet deep well boring (RG-77686) located approximately 2 miles north of Santa Fe. The basalt is directly overlain by a thick sequence of greenish gray mudstone with significant $CaCO_3$ and minor coarse arkosic sand. This clay layer is overlain by 49 feet of coarse arkosic, pink sand of the Nambé Member. This sequence is similar to descriptions of a nearby basalt outcrop along Bishop's Lodge Road. The top of the basalt in the borehole is at an elevation of approximately 6260 feet (above msl), which is approximately 820 feet lower than an outcrop of the basalt exposed on the west side of Bishop's Lodge Road approximately 1 mile southeast of the well. This difference suggests a total down-to-the-west throw of up to 820 feet across several fault splays mapped between the Bishop's Lodge Road outcrop and well RG-77686 (Read et al., 1999). While some of these splays indicate down-to-the-east motion, the majority of the faults in this area have down-to-the-west motion. The basalt in RG-77686 may correlate to the basalt of the outcrop, described by Read et al., 1999, that contains one basalt flow of 1 1.7 m (~3 6 ft) thick. The basalt encountered in well RG-77686 has a minimum thickness of 25 feet (~7m). The greater thickness of the basalt encountered in the well could be due to accumulation of flow(s) in a paleo-low. An outcrop exposure of the basalt in the Tesuque Quadrangle (Borchert et al., 1998) contains five separate flows with a total thickness of 3 8m (~9 24 ft). Due to the mixing of cuttings during mud-rotary drilling, separate basalt flows could not be identified in the drill cuttings from the well boring.

Pumping tests were conducted on three separate wells in the vicinity of RG-77686. The lithologic logs and pumping test data indicate a significant variation in aquifer characteristics in the area. Transmissivity ranges from 60 to 250 ft^2/day and appears to be mainly dependent on grain size. One limiting boundary was observed in pumping test data from RG-77686 and may be related to pinching out of coarser sand lenses into finer, clay bearing sediments, rather than structural influences.



Geologic Setting

The area of study is located in the Santa Fe embayment of the Española Basin within the Rio Grande Rift, west of the Sangre de Cristo Mountains and southeast of the Jemez Mountains (Kelley, 1978). Quaternary to Tertiary age Ancha Formation, or more recent, Quaternary age alluvium (Spiegel and Baldwin, 1963; Kelley, 1978), overlies sediments of the Tesuque Formation of the Santa Fe Group discontinuously in this area and can be found outcropping along the mountain front (Spiegel and Baldwin, 1963; Kelley, 1978; Read et al., 1999).

Based on Kelley's (1978) mapping and description of the Española basin, and mapping in the Santa Fe Quadrangle (Spiegel and Baldwin, 1963, Read et al., 1999), in conjunction with cuttings analyzed during the drilling process of local wells, the units encountered in the Tesuque area include: Precambrian crystalline bedrock, Pennsylvanian Magdalena Group, Olivine Basalt, the Bishop's Lodge Member, and Nambé Member of the Tesuque Formation. The lower portion of the Bishop's Lodge and Nambé Members of the Tesuque Formation are inter-fingered with Olivine Basalt flows.

Precambrian Bedrock (pC) - The crustalline bedrock of the Sangre de Cristo Mtns is mapped as one unit for simplicity.

Tesuque Formation of the Santa Fe Group

Nambé Member (Tfn)

The Nambé Member of the Tesuque Formation is Early Miocene age and consists of predominantly coarse-grained, alluvial fan deposits (Galusha and Blick, 1971). The Nambé Member is made up of pink to buff sand, silt, and clayey sand with lenses of conglomerate that are derived mainly from the granitic rocks of the Sangre de Cristo Mountains. The Nambé Member is subdivided into an upper fossiliferous portion of finer grained sediments and a lower conglomeratic sandstone and sand portion (Galusha and Blick, 1971), with a total thickness of up to 3,400 feet (Kelley, 1978). The upper portion contains more silt, clay, and ashy layers. The lower portion rests unconformably on the Precambrian crystalline rocksto the north and south of the study area.

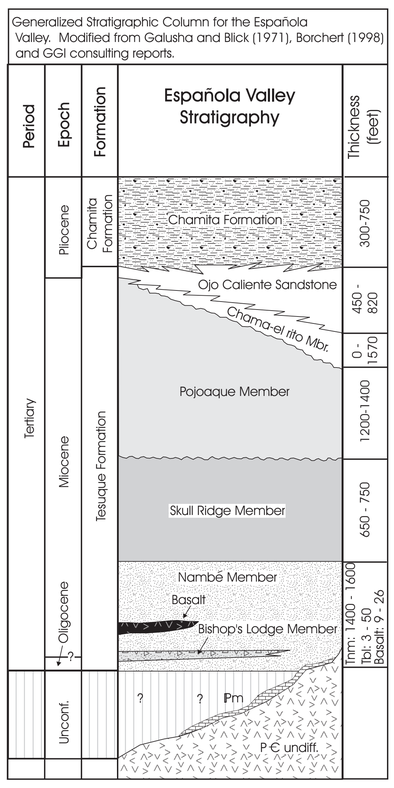
Olivine Basalt (Tfnb)

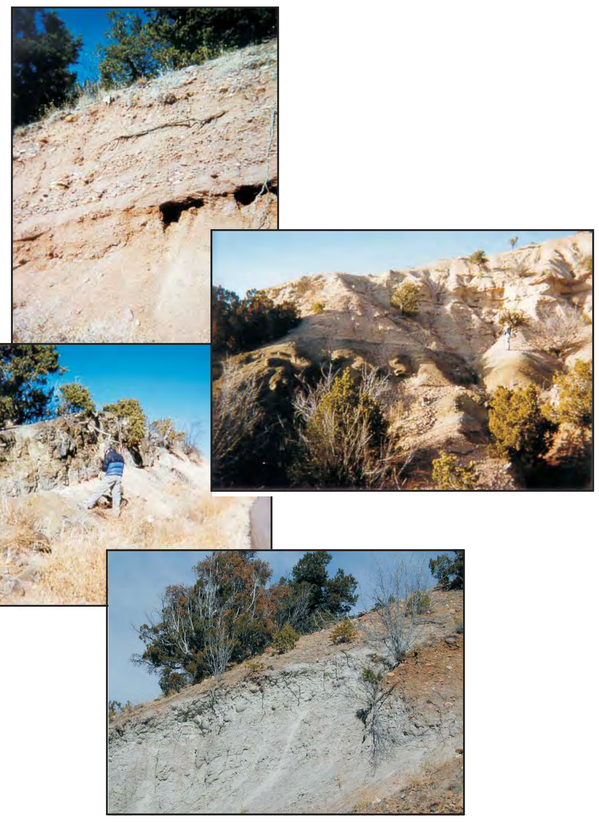
Locally the Nambé Member includes a weathered, Early Miocene olivine basalt that can be correlated to a 24.9 ± 0.6 Ma basalt (Baldridge et al., 1980) located 3.1 miles east-northeast of Nambé Pueblo (Borchert, 1998; Read et al., 1999). Olivine Basalt was encountered during the drilling of the Well #1 at the bottom of the well bore. The Nambé Member encountered during drilling consisted of granitic sand, pink to red in color, from very fine to coarse with gravel, silt, and clayey sand, tan to brown in color. Total thickness of the Nambé Member of the Tesuque Formation observed in the well bore is in excess of 955 feet, including 191 feet of Bishops Lodge formation, interbedded within the Nambé Member.

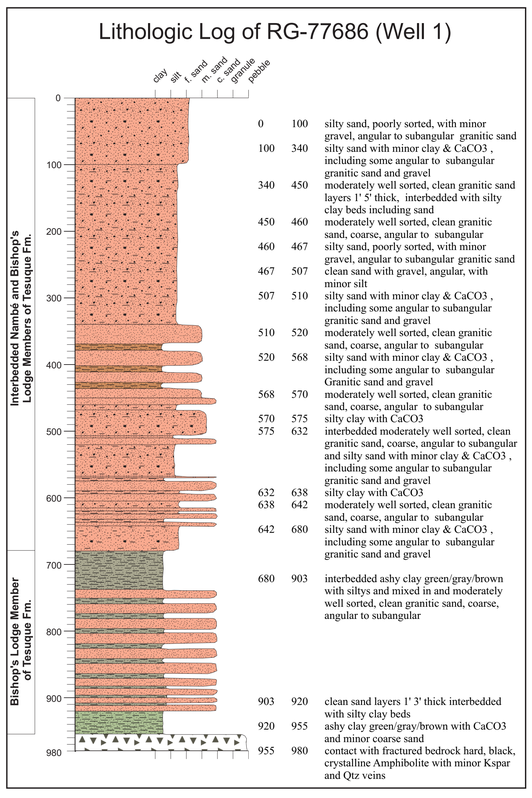
Bishops Lodge Member (Tfbl)

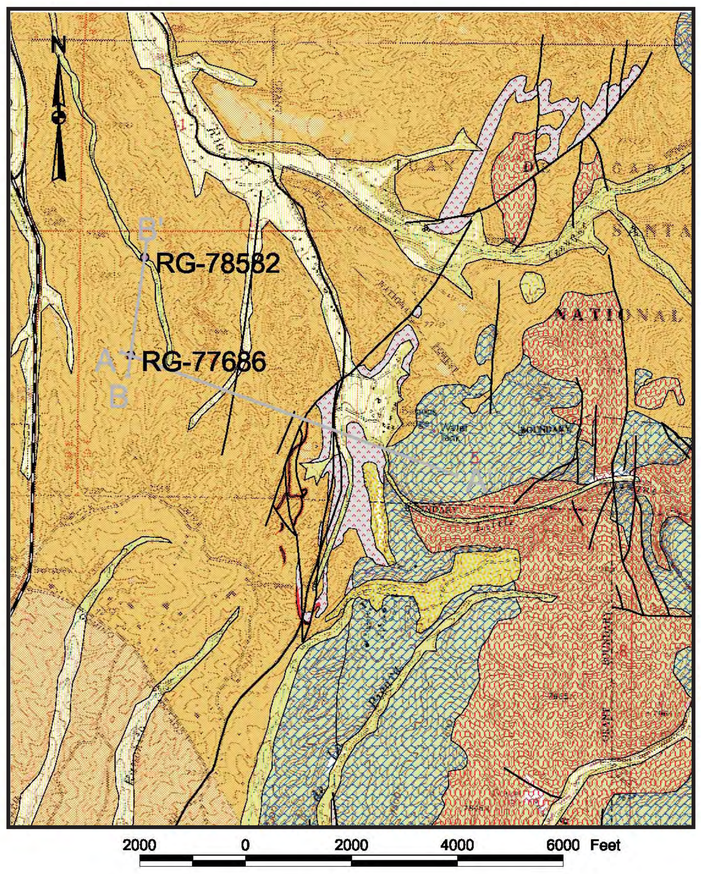
The Bishops Lodge Member of the Nambe Member of theTesuque Formation is Oligocene to Early Miocene in age (Borchert, *pers. comm.)* and is exposed in small fault-bounded blocks near the mountain (Read et al., 1999). In these blocks, the Bishops Lodge Member consists primarily of " White tuffaceous mudstone, gray pebbly volcaniclastic sandstone and pebble to cobble conglomerate." (Read et al., 1999). In addition to volcanic clasts, the Bishops Lodge member may include clasts of pre-Tertiary rocks, especially near the contact with the Nambé Member. The contact with the Nambé Member is gradational and the units interfinger with one another (Borchert, 1998; Read et al., 1999). In some areas within the Santa Fe Quadrangle, the Bishops Lodge Member is deposited directly on Paleozoic or Precambrian rocks, while at other locations more than 1300 feet of Nambé Member underlies the Bishops Lodge Member. The Bishops Lodge Member is distinguished from the Nambé Member by the abundance of volcanic clasts and ash. Thickness of the Bishops Lodge member is variable, with a maximum thickness of approximately 300 feet in the Santa Fe Quadrangle (Read et al., 1999). A distinct color change is visible from the pinkish-red/brown of the Nambé Member to the ashy greenish-gray/brown of the Bishop's Lodge Tuff. From 680-871 feet bgs, in Well #1, the silty clay formed by alteration of the ash of the Bishop's Lodge Tuff is abundant, but not totally continuous. It is interfingered with beds of moderately well sorted coarse, angular to sub-angular, granitic sand with gravel of the Nambé Member. Bishop's Lodge Tuff was inspected in outcrop south of the Bishop's Lodge and west of Bishop's Lodge Road.

Generalized Stratigraphic Column for the Española Valley. Modified from Galusha and Blick (1971), Borchert (1998) and GGI consulting reports.





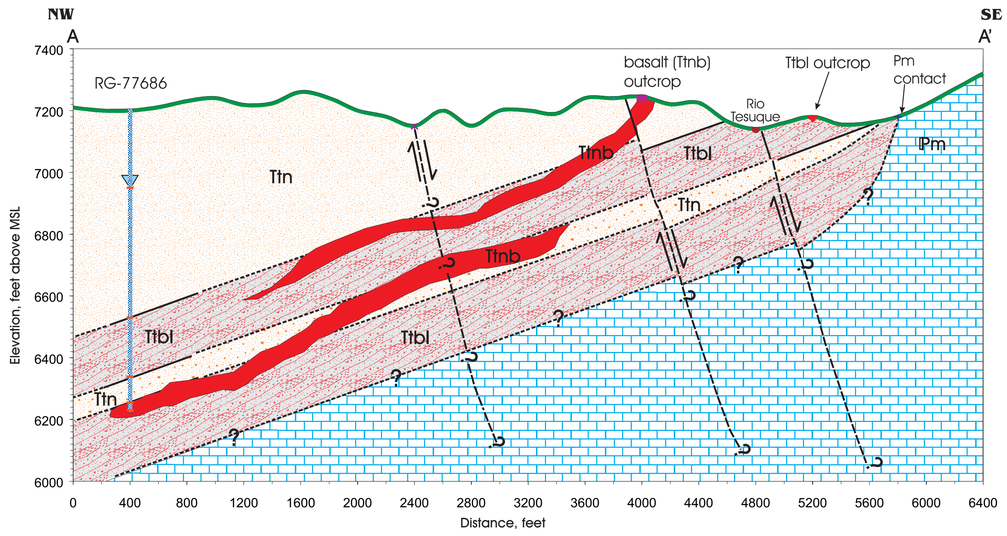




Cross Sections

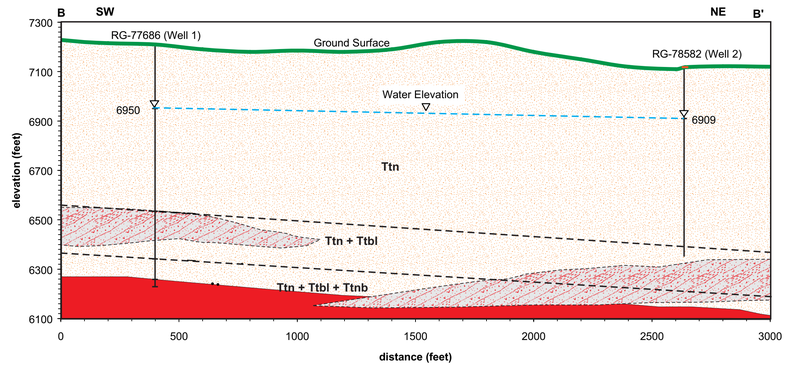
Stratigraphic data compiled from drill cuttings of well bores in the Tesuque area were used to create two cross sections. Section line A A' was drawn parallel to the general direction of dip, northwest to southeast, from Well #1 to the contact observed by GGI south of the Bishop's Lodge between the Bishop's Lodge Tuff and rocks of the Pennsylvanian Magdalena Group. Along this section line, outcrops of Olivine Basalt and Bishop's Lodge Tuff are located and correlated with the stratigraphic column from Well #1. The two faults closest to the mountain-front encountered along the section line were derived from surficial geologic mapping by Read et al., 1999 and cannot be confirmed at depth. Offset, with down to the east motion, was projected along these mapped faults. The third fault depicted to the west was mapped by GGI during drilling of Well #1, however offset was not projected along this fault in the cross section. Section line B B' was drawn parallel to the general direction of strike, southwest to northeast, from Well #1 to Well #2. This cross section correlates the top of the Bishop's Lodge Tuff between the two well bores. Production from the portion of the aquifer encountered in Well #2 is much greater than from Well #1, possibly due to abundance of coarser sediments and intersection of minor fractures.

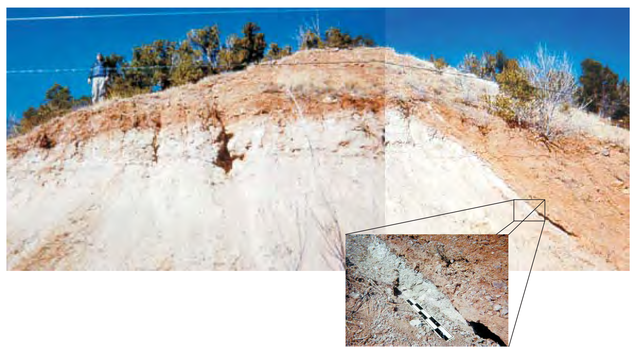
Geohydrologic cross-section from well RG-77686 to basal Tesuque Formation / bedrock contact at Sangre de Cristo Mountain Front



V.E.= 2.5x Cross-section is drawn parallel to average dip direction of Tesuque Formation sediments

Geohydrologic Cross-Section: Well 1 to Well 2





48-Hour Pumping Test: Well #2

A 48-hour pumping test was conducted on Well 2, commencing on August 21, 2002. Static water level measured at the onset of the test was 214.01feet bgs. The generator failed 120-minutes into pumping on August 21; however, it was only off for only 10 minutes and drawdown resumed at the same slope observed prior to the shut-off after approximately 100 minutes of additional pumping. Discharge during the pumping test was measured using a 4-inch circular orifice weir with a 1.5-inch orifice and was calculated at 35 gpm.

Drawdown

Total drawdown in the well after pumping for 2880 minutes (48 hours), on August 23, 2002, was 40.15 feet, with approximately 25.5 feet of drawdown occurring in the first 14.7 minutes of the test, due to casing storage. Transmissivity (T) of the aquifer was calculated from early and late-time drawdown data. T_1, calculated from early-time data, is 1690 gpd/ft (226 ft^2/day), and T_2, calculated from late-time data, is 1207 gpd/ft (161 ft^2/day) (Table 1). The relatively small difference in T_1 vs. T_2 is likely due to a facies change from coarser-grained to finer-grained sediments away from the well location.

Pumping test data from the Well #1 48-hour pumping test yield somewhat different results and show both a limiting boundary condition and much lower T for the aquifer. Transmissivity (T) of 160 to 80 gpd/ft calculated from the Well #1 pumping test are an order of magnitude lower than T calculated from the Well 2, RG-78582 pumping test. The pumping test data and lithologic data indicate that RG-78582 was drilled into a much coarser-grained, higher-transmissivity section of the aquifer than was Well #1.

Recovery

Recovery measurements were started immediately upon cessation of pumping Well 2 on August 23, 2002. The well recovered to within 3.25 feet of the original static water level after 4300 minutes (approximately 3 days) of recovery. Recovery was monitored through August 28, 2002, at which time the well had recovered to within 2.54 feet of the static water level, after 7320 minutes (approximately 5 days) of recovery. Transmissivity calculated from recovery data ranges from T_1 = 1859 gpd/ft (249 ft^2/day) (early-time data) to T_2 = 1240 gpd/ft (166 ft^2/day) (late-time data). T calculated from Well #1 pumping test recovery data ranges from 244 to 112 gpd/ft, nearly an order of magnitude lower than T calculated from Well 2.

Boundary Conditions

Neither the drawdown nor the recovery data from the RG-78582 test indicate impermeable or recharge boundaries were encountered.

Description of Aquifer System

The primary aquifer at the Tesuque drilling site is in the coarse sediments of the Nambé Member of the Tesuque Formation (McAda and Wasiolek, 1988; Grant, 1998). Recharge to the aquifer is primarily mountain-front recharge resulting from infiltration of rainfall and snowmelt into fractured bedrock on the western flank of the Sangre de Cristo uplift (McAda and Wasiolek, 1988; Grant, 1998). Mountain-front recharge is supplemented by direct infiltration of rainfall and snowmelt into exposures of Tesuque Formation sediments or indirect infiltration through permeable alluvial deposits overlying Tesuque Formation sediments (McAda and Wasiolek, 1988). Discharge from the aquifer is primarily to the Rio Grande, with minor discharge locally to the Rio Tesuque. Ground water flow in the Española Basin east of the Rio Grande and north of the Santa Fe River is generally from east to west.

WELL 2		
Test Stage / Calculation	Early -Time: T_1	Late-Time: T_2
Drawdown (ft^2/day)	226	161
Recovery (ft^2/day)	249	166
Average (ft^2/day)	237.5	163.5
Hydraulic Conductivity = (T / b) (ft/day)	*237.5 / 320 = 0.74*	*163.5 / 320 = 0.51*

WELL #1		
Test Stage / Calculation	Early-Time: T_1	Late-Time: T_2
Drawdown (ft^2/day)	21	11
Recovery (ft^2/day)	33	15
Average (ft^2/day)	27	13
Hydraulic Conductivity = (T / b) (ft/day)	*27 / 336 = 0.08*	*13 / 336 = 0.04*

48-Hour Pumping Test: Well #1

A 48-hour pumping test was conducted on Well #1, commencing on June 3, 2002. Static water level measured at the onset of the test was 258.78 feet bgs. The pump was set at a depth of 537 feet bgs. Discharge from the well was variable for the first 5 minutes of the test as the gate valve was adjusted to discharge 25 gpm.

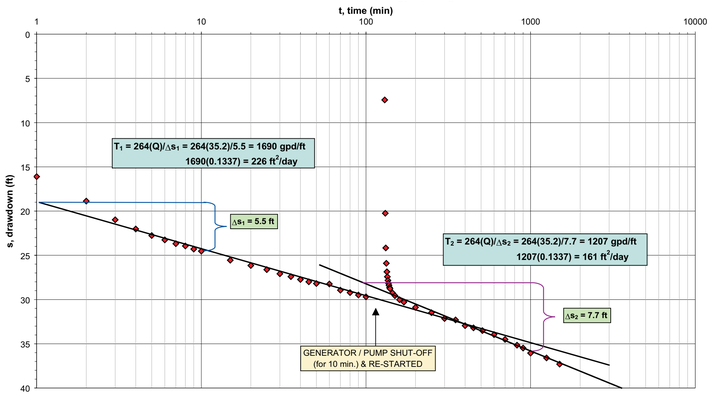
Drawdown

Total drawdown in the well after pumping for 2880 minutes (48 hours) was 126.45 feet, with approximately 41 feet of drawdown occurring in the first 20 minutes of the test, due to casing storage effects. A limiting boundary was encountered approximately 800 minutes into the test. Transmissivity (T) of the aquifer was calculated from drawdown data prior to and after the effect was seen at 800 minutes; Transmissivity prior to 800 minutes, T_1 = 157 gpd/ft (21 ft^2/day), transmissivity after 800 minutes, T_2 = 82.5 gpd/ft (11 ft^2/day).

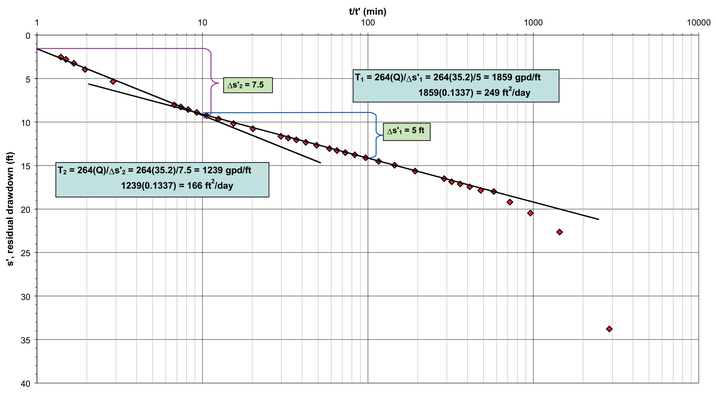
Recovery

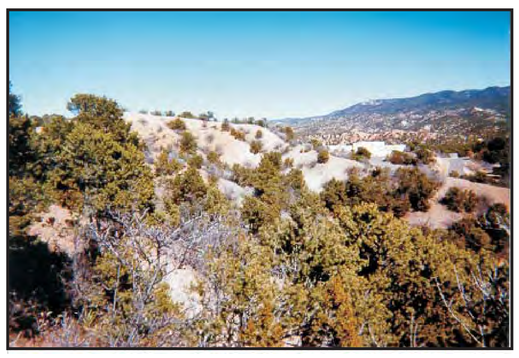
Recovery measurements were started immediately upon cessation of pumping. The well recovered to within 34.08 feet of the static water level, measured prior to the 48-hour drawdown test, after 2880 minutes of recovery. Recovery was monitored through June 26, at which time the well had recovered to within 14.07 feet of the static water level, after 30130 minutes of recovery. The same boundary seen in the drawdown test was encountered during the recovery test, approximately 500 minutes into the recovery period. Transmissivity (T) of the aquifer was calculated from recovery data prior to and after the boundary was encountered. Transmissivity prior to the boundary, T_1 = 244 gpd/ft (33 ft^2/day), transmissivity after the boundary effect, T_2 = 112 gpd/ft (15 ft^2/day).

WELL 2: RG-78582
48-HOUR PUMPING TEST (Q = 35.2 gpm): Aug. 21- 23, 2002

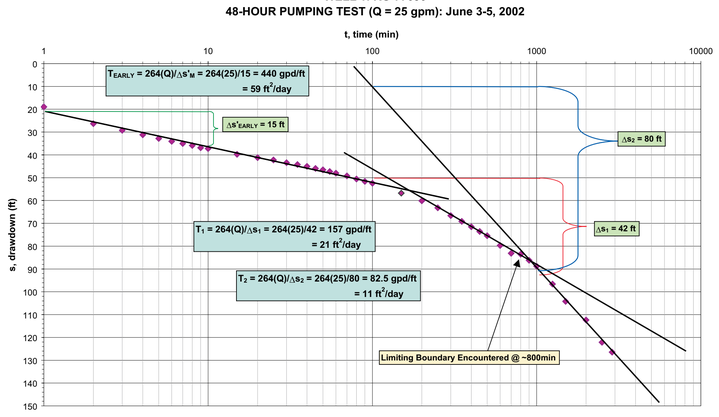


WELL 2: RG-78582
RECOVERY TEST: Aug. 23-28, 2002

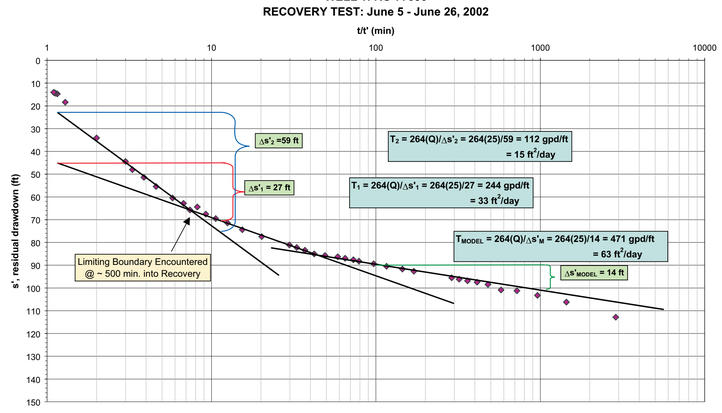




WELL 1: RG-77686
48-HOUR PUMPING TEST (Q = 25 gpm): June 3-5, 2002



WELL 1: RG-77686
RECOVERY TEST: June 5 - June 26, 2002



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