MODEL OF GROUNDWATER FLOW IN THE ANIMAS UPLIFT AND PALOMAS BASIN, COPPER FLAT PROJECT, SIERRA COUNTY, NEW MEXICO

prepared by

Michael A. Jones

John W. Shomaker, PhD, CPG

Steven T. Finch, Jr., CPG

JOHN SHOMAKER & ASSOCIATES, INC.
Water-Resource and Environmental Consultants
2611 Broadbent Parkway NE
Albuquerque, New Mexico 87107
505-345-3407
www.shomaker.com

prepared for

New Mexico Copper Corporation
a wholly owned subsidiary of THEMAC Resources Group, Ltd.
2424 Louisiana Blvd NE, Suite 301
Albuquerque, NM 87110

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EXECUTIVE SUMMARY

This report documents a numerical model of groundwater flow in and around Copper Flat, near Hillsboro, New Mexico. The model was developed and calibrated based on previously available information and on new studies of the system. The calibrated model will be used to project the effects, to groundwater and surface water, of the proposed development of the Copper Flat Mine.

The report first introduces the study area then summarizes the climate and meteorology, hydrology and water balance, and geology and hydrogeology of the area. Then an overall conceptual model of the hydrological and hydrogeological system is presented, followed by a presentation of data available to confirm and calibrate the model. Next the numerical model is presented, including model structure, inputs and calibration. Finally, the sensitivity of model results to unknown parameters is evaluated.

Extensive information on the system is available, from previous studies and previous mine operations, and from new studies including the 2012 extended well field pumping test. The model accurately represents the conceptual model and accurately reproduces the calibration data, particularly the results of the 2012 well field pumping test. As a result the model is considered suitable for use in projecting the effects of future well field pumping.

The calibrated model will be used to generate projections related to the results and effects of mine development. Projections will be generated as required and reported separately. Results of interest include the following:

- Groundwater drawdown due to water-supply pumping, for selected mine development scenarios
- Effects on surface discharge to the Las Animas Creek and Rio Grande systems
- Long-term post-mining residual groundwater drawdown and effects to surface discharge
- Potential ground subsidence due to groundwater drawdown
- Open pit dewatering rates and groundwater drawdown in bedrock
- Post-mining open-pit water level and water balance
- Down-gradient migration of potential leakage from tailings and waste rock storage facilities

The large amount of information has allowed development of a model that can reliably project effects of future development. In particular, aquifer properties around the well field are relatively known, and sensitivity of the primary model projection results, groundwater drawdown and surface discharge changes due to well field pumping, to plausible variation in model inputs, is low.

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1.0 INTRODUCTION

The report presents a numerical model of the hydrogeological system in the area of the Copper Flat Project (Project) near Truth or Consequences, New Mexico. The Project location is shown on Figure 1.1.

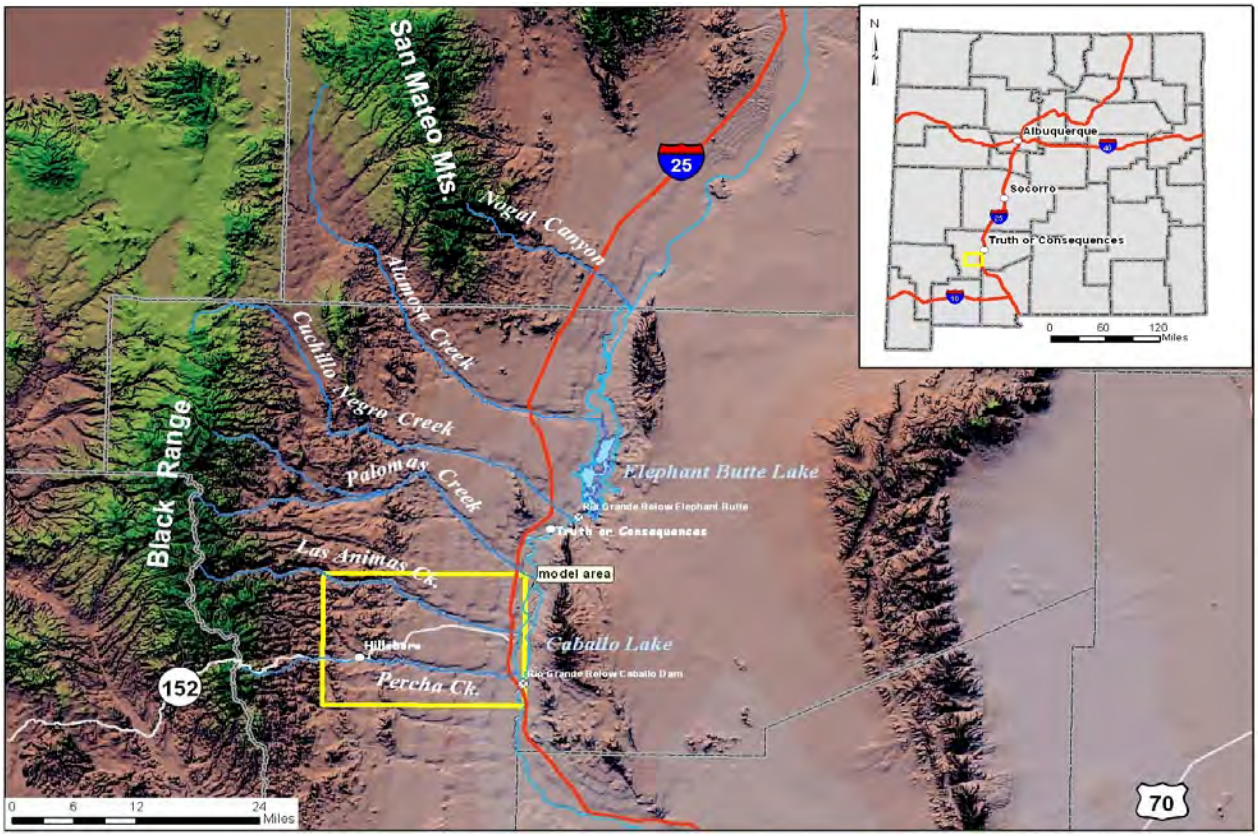


Figure 1.1. Copper Flat Project location.

The report first summarizes the climate and meteorology of the study area, then summarizes the hydrology and estimates a basin water balance. Then the geological and hydrogeological framework is presented. These are used to formulate and present a conceptual model of the system. Then the data available for model calibration are presented, followed by the details of the numerical model and results of the model calibration. Finally, sensitivity of model results to unknown parameters is evaluated. Model projections of the effects of the proposed mining project are reported separately.

2.0 CLIMATE AND METEOROLOGY

Precipitation and evaporation in the study area are examined using data from regional meteorological stations. The station at Hillsboro, New Mexico, has a long record (with at least partial data from 1893), is located nearby (about 4 miles from the Copper Flat open pit), and is at a similar elevation (5,270 ft above mean sea level (amsl)) as the Copper Flat Mine site. Locations of the Hillsboro station and other meteorological stations along the east side of the Black Range are shown on Figure 2.1.

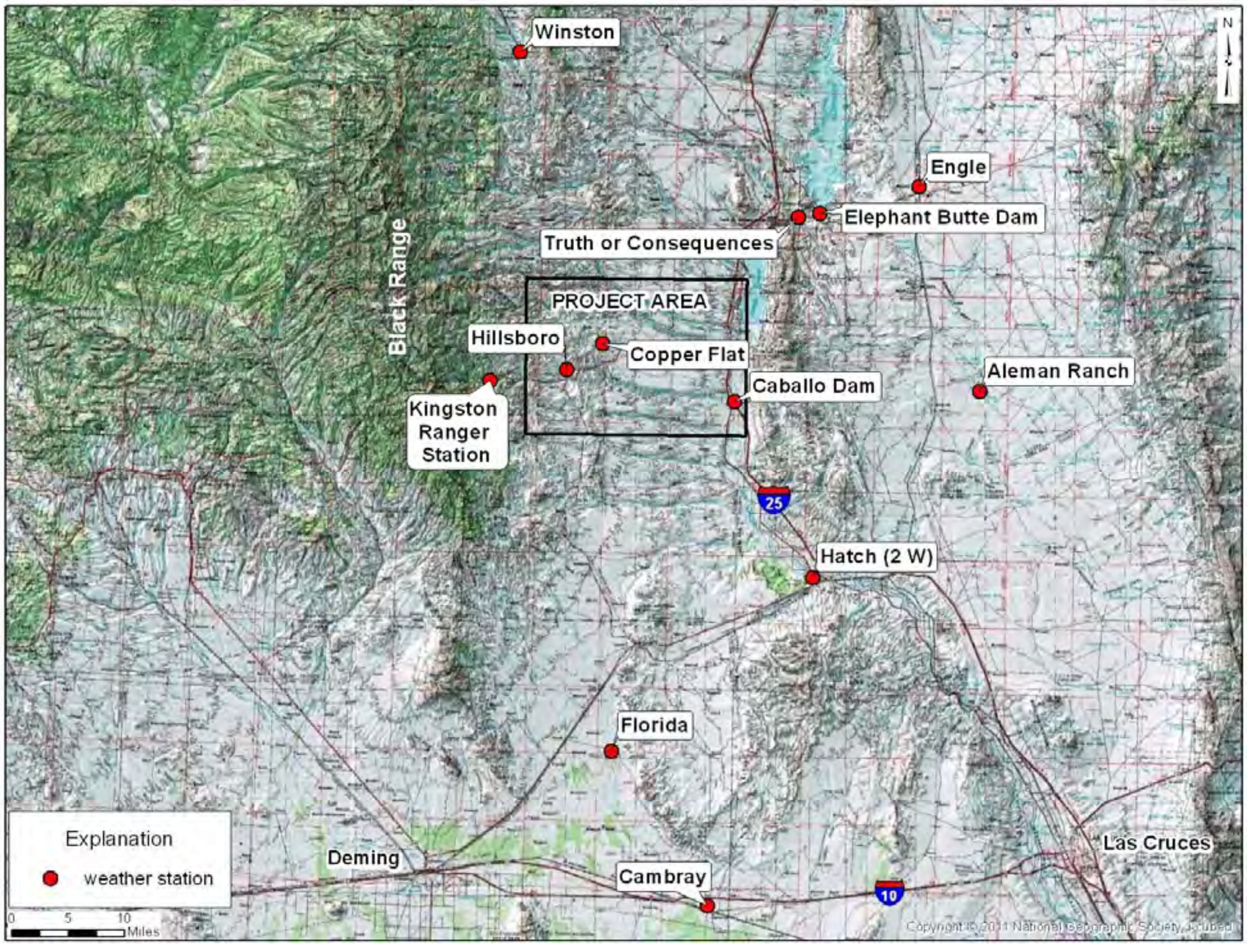


Figure 2.1. Locations of meteorological stations surrounding the Project area.

2.1 Annual Precipitation

The range of variability between wet and dry climatic conditions is seen in the annual precipitation recorded at Hillsboro from 1925 through 2010, shown on Figure 2.2. Annual precipitation ranges from less than 5 to more than 20 inches per year (in./yr) and averages about 12.5 in. Copper Flat weather station recorded 7.7 in. of precipitation in 2011, and 3.8 in. in 2012, signifying drought conditions during this period.

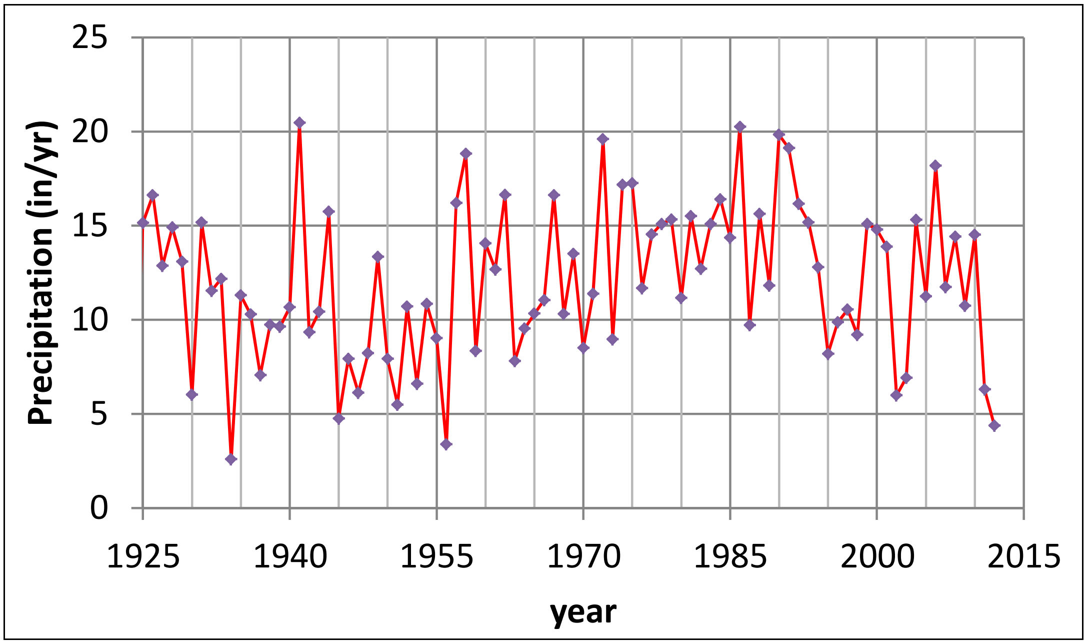


Figure 2.2. Recorded annual precipitation at Hillsboro meteorological station.

2.2 Precipitation Events

The frequency and magnitude of precipitation events are examined in the statistical distribution of daily precipitation at Hillsboro, shown on Figure 2.3. Daily precipitation of 1 in. or more occurs, on average, twice per year. Storm events of magnitude 2 in. can be expected to occur every 4 years, and the 100-year storm event is about 3.5 in.

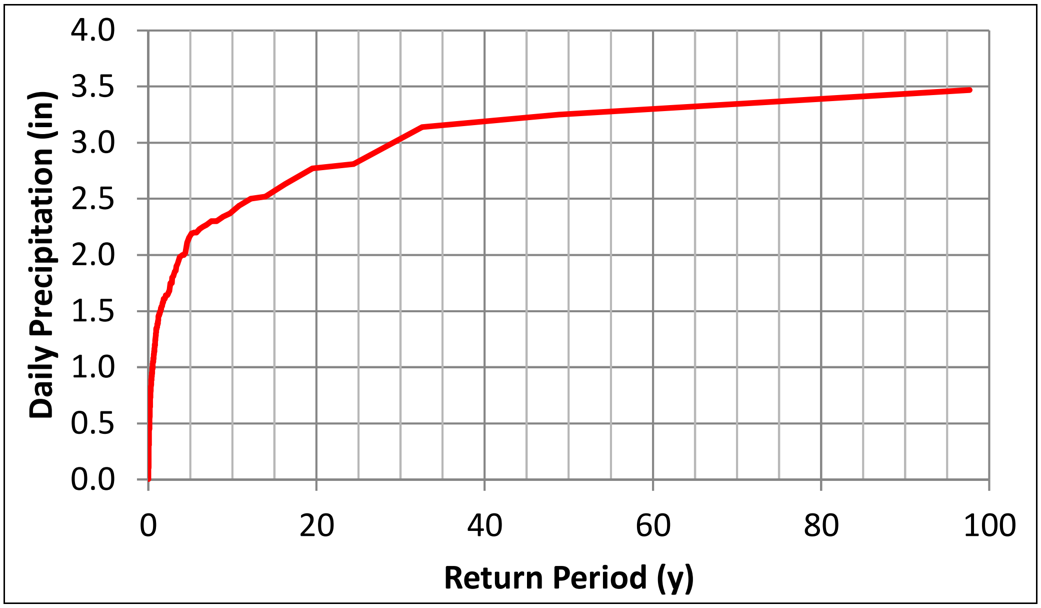


Figure 2.3. Distribution of daily precipitation at Hillsboro meteorological station.

2.3 Precipitation and Elevation

Precipitation is known to increase with elevation, and the bulk of surface-water runoff and groundwater recharge in the study area is generated by precipitation on the higher elevations of the Percha Creek and Las Animas Creek watersheds.

Mean annual precipitation was compared to elevation for other meteorological stations east of the Black Range as shown on Figure 2.4. The best-fit linear relationship estimates about 8.6 in./yr mean annual precipitation at elevation 4,000 ft amsl, and about 26.2 in./yr at elevation 10,000 ft amsl, approximately the maximum in the study area.

Given the large spatial and temporal variability of annual precipitation, the trend line shown on Figure 2.4 does not characterize precipitation patterns in any detail. It does however give realistic average precipitation rates for the study area that increase with elevation. The average annual precipitation trend shown on Figure 2.4 is used below to compute a realistic upper bound for basin water yield (water yield is a portion of total precipitation over the basin).

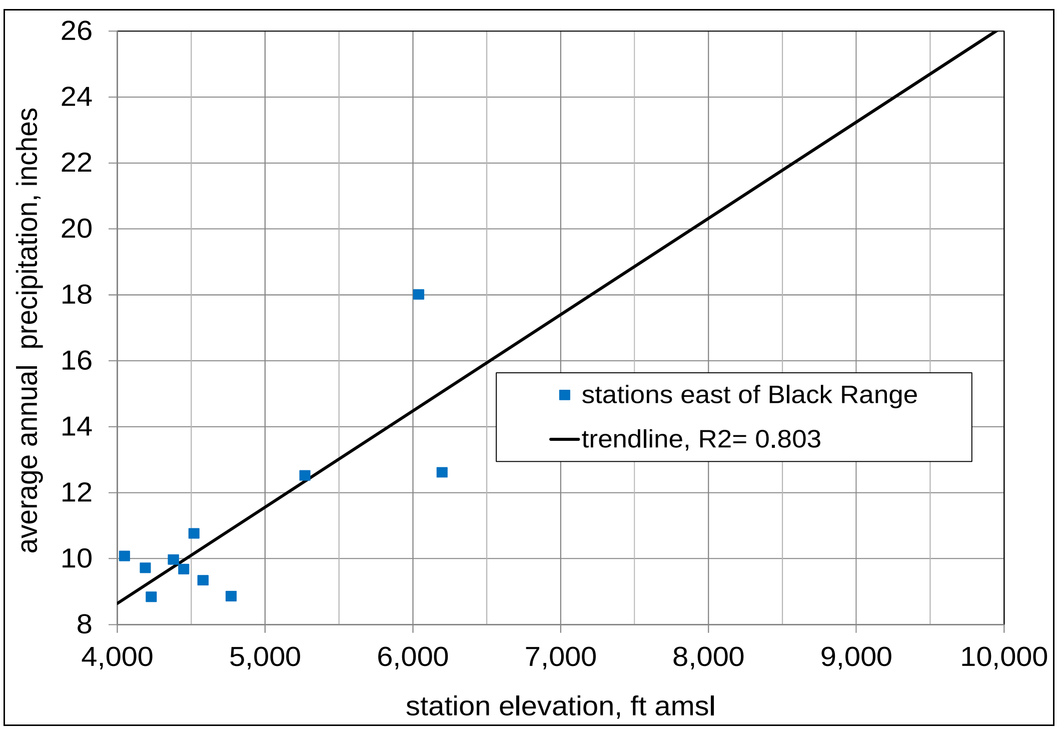


Figure 2.4. Mean annual precipitation versus elevation of meteorological station.

2.4 Evaporation and Transpiration

Most precipitation evaporates where it falls, or is consumed (transpired) by nearby vegetation. Of the remaining precipitation, most eventually discharges down-gradient as evapotranspiration (ET) from vegetated areas and open water surfaces.

Potential ET, or the maximum evaporation and plant transpiration that can occur given full availability of water, is a function of geographical and climatic conditions and is commonly estimated using the Penman-Monteith equations (Monteith, 1965). These relate maximum ET (ET_0) to meteorological parameters including temperature, relative humidity and wind speed, and to geographical parameters (altitude, latitude and time of year).

Annual ET_0 computed from results at Hillsboro meteorological station (incomplete weather data for 1997 and 1998 filled in with data from comparable years) is shown on Figure 2.5 to be about 60 in./yr. This compares well to previous estimates (SRK, 1997) of 65 in./yr of potential evaporation, and 64.6 in./yr estimated as 74 percent (an accepted conversion factor for the region (NOAA, 1982) between pan evaporation and evaporation from a normal open water surface) of Copper Flat pan evaporation (measured between October 2010 and September 2011, except for four winter months. The missing months were estimated by extrapolation of Hillsboro ET_0 data). Actual evaporation or ET is less, depending on sun and wind exposure, ground conditions, and availability of water.

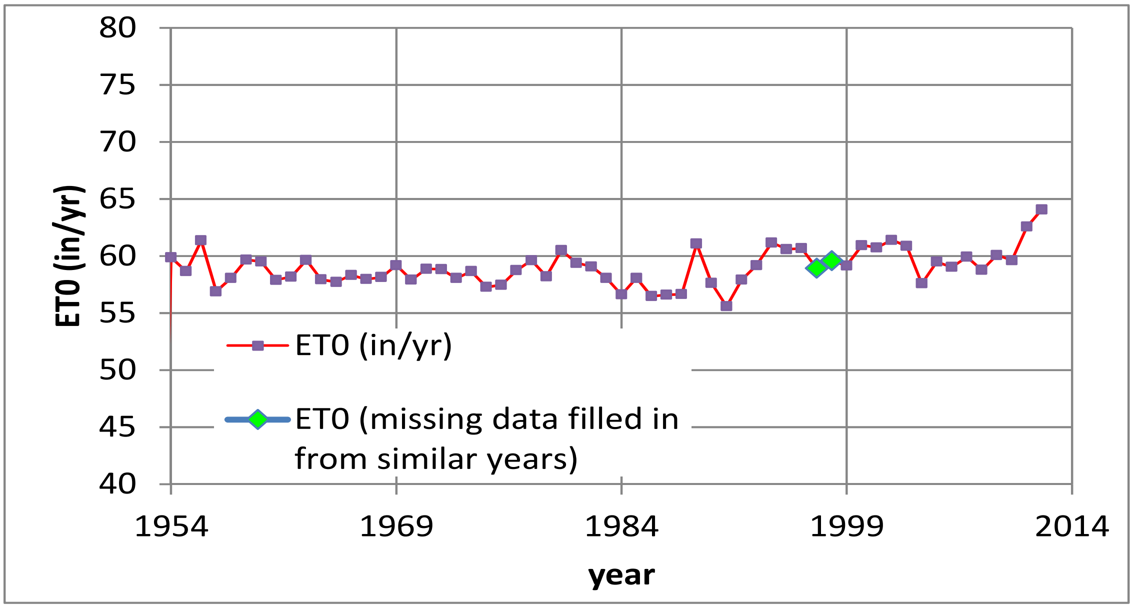


Figure 2.5. Computed Penman-Monteith evapotranspiration (ET_0) at Hillsboro meteorological station.

Evaporation in the study area is higher at lower elevations. An estimate of reservoir evaporation along the Rio Grande (Middle Rio Grande Endangered Species Collaborative, 2003) is:

$$\text{annual evaporation} = 135.8 \text{ in.} - (0.0135 \text{ in./ft amsl}) * Z,$$

where,

Z is elevation in feet above mean sea level (ft amsl).

The equation predicts evaporation of 62.4 in./yr at the Copper Flat open pit (elevation 5,440 ft amsl), in agreement with the above-presented estimates, and 79.1 in./yr at Caballo Lake (elevation 4,200 ft amsl), in agreement (equivalent to 74 percent of pan evaporation) with measurements at Caballo Dam (WRCC, 2012).

The estimated average evaporation, precipitation (from Fig. 2.4) and net evaporation for Caballo Lake and the Copper Flat open pit are presented in Table 2.1.

Table 2.1. Estimated average total and net reservoir evaporation

location	elevation (ft amsl)	mean annual precipitation (in.)	annual reservoir evaporation (in.)	net evaporation (in./yr)
Caballo Lake	4,200	9.2	79.1	69.9
Copper Flat open pit	5,440	12.8	64.6	51.8

ft amsl - feet above mean sea level

3.0 HYDROLOGY AND WATER BALANCE

Topographic basins of the study area are shown on Figure 3.1 and include Las Animas Creek and Percha Creek watersheds as well as the Grayback and Greenhorn Arroyo drainages. A portion (approximately 230 acres) of the original Grayback Arroyo watershed now drains to the Copper Flat open pit.

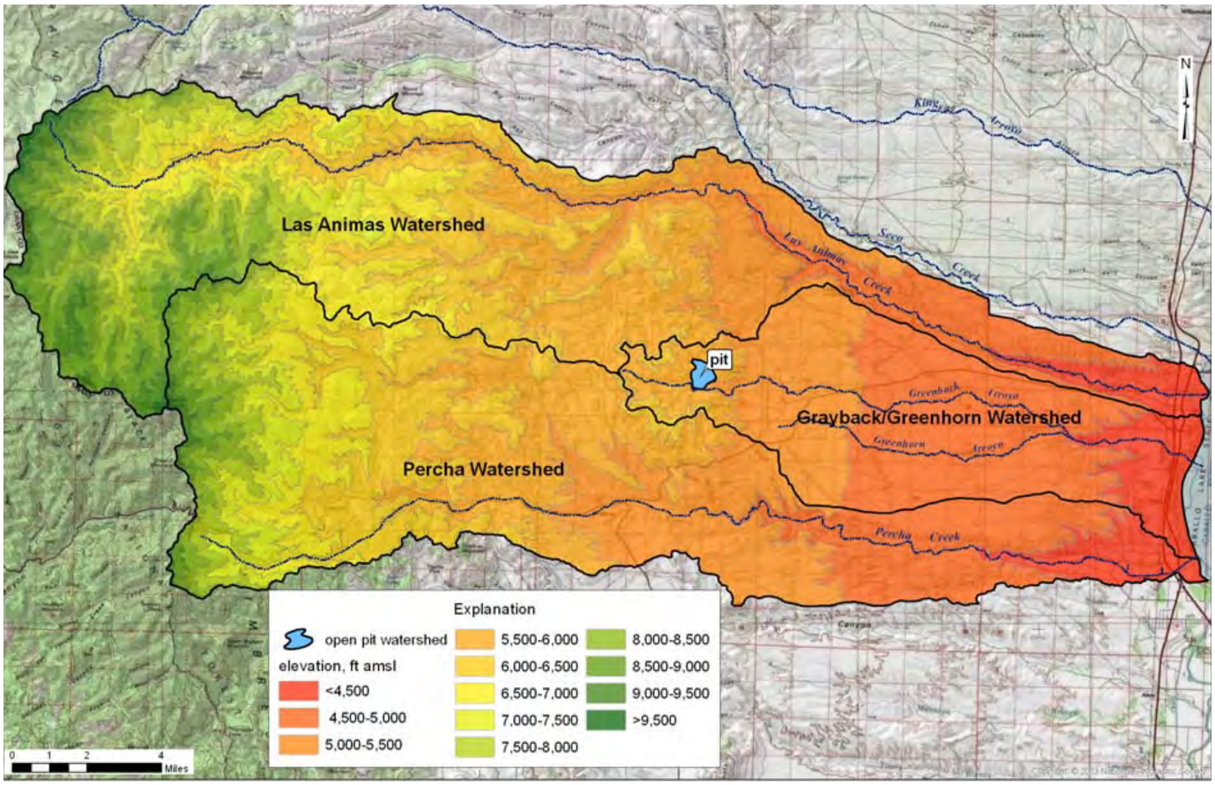


Figure 3.1. Study area watersheds.

3.1 Watershed Area and Precipitation

The areas of each of the watersheds within defined elevation bands are listed on Table 3.1. The mean annual precipitation (Fig. 2.4) estimated for the midpoint of each band is presented on Table 3.2, along with the estimated total annual volume of precipitation for each watershed.

3.2 Runoff and Groundwater Recharge

Basin water yield (surface water runoff plus groundwater recharge) is estimated here following the method of Maxey and Eakin (1949), in which estimated mean annual precipitation, a function of elevation, is correlated with an independent estimate of discharge. The result is a set of recharge factors, defined as the proportion of precipitation that becomes runoff or recharge (excess precipitation), for a given level of mean annual precipitation (an elevation band).

Table 3.1. Study area watershed areas and hypsometry

elevation range (ft amsl)	Las Animas watershed	Percha watershed	Grayback / Greenhorn watershed	open pit watershed
	area (acres)			
<4,500	2,888	3,576	4,539	
4,500-5,000	7,030	11,035	17,095	
5,000-5,500	8,412	12,614	9,708	230
5,500-6,000	14,539	14,072	2,864	
6,000-6,500	12,369	13,030	635	
6,500-7,000	10,279	8,219		
7,000-7,500	6,507	5,355		
7,500-8,000	5,808	4,159		
8,000-8,500	6,160	3,021		
8,500-9,000	6,362	1,749		
>9,000	3,305	509		
total	**83,659**	**77,339**	**34,841**	**230**

ft amsl - feet above mean sea level

Table 3.2. Study area precipitation by watershed and elevation band

midpoint elevation (ft amsl)	precipitation (in./yr)	Las Animas watershed	Percha watershed	Grayback / Greenhorn watershed	open pit watershed
		precipitation (ac-ft/yr)			
4,350	9.7	2,326	2,880	3,655	
4,750	10.8	6,345	9,961	15,431	
5,250	12.3	8,617	12,921	9,944	236
5,750	13.8	16,661	16,126	3,282	
6,250	15.2	15,679	16,516	804	
6,750	16.7	14,279	11,417		
7,250	18.1	9,832	8,091		
7,750	19.6	9,482	6,790		
8,250	21.0	10,805	5,298		
8,750	22.5	11,933	3,280		
9,500	24.7	6,802	1,048		
total		**112,761**	**94,328**	**33,116**	**236**

ft amsl - feet above mean sea level
ac-ft/yr - acre-feet per year

Some example sets of recharge factors are presented in Table 3.3. These include the formulation of Bennett and Finch (2002) used to estimate recharge in the trans-Pecos region of Texas, that was subsequently used to estimate recharge to the Salt Basin in New Mexico and Texas (JSAI, 2010), and the Davis Mountains/Salt Basin in Texas (LBG-Guyton, 2004).

Another example is that of Maxey and Eakin (1949), which studied dry, closed basins in southern Nevada, estimating discharge as playa ET. This example was modified by McDonald-Morrissey (1998) in BLM (2000), in a study of wetter, exoreic (outflowing) basins along the Carlin Trend in northern Nevada. Total basin discharge was estimated from gaged surface flows and from ET in vegetated areas.

Actual runoff and recharge are influenced by site-specific conditions including topography, soil type and thickness, land cover, and surface geology. However, in the absence of an independent estimate of discharge, the previously published estimates may indicate a potential range of basin water yield.

The above formulas suggest, respectively, a study-area water balance of 8,000 ac-ft/yr (Bennett and Finch), 30,000 ac-ft/yr (Maxey and Eakin) and 51,000 ac-ft/yr (BLM). In the absence of other information, water yield of the study area is anticipated to be within the range of these estimates, or between about 8,000 and 50,000 ac-ft/yr. This range of yield is compared below to a basin-specific estimate of discharge.

Table 3.3. Published recharge factors

midpoint elevation (ft amsl)	precipitation (in./yr)	fraction of precipitation that becomes runoff and/or recharge		
		Bennett and Finch (2002)	Maxey - Eakin (1949)	BLM (2000)
4,350	9.7	0.00	0.03	0.03
4,750	10.8	0.00	0.03	0.03
5,250	12.3	0.00	0.07	0.07
5,750	13.8	0.02	0.07	0.07
6,250	15.2	0.03	0.15	0.3
6,750	16.7	0.04	0.15	0.3
7,250	18.1	0.05	0.15	0.3
7,750	19.6	0.07	0.15	0.3
8,250	21.0	0.08	0.25	0.45
8,750	22.5	0.09	0.25	0.45
9,500	24.7	0.11	0.25	0.45

BLM - U.S. Bureau of Land Management ft amsl - feet above mean sea level

3.3 Discharge

Regional discharge from the study area occurs mainly as groundwater and surface-water discharge to Caballo Lake and the Rio Grande, and as ET discharge from riparian and irrigated areas along Las Animas and Percha Creeks. Areas of open-water evaporation and of ET discharge in the Palomas basin are shown on Figure 3.2.

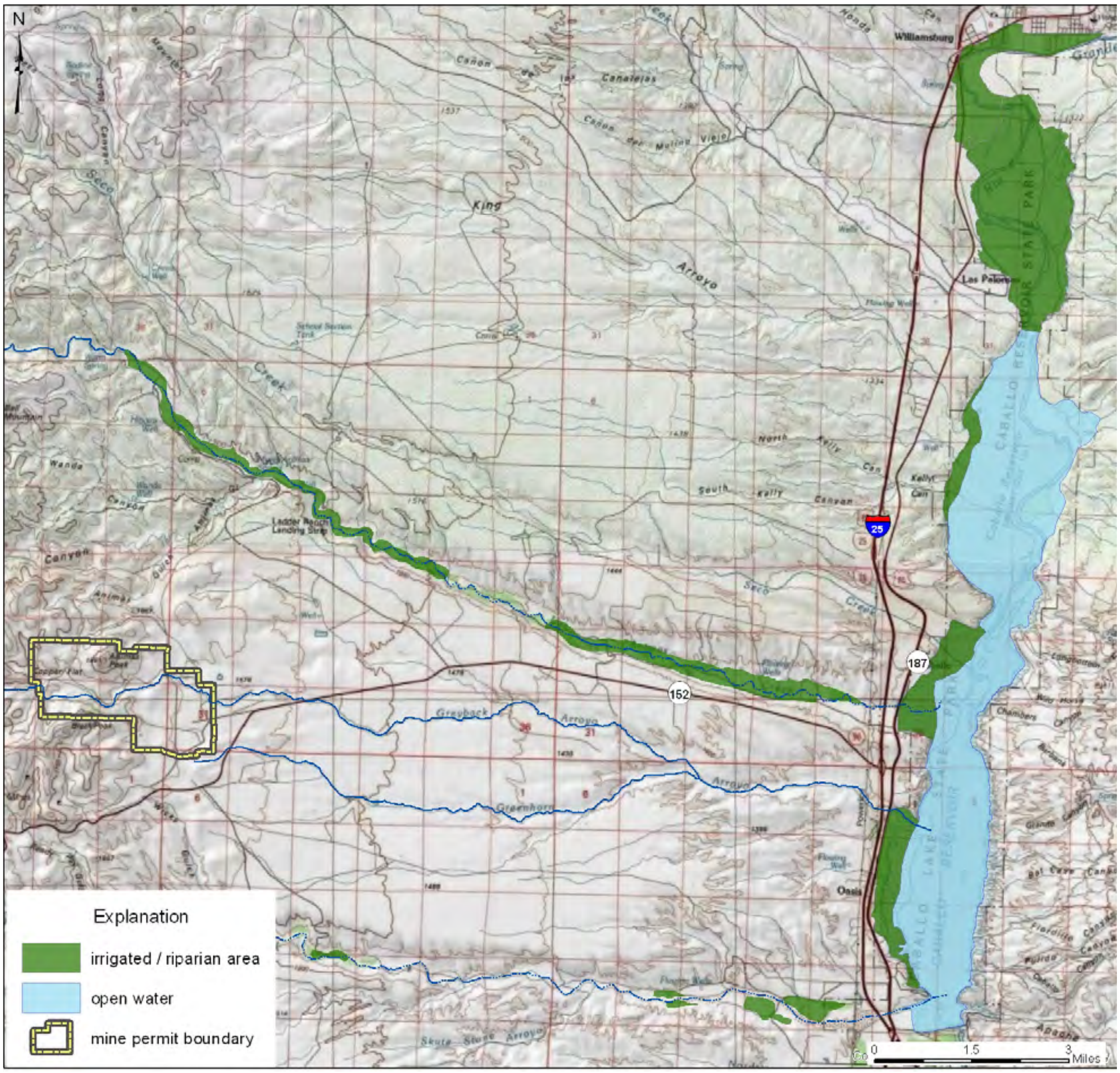


Figure 3.2. Regional discharge areas.

The Caballo Lake and North Caballo Lake discharge areas shown on Figure 3.2 are only partly supplied from the study area. Water is also provided by:

- Direct contribution from the Rio Grande upstream; based on average daily discharge below Elephant Butte dam (U.S. Geological Survey (USGS) station No. 08361000) and below Caballo dam (USGS station No. 08362500) from 1938 through 2010, an average of 12,364 ac-ft/yr more water is released from Elephant Butte (into Caballo) than from Caballo.

- Runoff from the watersheds east of Caballo Lake. These basins lack large high-altitude catchment areas and yield less water than basins west of the lake. They do, however, contribute water to Caballo after major precipitation events.

- Contribution from the Palomas Creek (catchment area 233,942 ac) and Cuchillo Creek (catchment area 235,493 ac) basins north of the study area, with similar hypsometry to the study area basins. Assuming water yield proportional to (elevation-weighted) catchment area (Table 3.1), Palomas and Cuchillo Creek basins would be expected to produce about 71 percent of the total yield from the basins west of Caballo, with the study area basins contributing the remainder.

In addition to regional discharge from the Palomas Basin, local discharge areas over the Animas Uplift and in the Animas Graben include riparian areas along perennial stretches of upper Las Animas and Percha Creeks. These areas are shown on Figure 3.3 including about 600 acres in the "Percha Box" (Percha Creek above the mountain front) and about 200 acres along the Upper Animas.

Also shown on Figure 3.3 is a stretch of upper Grayback Arroyo in the area of Copper Flat. This part of Grayback does not flow perennially, but groundwater levels are close to the surface, and there is baseflow discharge to Grayback Arroyo following wet periods (S. Finch, personal communication, 2012).

Evaporation/ET for Caballo Lake and for the study area watersheds is estimated on Table 3.4; ET from irrigated crops or riparian vegetation was estimated at 36 in./yr. Net evaporation for Caballo Lake, estimated at about 70 in./yr (Table 2.1), was rounded down to 60 in./yr, to account for runoff from the east side of the lake. Net evaporation for North Caballo Lake and ET for Rio Grande riparian areas were estimated as the average of combined net Caballo evaporation and riparian ET rate, or 48 in./yr.

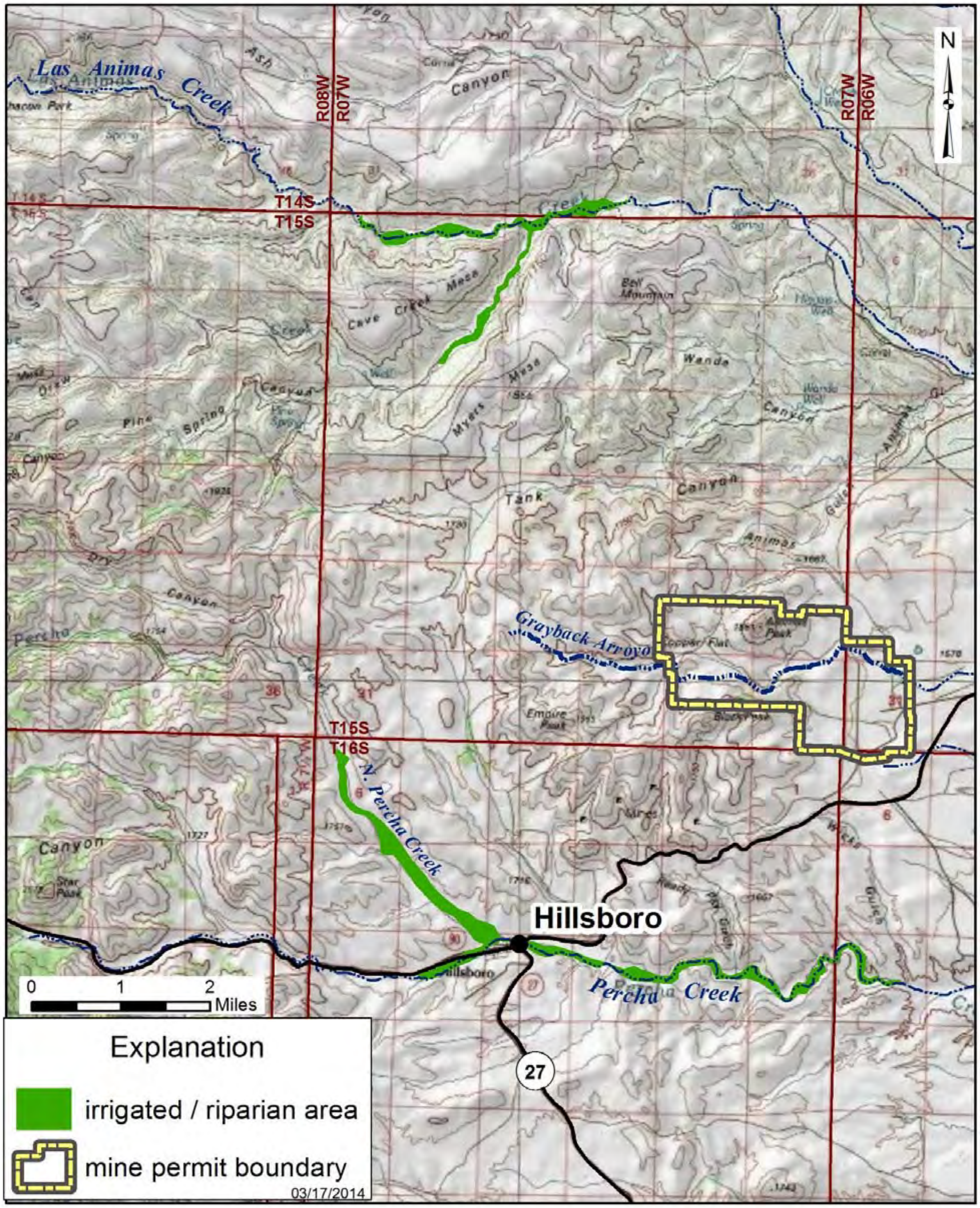


Figure 3.3. Local discharge areas.

Table 3.4. Estimated evaporation and evapotranspiration (ET)

		area (acre)	net ET (ft/yr)	net ET (ac-ft/yr)
Palomas Basin	Caballo Lake (water surface at 4,200 ft amsl)	6,344	5	31,720
	North Caballo Lake / Rio Grande	5,214	4	20,856
	Lower Las Animas Creek	1,421	3	4,263
	Lower Percha Creek	280	3	840
Animas Uplift Animas Graben	Upper Animas Creek	200	3	600
	Upper Percha Creek	600	3	1800
	Copper Flat open pit	5	4	20
	total			**60,079**

ac-ft/yr - acre-feet per year ft amsl - feet above mean sea level

3.4 Water Balance

The Caballo Lake and North Caballo Lake discharge components in Table 3.4, totaling 52,576 acre-feet per year (ac-ft/yr), are only partly supplied from the study area. In order to estimate the portion provided from the study area, the following adjustments were made:

- Based on USGS gage data discussed above (Sec. 3.3), 12,364 ac-ft/yr is assumed to be provided by the Rio Grande upstream of Caballo Lake.
- The estimated rate of evaporation from Caballo Lake was rounded down to account for runoff from the watersheds east of the lake as described above.
- Of the remaining Caballo Lake and North Caballo Lake discharge (40,212 ac-ft/yr), 71 percent was assumed to be provided by the Palomas and Cuchillo Creek Basins, as discussed above. The remainder was assumed to be generated within the study area.

Based on the discharge estimates in Table 3.4 and the adjustments listed above, an estimated water balance for the study area is presented in Table 3.5. The system receives water as runoff and recharge to the four watersheds listed in the upper part of the table. The estimated water yield of about 17,000 ac-ft/yr falls within the range of water yield (8,000-50,000 ac-ft/yr) estimated in Section 3.2 above.

The system discharges water as groundwater outflow and ET, as listed in the lower part of the table. The main component of discharge is groundwater flow to the Rio Grande / Caballo system. There is discharge of ET from three of the four watersheds, but not from Grayback/Greenhorn, which has no significant groundwater discharge area (depth to water is too great for ET of groundwater).

Table 3.5. Estimated water balance

	runoff and recharge (ac-ft/yr)	
	Las Animas Creek	11,509
	Percha Creek	7,874
	Grayback and Greenhorn Arroyos	201
	Copper Flat open pit	1
	total	**19,585**
	discharge (ac-ft/yr)	
Palomas Basin	Lower Las Animas Creek	4,263
	Lower Percha Creek	840
	discharge to Rio Grande and Caballo Reservoir	11,850
	total	**16,953**
Animas Uplift Animas Graben	Upper Animas Creek	600
	Upper Percha Creek	1800
	Copper Flat open pit	20
	total	**2,420**

ac-ft/yr - acre-feet per year

The water balance in Table 3.5 may also be compared with the water balance of the Upper Mimbres Basin, located on the opposite side of the Black Range from the study area, with a similar distribution of elevations. The average yield of the 300,000-acre basin above the Faywood gaging station is estimated (based on gaged flows) at 26,700 ac-ft/yr (White, 1930). The same per-acre water yield in the study area would be 17,450 ac-ft/yr, similar to the (regional) discharge estimate of about 17,000 ac-ft/yr from Table 3.5.

4.0 GEOLOGY AND HYDROGEOLOGY

The surface-water basins discussed above are shown on Figure 4.1, along with the smaller groundwater-flow model domain. Although most of the precipitation that recharges the groundwater system originates in the upper part of the watersheds (left-hand side of Fig. 4.1, outside of the groundwater study area), the main groundwater systems are found in sedimentary deposits downstream.

The study area consists of three major hydrogeologic zones (Fig. 4.1), shown in west-east cross-section on Figure 4.2. The three zones are 1) The sediment-filled Animas Graben west of the Animas Uplift and east of the Black Range mountain block, 2) The Animas Uplift, the bedrock in which the ore body is located, and 3) the Palomas Basin, the main sedimentary basin along the Rio Grande rift east of the Animas Uplift, in which the mine water-supply wells are located.

The Animas Graben between the Black Range and the Animas Uplift drains north to Animas Creek and south to Percha Creek via Warm Springs Valley. Santa Fe Group (SFG) sedimentary deposits overlie older sedimentary bedrock units (Fig. 4.2).

The Animas Uplift in the vicinity of Copper Flat (Fig. 4.1) consists of crystalline bedrock that conducts little water. The Copper Flat open pit and the main part of the other Project facilities, including waste rock and tailings storage facilities, would be located on the Animas Uplift. To the north and south of the Copper Flat area the Animas Uplift consists of sedimentary rocks that conduct more groundwater flow.

The Palomas (geologic) Basin lies within the Lower Rio Grande Underground Water (administrative) Basin. Parts of the waste rock and tailings storage facilities would be located overlying the western margin of the Palomas Basin. The Project water-supply wells are completed within the SFG aquifer between Las Animas Creek and Percha Creek (Fig. 4.1), and will be the main source of groundwater and surface-water effects of the Project.

The Project water-supply wells are completed within the Palomas Graben (Fig. 4.2), a significant geological and hydrogeological feature within the Palomas Basin. The feature was identified in the 1970s (Dunn, 1984), during water-supply exploration for the previous Copper Flat mine. The graben was identified as the western-most part of the Palomas basin with sufficient aquifer productivity to develop an adequate water supply.

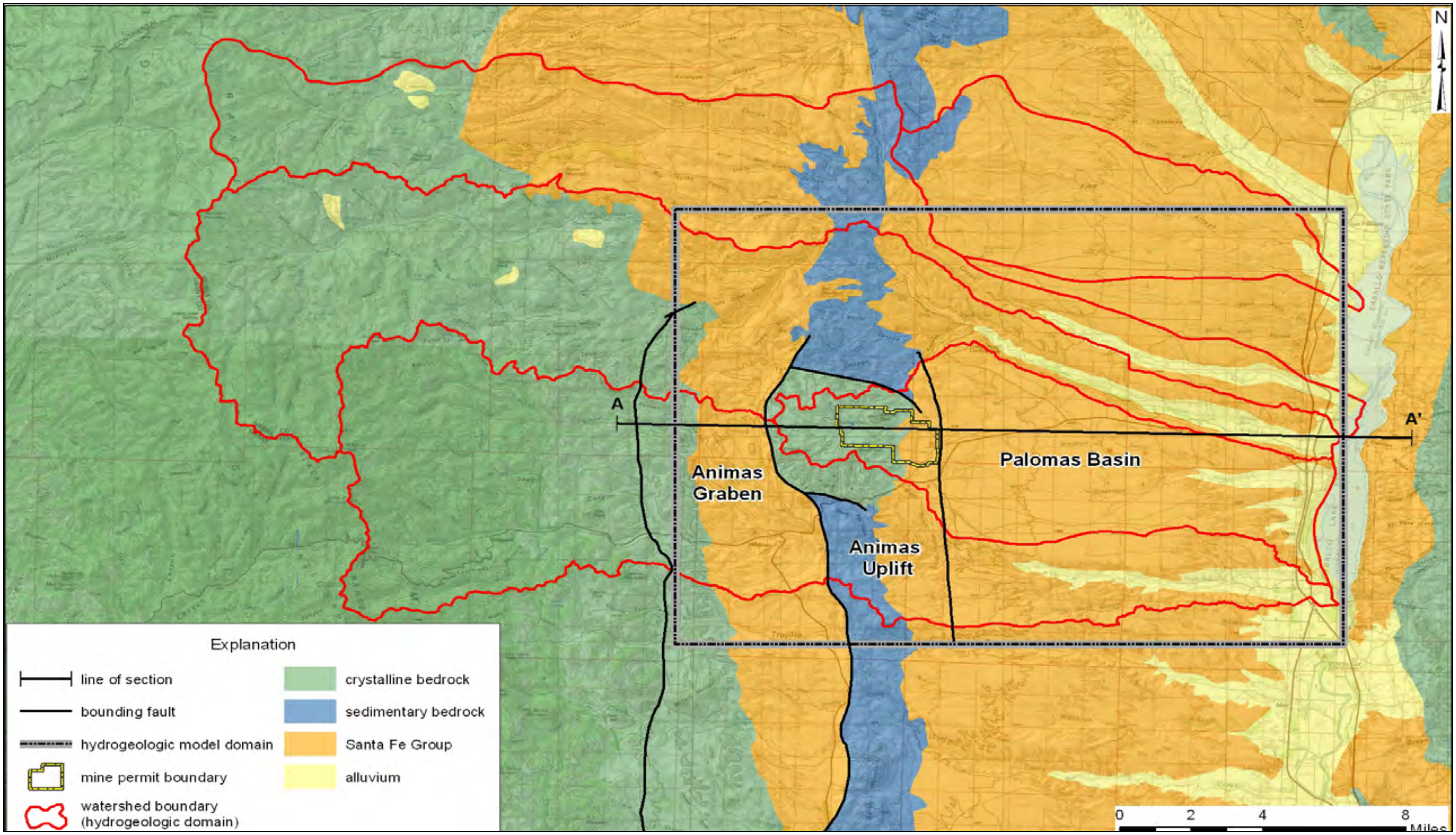


Figure 4.1. Hydrogeologic zones.

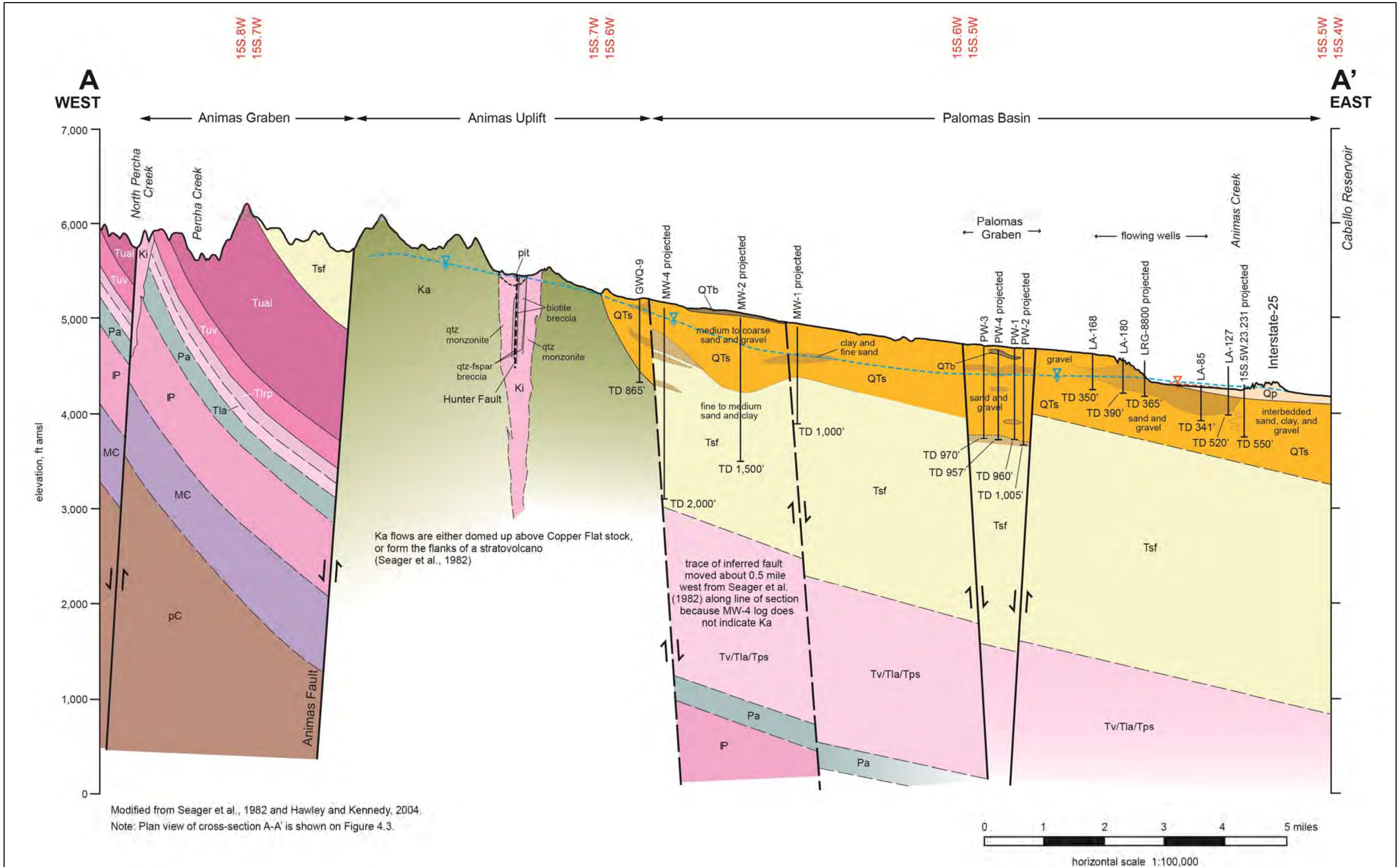


Figure 4.2. Hydrogeologic zones, west-to-east cross-section.

4.1 Geology

The geologic description is adapted from Shomaker (1993), who cites Harley (1934), Hedlund (1975), Dunn (1982), and Seager et al. (1982). An extended bibliography of geology references is presented as Appendix A. The geologic map of the study area is presented on Figure 4.3. Three major geologic subdivisions (Figs. 4.1 and 4.2), the Animas Uplift, the Animas Graben east of the Black Range, and the Palomas Basin, are described below.

4.1.1 Animas Uplift

The Animas Uplift is an upthrown block, ranging from less than 2 to about 4 miles wide, bounded by north-south trending faults (Fig. 4.1). The Copper Flat ore body is located within a nearly circular remnant of a Cretaceous-age andesite volcano about 4 miles in diameter that is part of the Animas Uplift. Drilling has shown that andesite is present to a depth of more than 3,000 ft (Dunn, 1982, p. 314).

The hills surrounding Copper Flat, referred to as the Hillsboro Hills, consist of Cretaceous-age andesite flows, breccias, and volcaniclastic rocks that were erupted from the volcano (McLemore, 2001; Raugust and McLemore, 2004).

The volcano intrudes through the Paleozoic-age sedimentary rock sequence. The andesite is bounded on the north and south by Paleozoic-age limestone, and on the east by the SFG sediments of the Palomas Basin, in fault contact. On the west, the andesite body is in fault contact with Paleozoic-age limestone, Tertiary-age volcanic rocks, and overlying SFG sediments of the Animas Graben (Fig. 4.2).

The ore body itself is in the Copper Flat quartz monzonite stock, within the body of andesite. The quartz monzonite porphyry intruded the vent of the volcano, and then dikes and mineralized veins intruded the monzonite porphyry and radiated outward from the porphyry into faults and fracture zones in the andesite. The porphyry copper deposit is concentrated within a breccia pipe in the quartz monzonite stock.

4.1.2 Graben West of Animas Uplift

West of the Animas Uplift, between it and the Black Range, lies a half-graben in which Tertiary-age alluvial-fan deposits, sandstones, and mudstones of the SFG overlie Tertiary-age volcanic rocks and Paleozoic-age sedimentary rocks. Dips are eastward, and the half-graben is bounded on the east by normal faults. The Santa Fe beds may reach a thickness of 1,000 ft on the east side of the half-graben (Seager et al., 1982, sheet 2).

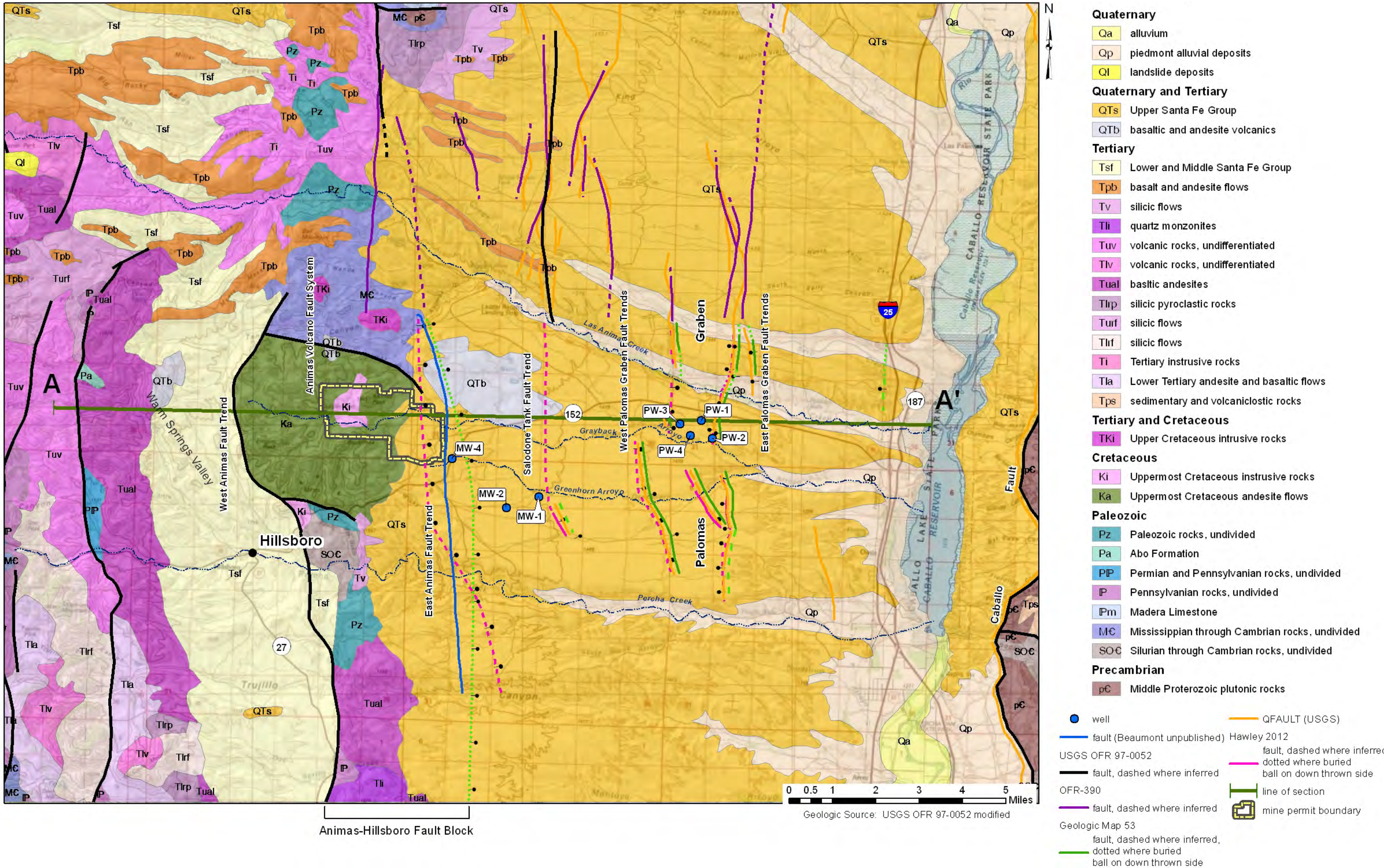


Figure 4.3. Geologic map of study area.

4.1.3 Palomas Basin

The Palomas Basin is a sediment-filled structural trough about 35 miles long by 12 miles wide. It is part of the Rio Grande rift, a north-south trending zone of approximately east-west oriented extension that bisects the state of New Mexico. The extension is caused by the Colorado Plateau crustal block pulling away from the High Plains block, which stretches and thins the Earth's crust in the area of the rift (Seager and Morgan, 1979).

Rio Grande rift extension began in southern New Mexico about 36 million years ago in late Eocene time, with the rate of extension peaking between 16 and 10 million years ago, in Miocene time (Lozinsky, 1986; Mack, 2004). The axial basins (such as the Palomas Basin) are in the form of half-grabens that are tilted strongly toward the east or the west, depending on which side of the main rift fault the basin is located.

The Palomas Basin is an eastward-tilted half graben as evidenced by gravity data and by geologic mapping of eastward dips of Santa Fe Group beds along the western edge of the basin (Lozinsky, 1986). The basin is defined between the north-south trending Caballo and Animas-Hillsboro fault blocks (Fig 4.3; Kelley, 1955; Kelley and Silver, 1952). Most of the displacement has occurred on the east side of the Palomas Basin along the Caballo Fault (the main rift fault system).

Basin-fill thickness is probably greater than 6,000 ft along the eastern side of the Palomas Basin (Lozinsky, 1986, figure 2). Basin-fill thickness is greater than 2,000 ft at well MW-4 (Fig. 4.3), located in the thinner western part of the basin, near the Animas Uplift.

The sedimentation of the Palomas Basin occurred contemporaneously with the down-dropping of the half graben and the rise of the Animas Uplift (Mack, 2004). Las Animas and Percha Creeks were established prior to structural development of the Animas Uplift and maintained the water course by channel cutting through the bedrock units, and downstream deposition of fluvial sediments in the Palomas Basin (Mack, 2004).

North-south extensional faulting followed the formation of the Palomas Basin and deposition of the majority of the Santa Fe Group sediments. North-south faults within the Santa Fe Group Sediments have been mapped by Kelley et al. (unpublished, 1979), Seager et al. (1982), Harrison et al. (1993), and Hawley (unpublished, 2012).

North-south extensional faulting formed the Palomas Graben (Figs. 4.2 and 4.3) which filled with sediments that are coarser-grained than the Santa Fe Group sediments on either side. The Palomas Graben was identified as a productive aquifer, and the Copper Flat well field was completed within it in the mid-1970s.

The faults forming the Palomas Graben are mapped from Percha Creek north to about Palomas Creek. However, similar north-south trending faults mapped by Harrison et al. (1993) suggest the Palomas Graben may continue as far north as the San Mateo Mountains (Hawley, personal communication, 2012). The graben is thought to be an ancestral tributary of the Rio Grande which joins the main channel south of the study area.

The mapped individual fault segments (Fig. 4.3) form several continuous north-south fault trends. A summary of the fault trends, from west to east, follows:

1. West Animas Fault Trend – north-south fault that forms boundary between Animas half-graben and west side of Animas Uplift. Normal fault downthrown on the west side. Primary references Murray (1959); Hedlund (1975).

2. Animas Volcano Fault System – faults formed around andesite volcano, downthrown on exterior side of volcano. Primary references Harley (1934); Hedlund (1975); Dunn (1982).

3. East Animas Fault Trend – north-south normal fault that forms boundary between Animas Uplift and Palomas Basin. Downthrown on east side. Mapped as inferred fault at slightly different longitude by Seager et al. (1982) than by Hawley (2012). Key references include Harrison et al. (1993), Beaumont (2011), JSAI (2011a), and Hawley (2012). Work performed by JSAI (2011a) and Beaumont (2011) is based on analysis of well logs and lineaments identified from aerial photographs.

4. Saladone Tank Fault Trend – north-south normal fault down thrown on the east side. Mapped by Kelley et al. (1979), Seager et al. (1982), Harrison et al. (1993), and Hawley (2012).

5. West Palomas Graben Fault Trends – north-south normal faults downthrown on the east side. Forms western boundary of the Palomas Graben. Faults mapped by Kelley et al. (1979), Seager et al. (1982), Harrison et al. (1993), and Hawley (2012).

6. East Palomas Graben Fault Trends – north-south normal faults downthrown on the west side. Forms eastern boundary of the Palomas Graben. Faults mapped by Kelley et al. (1979), Seager et al. (1982), Harrison et al. (1993), and Hawley (2012).

4.2 Hydrogeology

Hydrogeologic units, aquifer characteristics, and recharge and discharge locations are discussed below for the three geologic subdivisions of the study area. A hydrogeologic map of the study area is shown with surface water features and mapped springs on Figure 4.4.

Some of the mapped springs, such as “Las Animas Creek Community Spring” (Murray, 1959) and “LA-52” (Davie and Spiegel, 1967), were identified long ago and may no longer flow. However, the locations identified within the Santa Fe Group lie along the main faults, demonstrating the structural controls on groundwater flow.

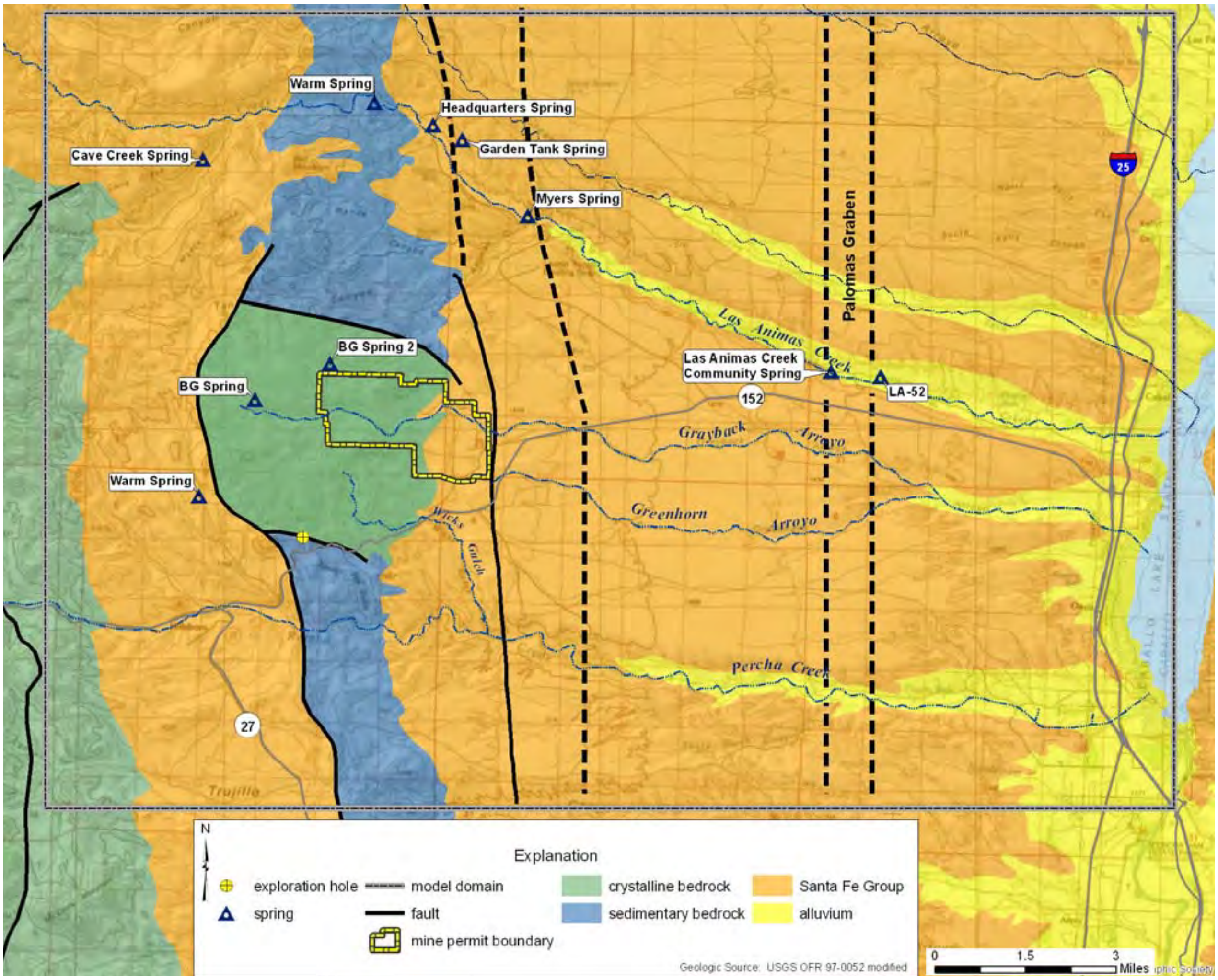


Figure 4.4. Hydrogeologic units and mapped spring locations.

4.2.1 Animas Uplift

Hydrogeologic units in the Animas Uplift include the relatively impermeable andesite and monzonite of the Copper Flat area and the relatively permeable carbonate rocks and other sedimentary rocks to the north and south of Copper Flat.

Groundwater recharge from local precipitation to the quartz monzonite and andesite is limited by low hydraulic conductivity. Recharge to the limestone outcrop areas north and south of the andesite is greater. Recharge to the limestone also includes infiltration of runoff generated at higher elevation, from the Las Animas Creek and Percha Creek watersheds.

Groundwater discharges from the limestone at the foot of the uplift, as spring flow (Fig. 4.4) and base flow to Percha and Las Animas Creeks. Groundwater discharges from the andesite as subsurface flow across the fault contacts with the Palomas Basin, and as evaporation from the open pit.

The existing Copper Flat open pit, which the New Mexico Copper Corporation (NMCC) proposes to expand, was excavated in 1982 by Quintana Minerals. The Quintana pit was excavated to a maximum depth corresponding to elevation 5,400 ft amsl. The current water level in the pit is about 5,439 ft amsl (April 2013). The pre-mining groundwater level (without lake evaporation) was about 5,450 ft amsl (JSAI, 2011b).

The low hydraulic conductivity of the quartz monzonite and andesite is reflected in the low pumping rates required in 1982 to dewater the Quintana pit. The dewatering rate required to maintain the greater-than 45-ft drawdown, in an excavation about 100 ft by 200 ft in area at maximum depth, was estimated at 22 gallons per minute (gpm) (Shomaker, 1993). SRK (1997) reports pumping rates up to 50 gpm. The range in reported dewatering rates was likely due to the variability of precipitation and runoff to the pit.

The low conductivity of the andesite and monzonite are confirmed below in the evaluation of the pit water balance (Sec. 5.4) and in the results of the 2011 pit-area pressure-injection testing (Sec. 5.4.1). It can be expected that the hydraulic conductivity of rock deeper in the andesite and quartz monzonite will have still lower hydraulic conductivity, because of the decrease in weathering effects and the closing of fractures with depth. The andesite acts as a hydrologic containment vessel for the existing and proposed open pits.

The radiating dikes and veins may be inferred to have relatively low conductivity as well. Several mine shafts in Wicks Gulch (Fig. 4.4) were examined, and found to be almost full of water; if there were significant hydraulic conductivity, either along fractures or through the rock matrix, water levels would be closer to the elevation of nearby surface channels.

Away from the andesite body, where the Animas Uplift consists of fractured, predominantly limestone and dolomite bedrock, it is likely that significant permeability has developed by the combination of fracturing and enlargement of fracture-openings by dissolution of carbonate minerals. This hypothesis is supported by the account of an air-drilled exploration hole (Fig. 4.4) in SW/4 SE/4 Sec. 3, T. 16 S., R. 7 W, which was abandoned because large water production overcame the capacity of the compressor to continue circulation (Sonny Hale, personal communication). The well is close to the fault which offsets the andesite against the predominantly limestone Paleozoic-age section.

4.2.2 Graben West of Animas Uplift

Local precipitation, and runoff from the Black Range, provide groundwater recharge to the graben. Discharge occurs mainly as spring flow and possibly also as subsurface discharge to the Animas Uplift. Spring flow in the Warm Springs drainage discharges as base flow to Percha Creek. The emergence of water at Warm Springs (Fig. 4.4) at the eastern edge of the graben demonstrates that the andesite of the Animas Uplift acts at depth as a barrier to flow from the graben. Groundwater in the graben flows west to east across the Animas Uplift, south toward Percha Creek and north toward Las Animas Creek, flowing around the body of low-permeability andesite (Fig. 4.4).

The contrast between the chemical makeup of water from Warm Springs, as compared with water from wells and springs within the Animas Uplift (Newcomer and Finch, 1993), indicates that the source of Warm Springs water is not within the uplift, as might otherwise be inferred from the relative heads at the spring and at wells and springs within the uplift (Fig. 4.4).

4.2.3 Palomas Basin

Water recharges the Palomas Basin at its western edge, through alluvial fans at the edge of the Animas Uplift, including infiltration of runoff from Greenhorn and Grayback Arroyos and infiltration of base flow and runoff from the upper catchments of Las Animas and Percha Creeks.

Groundwater flows mainly east toward the Rio Grande and Caballo Lake. Calibration of the groundwater-flow model (Sec. 6.0) presented below also suggests that there is a north-to-south component of groundwater flow within the Palomas graben, discharging toward the Rio Grande system south of the study area.

Besides discharging to the Rio Grande and Caballo, groundwater also discharges locally, by pumping, from flowing wells, and as evapotranspiration from irrigated and riparian vegetated areas along Las Animas Creek and Percha Creek. The principal water-bearing sediments of the Palomas Basin are (1) alluvial-fan deposits, fluvial sands and gravels of the Santa Fe Group, and (2) alluvium in the inner valleys of the Rio Grande and principal tributaries (Hawley and Kennedy, 2004).

Davie and Spiegel (1967, p. 9) describe the Santa Fe Group in Las Animas Creek area as consisting of (a) an alluvial fan facies, interfingering eastward with (b) a clay facies, possibly representing the distal or deltaic beds of the alluvial fan facies, which in turn interfingers with (c) an axial river facies consisting of well-sorted sand and gravel containing well-rounded quartzite pebbles. The sediments are stratified and in general dip to the east.

Geologic logs from wells along Las Animas Creek provide evidence that the coarse-grained sediments in the Palomas Graben are overlain by a clay layer that creates perched groundwater conditions in the alluvium along Animas Creek.

Stratification and heterogeneity of the SFG creates confined conditions at depth in the lower Palomas Basin. Seepage along Percha Creek, Grayback Arroyo, Greenhorn Arroyo, and Las Animas Creek alluvial systems recharges the SFG sediments in the upper basin and the recharge pressures the stratified sediments down-dip, creating upward vertical gradients in the lower basin. Overlying clay beds create artesian conditions in the basin down-dip of recharge zones.

Artesian pressures are relatively low, generally less than 10 ft of head above land surface. A survey of artesian wells (Shomaker, unpublished) from 1993 has been updated (JSAI, 2011c), indicating reduction of artesian flow and pressure over 18 years. The history and effects of artesian discharge are discussed further below.

4.3 Hydrogeologic Conceptual Model

The hydrogeologic system described above is summarized on Figure 4.5, a map of hydrogeologic units, and on Figure 4.6, a map of the boundary conditions (inflows and outflows of water) on the system. The hydrogeologic units (Fig. 4.5) and boundary conditions (Fig. 4.6) presented form the basis of the numerical groundwater-flow model.

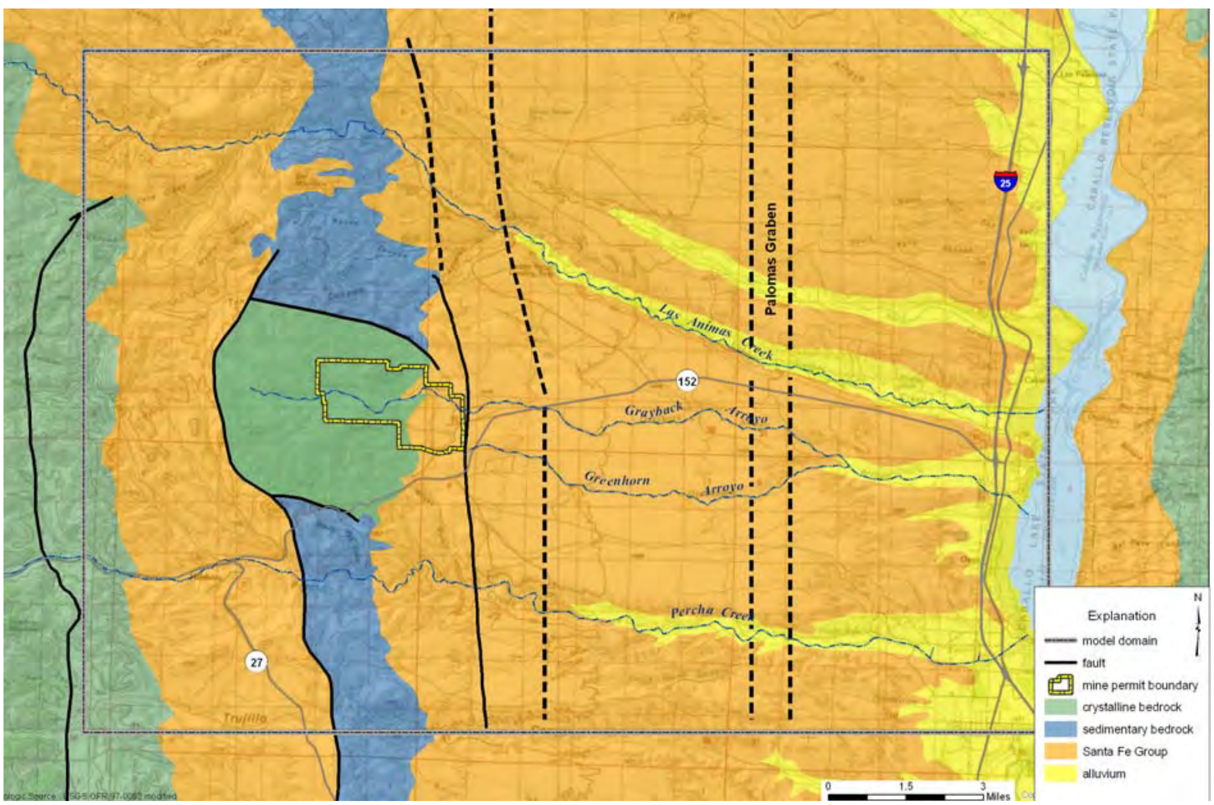


Figure 4.5. Hydrogeologic map of study area.

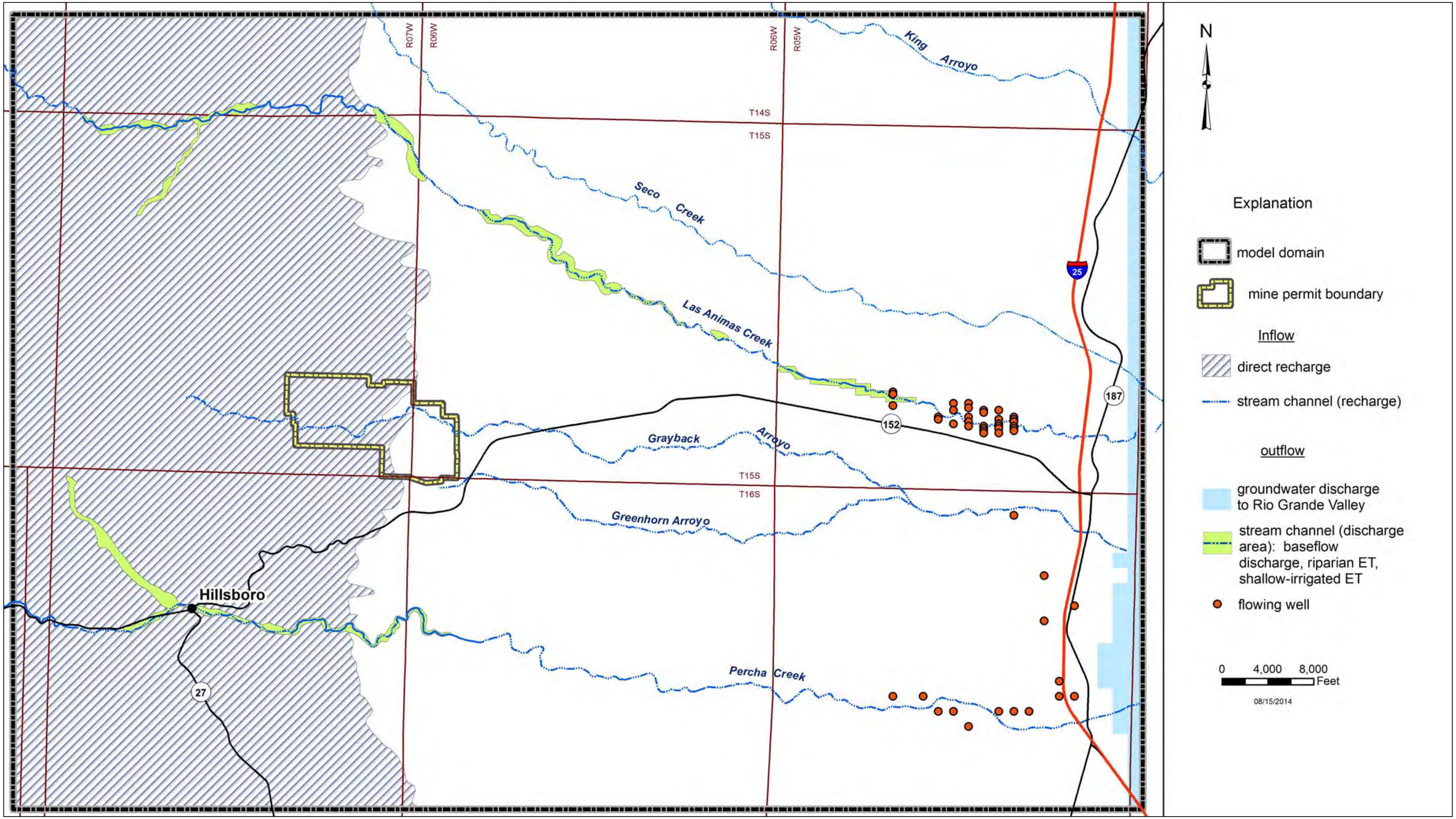


Figure 4.6. Hydrogeologic boundary conditions

5.0 CALIBRATION DATA

This section describes the data on aquifer stresses and responses available to guide the development and calibration of a numerical groundwater-flow model. These include information on (1) regional water levels, (2) the Palomas Graben and the area of the water-supply wells (well field), (3) the former tailings facility, (4) the open pit, and (5) the artesian zone in the lower Las Animas Creek and lower Percha Creek basins.

5.1 Regional Water Levels

Locations of wells and water-level measurements are presented with recent (December, 2012) potentiometric surface contours on Figure 5.1. Interpreted contours are shown for three aquifers: (1) bedrock and SFG of the Animas Uplift and Animas Graben, (2) the SFG aquifer of the Palomas Basin, and (3) the shallow alluvial aquifer along Las Animas Creek. Groundwater levels range from above 5,800 ft amsl at the western edge of the Animas graben to about 4,200 ft amsl at Caballo Lake.

Piezometers and production wells discussed below are shown on Figure 5.2. Available well construction diagrams are presented in Appendix B.

5.2 Well Field Area

The NMCC water supply wells (PW-1, PW-2, PW-3, and PW-4) were constructed and tested in 1975-80 (Green and Halpenny, 1976, 1980). Local transmissivity of the SFG aquifer is estimated below from the PW-1 and PW-2 test data. Effects of the period of well field operation, from March through June 1982, are then discussed. Next, results of a 1994 pumping test of MW-9, evaluating vertical transmission of effects, is presented. Finally, results of the 2012 aquifer test are discussed.

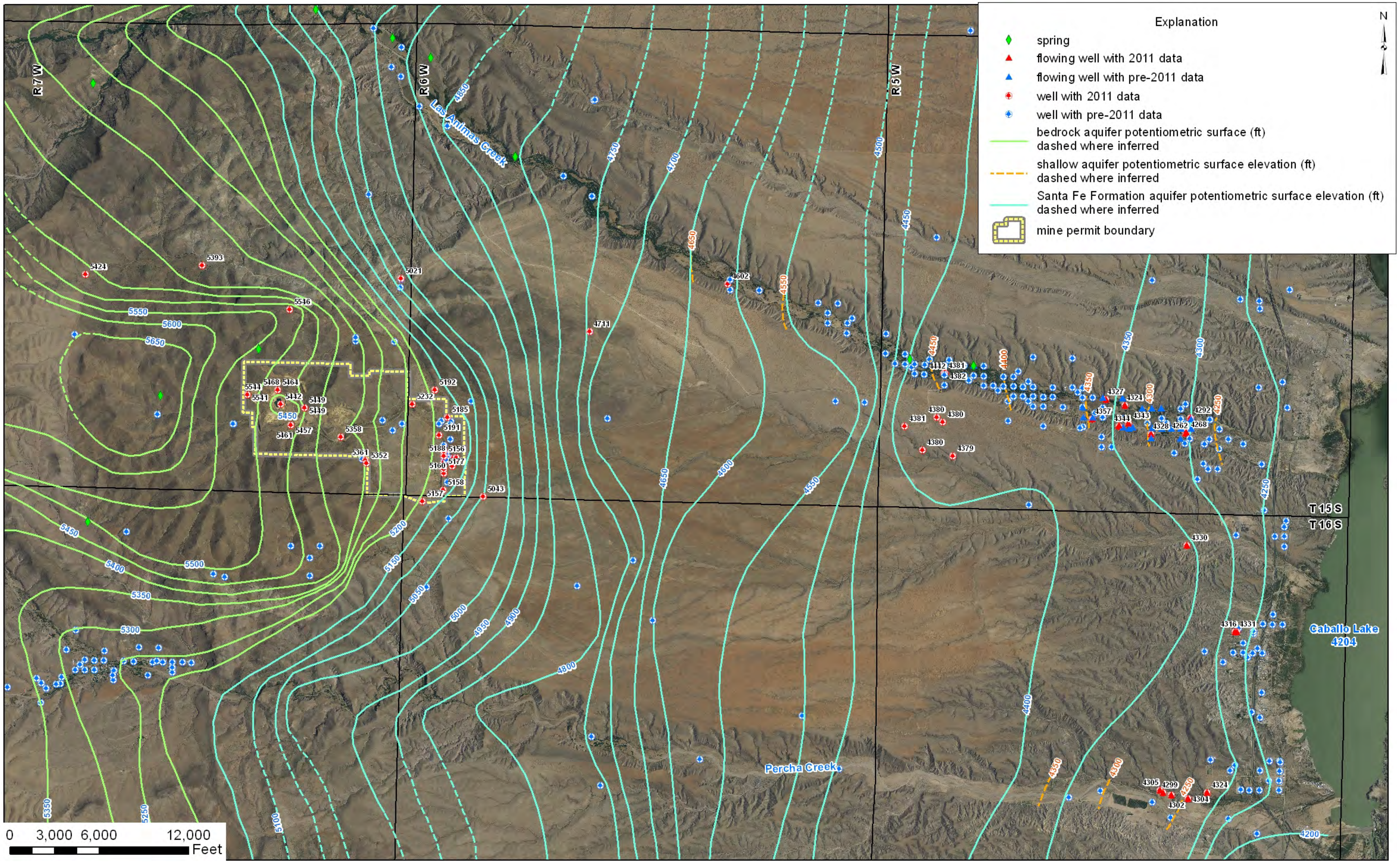


Figure 5.1. Regional water-level measurements and potentiometric surface contours.

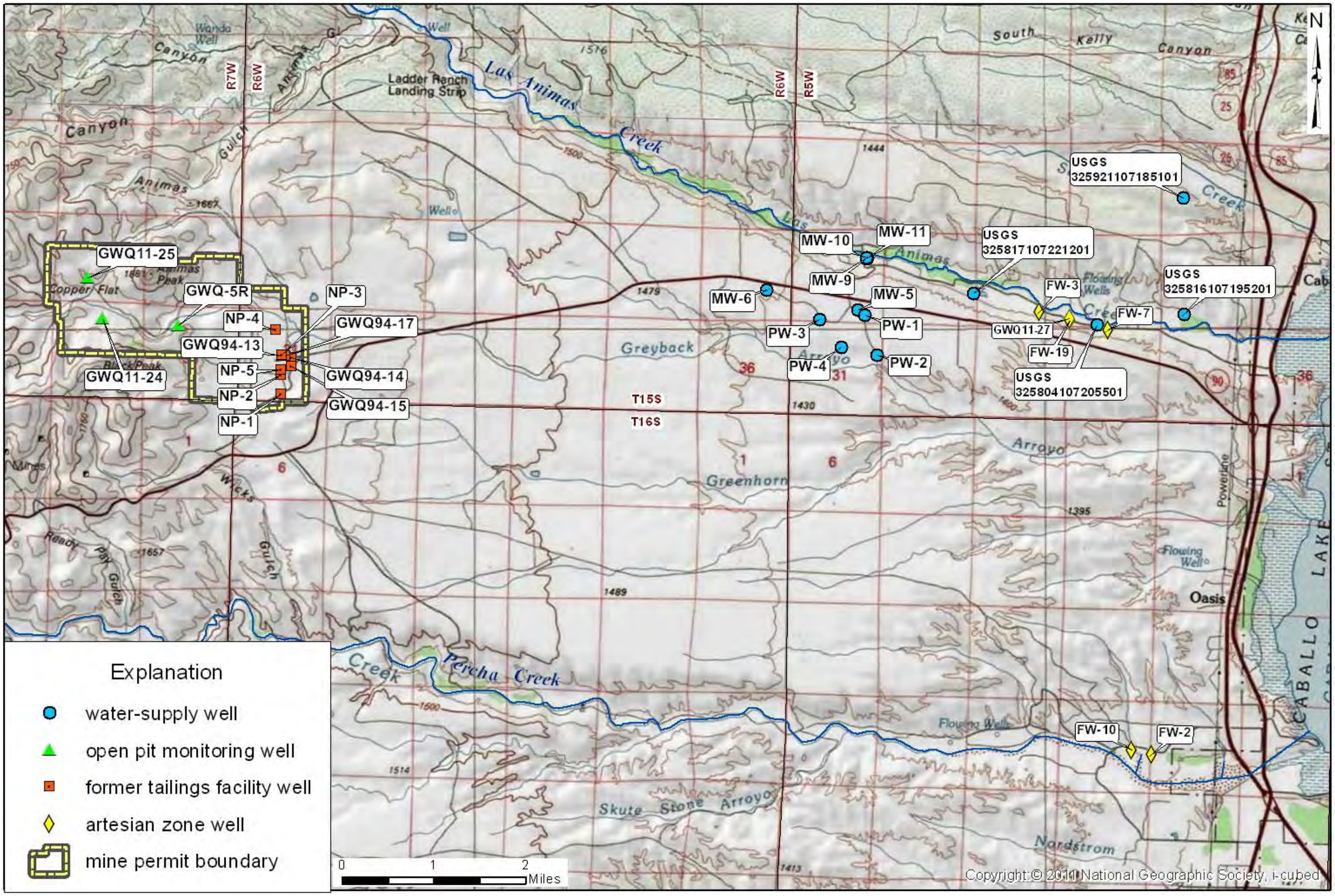


Figure 5.2. Well locations.

5.2.1 Initial Production Well Testing, 1975-1976

PW-2 was pumped at 2,020 gpm for 72 hours in January 1976 (Appendix C1). Measured drawdown and recovery at observation wells PW-1 and MW-5 are shown on Figures 5.3 and 5.4. Aquifer transmissivity is estimated at about 20,000 ft^2/day by matching the solution of Theis (1938) to measured drawdown and recovery at PW-1 and MW-5 (WDC, 1976).

Measured drawdown and recovery at the pumping well PW-2, is shown on Figure 5.5, along with the Theis solution match. In addition, because the PW-2 curves exhibit a shape characteristic of a leaky confined aquifer, the modified Theis solution of Hantush (1956) is shown as an alternate analysis.

PW-1 was pumped at 1,500 gpm for 70 hours in December 1975 (WDC, 1976). Measured drawdown and recovery at observation well MW-5 are shown on Figure 5.6. Aquifer transmissivity of about 17,000 ft^2/day is estimated by matching the solution of Theis (1938) to measured drawdown and recovery at MW-5, and to measured recovery at the pumping well PW-1, shown on Figure 5.7. In addition, the PW-1 curves exhibit a "leaky" shape and a Hantush curve match is shown as an alternate analysis.

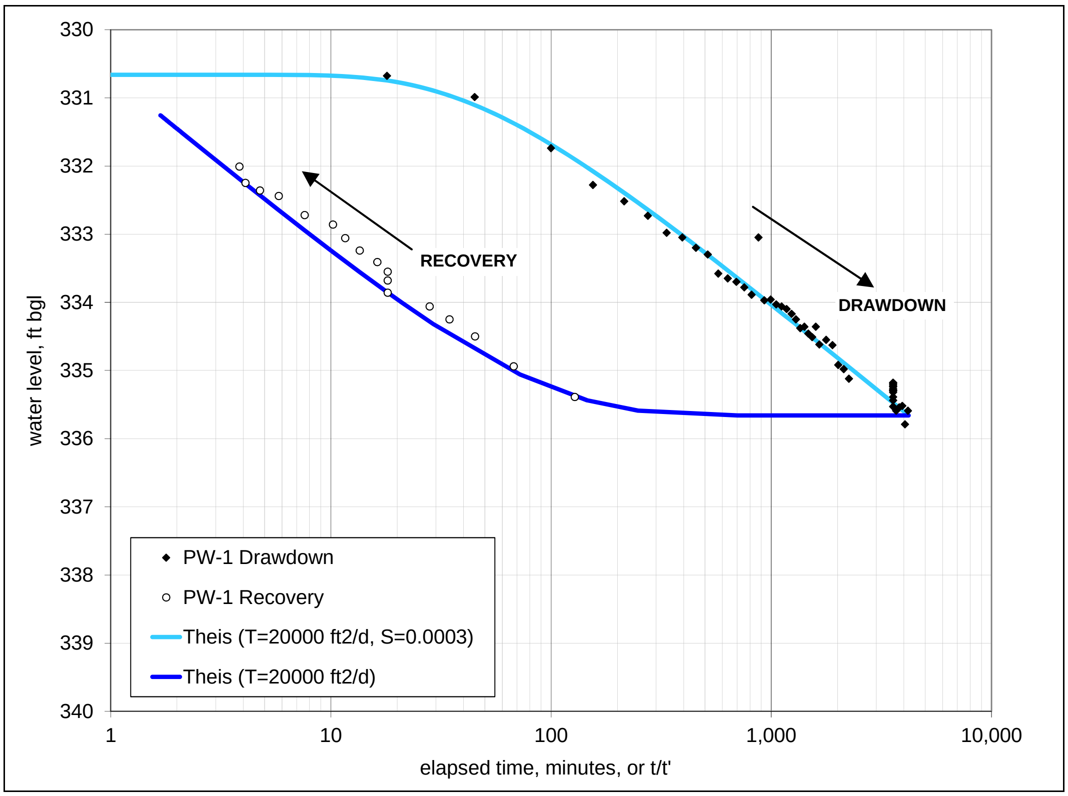


Figure 5.3. Drawdown and recovery in PW-1 during January 1976 PW-2 pumping test.

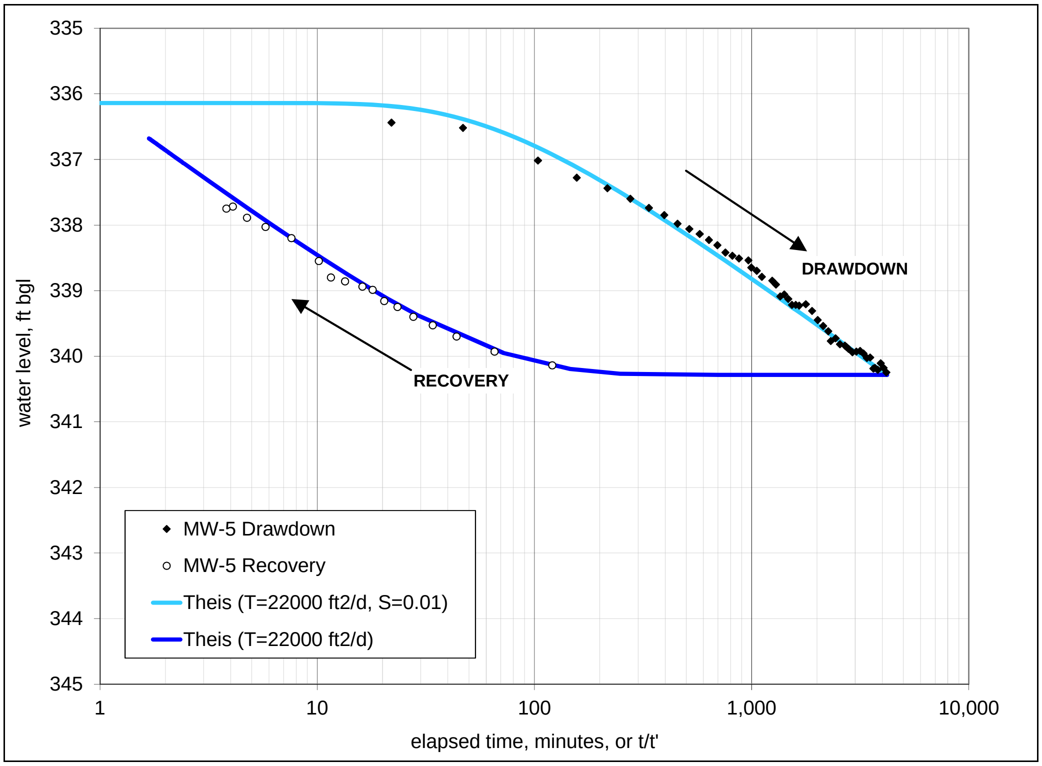


Figure 5.4. Drawdown and recovery in MW-5 during January 1976 PW-2 pumping test.

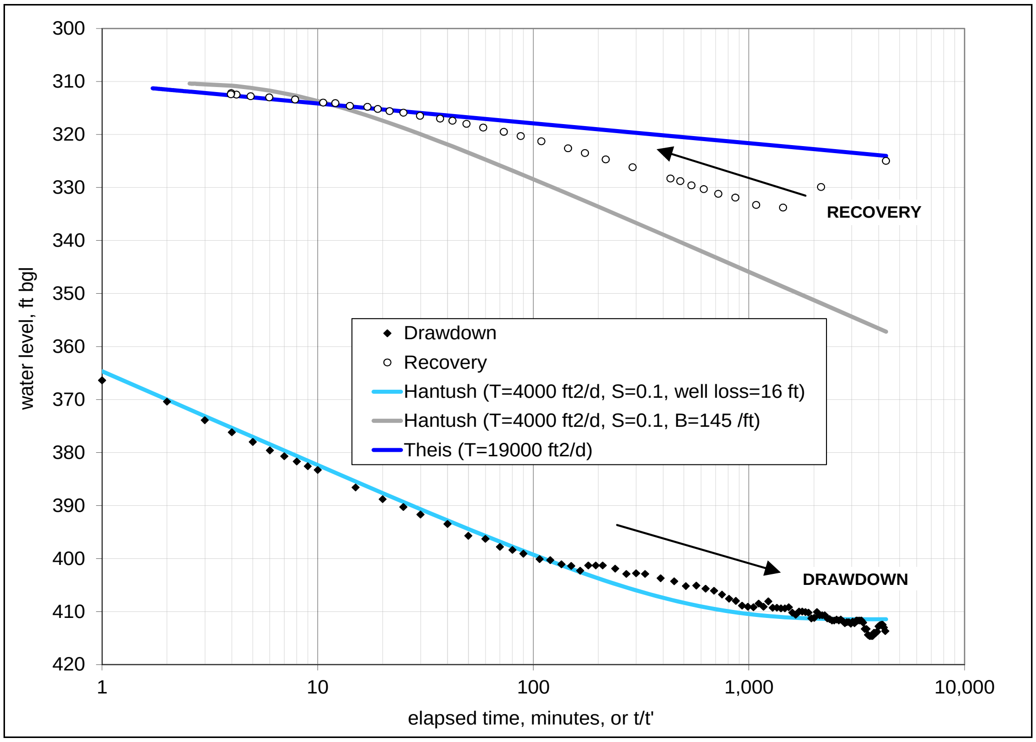


Figure 5.5. Drawdown and recovery in PW-2 during January 1976 PW-2 pumping test.

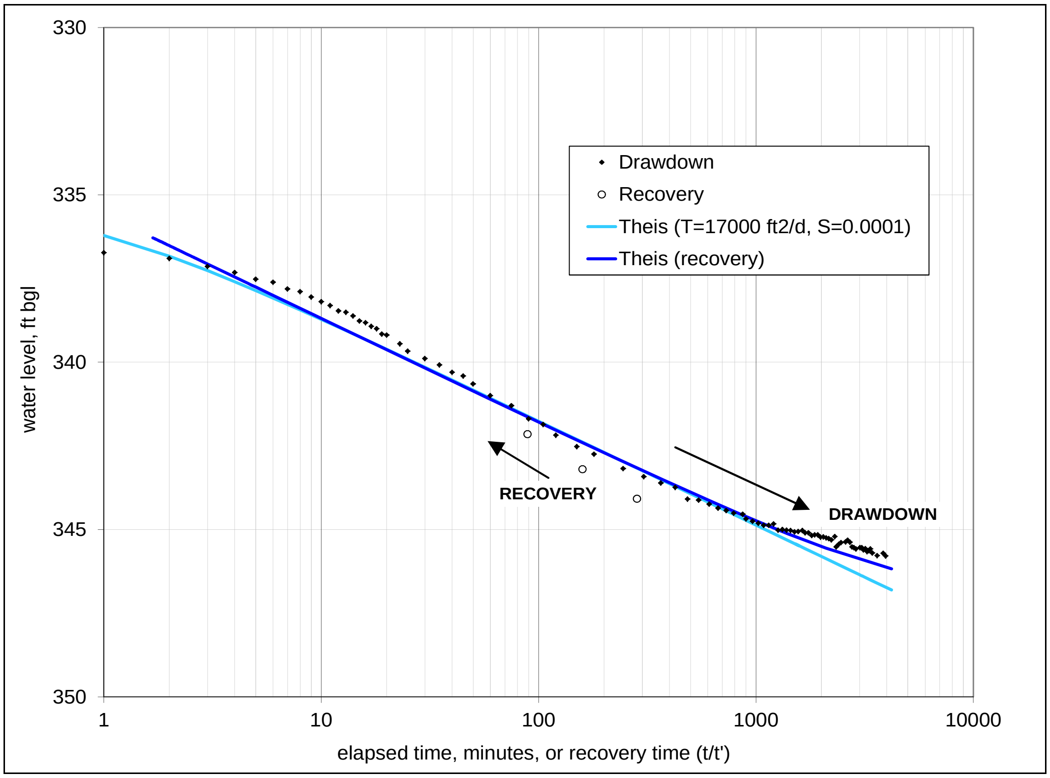


Figure 5.6. Drawdown and recovery in MW-5 during December 1975 PW-1 pumping test.

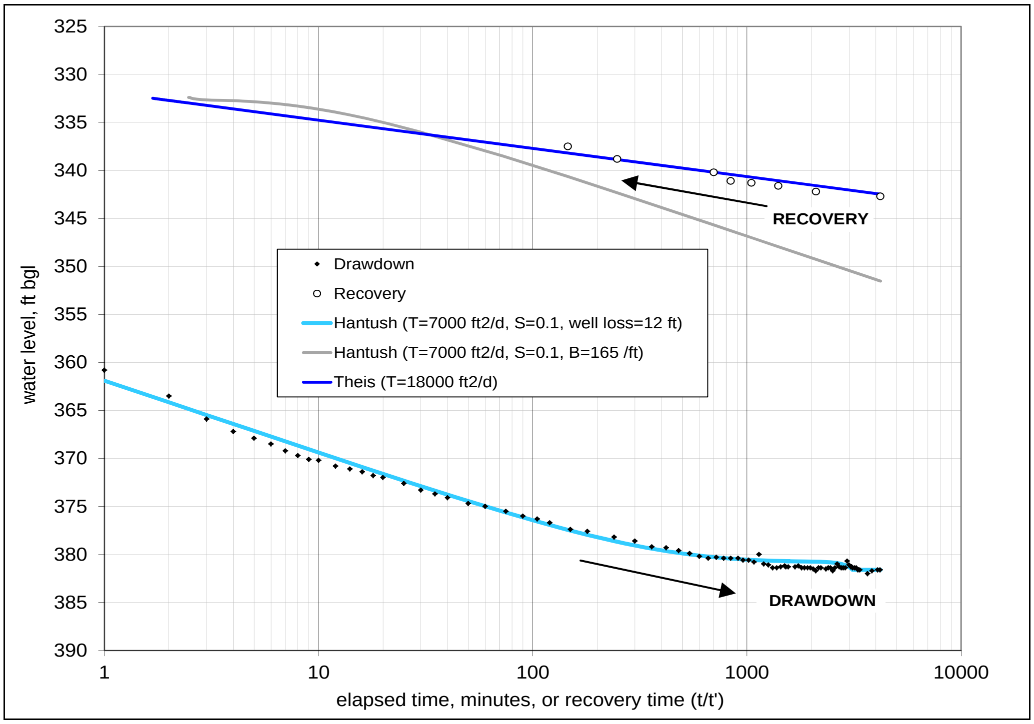


Figure 5.7. Drawdown and recovery in PW-1 during December 1975 PW-1 pumping test.

5.2.2 Period of Mine Operation, 1982

The well field was operated for 4 months from March through June 1982, at an average pumping rate of 2,272 gpm. Some pumping, averaging 40 gpm, continued for 16 months more. Average pumping rates (Bailey, 2010) are presented in Table 5.1. Total volume pumped for 1980-83 was 1,317 ac-ft.

Water levels measured in MW-5, in the immediate area of the production wells, are shown along with well field pumping on Figure 5.8, showing about 20 ft of water level drawdown due to pumping.

West of the well field, no response to pumping can be seen in water levels at MW-6, shown on Figure 5.9.

Long-term water-level trends from MW-6 show a slow rise of approximately 170 ft over 30 years. When compared to other wells in the region, water-quality data indicates groundwater from MW-6 has an anomalously high sodium chloride component. Furthermore, there are mapped north-south fault traces in the immediate vicinity of MW-6 (Seager, et al. 1982; Hawley, 2012).

Water Development Corporation (1975) reported the following: “the anomalous highs to which the water level recovered indicated that the well was being recharged by an unknown source of water (either perched water or possibly slow seepage up the well bore from the sand stringers underlying the clay layer) and that the aquifer materials were too plugged with drilling mud to allow this water to move freely into the formation.”

Over time, as MW-6 was pumped, the well slowly developed and became hydraulically connected to sodium-chloride groundwater locally upwelling along an extensional fault zone. Sodium-chloride groundwater is known to upwell along structures in the Rio Grande Rift (Witcher et al., 2004). In conclusion, the observed groundwater head and water level trend from MW-6 is not representative of the regional Santa Fe Group aquifer system.

Table 5.1. Recorded average well field pumping in gallons per minute

1980	1	Jul-82	70	Mar-83	29
1981	1	Aug-82	43	Apr-83	31
Jan-82	29	Sep-82	60	May-83	68
Feb-82	29	Oct-82	34	Jun-83	26
Mar-82	1,817	Nov-82	40	Jul-83	43
Apr-82	3,042	Dec-82	43	Aug-83	25
May-82	1,501	Jan-83	43	Sep-83	16
Jun-82	2,727	Feb-83	48	Oct-83	29

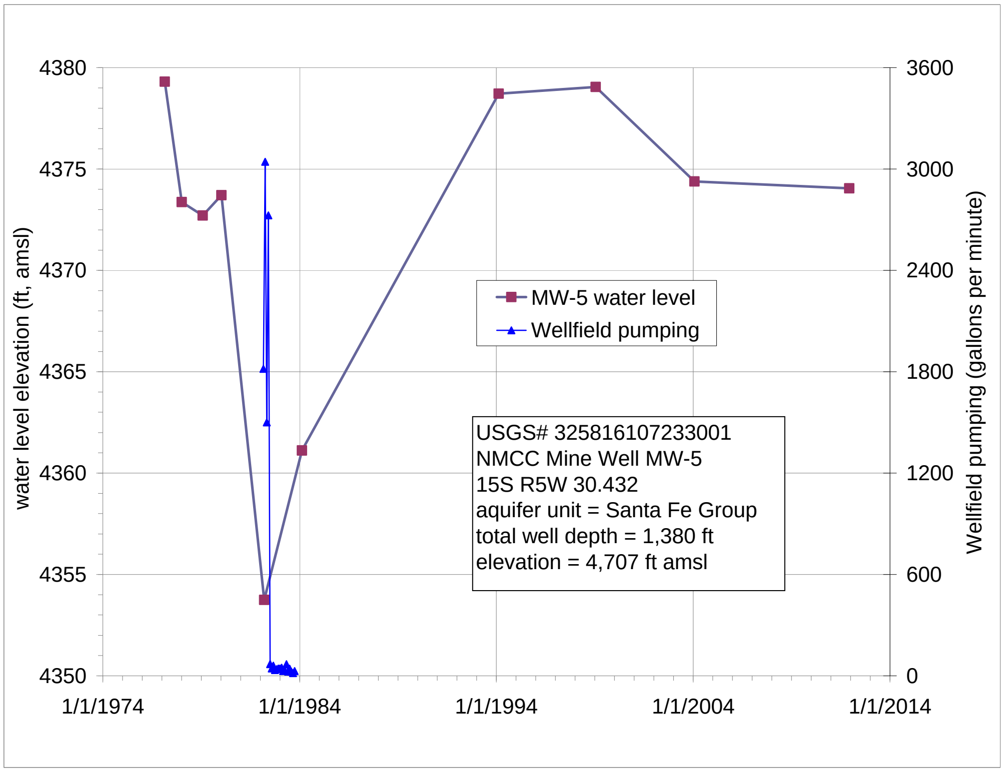


Figure 5.8. Well field pumping history and water level in MW-5.

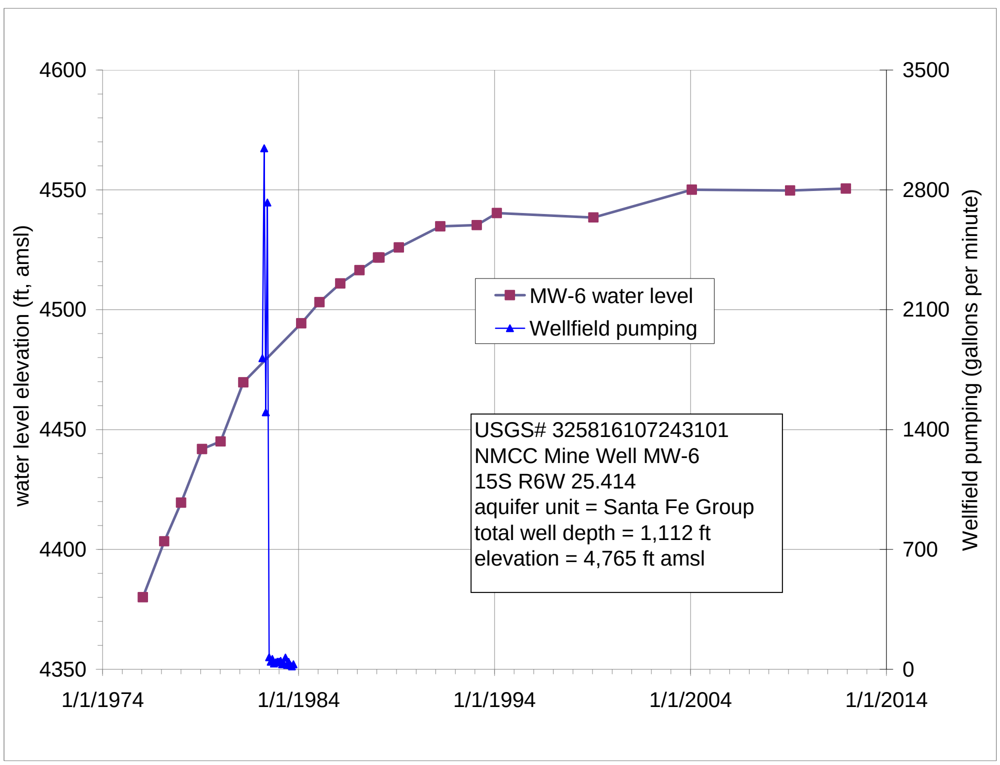


Figure 5.9. Well field pumping history and water level in MW-6.

Water levels in four wells monitored by the USGS, located east of the well field along Las Animas Creek and Seco Creek (Fig. 5.2), are shown on Figure 5.10 along with the recorded well field pumping. There is no clear response to pumping seen in any of the wells.

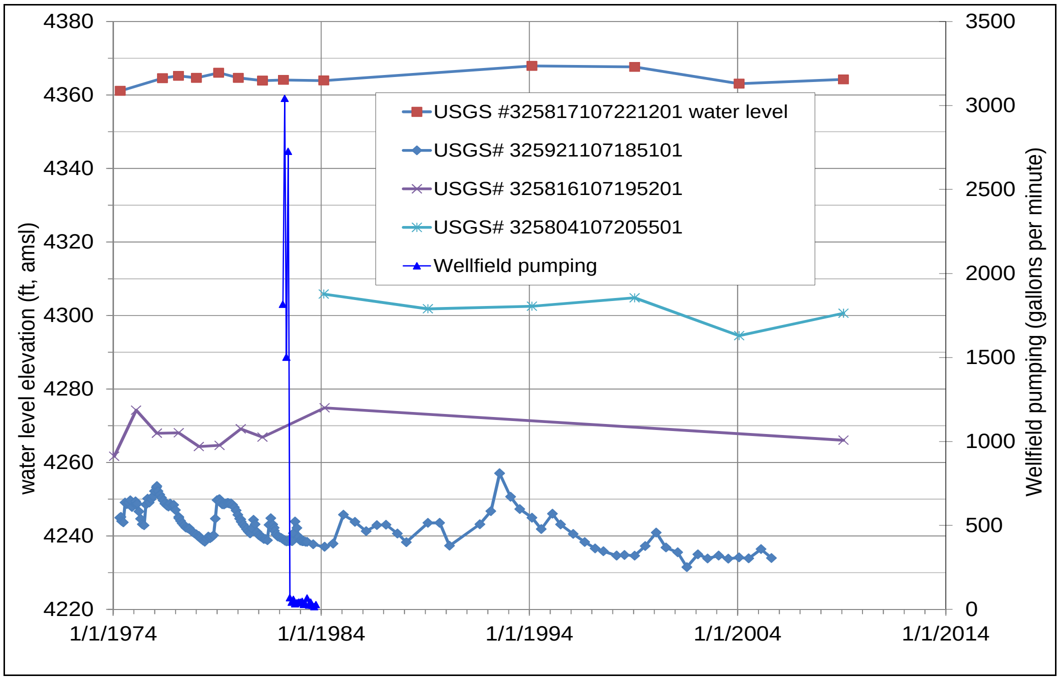


Figure 5.10. Well field pumping history and water level in USGS wells.

5.2.3 MW-9 Test, October 1994

Well MW-9, in the Palomas Graben near Las Animas Creek (Fig. 5.2.), is completed at a depth of about 250 ft. MW-10 and MW-11 are each about 50 horizontal ft from MW-9. MW-10 is completed at a depth of 125 ft and MW-11 at 37 ft. Responses at MW-10 and MW-11 to pumping at MW-9 therefore characterize the resistance to vertical flow through the SFG and alluvial aquifers.

In order to characterize vertical hydraulic communication between the SFG and alluvial aquifers (Adrian Brown Consultants, 1996), MW-9 was pumped at 90 gpm for 24 hours (Appendix C2). Drawdown and recovery at MW-9 are presented on Figure 5.11 along with a matching Hantush leaky-aquifer type-curve corresponding with transmissivity of 900 ft^2/day.

Drawdown and recovery in MW-10 are shown on Figure 5.12, showing a small response (<1 ft) to pumping, indicating possible limited vertical transmission of effects, but also showing more fluctuation due to background influences than drawdown in response to pumping. No response to pumping was detected in the shallow alluvium well MW-11; water levels rose during the test, as shown on Figure 5.13 (no analytical curves are shown on Figures 5.12 and 5.13, as the measured data show no drawdown-recovery trends to analyze).

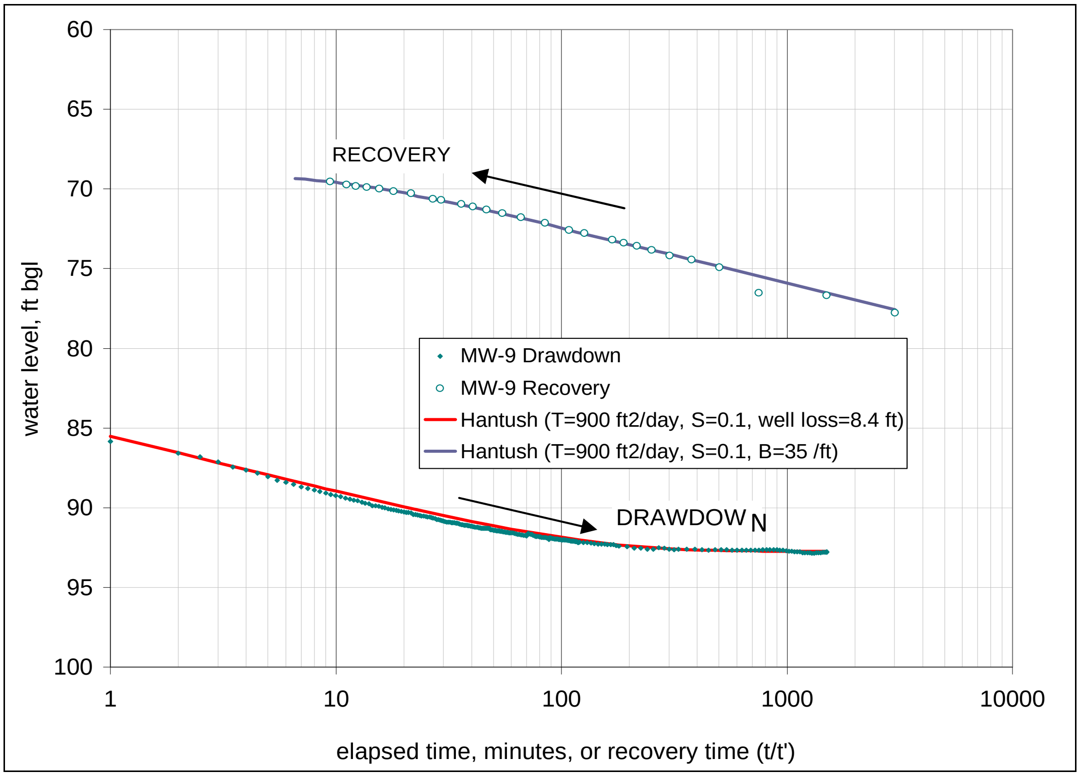


Figure 5.11. Drawdown and recovery in MW-9 during 1994 pumping test.

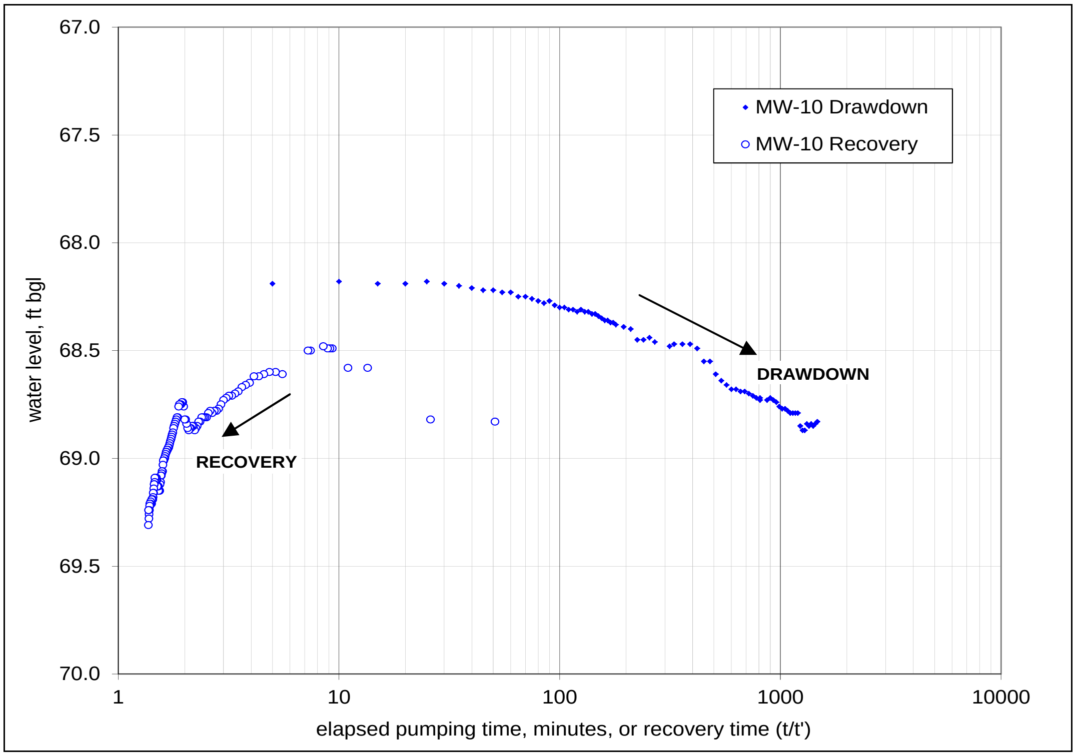


Figure 5.12. Drawdown and recovery in MW-10 during and after 1994 pumping of MW-9.

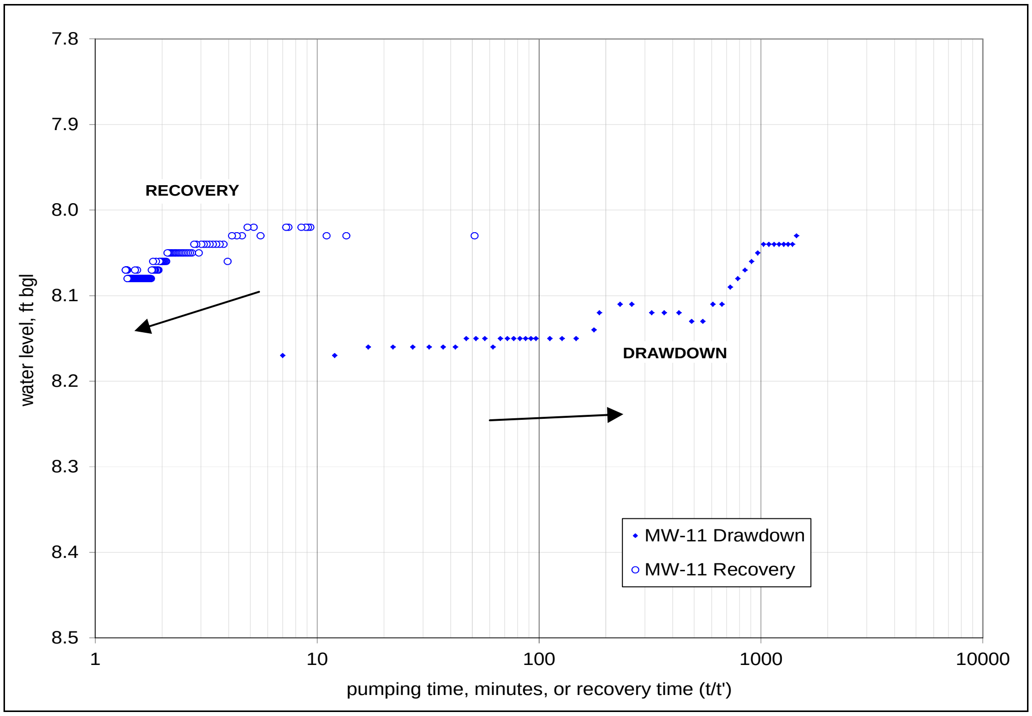


Figure 5.13. Drawdown and recovery in MW-11 during and after 1994 pumping of MW-9.

5.2.4 December, 2012 Aquifer Test

Pumping of wells PW-1 and PW-3 began on 19 November 2012 with initial testing of the pumps, circuitry and plumbing. Sustained pumping began on 3 December, was interrupted by technical difficulties on 8 December, resumed on 10 December and continued until 21 December 2012. Recorded pumping periods and rates are shown on Figure 5.14. Measured pumping-well and observation-well water levels are presented in Appendix C3. Due to the multiple pumping wells, periods and rates, the 2012 aquifer test is not easily characterized using the analytical type curves shown on Figures 5.3 through 5.7 and 5.11 above.

In addition, the analytical type curves do not reflect the particular geometry of the aquifer including the Palomas Graben. Wells within the Palomas Graben did not respond to pumping as they would in an extensive aquifer; initial drawdown was rapid and followed a semi-linear trend with time. Initial post-pumping water-level recovery was also rapid. These drawdown and recovery responses to pumping are characteristic of a high-transmissivity, semi-isolated hydrogeologic unit of finite size (the Palomas Graben).

The 2012 test is analyzed using the numerical model (Section 6.4.3 below). Measured responses in the pumping and observation wells shown on Figure 5.15 were used to calibrate the aquifer parameters for the numerical model, particularly the aquifer parameters of the Palomas Graben (Table 6.1 below) and the conductive properties of the graben-bounding faults (Table 6.2).

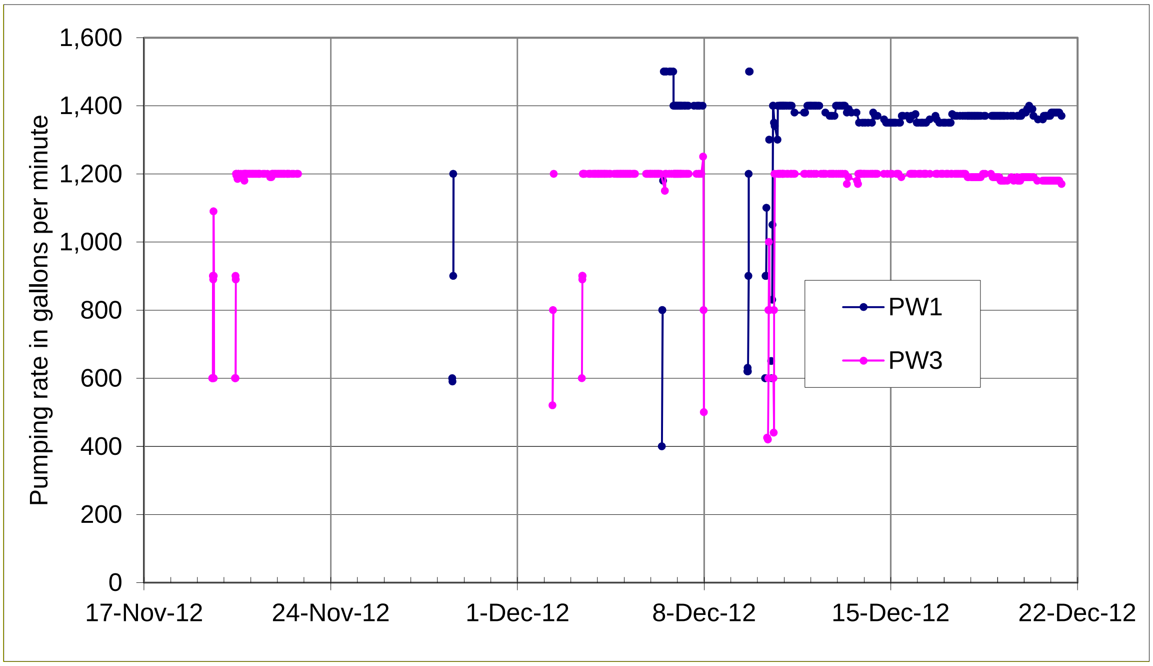


Figure 5.14. Measured aquifer test pumping rates.

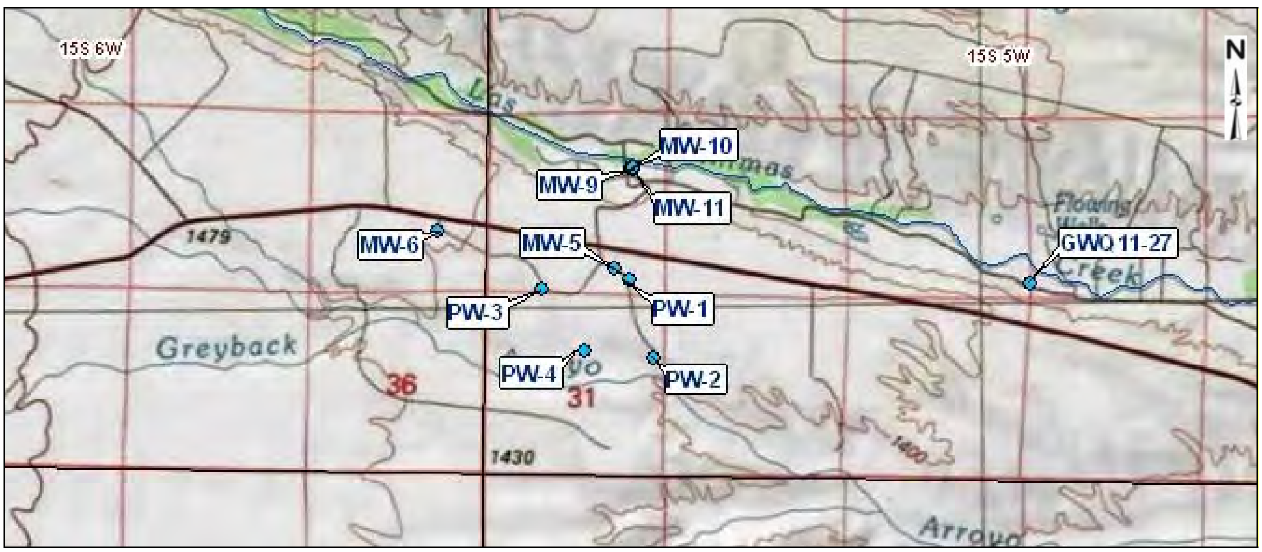


Figure 5.15. Aquifer test pumping and observation wells.

5.3 Tailings Impoundment Area

During and after the period of mine operations in 1982, the groundwater system beneath the unlined tailings facility was recharged by seepage from the tailings, in the portion of the impoundment overlying alluvium. Measured tailings-area (Fig. 5.2) water levels, shown on Figure 5.16, indicate 60 to 70 ft of water-level rise that has persisted to the present, indicating a fault, or other barrier to flow, holding the water in place.

Transmissivity in the range of 100 to 240 ft^2/day is estimated for this area at the edge of the SFG aquifer, based on the results of a 1994 aquifer test at well GWQ94-17, presented below.

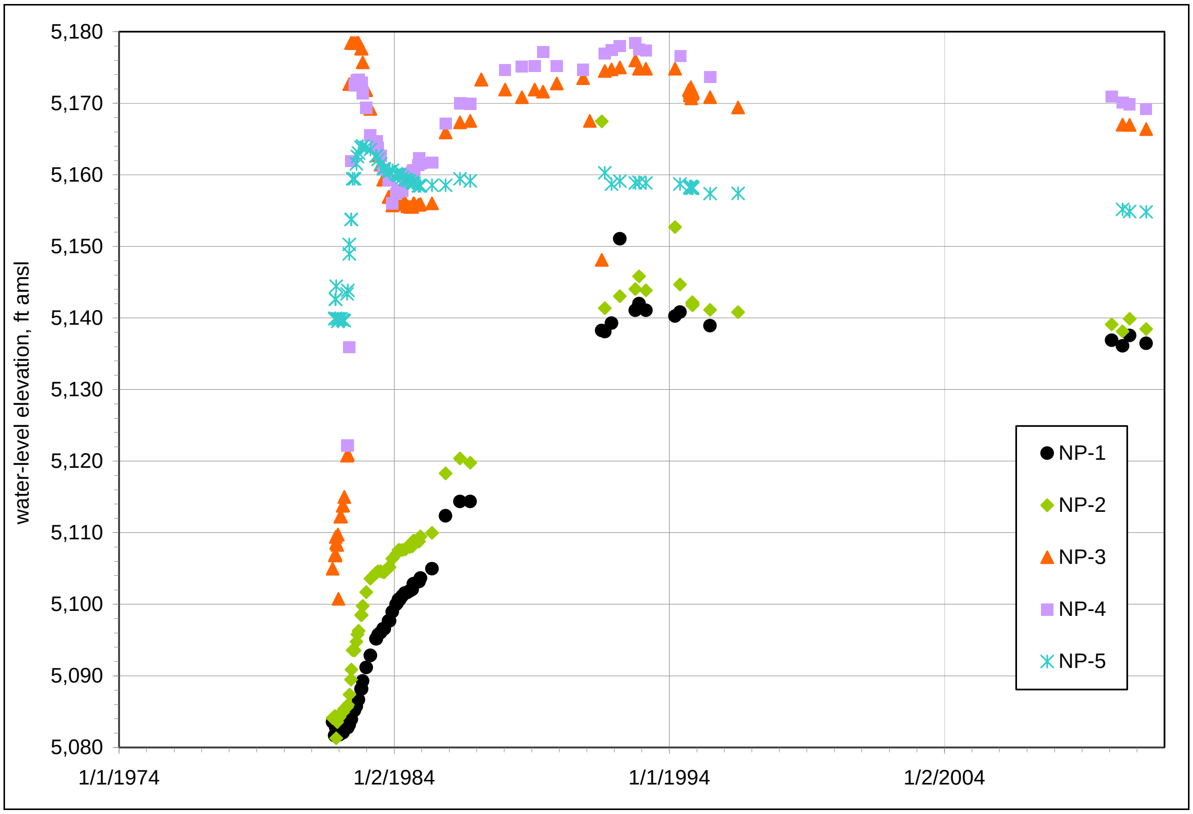


Figure 5.16. Tailings-area water levels.

5.3.1 GWQ94-17 Test, November 1994

As part of an investigation of leakage from, and groundwater flow beneath, the existing tailings impoundment (Adrian Brown Consultants, 1996), well GWQ94-17 was pumped at 23 gpm for 4,688 minutes (3.3 days), with responses measured in GWQ-13, GWQ-14 and GWQ-15 (Fig. 5.2). Complete test results are presented as Appendix C4.

Drawdown and recovery in GWQ-13 and GWQ-14 are presented on Figures 5.17 and 5.18 respectively, along with analytical (Theis, 1938) solutions. Drawdown in GWQ-15 is presented on Figure 5.19 (recovery data were unavailable) along with two Theis solutions, respectively matching distinct early and late-time trends and showing a range of possible transmissivity. Recovery in the pumping well GWQ-17 is presented on Figure 5.20 (pumping water level was constant at about 123 ft).

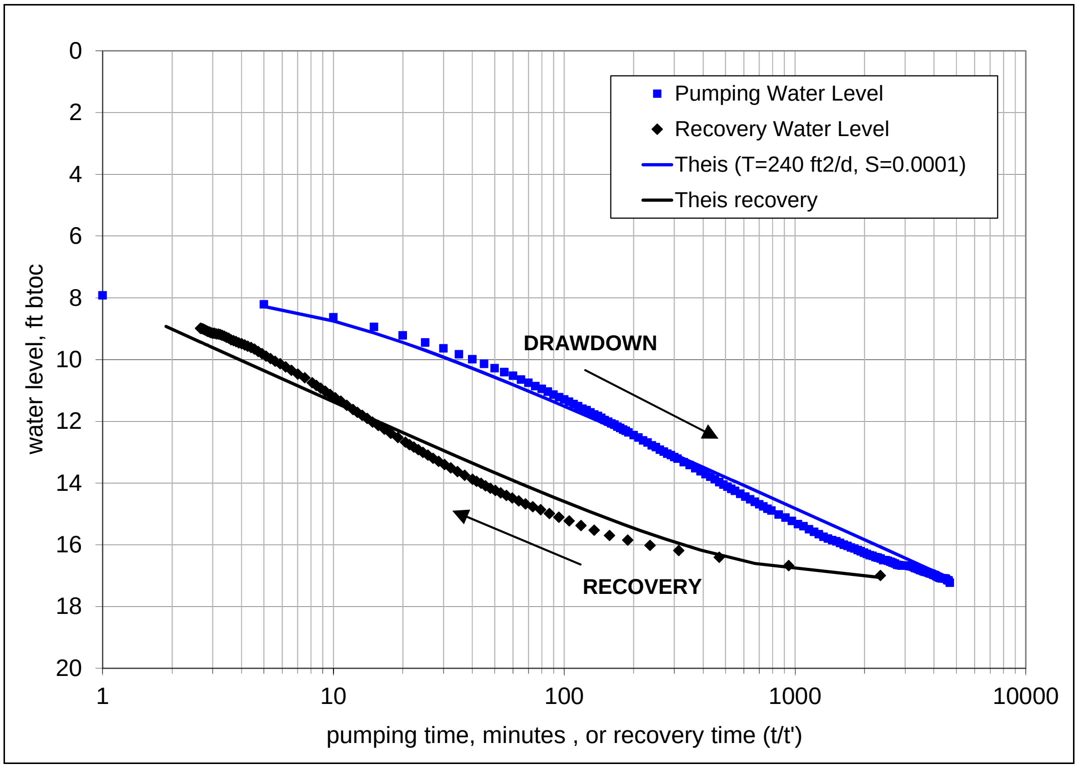


Figure 5.17. Drawdown and recovery in GWQ-13 during 1994 GWQ-17 pumping test.

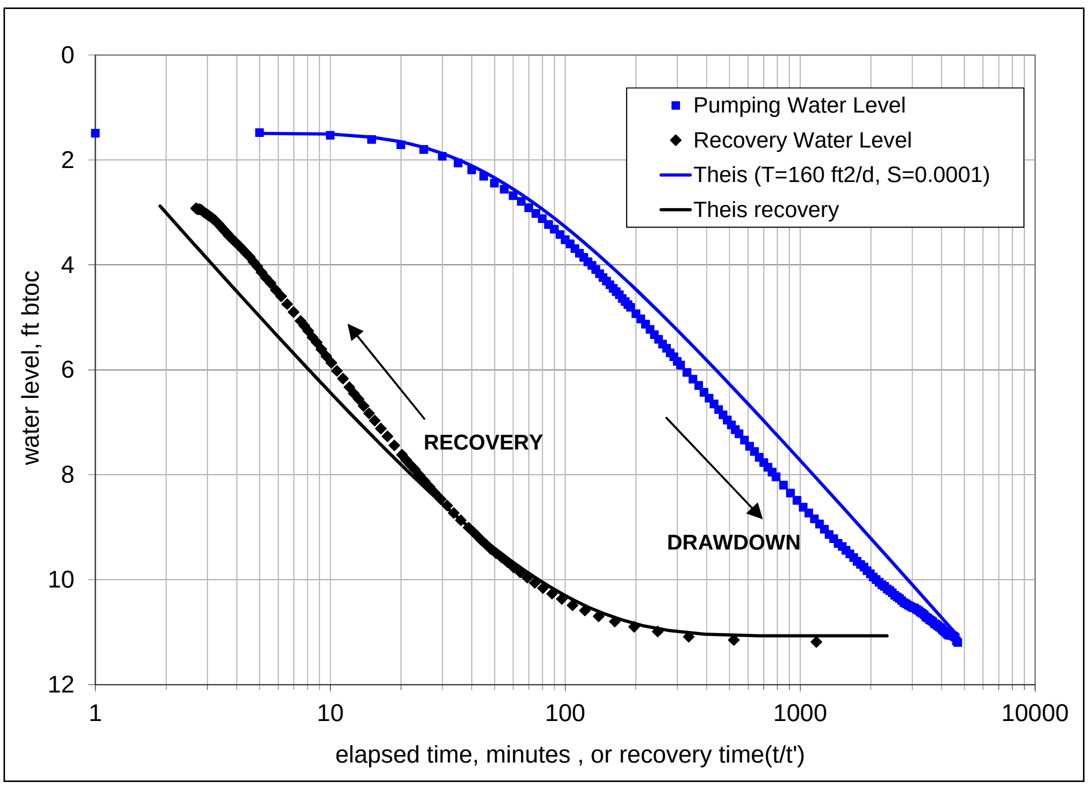


Figure 5.18. Drawdown and recovery in GWQ-14 during 1994 GWQ-17 pumping test.

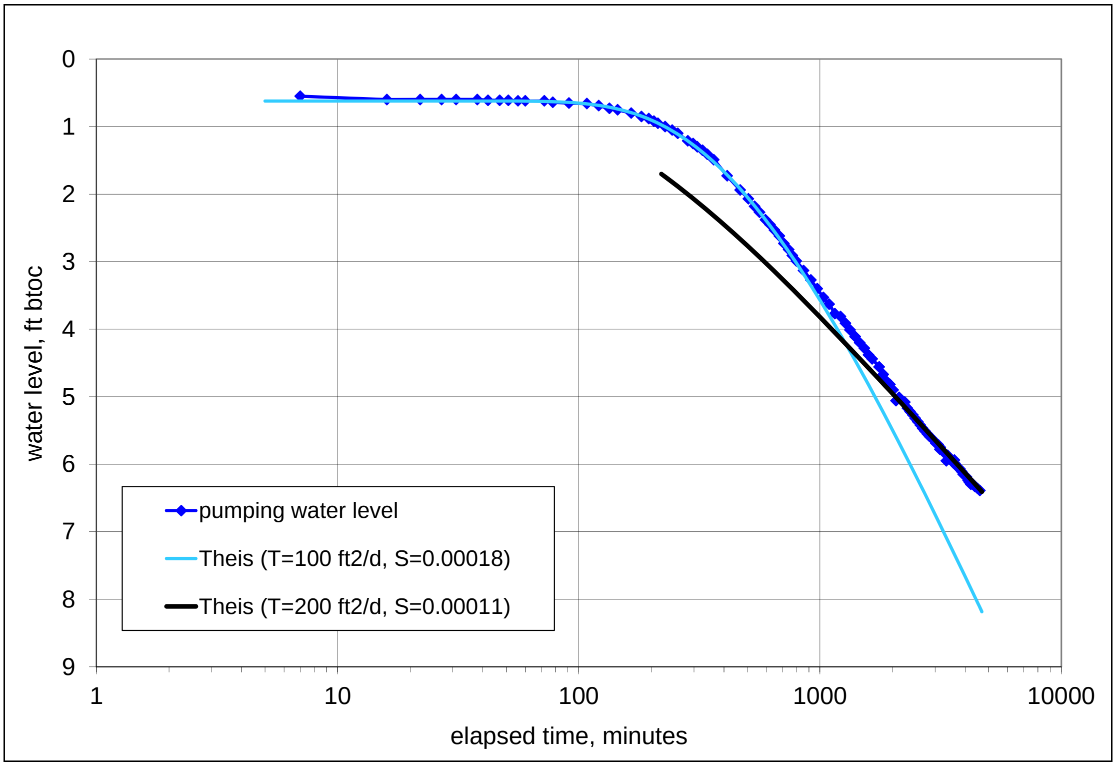


Figure 5.19. Drawdown in GWQ-15 during 1994 GWQ-17 pumping test.

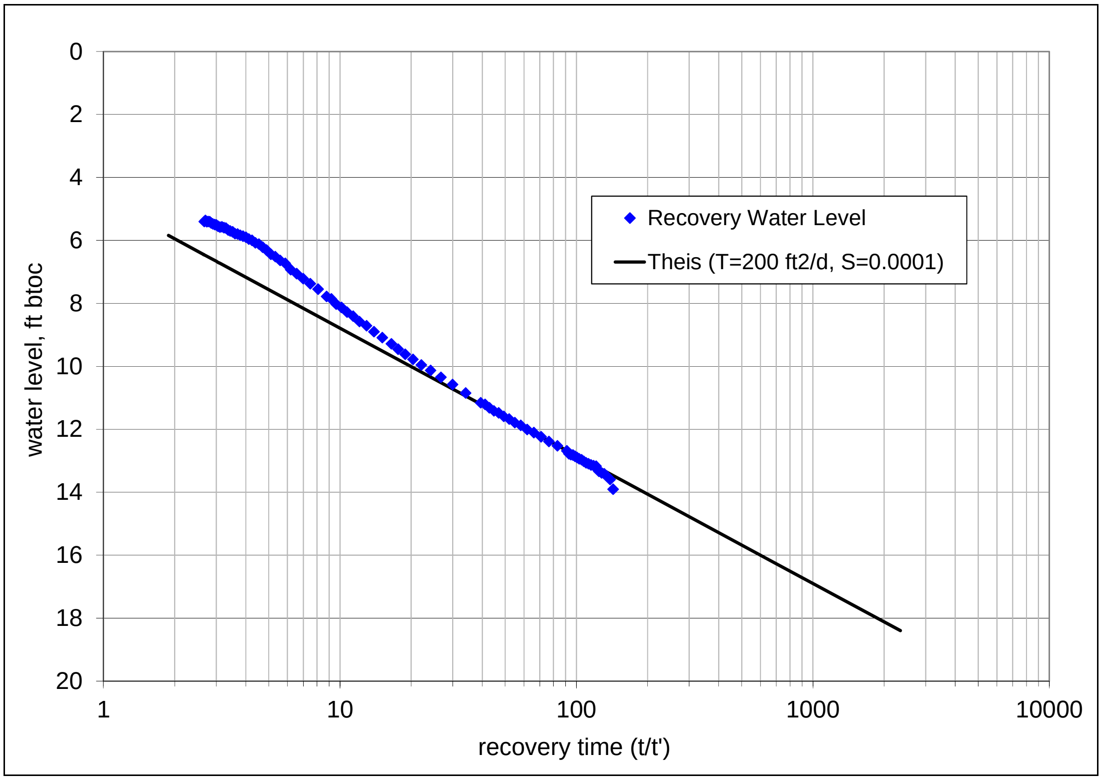


Figure 5.20. Recovery in GWQ-17 after 1994 pumping test.

5.4 Open Pit Area

The historical water level in the open pit has ranged between 5,435 and 5,450 ft amsl, corresponding to a water-surface area between 5 and 14 acres. Based on an evaporation rate of 64.6 in./yr (Table 2.1), annual open-pit evaporation has ranged from about 16 gpm to 45 gpm.

This discharge is supported by a combination of groundwater inflow, direct precipitation and runoff. Based on precipitation records it is estimated that the annual pit water balance (16 to 45 gpm of discharge by evaporation) is provided by 6 to 10 gpm of groundwater inflow and the rest (6 to 40 gpm) by precipitation and runoff.

The groundwater inflow component would increase with future pit expansion and dewatering. The post-mining open pit, larger and deeper than the existing pit, would have a larger groundwater inflow and larger evaporation.

Current pit water levels are below 5,440 ft amsl, with water balance in the low range of the estimate. The pit is a hydrologic sink, as shown on the contour map of the local piezometric surface, Figure 5.21.

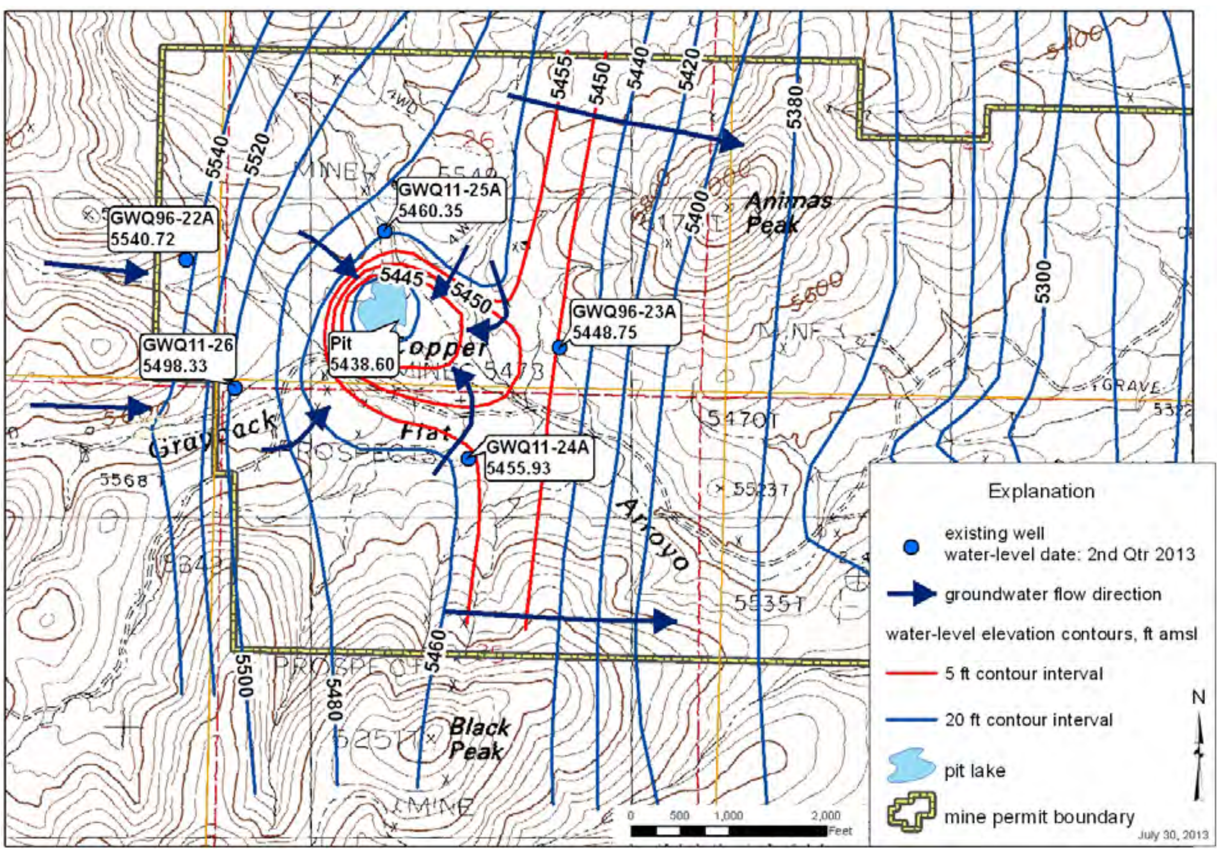


Figure 5.21. Measured pit-area groundwater levels.

5.4.1 Pit Area Pressure-Injection Tests, September 2011

Pressure-injection testing in the bedrock around the pit, in wells GWQ 5-R, GWQ 11-24, and GWQ 11-25 (Appendix C5), is summarized in Table 5.2. Apparent permeability of the bedrock ranges from near zero, to about 0.1 ft/day in the most fractured zones.

Table 5.2. Summary of pressure-injection test results

borehole and zone	depth interval (ft)	apparent permeability	
		(cm/sec)	(ft/day)
GWQ 5-R, Zone 1	64-100	~0	~0
GWQ 11-24, Zone 1	100-147	7×10^{-6}	0.02
GWQ 11-24, Zone 2	150-197	3.0×10^{-5}	0.085
GWQ 11-24, Zone 3	204-251	4.9×10^{-5}	0.14
GWQ 11-25, Zone 1	100-148	~0	~0
GWQ 11-25, Zone 2	150-198	2.9×10^{-5}	0.081
GWQ 11-25, Zone 3	207-251	2.6×10^{-5}	0.074

cm/sec - centimeters per second

5.5 Flowing Wells

The first artesian wells in the study area were drilled in the late 1930s. Most of the artesian wells were drilled prior to the New Mexico Office of the State Engineer (NMOSE) declaration of Las Animas Creek and Lower Rio Grande Underground Water Basins in 1968 and 1980, respectively.

Flow from selected artesian wells (Fig. 5.2) has been measured by Murray (1959), Davie and Spiegel (1967), JSAI (1995), and JSAI (2011c). A summary of aggregate measured artesian flow rates is presented in Table 5.3. Note that the “total artesian flow” estimates in Table 5.3 considered only a partial sample of flowing wells in the area; total artesian discharge for the study area is greater than the flows presented in Table 5.3.

Table 5.3. Summary of measured artesian flow rates

source	number of wells	year	total artesian flow (gpm)	comments
Murray (1959)	23	1946	460	included Percha, Las Animas Creek, and Oasis areas
Davie and Spiegel (1967)	29	1966	1,186	Las Animas Creek area only
JSAI (1995)	12	1995	1,319	survey limited to accessible wells with owner permission
JSAI (2011c)	21	2011	222	survey limited to accessible wells with owner permission

JSAI - John Shomaker & Associates, Inc. gpm - gallons per minute

Construction details for the artesian wells are limited, but it appears a number of artesian wells were drilled without proper annular seals to prevent flow of water from the artesian zone into the overlying alluvium and stream channels. Furthermore, many of the artesian wells were never valved, and therefore left open to flow continuously at the land surface. Valves to regulate artesian flow, and metering, have been conditions to permits since the State Engineer declaration of the basin.

Over the last 50 years significant changes in flow rates have been observed in the few artesian wells that have time-series data. Measured artesian flow rates over time are presented in Figure 5.22, showing declines in flow rates from individual wells (except, apparently, from FW-7) along Percha and Las Animas Creeks.

There are many factors that affect artesian flow, including time of year, climatic conditions, and water level in Caballo Reservoir. Some wells may have been modified, repaired, or re-drilled. Upward leakage via artesian wells and open flow, however, appear to be mainly responsible for the long-term decline in artesian flow rates.

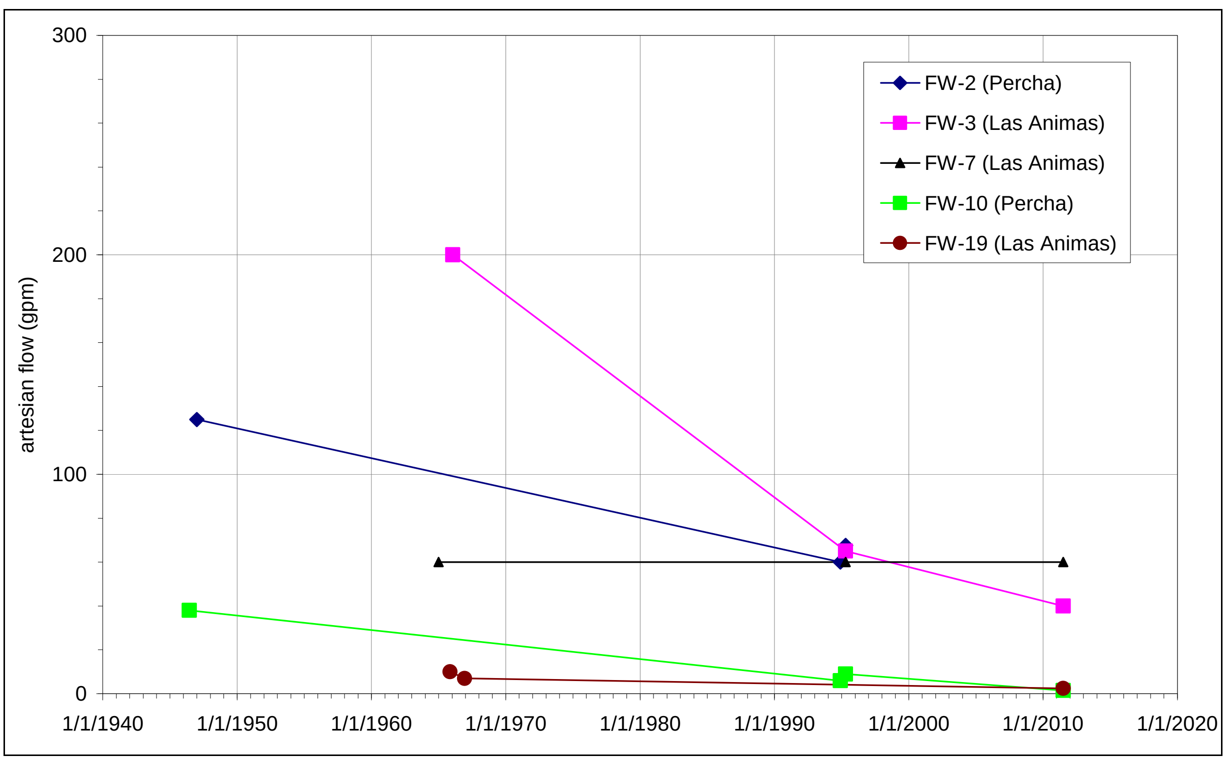


Figure 5.22. Measured artesian flow rates.

6.0 NUMERICAL MODEL

The computer program used for the hydrologic model is a version of the U.S. Geological Survey *Modular Three-Dimensional Finite Difference Ground-Water Flow Model, MODFLOW* (McDonald and Harbaugh, 1988). Modifications to the original computer program are documented in Appendix D.

Inputs to the model include (1) hydraulic parameters that control the flow of water within the model domain, and (2) boundary conditions that control the addition and removal of water to and from the model domain.

Several model simulations were developed representing different time periods and conditions:

1. **Steady-state**: Represents hypothetical pre-development steady conditions, used as starting condition for the pre-mining transient simulation.
2. **Pre-mining** (transient): Simulates the period 1940 to mid-1980, including the effect of flowing artesian wells on the system.
3. **Mining and post-mining**: Simulates the period from mid-1980 through November, 2012 including the brief period of mine operation in 1982 and the post-mining period.
4. **Aquifer test**: Simulates the period from the start of the 2012 well-field pumping test (late November, 2012), through year 2014.
5. **Future-mining scenarios**: Simulate the estimated water demand for selected scenarios. In addition, a no-mining scenario simulates continued background conditions. The effects of each mining scenario, including groundwater level drawdown and surface-discharge reduction, were evaluated by comparing results of each simulation to the equivalent results of the no-mining scenario.
6. **Future-post-mining scenarios**: Simulate the post-mining period for each future-mining (and no-mining) scenario, including continued surface-discharge effects and recovery of water levels in the SFG aquifer and in the open pit.

6.1 Model Discretization

The model grid, consisting of 87 rows, 109 columns, and 4 layers, is shown on Figure 6.1. Horizontal grid spacing ranges from 200 ft in the pit area, increasing to 1/4 mile (1,320 ft) away from the mine. Layer 1 is active only along lower Las Animas and Percha Creeks and near the axis of the Rio Grande, representing the shallow aquifer composed of alluvium and SFG sediments, with modeled thickness ranging from 100 to 200 ft. Layers 2 through 4 represent the SFG aquifer and different bedrock units, with modeled thicknesses ranging from 500 to 3,000 ft (Table 6.1).

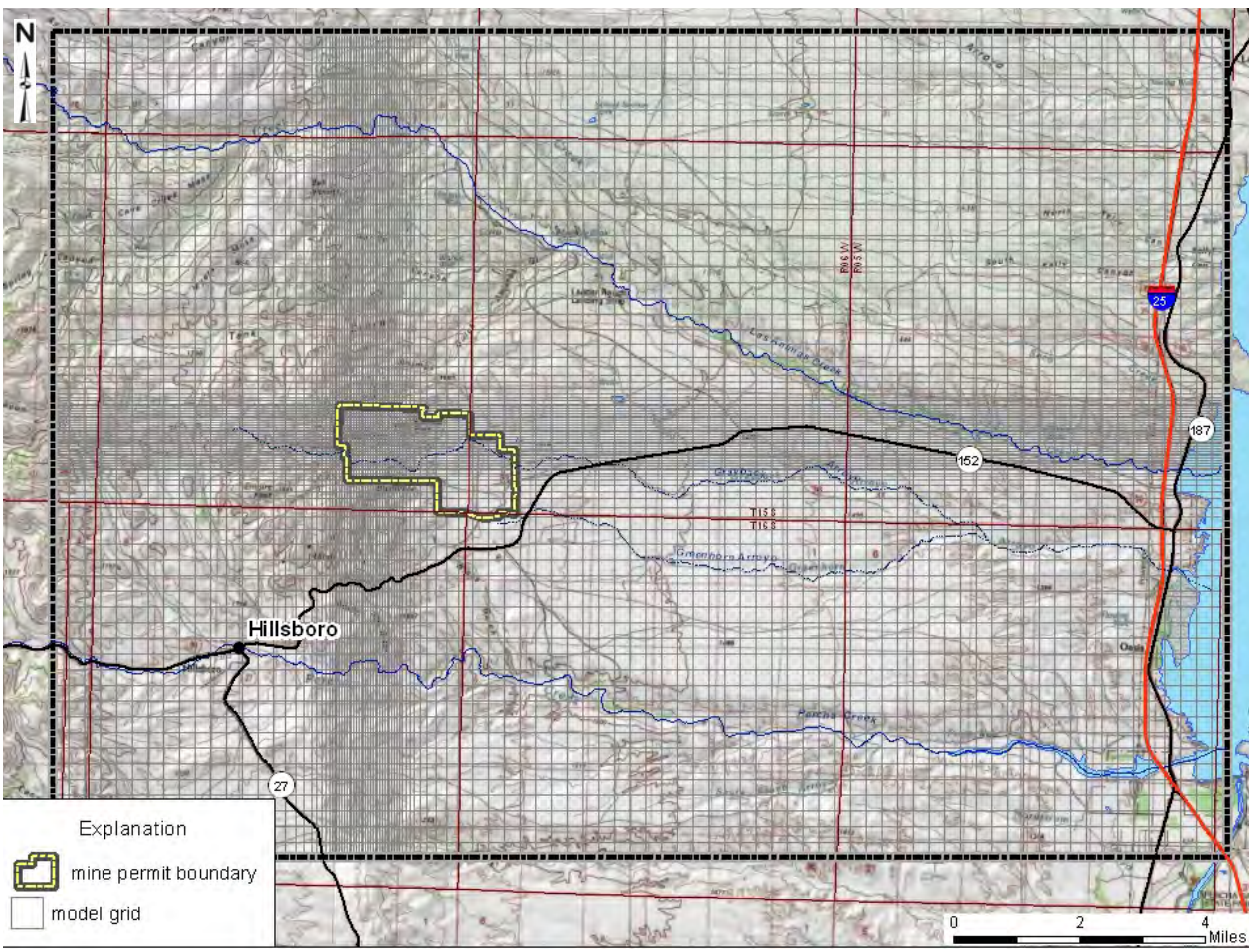


Figure 6.1. Model domain and grid.

6.2 Aquifer Parameters

Hydrogeologic units and fault barriers represented in each model layer are shown for layers 1 and 2 on Figures 6.2 and 6.3, and for layers 3 and 4 on Figures 6.4 and 6.5. Modeled aquifer parameters for each unit are shown on Table 6.1. Conductances of modeled fault barriers are shown on Table 6.2.

The layer 1 zones shown on Figure 6.2 include the shallow aquifer alluvium-SFG package along Las Animas Creek and a second, thicker zone along lower Animas, lower Percha and the Rio Grande Valley. Modeled aquifer parameters are shown on Table 6.1.

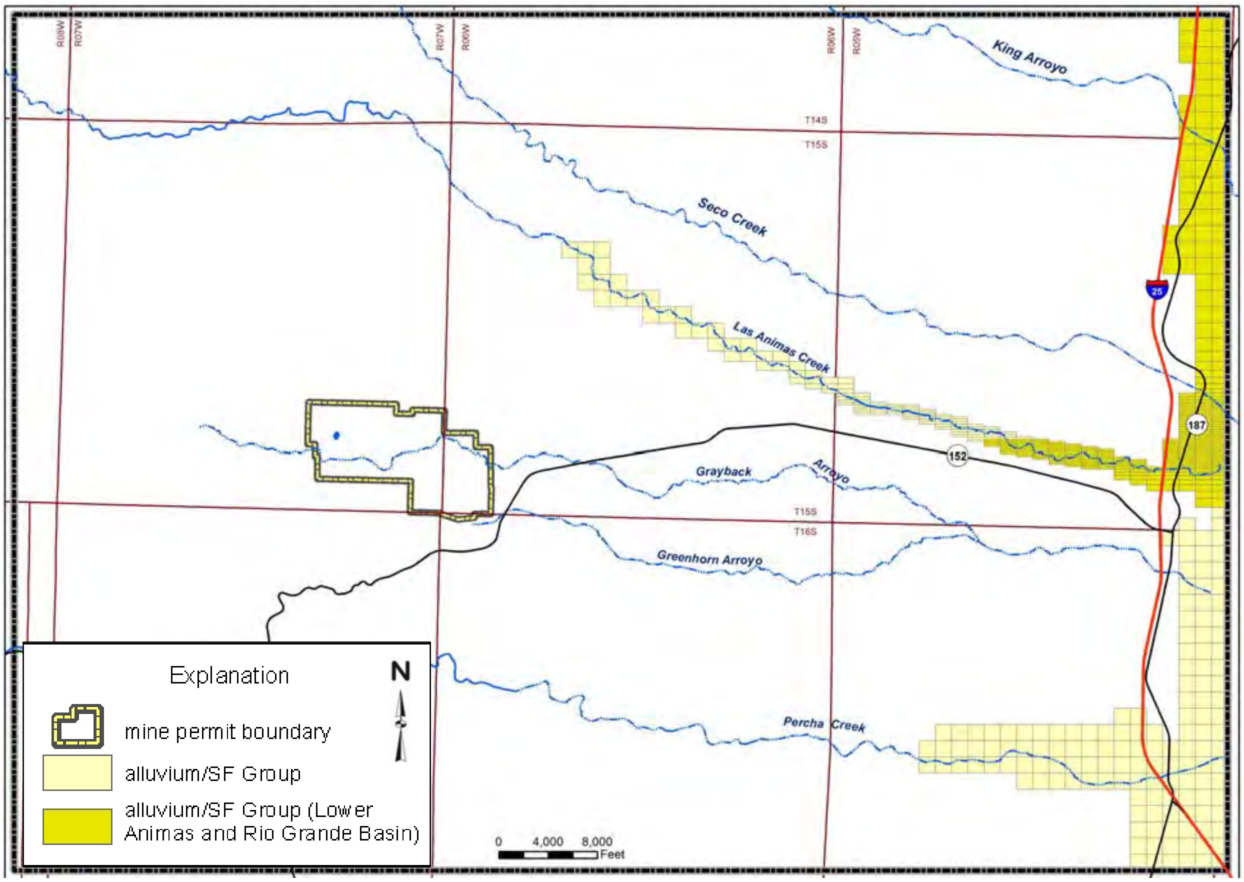


Figure 6.2. Layer 1 hydrogeologic zones

The modeled aquifer parameters (Table 6.1) include a high-transmissivity zone representing the Palomas Graben (Figs. 6.3, 6.4, and 6.5). The 2012 aquifer test results and subsequent model calibration further support the existence of the feature. Aquifer parameters of the graben (Table 6.1) and conductances of its bounding faults (Table 6.2) are based mainly on model calibration to the 2012 aquifer test results (Section 6.4.3 below).

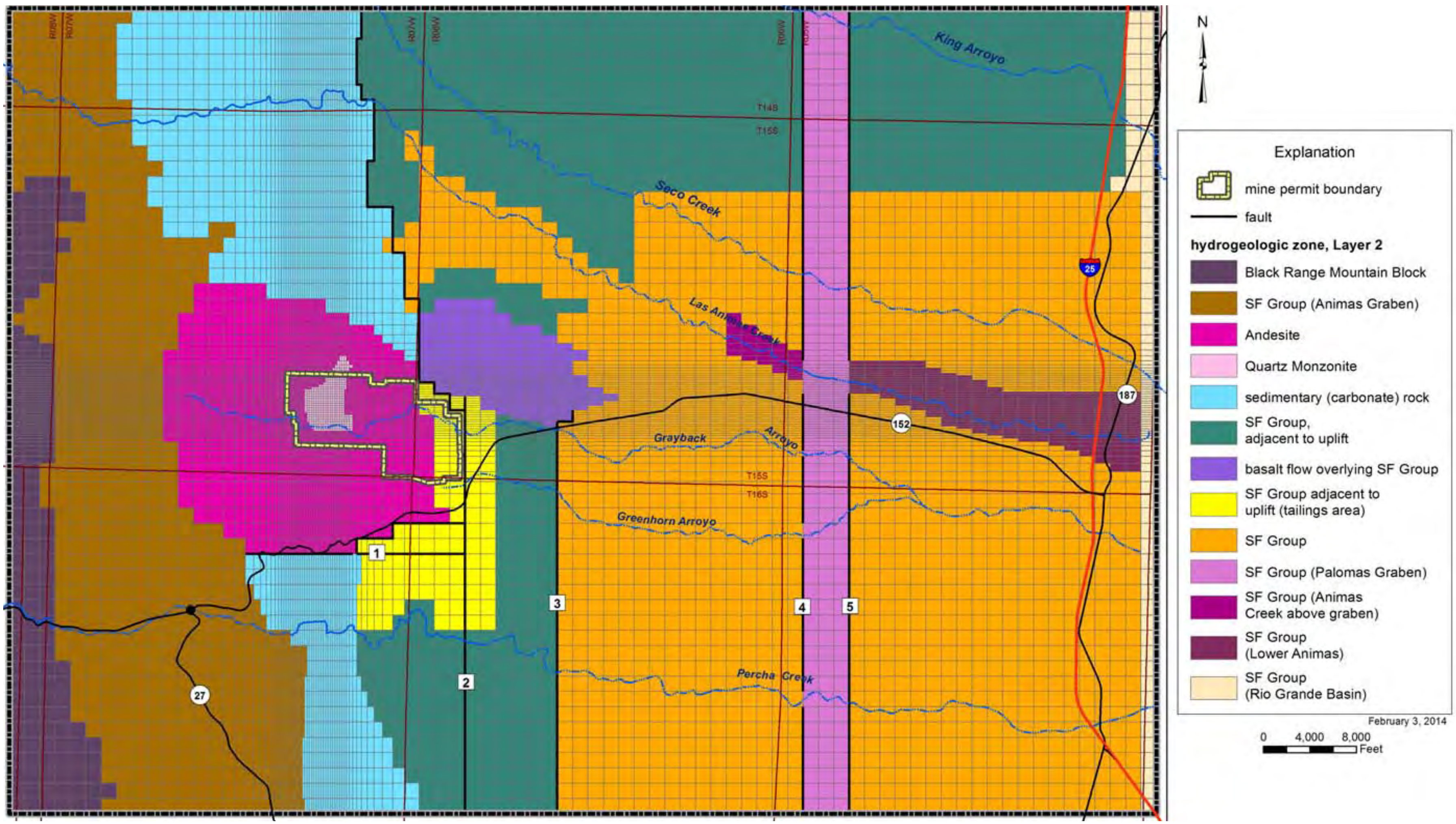


Figure 6.3. Layer 2 hydrogeologic zones.

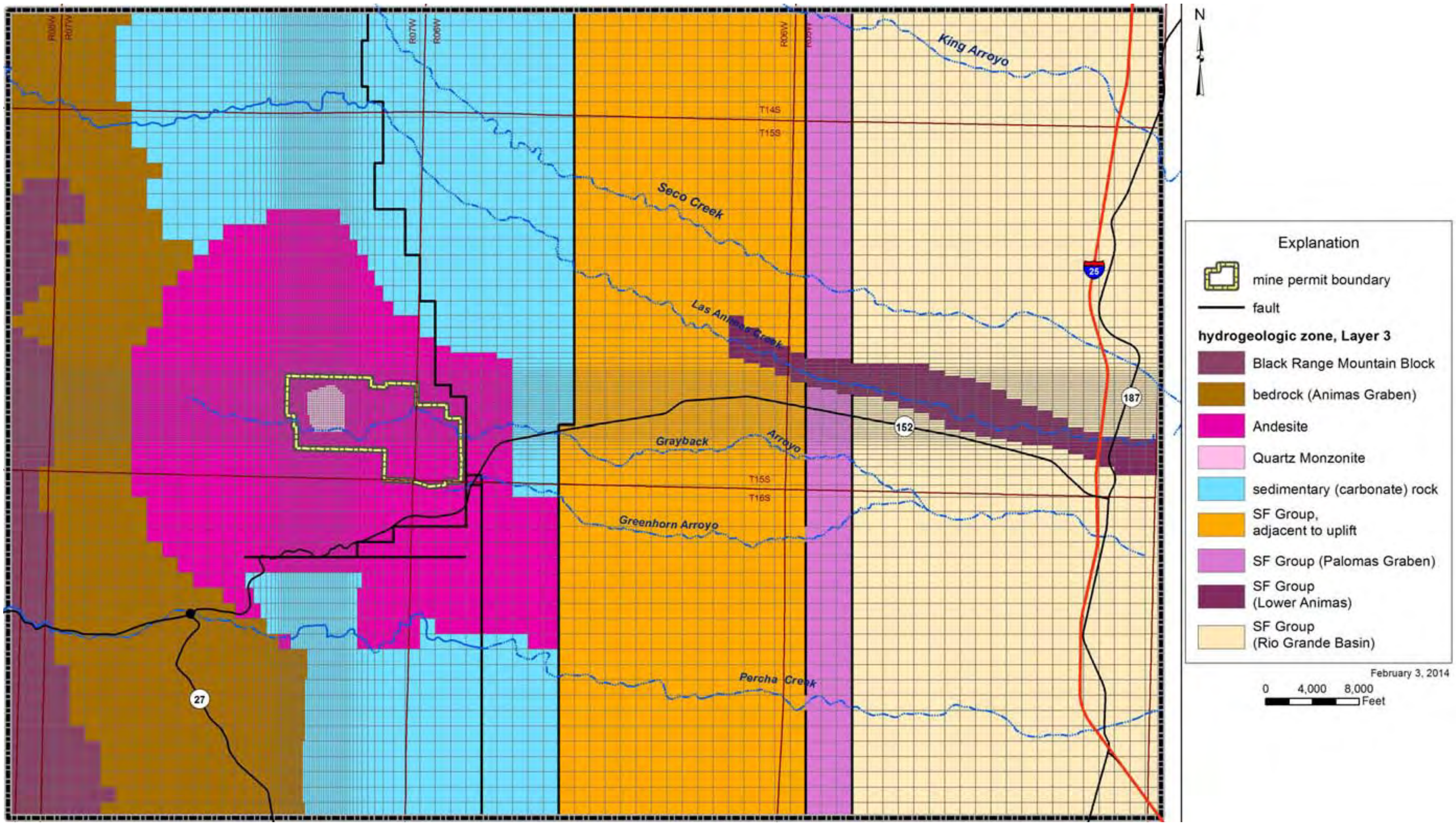


Figure 6.4. Layer 3 hydrogeologic zones.

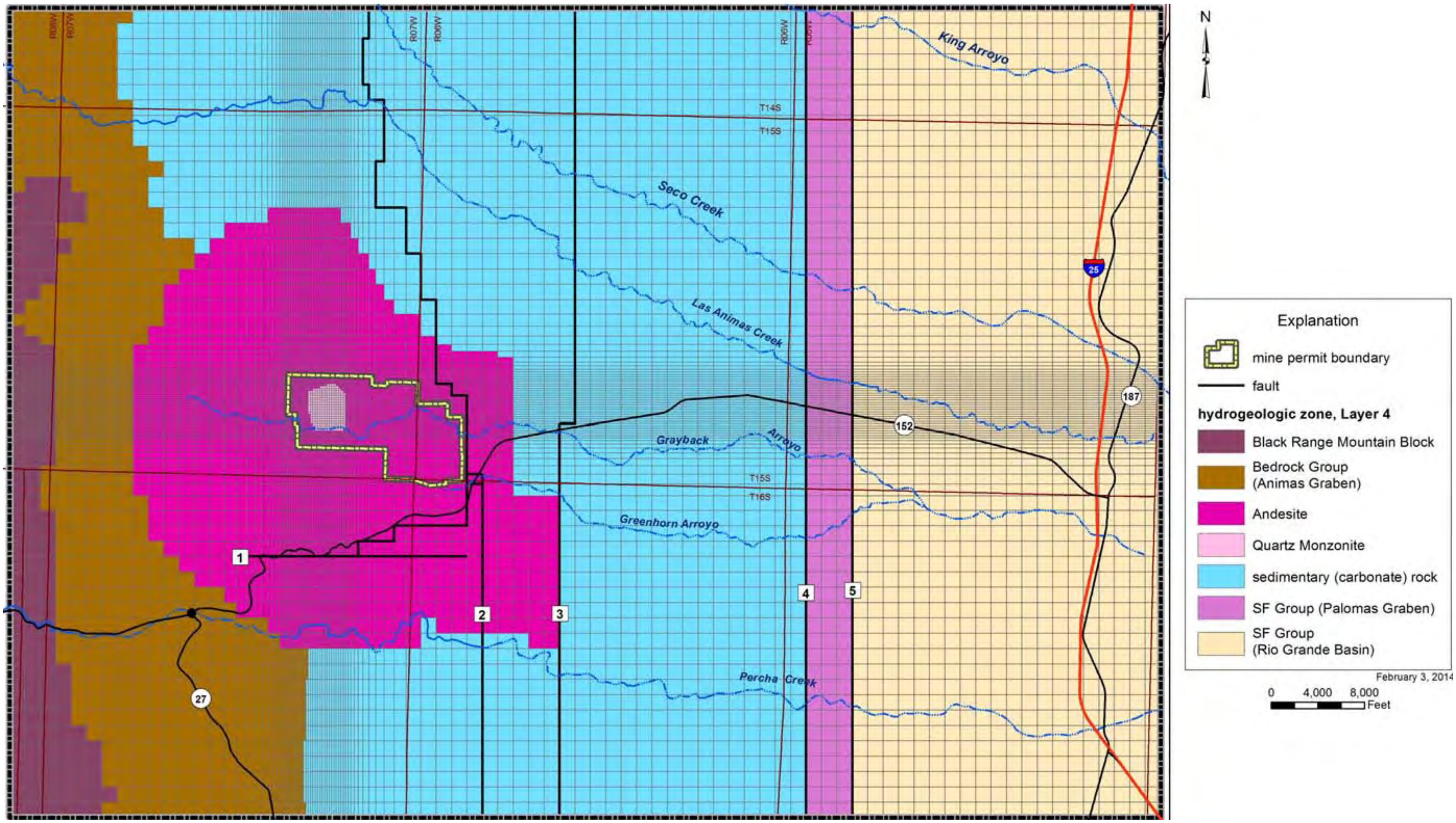


Figure 6.5. Layer 4 hydrogeologic zones.

The modeled aquifer parameters shown on Table 6.1 are based primarily on calibration of the model as a representation of the real system that is consistent with the different sources of information presented in Sections 3, 4 and 5 above. The model calibration results are presented below.

Different aquifer parameters are known with different degrees of certainty. Plausible ranges for different parameters, and the sensitivity of model results to variation of parameters within the plausible range, are discussed in Section 7 below.

Table 6.1. Modeled aquifer parameters

Hydrogeologic Unit	Transmissivity (ft^2/dy)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/dy)	Vertical Anisotropy (ratio)	Specific Yield (%)	Storage Coefficient (%)
Layer 1						
Alluvium / SF Group	2,400	50	48.0	1.25E-04	10%	
Alluvium / SF Group (Lower Animas and Rio Grande Basin)	10,000	200	50.0	1.60E-04	10%	
Layer 2						
Black Range Mountain Block	2	1,000	0.002	0.01	0.1%	0.1%
SF Group (Animas Graben)	500	500	1.000	0.01	10%	10%
Andesite	2	1,000	0.002	0.01	0.1%	0.1%
Quartz Monzonite	2	1,000	0.002	0.01	0.1%	0.1%
Sedimentary (carbonate) rock	80	1,000	0.080	0.01	0.5%	0.5%
SF Group adjacent to uplift, edge of basin	200	1,000	0.200	1.0	5%	5%
SF Group adjacent to uplift (Upper Animas)	40	200	0.200	0.01	5%	5%
Basalt flow overlying SF Group	0.2	200	0.001	0.01	1%	1%
SF Group	900	1,000	0.900	0.01	10%	0.1%
SF Group (Palomas Graben)	1000	1000	10.000	1.0	10%	0.2%
SF Group (Animas Creek above graben)	2000	200	10.000	0.0001	10%	0.1%
SF Group (Lower Animas)	20000	1,000	20.000	0.01	10%	0.1%
SF Group (Rio Grande Basin)	20000	1000	20.000	1.0	10%	0.1%
Layer 3						
Black Range Mountain Block	2	2,000	0.001	0.01		0.01%
Bedrock (Graben)	700	1,000	0.700	0.01		0.01%
Andesite	2	2,000	0.001	0.01		0.01%
Quartz Monzonite	2	2,000	0.001	0.01		0.01%
Sedimentary (carbonate) rock	100	2,000	0.050	0.01		0.01%
SF Group, adjacent to uplift	400	2,000	0.200	0.01		0.4%
SF Group (Palomas Graben))	8,000	2,000	4.000	1.0		0.4%
SF Group, lower Animas	10,000	1,000	10.000	0.01		0.1%
SF Group (Rio Grande Basin)	800	2,000	0.400	0.01		0.4%
Layer 4						
Black Range Mountain Block	3	3,000	0.001	0.01		0.01%
Bedrock (Graben)	100	2,000	0.050	0.01		0.01%
Andesite	3	3,000	0.001	0.01		0.01%
Quartz Monzonite	3	3,000	0.001	0.01		0.01%
Sedimentary (carbonate) rock	150	3,000	0.050	0.01		0.01%
SF Group (Palomas Graben)	2,000	3,000	0.667	0.01		1%
SF Group (Rio Grande Basin)	2,000	3,000	0.667	0.01		0.6%

The modeled fault barriers are based on geologic interpretation and on model calibration. The barriers mainly represent a series of parallel north-south trending faults (Hawley, personal communication, 2012). The barriers shown on Figures 6.3 through 6.5 are simulated with conductance (transmissivity / fault thickness) shown on Table 6.2. The fault barriers include (Fig. 6.3):

1. A fault along the south side of the andesite cone, separating andesite from carbonate rock (Animas volcano fault system).
2. The mountain front fault (East Animas fault trend), generally following the bedrock / SFG contact, but running east of an embayment of SFG in the area of the 1982 tailings impoundment.
3. A parallel fault, east of the mountain front (Saladone Tank fault trend).
4. The west boundary of the Palomas Graben (West Palomas Graben Fault trend).
5. The east boundary of the Palomas Graben (East Palomas Graben Fault trend).

Conductance of the fault south of the andesite was based on the rapid change of water levels from the andesite to Percha Creek. Conductance of the mountain-front fault was based in part on the sustained elevated water levels in the vicinity of the tailings impoundment. The Saladone tank fault trend conductance was based on regional water-level gradient.

The Palomas graben-bounding fault conductances were based mainly on results of the 2012 aquifer test (Section 6.4.3 below). The west graben-bounding fault is simulated as a strong barrier to flow using a small conductance. The east graben-bounding fault is simulated as a weak barrier to flow using a large conductance; resistance to flow across the east edge of the graben is accomplished mostly by the simulated permeability contrast.

Table 6.2. Modeled fault barrier conductance

	fault	**section**	**layer 2 conductance (ft/day)**	**layers 3-4 conductance (ft/day)**
1.	andesite south boundary		1.0E-04	2.0E-05
2.	mountain-front fault	north	8.0E-02	1.2E-01
		mountain front center: andesite, TSF embayment	5.0E-03	1.0E-10
		south	5.0E-08	2.0E-07
3.	Saladone Tank trend		1.0E-03	1.0E-03
4.	Palomas Graben west		1.0E-08	1.0E-08
5.	Palomas Graben east		1.0E+00	1.0E+00

6.3 Boundary Conditions

Model boundary conditions fall under the categories of (1) natural boundary conditions including direct recharge, stream-channel runoff and infiltration, base flow discharge, evapotranspiration and groundwater discharge to the Rio Grande Basin, and (2) anthropogenic boundary conditions including flowing wells, mine water-supply wells, the current and future open pits, and infiltration from the 1982 tailings impoundment.

Anthropogenic boundary conditions in the shallow systems along Animas Creek and Percha Creek are for purposes of the model considered natural boundary conditions. The different discharges from the shallow systems, including natural ET, crop ET supplied by wells or surface diversions, pumping from wells for stock or domestic use, and discharge from flowing wells, are difficult to distinguish.

The natural boundary conditions are applied to all model simulations: steady-state, historical pre-mining, historical mining and post-mining, aquifer test, future mining, and future post-mining.

The anthropogenic boundary conditions are applied to the historical pre-mining (flowing wells only) and historical mining and post-mining (flowing wells, mine water-supply wells, open pit and tailings infiltration) simulations as described below.

Different anthropogenic boundary conditions (future water-supply pumping, future open pit) apply to the future mining and future post-mining simulations, which are reported separately.

6.3.1 Natural Boundary Conditions

Natural boundary conditions represented in the model are shown on Figure 6.6 and include the following:

- Direct recharge of precipitation to groundwater is represented as a specified-flow boundary condition, using MODFLOW module RCH. Direct recharge rates are shown on Figure 6.6.

- Stream-channel runoff, infiltration of stream flow to groundwater, and discharge of groundwater to stream channels, are represented using module RIV2. In addition to simulation of Las Animas Creek, Percha Creek, and Grayback and Greenhorn Arroyos, model calibration required consideration of runoff in Seco Creek and King Arroyo to the north of the main study area watersheds.

- ET from riparian zones along Animas and Percha Creeks is represented using module EVT. (Irrigated ET, taken from surface water or shallow wells, is simulated as part of the shallow system using the head-dependent discharge (RIV2) boundary conditions along the stream channels.)

- Groundwater discharge to the Rio Grande Basin and Caballo Reservoir is simulated with head-dependent boundary conditions using module GHB.
- Groundwater flow in the Palomas Graben, into the model domain at the north end and out at the south end, is simulated with head-dependent boundary conditions using module GHB.

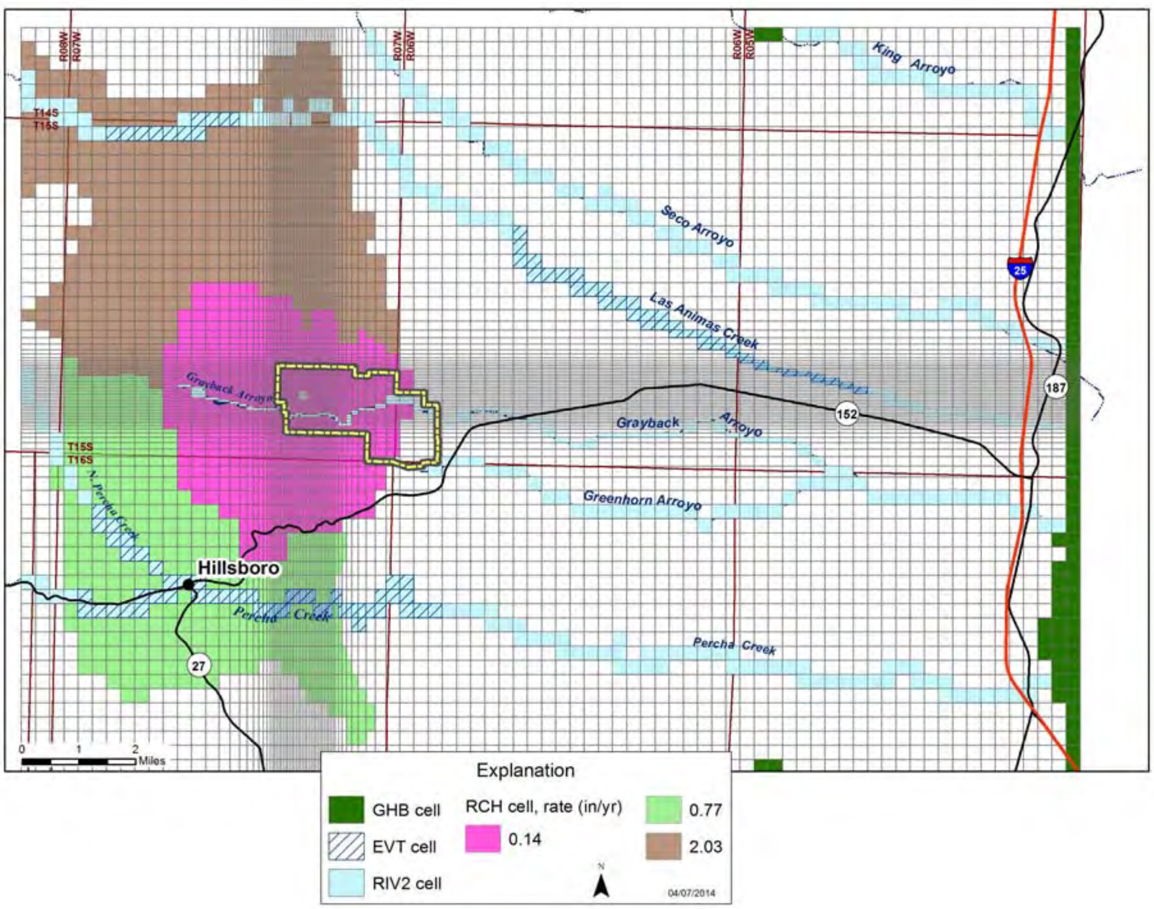


Figure 6.6. Natural boundary conditions.

RIV2 cells are grouped into reaches to define the stream network; each reach defines a length of stream, with a defined downstream reach, and total flow is tracked downstream. Infiltration to groundwater from RIV2 cells is limited to the simulated stream flow. Base flow discharge from groundwater to RIV2 cells is added to the total flow available for infiltration downstream.

Runoff is added at the upstream end of each reach. For each cell within a reach, infiltration to groundwater or discharge from groundwater is computed, and the resulting total flow, if any, is passed to the next cell downstream.

Flow between RIV2 cells and the corresponding aquifer model cell is computed based on RIV2 cell conductance, multiplied by either (1) the stream stage-aquifer head difference (aquifer in contact with stream bed) or (2) the stream stage-streambed bottom difference (aquifer below stream bed). Infiltration to the aquifer is further limited to the amount of simulated flow available in the stream.

The model reproduces the observed pattern of stream flow in the region; runoff is generated in the mountain watersheds, flows downstream until it crosses the mountain front, where it recharges the Santa Fe Group aquifer. Farther below the mountain front, streams flow only after storm events. Still further downstream, near the bottom of the basin, the streams emerge again as groundwater enters the channels as base flow.

The stream reaches defined are listed on Table 6.3, along with simulated annual runoff to each reach. RIV2 cell parameters include elevation and conductance. Conductance is computed from the length of stream in each cell and from hydraulic conductivity and thickness of the underlying material. Modeled RIV2 cell hydraulic conductivities are listed by reach and material, in downstream order, on Table 6.3. Elevation for RIV2 cells was determined from USGS topographic maps. Thickness of streambed was assumed at 1 ft.

EVT cell parameters include ET surface elevation, annual average potential ET rate of 64.6 in./yr and extinction depth of 15 ft. ET from each EVT cell is computed as the potential ET rate whenever water level is at or above the ET surface elevation (depth-to-water of zero), decreasing linearly to zero at the extinction depth. ET is zero for water levels below the extinction depth.

GHB cells simulate groundwater flow from the model area to the Rio Grande basin. GHB cell parameters include elevation, specified at 4,200 ft amsl, and conductance, calibrated at 100 ft^2/day in the north part (rows 1-60), 10,000 ft^2/day along the axis of Las Animas Creek (rows 61-73), and 1,000 ft^2/day in the south part, adjacent to Caballo Reservoir. Flow is computed as the product of GHB conductance and the difference between GHB elevation and aquifer head in the model cell.

Table 6.3. Stream reach specifications

reach No.	name	downstream reach	runoff (ac-ft/yr)	streambed hydraulic conductivity (ft/day)	underlying material
1	Upper Percha	2	5,249	0.001 1	bedrock SFG (graben)
2	Lower Percha	none	0	0.001 1 0.1 10 20	bedrock SFG (graben) carbonate bedrock (uplift) SFG alluvium
3	Las Animas	none	7,898	1 0.1 1 24	SFG (graben) carbonate bedrock (uplift) SFG alluvium
4	Grayback	6	74	0.001 1	bedrock SFG
5	Upper Greenhorn	6	66	1	SFG
6	Lower Greenhorn	none	0	10	alluvium
7	Seco Creek	none	18	0.15 0.8 20	SFG SFG (Las Animas Creek) alluvium
8	King Arroyo	none	0	0.15 20	SFG alluvium

ac-ft/yr - acre-feet per year
SFG - Santa Fe Group

6.3.2 Anthropogenic Boundary Conditions

Anthropogenic boundary conditions represented in the model include discharge from artesian wells, pumping from mine water supply wells, infiltration beneath the 1982 (historical) tailings impoundment, and the open pit. Locations of model-simulated anthropogenic boundary conditions are shown on Figure 6.7.

Flow from artesian wells was simulated as drain (head-dependent, outflow only) boundary conditions with MODFLOW module DRN. Flow from each DRN cell is computed as the product of DRN conductance (assumed at 1,000 ft^2/day, or 5.2 gpm/ft of head above the discharge elevation) and aquifer cell head minus DRN elevation. Flow is zero when aquifer cell head is below DRN elevation.

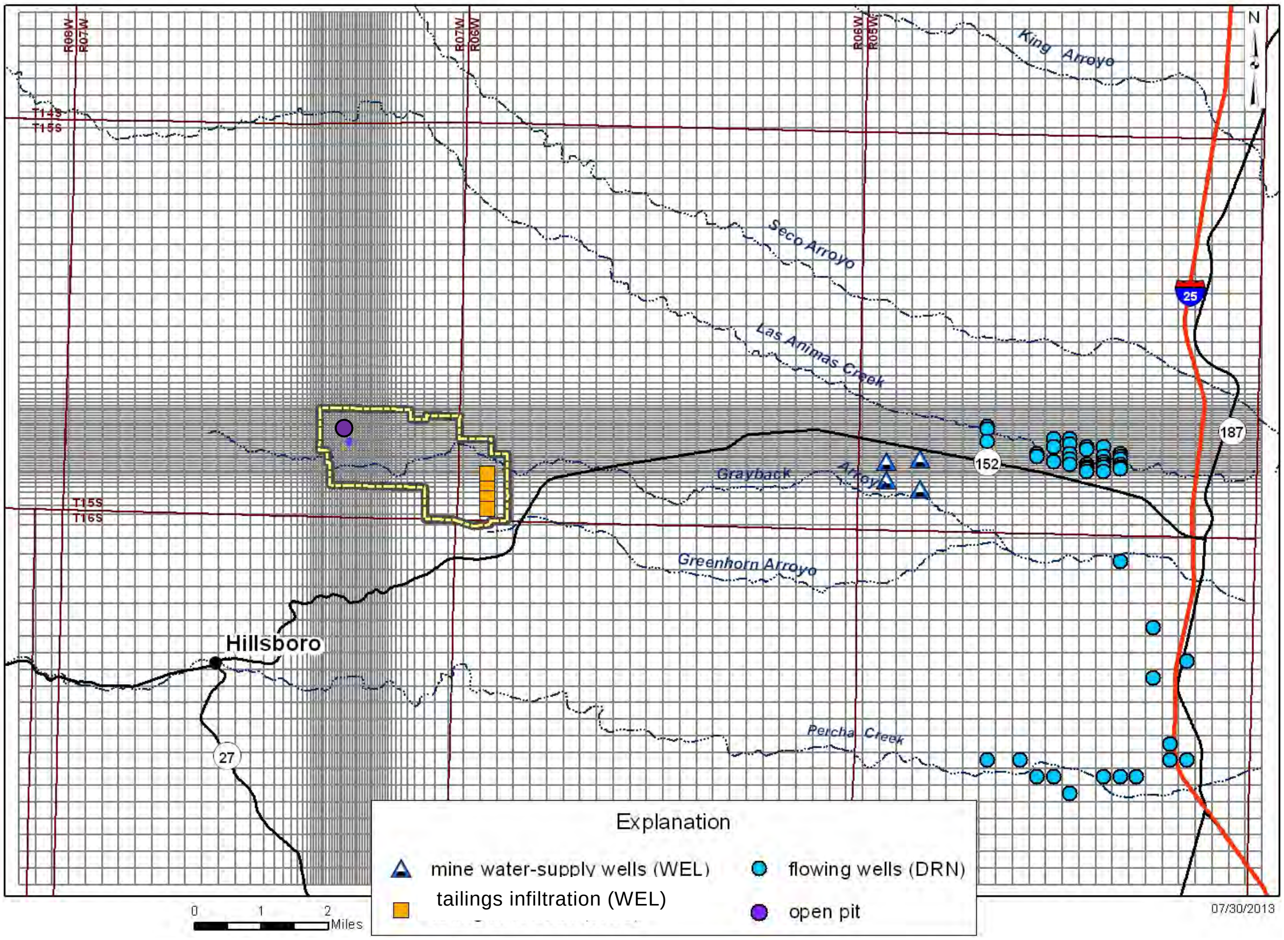


Figure 6.7. Anthropogenic boundary conditions.

Historical pumping from mine water supply wells was simulated as specified-flow boundary conditions with MODFLOW module WEL. Pumping rates were specified from Table 5.1. Pumping during the 2012 aquifer test was simulated using module LAK2, in order to simulate in-bore water levels in the pumping wells.

Infiltration from the historical tailings impoundment was also simulated as specified-flow boundary conditions using WEL. Infiltration rates were estimated based on model calibration, constrained by an upper limit based on the amount of water actually added to the impoundment (Fig. 6.8).

Water level and water balance of the open pit were simulated using MODFLOW module LAK2. The geometry of the existing pit is represented in the historical post-mining simulation, as shown by the actual and simulated pit water stage – area curves presented on Figure 6.9 (Note that Figure 6.9 does not represent model calibration; it simply verifies the accurate simulation of the current pit geometry.).

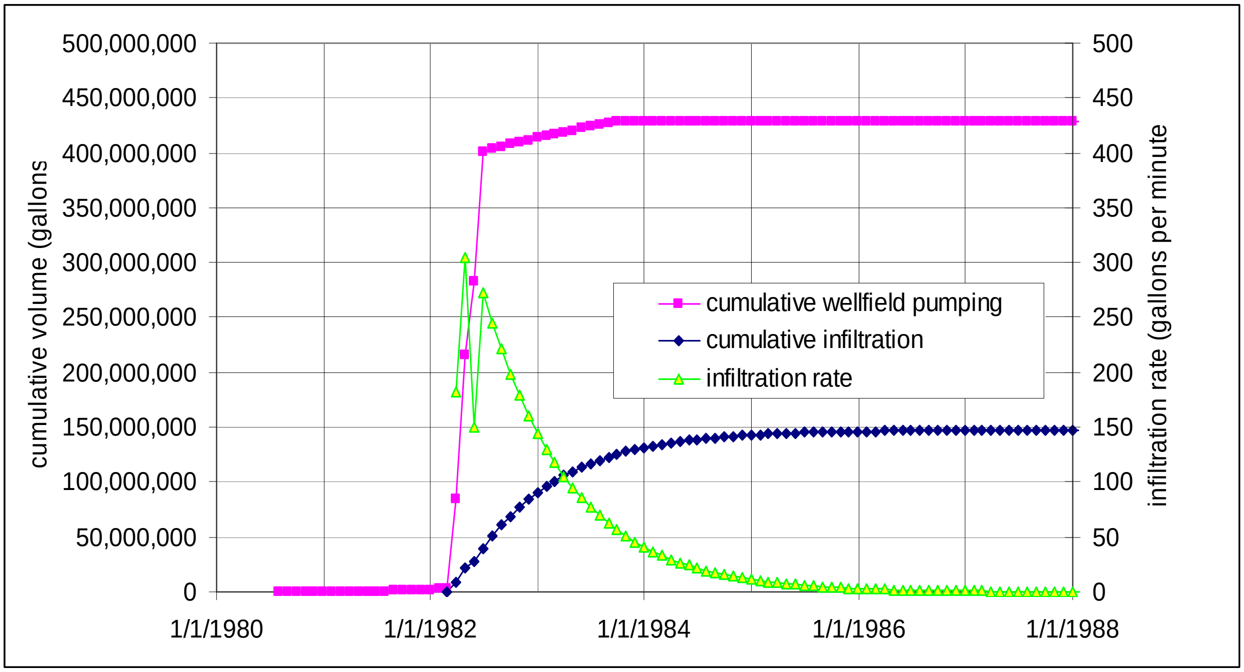


Figure 6.8. Modeled historical tailings infiltration.

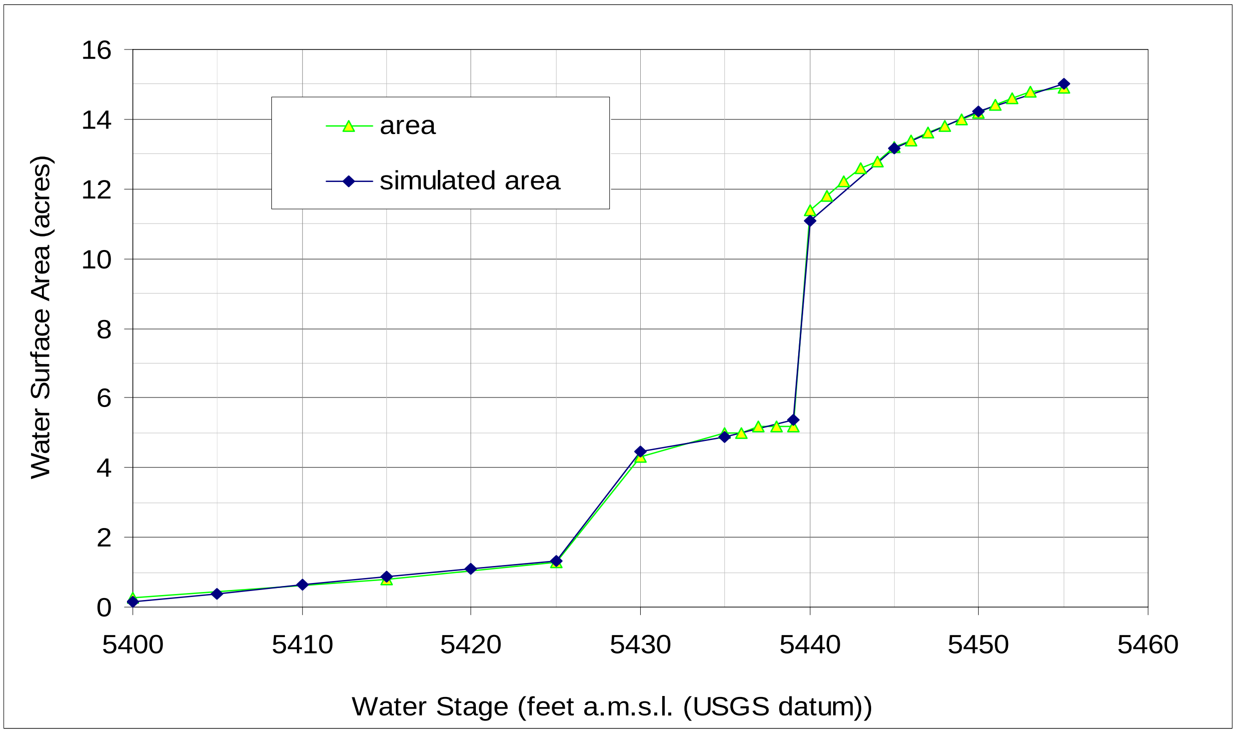


Figure 6.9. Existing open pit water elevation - water surface area relationship.

Hydrologic parameters for the open pit, including monthly average precipitation and evaporation rates, and runoff coefficients for the pit walls and for the 230-acre pit watershed, are listed on Table 6.4.

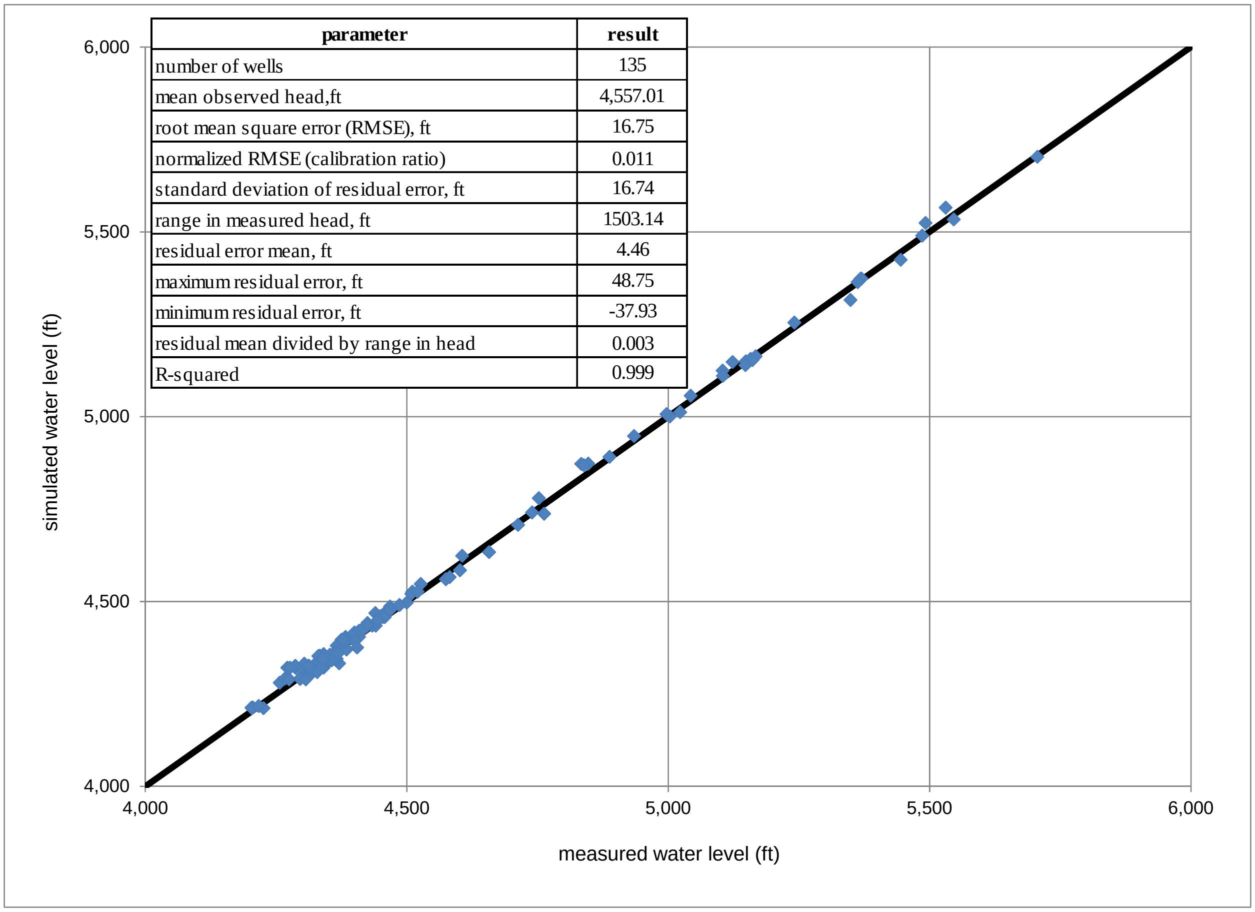
Table 6.4. Simulated open-pit hydrologic parameters

meteorological parameters		
month	**average precipitation (inches)**	**average evaporation (inches)**
Jan	0.6	3.2
Feb	0.6	4.2
Mar	0.4	6.4
Apr	0.3	7.1
May	0.5	8.4
Jun	0.7	10.7
Jul	2.3	7.8
Aug	2.5	4.5
Sep	2.1	4.6
Oct	1.2	3.0
Nov	0.6	2.8
Dec	0.8	2.1
total	12.5	64.6
runoff coefficients		**(percent of precipitation)**
pit wall		0.30
watershed		0.05

6.4 Model Results and Calibration

6.4.1 Steady-State Simulation

Estimated and simulated steady-state water levels are compared on Figure 6.10. The simulated steady-state basin water balance is shown on Table 6.5. Contours of the simulated steady-state water table are shown on Figure 6.11.



parameter	result
number of wells	135
mean observed head,ft	4,557.01
root mean square error (RMSE), ft	16.75
normalized RMSE (calibration ratio)	0.011
standard deviation of residual error, ft	16.74
range in measured head, ft	1503.14
residual error mean, ft	4.46
maximum residual error, ft	48.75
minimum residual error, ft	-37.93
residual mean divided by range in head	0.003
R-squared	0.999

Figure 6.10. Comparison of measured and simulated water levels.

Table 6.5. Simulated steady-state water balance

	watershed				TOTAL
	Animas	**Percha**	**Grayback / Greenhorn**	**Seco / King**	
direct recharge	2,811	825	61	0	3,697
runoff	8,720	7,052	140	18	15,931
groundwater inflow	0	0	0	1,827	1,827
TOTAL IN (ac-ft/yr)					**21,455**
Riparian ET (Palomas Basin)	1052	0	0	0	1052
Riparian ET (Animas Uplift, Animas Graben)	617	1,730	0	0	2347
Crop ET, domestic, etc.	4193	1074	0	0	5267
groundwater discharge	3589	3339	2487	3374	12789
TOTAL OUT (ac-ft/yr)					**21,455**

ac-ft/yr - acre-feet per year

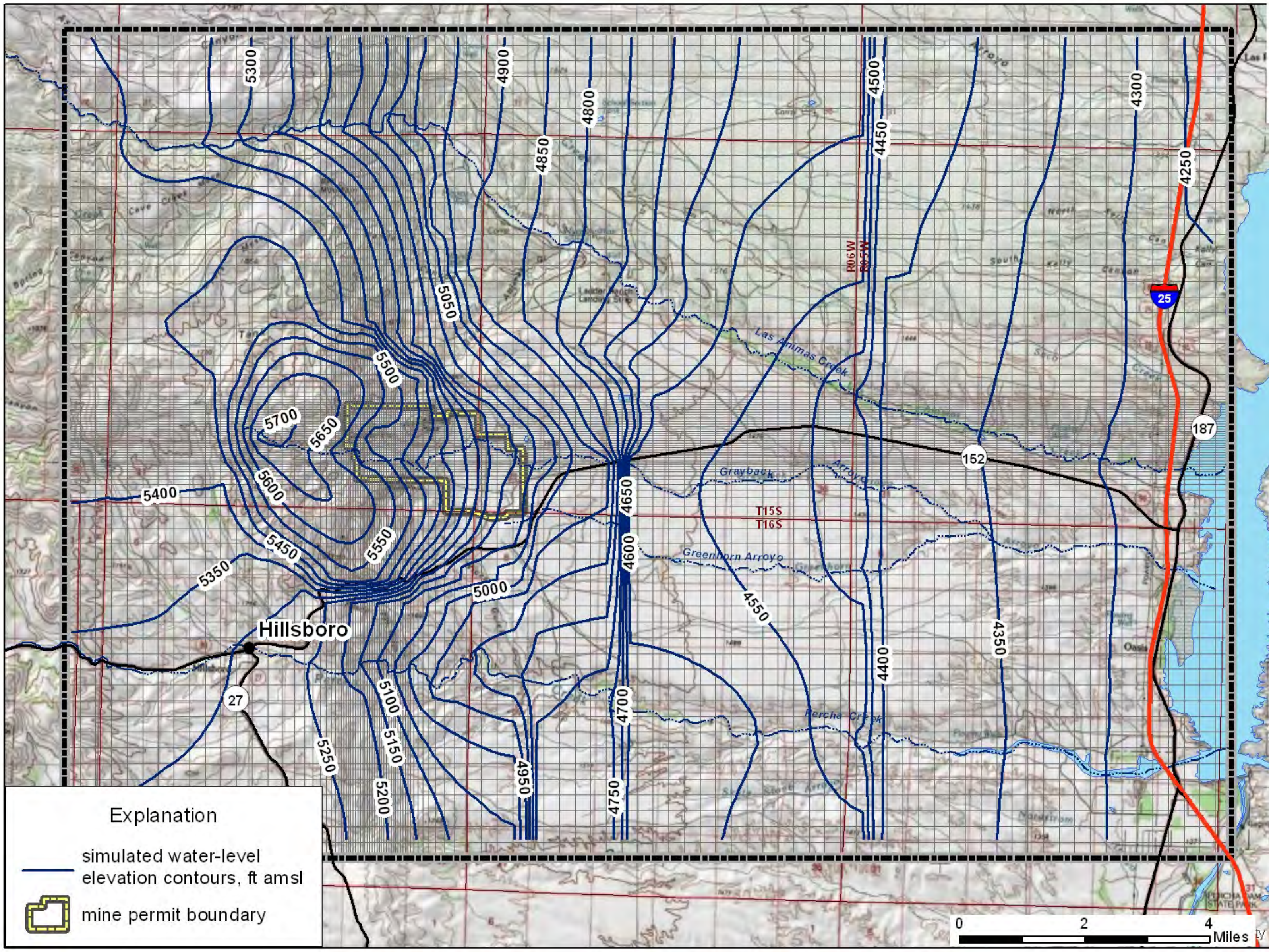


Figure 6.11. Contours of simulated 2012 groundwater levels.

6.4.2 Historical Transient Simulation

The historical transient simulations include the pre-mining (1940 to June 1980), and mining and post-mining (June 1980 to November 2012) simulations. Measured and simulated water-level hydrographs are compared for calibration well locations shown on Figure 6.12. Measured and simulated water levels are presented on Figures 6.13 through 6.27.

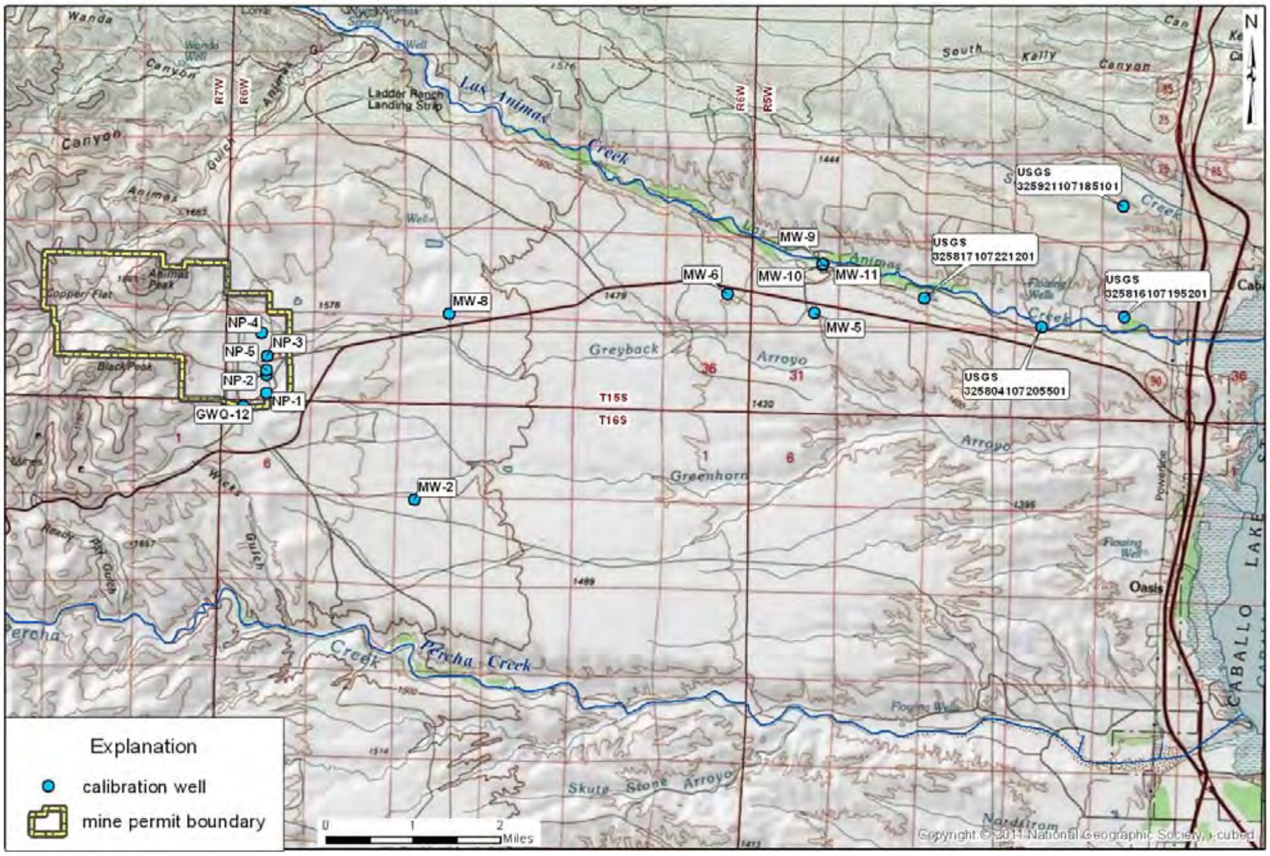


Figure 6.12. Locations of measured water-level hydrographs.

Measured and simulated water levels near the well field, at MW-5, are presented on Figure 6.13, showing drawdown and recovery in response to the period of well field operation in 1982. Measured and simulated water-level changes are in agreement. The small difference (~10 ft) between measured and simulated water-level elevations is appropriate, considering the range of water levels represented by a single model cell, and the fact that the well is not at the cell center.

Measured and simulated water levels west of the well field, at MW-6, are shown on Figure 6.14. The 35-year, 175-ft rise in the measured MW-6 water level (discussed in Section 5.2.2 above) is not simulated in the model.

Measured and simulated water levels north of the well field along Las Animas Creek, at MW-9, -10 and -11, are shown on Figure 6.15. The measured water levels include data from the mid-1990s as well as data from 2012. The vertical gradient measured between the shallow well (MW-11) and the deeper wells (MW-10 and -9) is reproduced in the model.

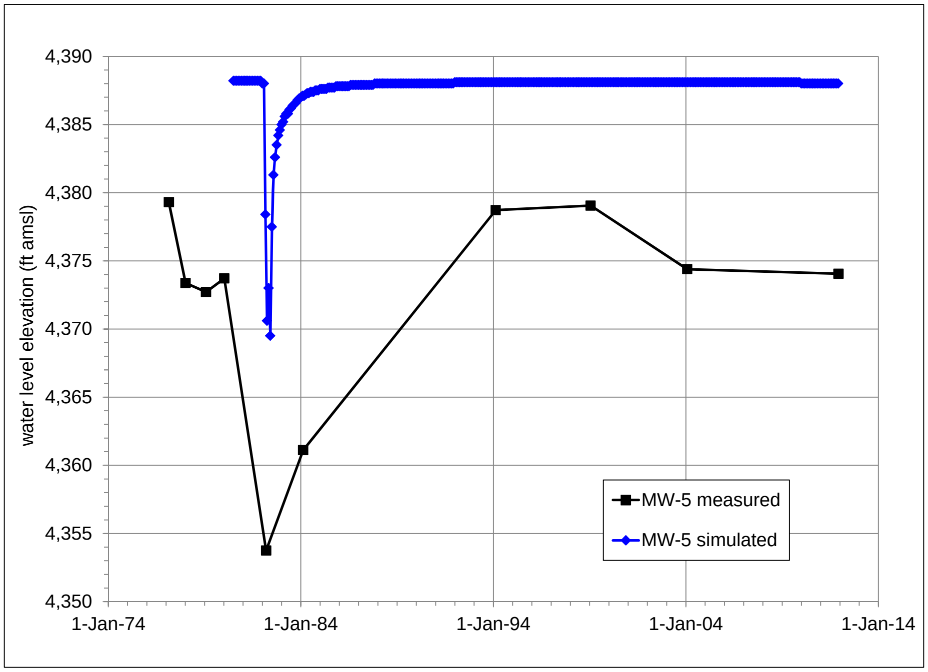


Figure 6.13. Measured and simulated water-level hydrographs in MW-5.

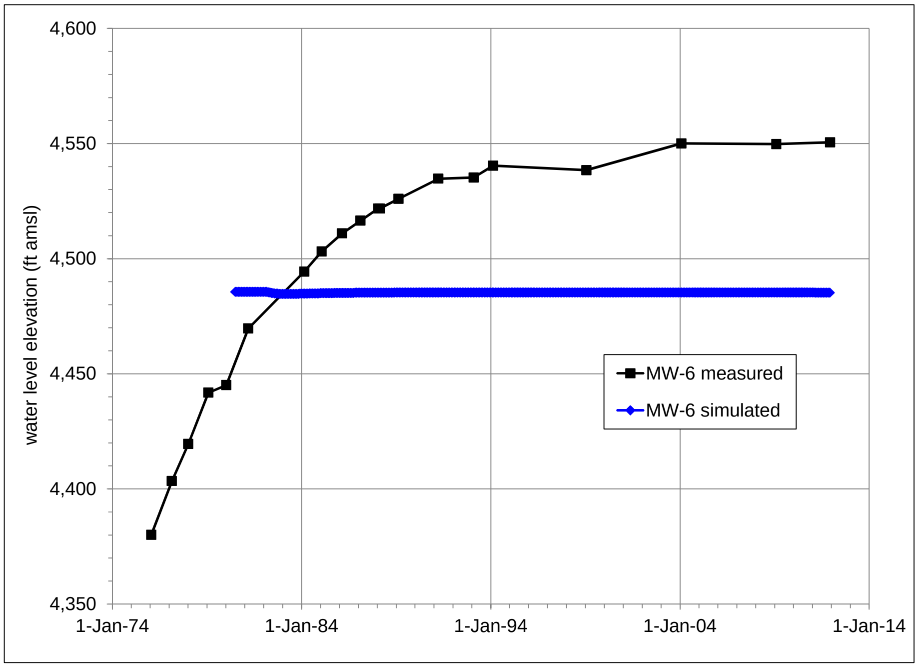


Figure 6.14. Measured and simulated water-level hydrographs in MW-6.

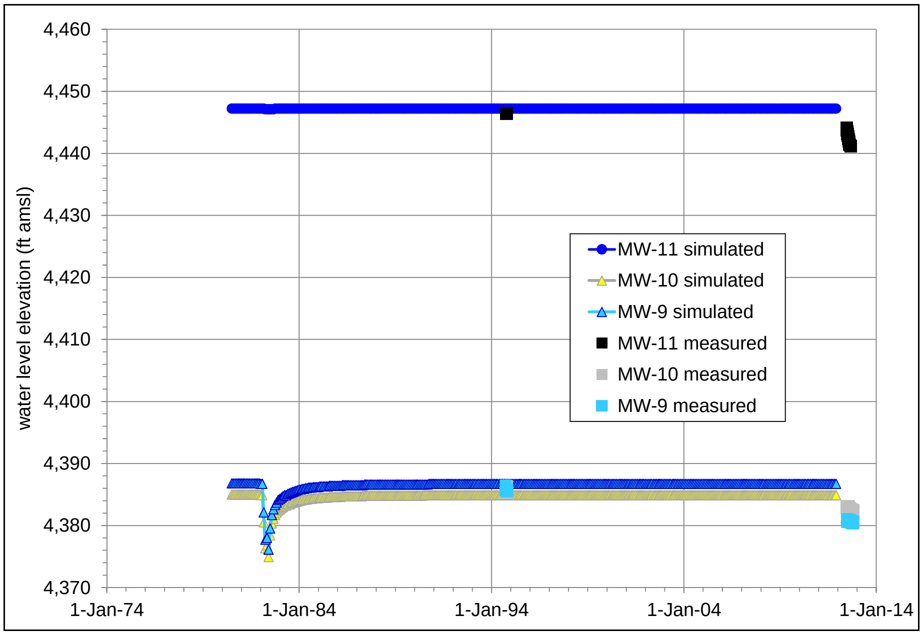


Figure 6.15. Measured and simulated water-level hydrographs in MW-9, MW-10, and MW-11.

Measured and simulated water levels farther down Las Animas Creek (Fig. 5.2) are shown on Figures 6.16 through 6.19. The background variation in the measured water levels reflects unidentified local and temporal stresses that are not simulated in the model. The model simulates the measured water levels generally within the range of water-level variation found in a single model cell in this area. The simulation is acceptably accurate considering the water-level variation within a single cell and the not-simulated local processes affecting the measured water level.

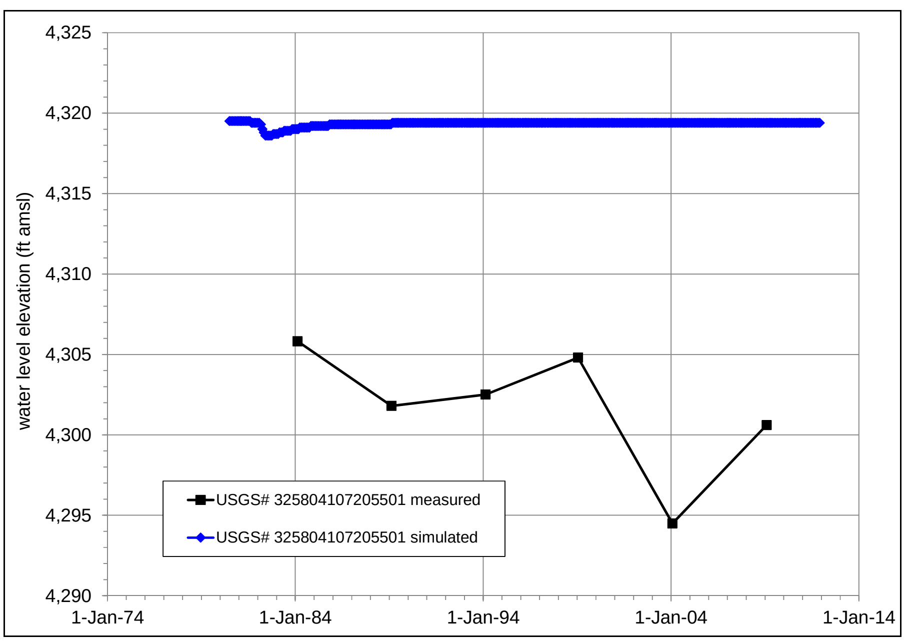


Figure 6.16. Measured and simulated water-level hydrographs in USGS No. 325804107205501.

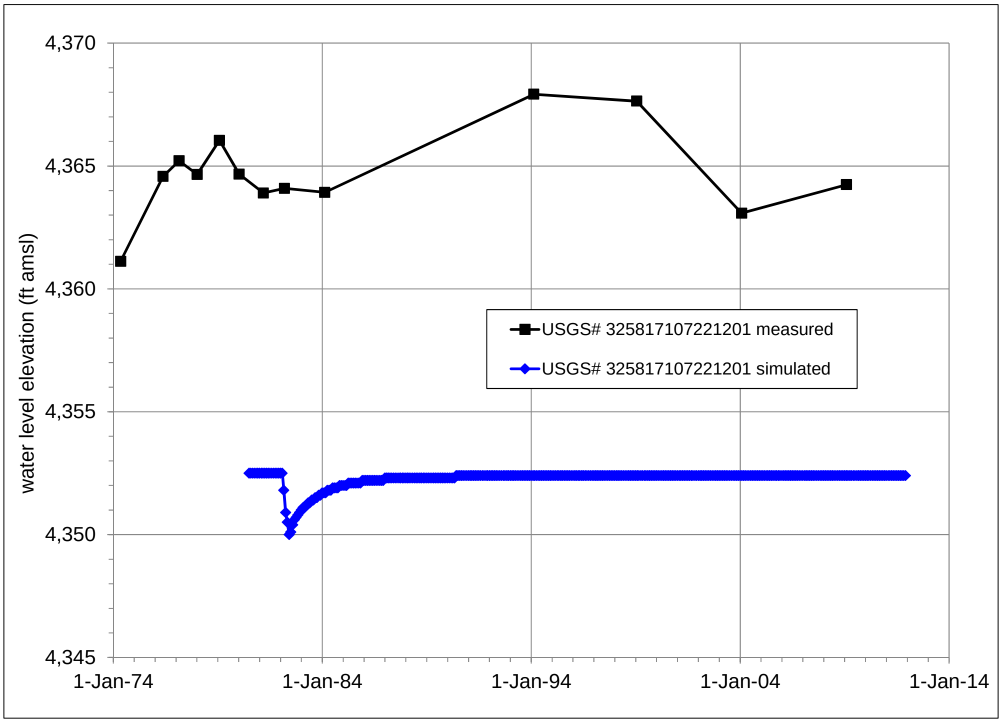


Figure 6.17. Measured and simulated water-level hydrographs in USGS No. 325817107221201.

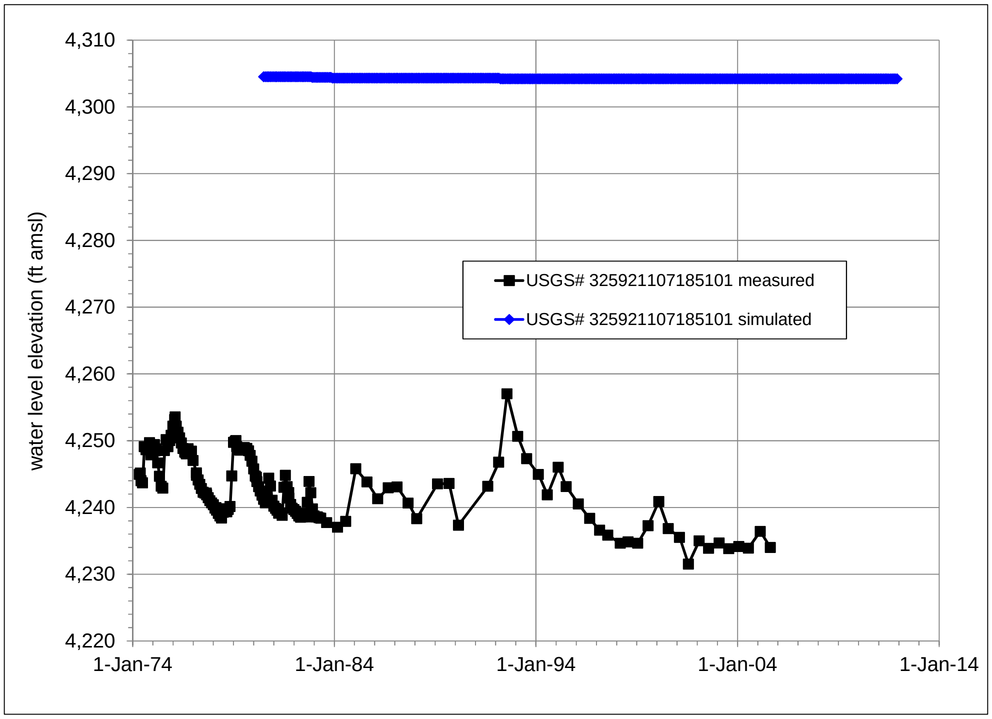


Figure 6.18. Measured and simulated water-level hydrographs in USGS No. 325921107185101.

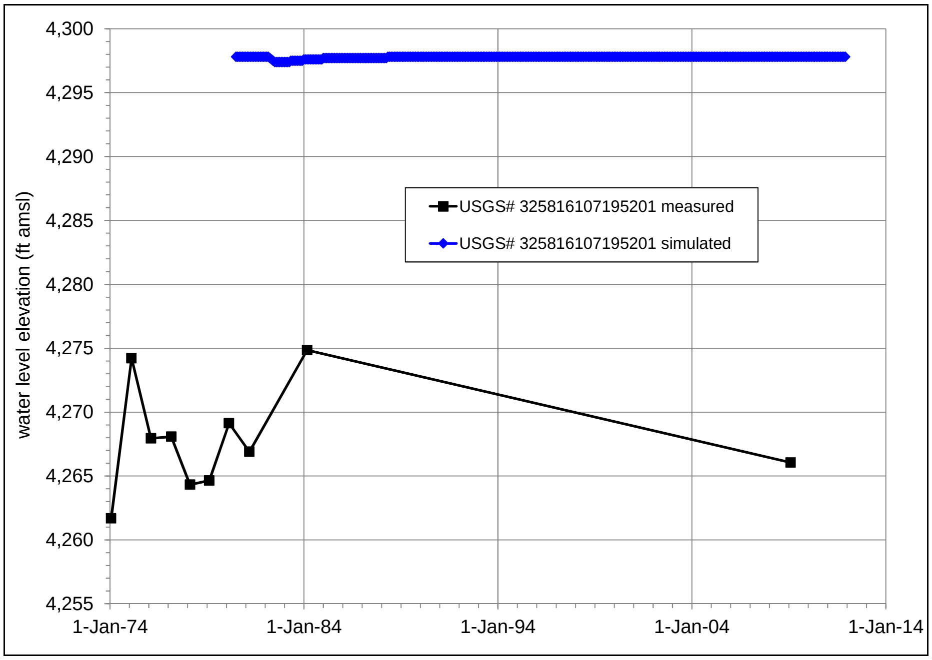


Figure 6.19. Measured and simulated water-level hydrographs in USGS No. 325816107195201.

Measured and simulated water levels downstream of the tailings impoundment (Fig. 5.2), at MW-2 and MW-8, are shown on Figures 6.20 and 6.21, also showing substantial background water-level fluctuations not simulated in the model. The simulation is acceptably accurate considering the amount of water-level variation within a single cell and the not-simulated local processes affecting the measured water level.

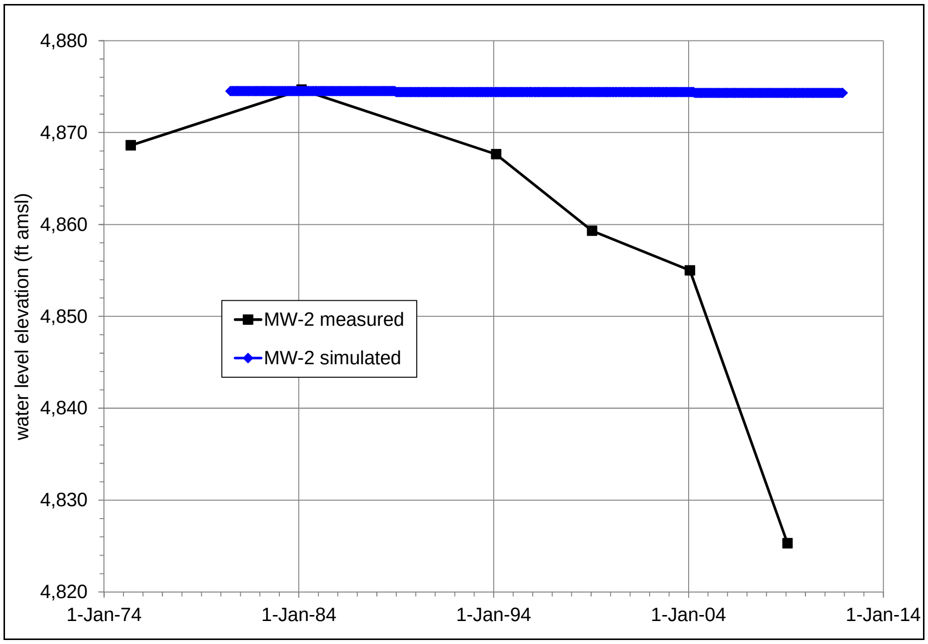


Figure 6.20. Measured and simulated water-level hydrographs in MW-2.

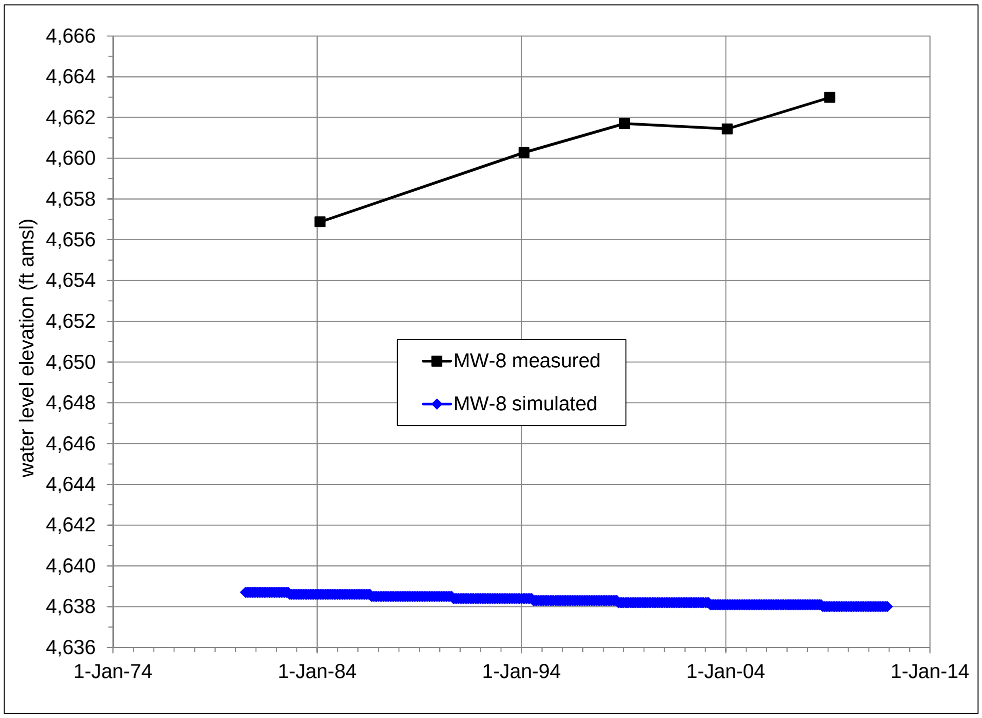


Figure 6.21. Measured and simulated water-level hydrographs in MW-8.

Measured and simulated water levels in the vicinity of the 1982 tailings impoundment (Fig. 5.2) are shown on Figures 6.22 through 6.27. The model reproduces the phenomenon of sustained elevated water levels measured in the vicinity of the impoundment, caused by a fault barrier to the east. The barrier appears to largely contain seepage from the tailings within the fault-bounded block.

Simulated water levels do not exactly match the measured, which indicate even less flow across the fault barrier than is simulated. The measured water levels also reflect unknown local processes and uncertainty in measurements taken over several periods. However the major feature, that of sustained elevated water levels caused by the dam effect of the fault barrier, is reproduced. Seepage from the tailings has mainly been contained behind the fault and has not flowed down gradient.

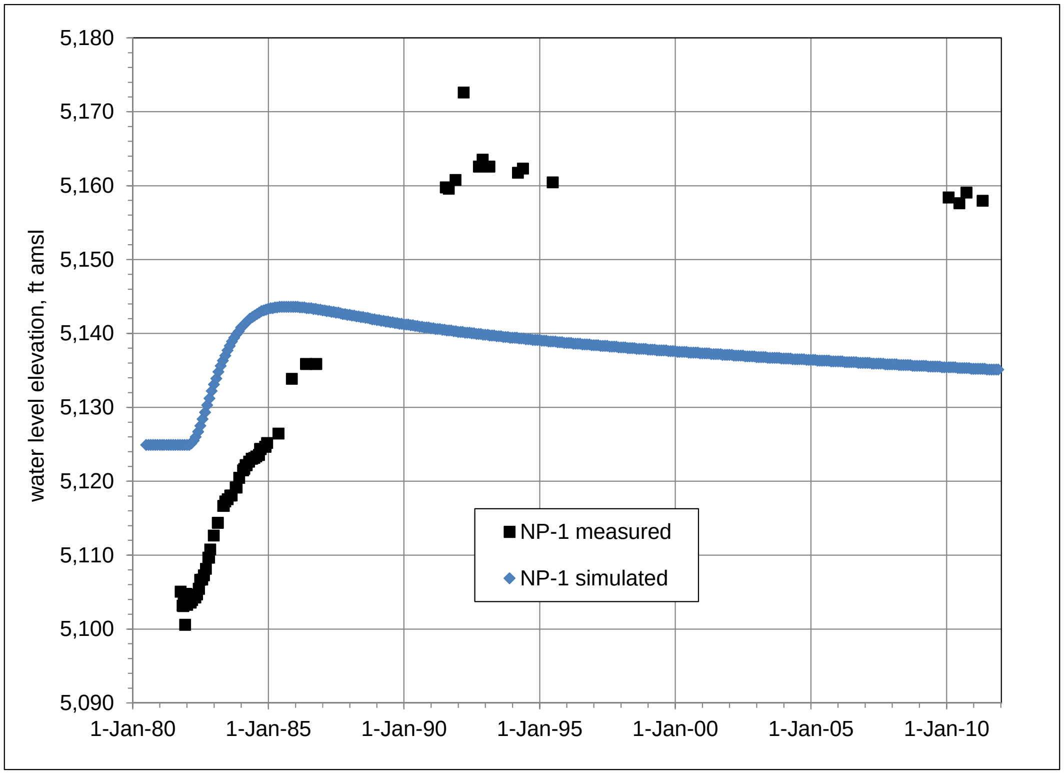


Figure 6.22. Measured and simulated water-level hydrographs in NP-1.

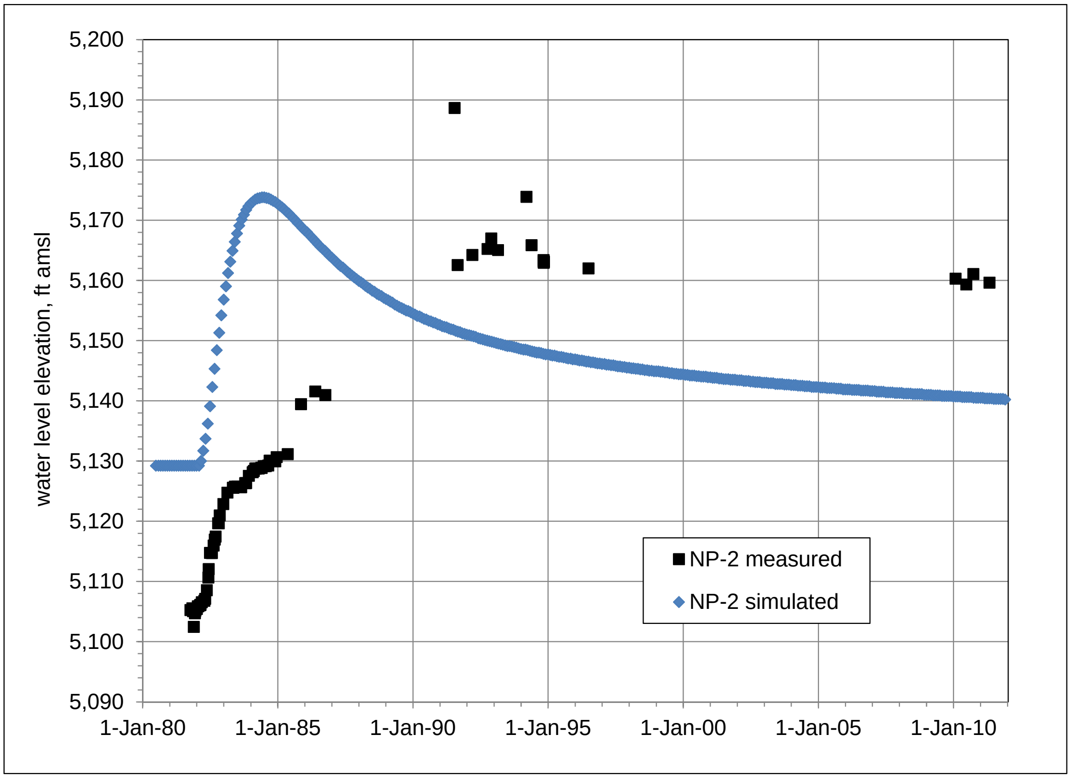


Figure 6.23. Measured and simulated water-level hydrographs in NP-2.

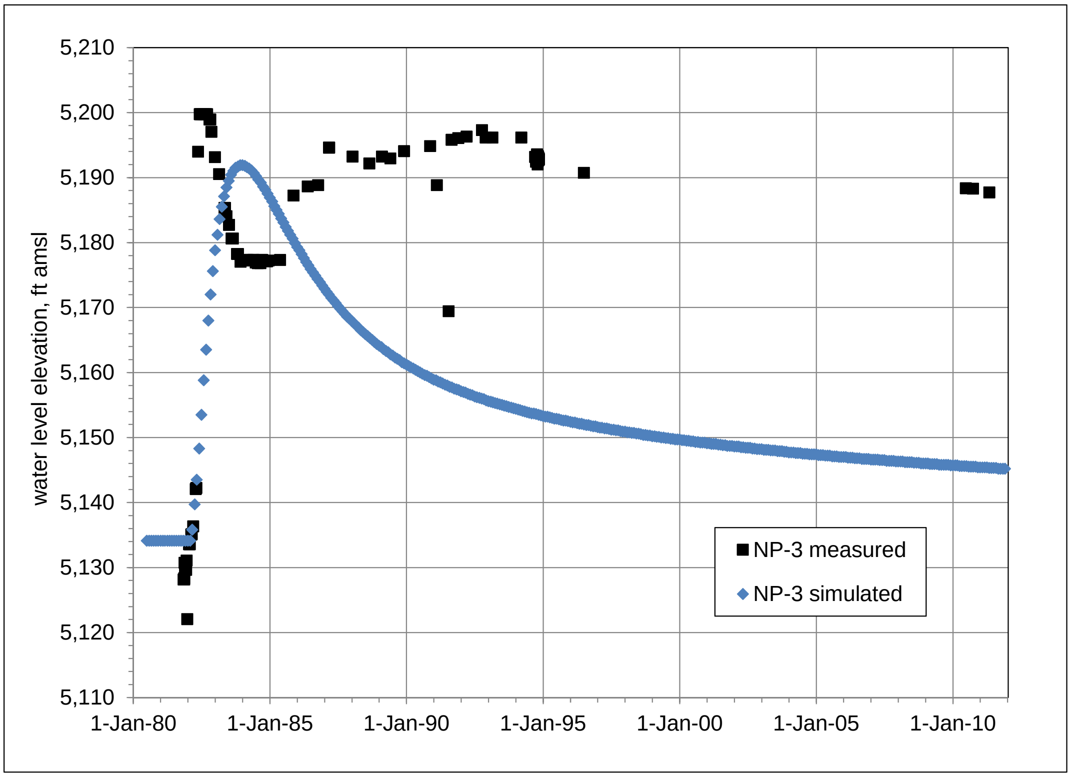


Figure 6.24. Measured and simulated water-level hydrographs in NP-3.

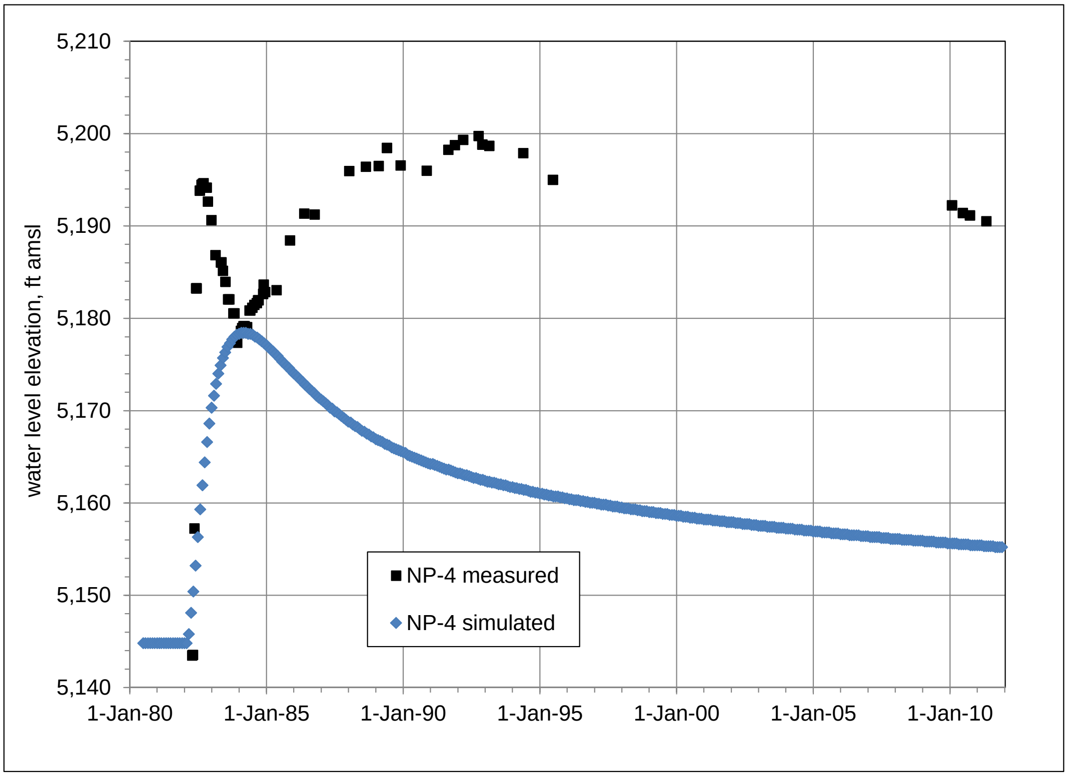


Figure 6.25. Measured and simulated water-level hydrographs in NP-4.

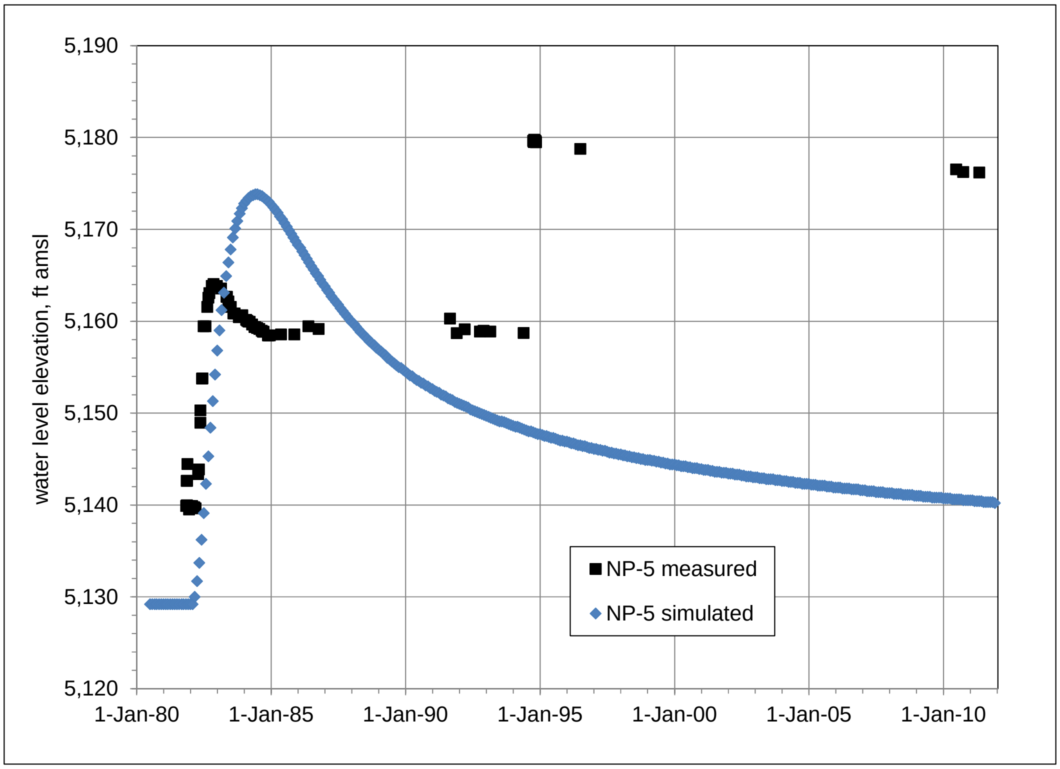


Figure 6.26. Measured and simulated water-level hydrographs in NP-5.

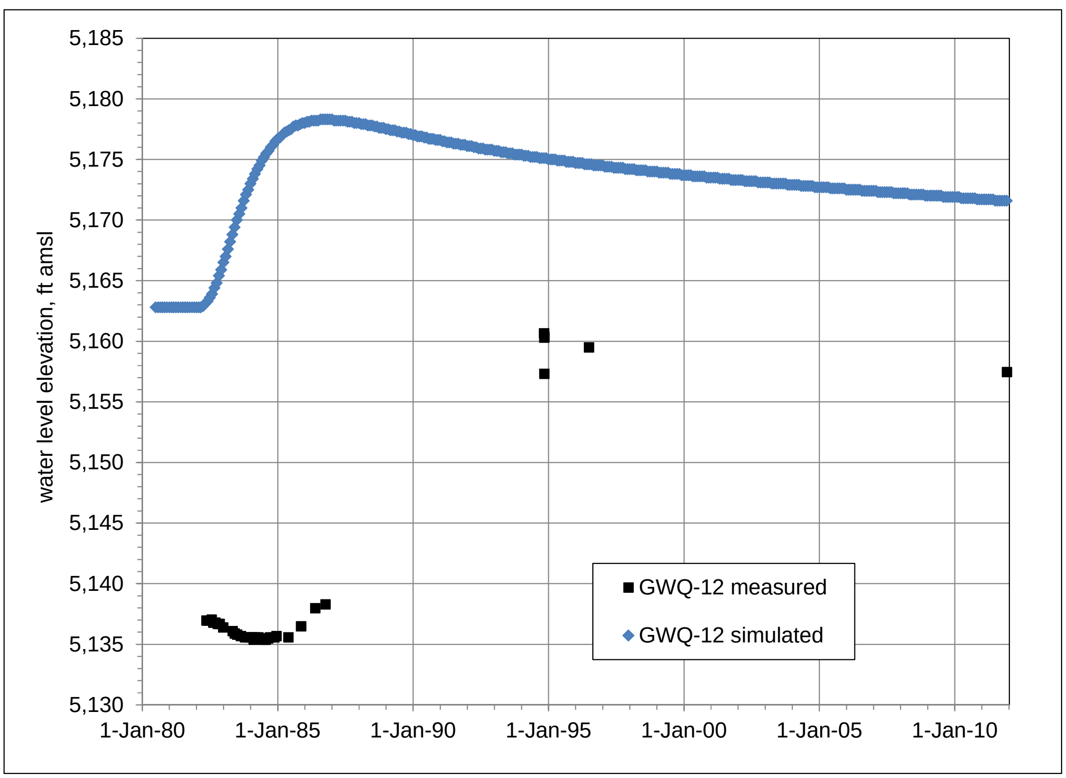


Figure 6.27. Measured and simulated water-level hydrographs in GWQ-12.

Simulated water level and water balance for the current open pit are shown on Table 6.6, indicating general agreement with current measured pit water level and estimated pit water balance. The future (larger and deeper) open pit, both during dewatering and after mining, will have more groundwater inflow with a larger water surface and more evaporation.

Table 6.6. Simulation results for current open pit

water level (ft amsl)	5,433	
water surface area (acres)	4.8	
simulated annual average water balance		
	ac-ft/yr	**gpm**
precipitation and runoff	18.4	11.4
groundwater inflow	6.7	4.2
TOTAL IN (ac-ft/yr)	**25.1**	**15.5**
evaporation out	25.1	15.5
TOTAL OUT (ac-ft/yr)	**25.1**	**15.5**

ac-ft/yr - acre-feet per year

The model correctly simulates the location of graining stream reaches, in the upper parts of the Animas Creek and Percha Creek watersheds over the Animas Uplift. Below the uplift, the streams generally lose flow to the SFG aquifer. However, in the alluvial aquifer along lower Animas Creek, and in the lowest parts of Percha Creek and Greenhorn Arroyo, the model simulates alternating gaining and losing river segments. This is partly an artifact of model discretization (caused by the relatively large change in river stage from cell to cell), but also reflects the reality of a water table that is close to land surface and may rise above the stream bed intermittently or seasonally, causing the stream to flow.

Simulated total flowing-well discharge over time for the study area is shown on Figure 6.28. There are no data for calibrating the total flowing-well discharge, except that the simulated flow should exceed the totals shown on Table 5.3 (and does). The model result represents the known background (independent of the Project) trend of drawdown in the model area. The model-simulated artesian well locations are shown on Figure 6.29, indicating which locations were still flowing (in the model) as of November, 2012.

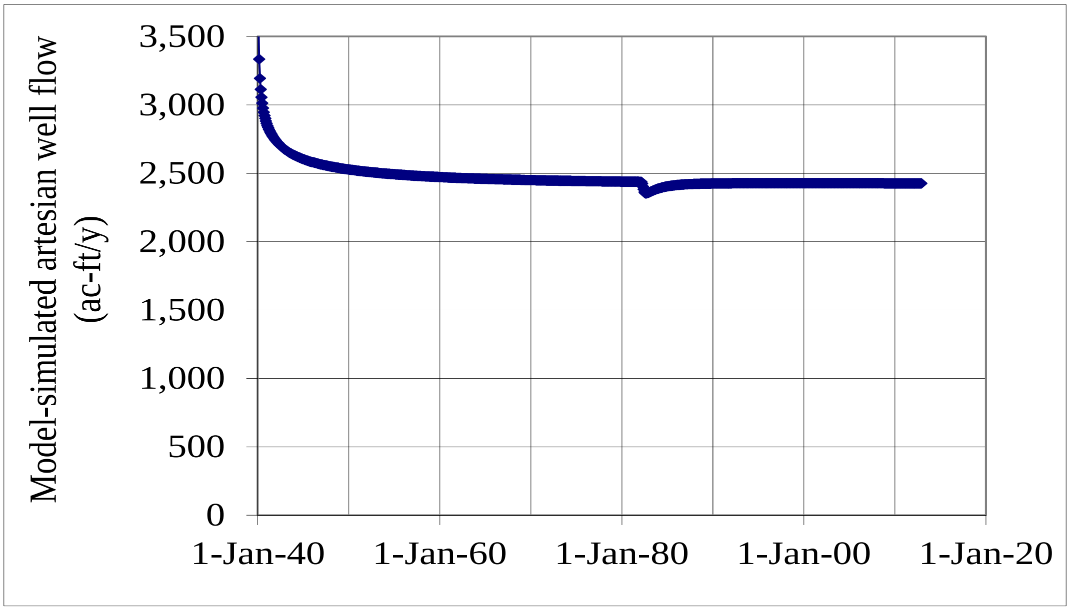


Figure 6.28. Simulated artesian well discharge.

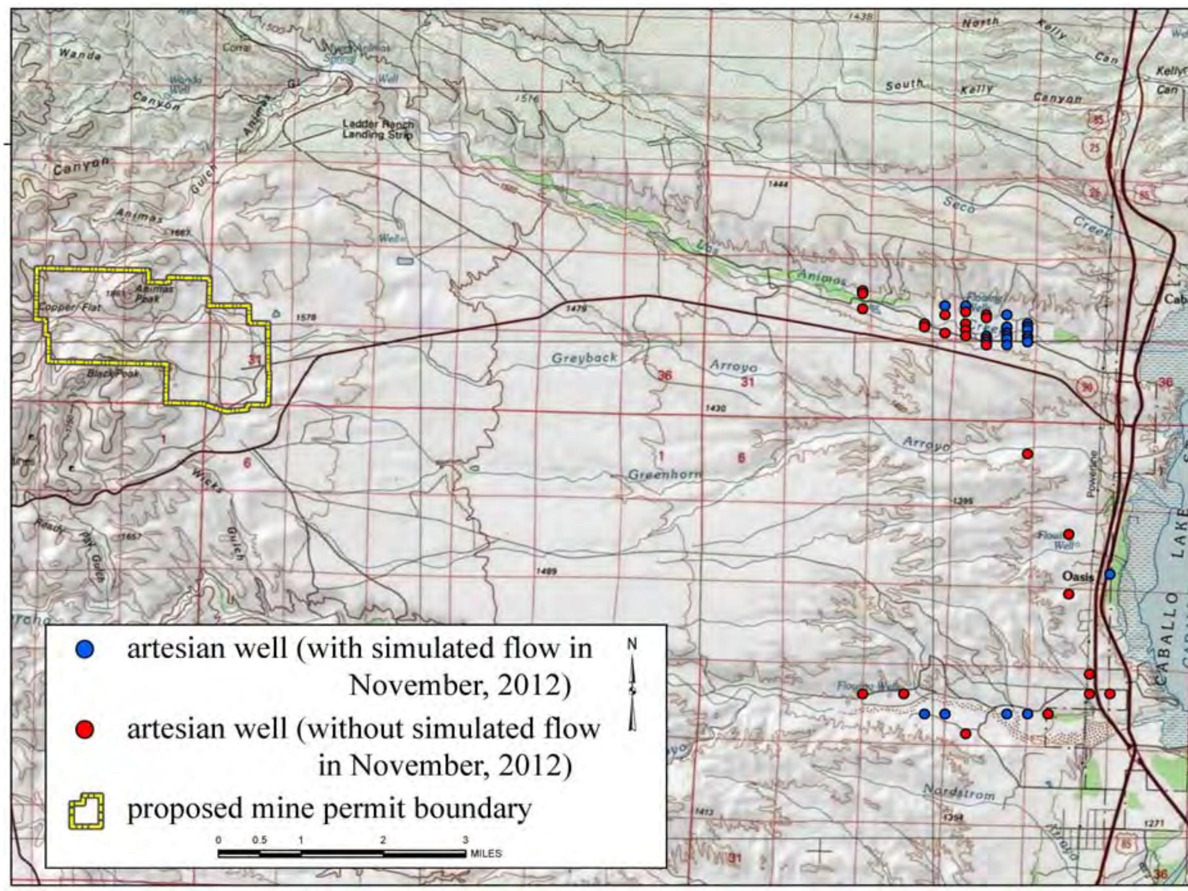


Figure 6.29. Simulated artesian wells, discharging and not discharging in November 2012.

6.4.3 Aquifer Test Simulation

Pumping of wells PW-1 and PW-3 began in late November 2012 and continued, with two stops and starts, until 21 December 2012. Recorded pumping periods and rates (Fig. 5.14) were simulated in the model using MODFLOW module LAK2 (JSAI, 2010), which simulates water level inside the pumping bores in addition to the withdrawal from the aquifer. Water-level responses were measured at locations shown on Figure 6.30. Measured and simulated aquifer test drawdown and recovery are presented on Figures 6.31 through 6.39.

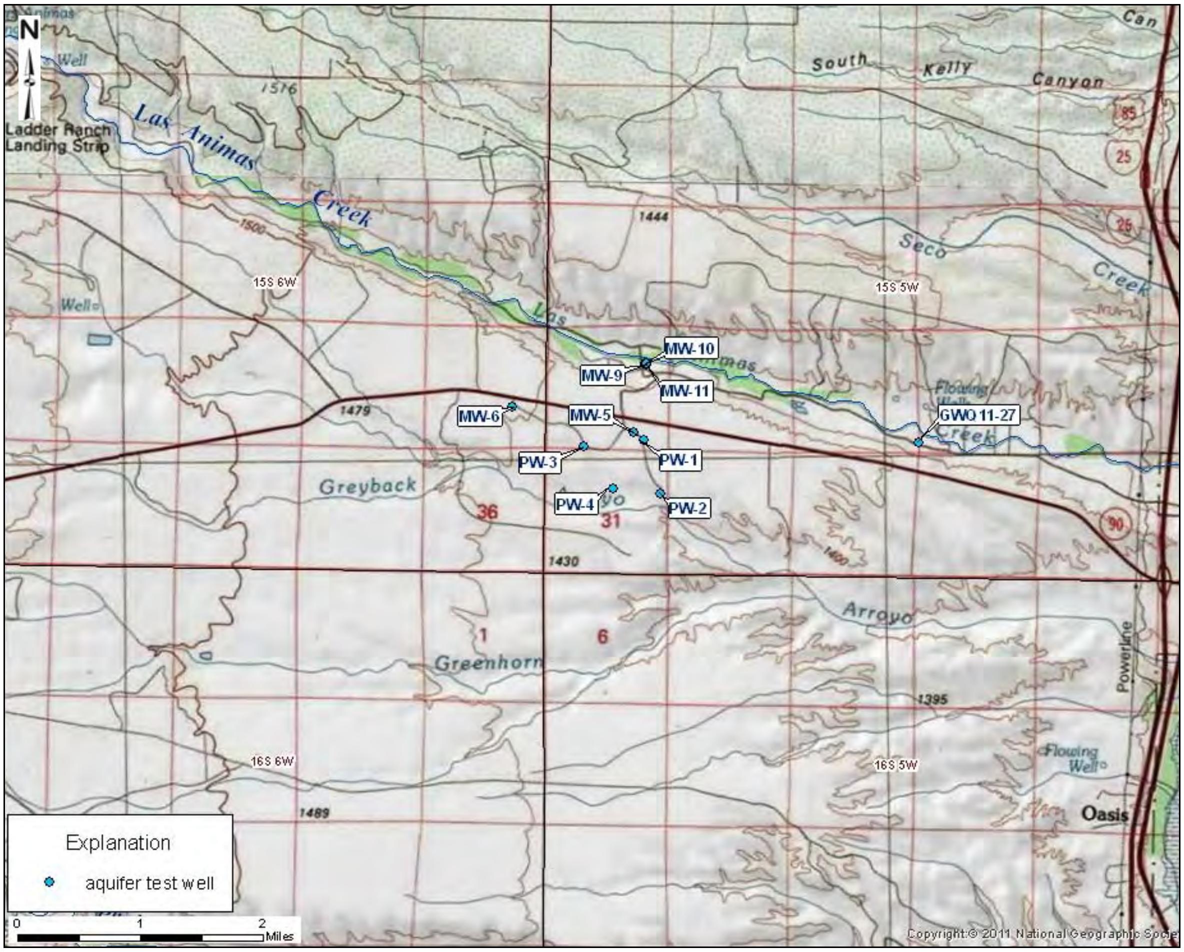


Figure 6.30. 2012 aquifer test pumping and observation locations.

Measured and simulated drawdown in the pumping wells, PW-1 and PW-3, are shown on Figures 6.31 and 6.32. Simulated water levels in the well-bore, and in the adjacent aquifer, are shown on both figures. The simulated and measured well-bore water levels agree, although the measured water level in PW-3 shows an unexplained additional decline, late in the pumping period, that is not simulated in the model. The difference between well-bore and aquifer water levels characterizes the well losses and pumping efficiency of PW-1 and PW-3.

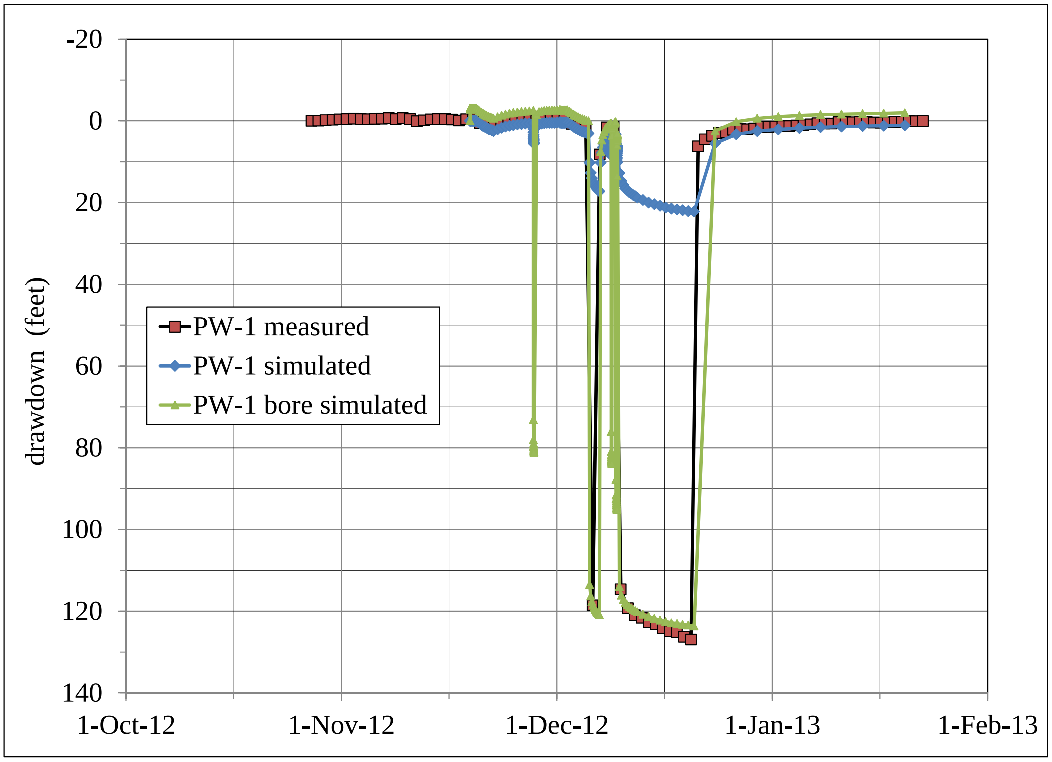


Figure 6.31. Measured and simulated water-level hydrographs in PW-1.

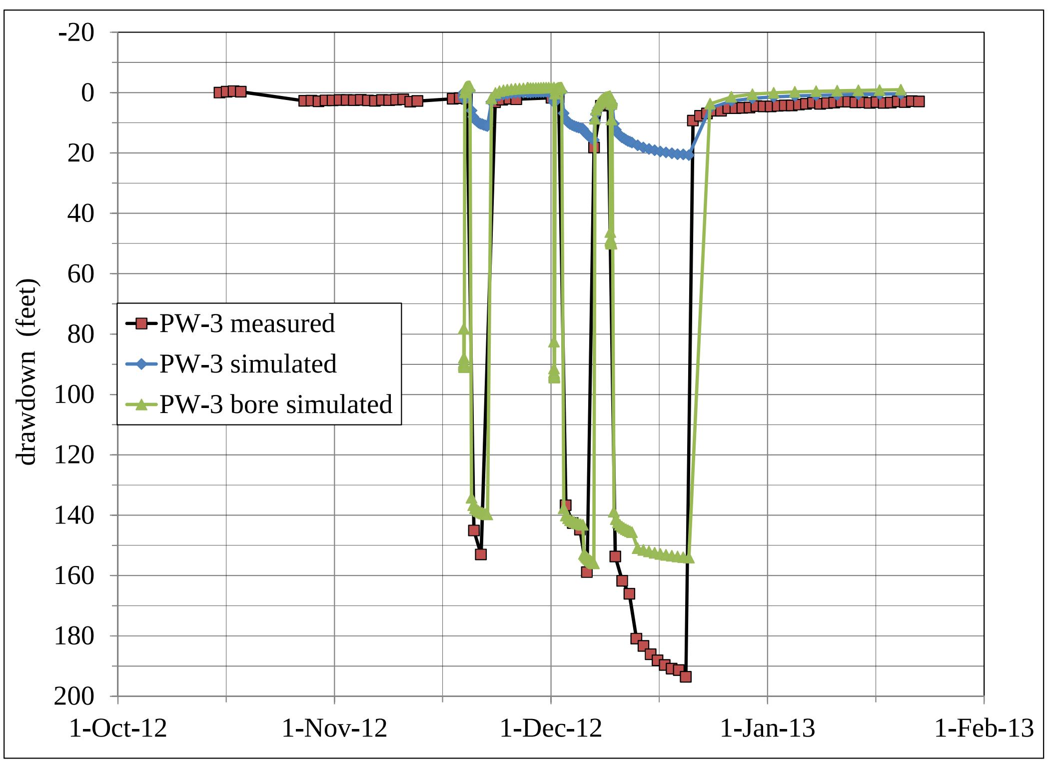


Figure 6.32. Measured and simulated water-level hydrographs in PW-3.

Measured and simulated drawdown elsewhere in the well field area, at PW-2, PW-4, and MW-5, are shown on Figures 6.33, 6.34, and 6.35. For unknown local reasons, measured drawdown in PW-2 (Fig. 6.34) is less than simulated, and less than would be expected from the results at PW-2 (Fig. 6.33) and MW-5 (Fig. 6.35).

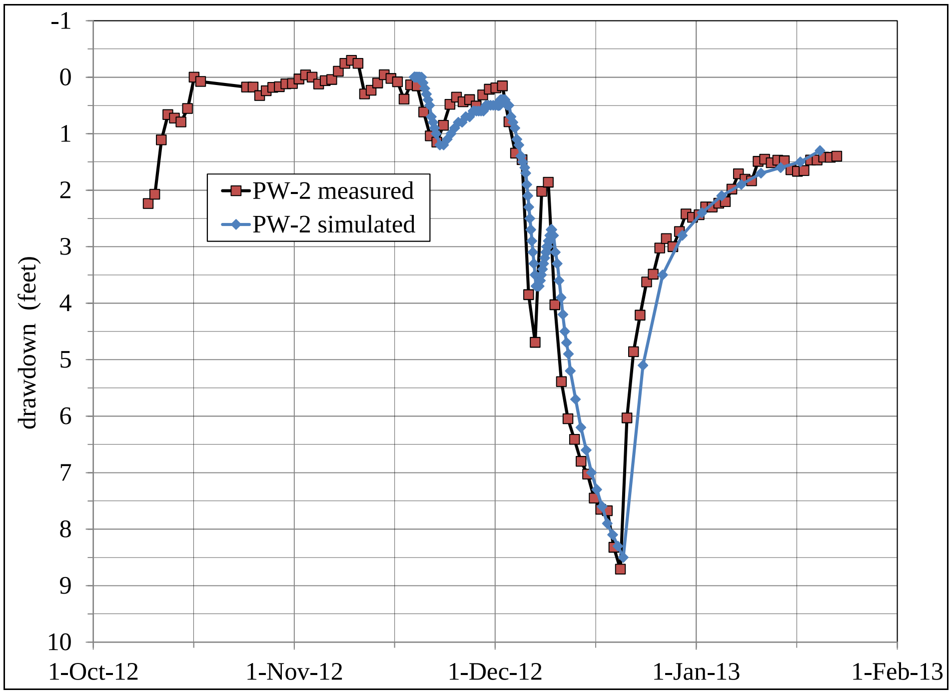


Figure 6.33. Measured and simulated water-level hydrographs in PW-2.

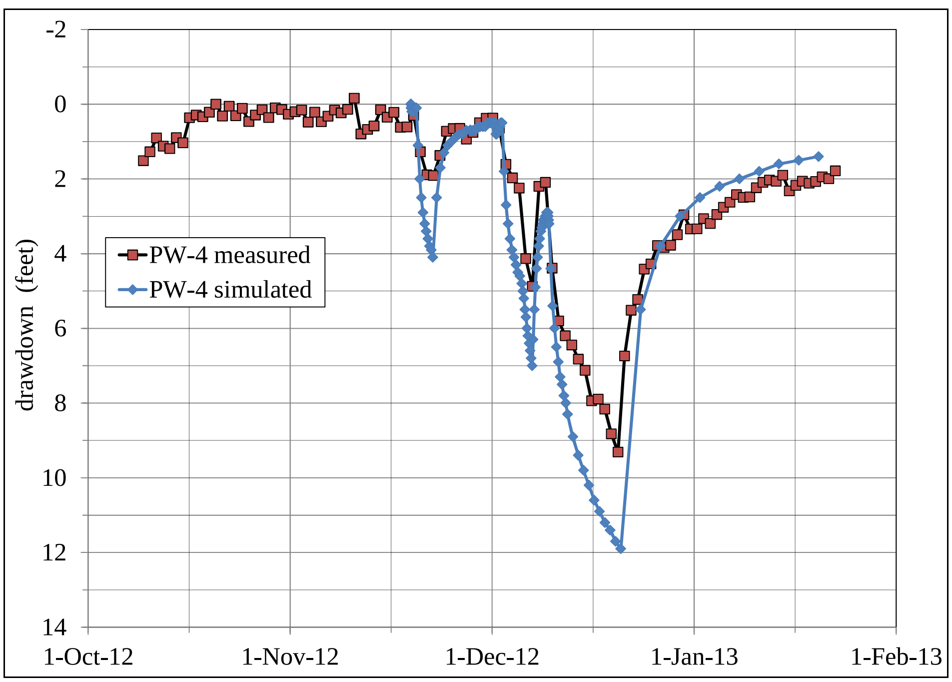


Figure 6.34. Measured and simulated water-level hydrographs in PW-4.

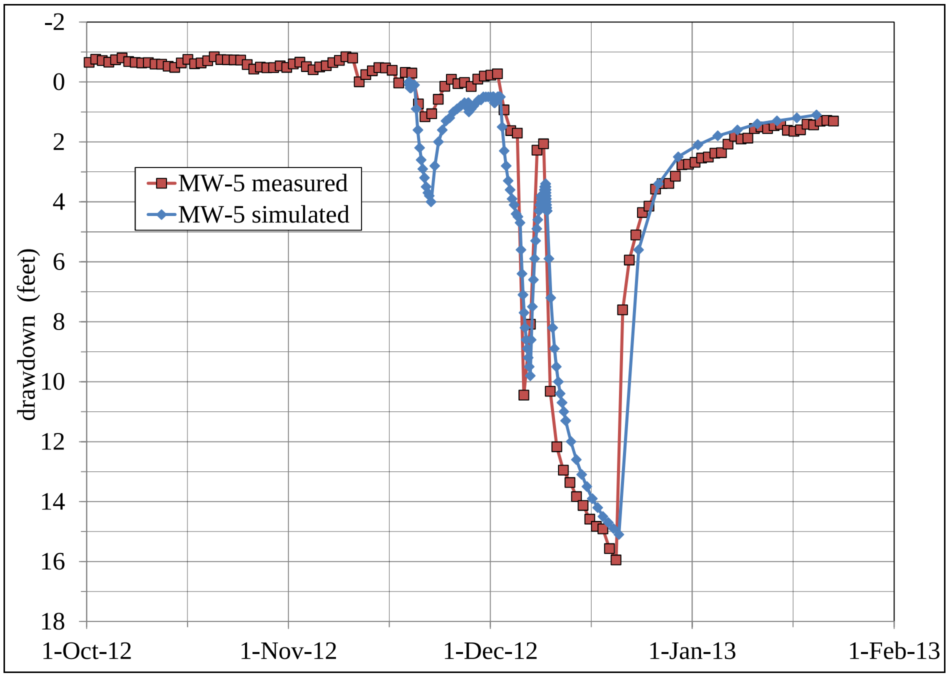


Figure 6.35. Measured and simulated water-level hydrographs in MW-5.

The rapid initial response, semi-linear drawdown trend and rapid recovery measured in the well field area is not characteristic of the response in an extensive aquifer, but in a limited-size, high-permeability unit (the Palomas graben) partly isolated from surrounding hydrogeologic units.

This response is reproduced in the model using a combination of (1) leaky fault barriers bounding the Palomas Graben, (2) high permeability within the graben and (3) lower permeability units adjacent to the graben. The combination reproduces both the aquifer test response and the overall background water levels and gradients in the basin.

Measured and simulated drawdown north of the well field along Las Animas Creek (Fig. 6.30) is shown for the SFG aquifer (wells MW-9 and MW-10) on Figure 6.36 and for the alluvium (well MW-11) on Figure 6.37.

The sharp initial drawdown and rapid recovery in the SFG aquifer is similar to that in the other Palomas Graben wells (Figs. 6.31 through 6.35). The response in the SFG aquifer (Fig. 6.36), and the lack of response in the alluvium (Fig. 6.37) are both reproduced in the model.

Instead of responding to the aquifer test, measured water levels in the very shallow (37 ft) well MW-11 (Fig. 6.37) can be seen to be rising before and throughout the test, due to some local influence, such as a neighboring well stopping pumping.

Measured and simulated drawdown east of the well field, at GWQ11-27 (Fig. 6.30), is shown on Figure 6.38. The model-simulated response is not as rapid or as large as the apparent measured response, but the figure also shows substantial background water-level fluctuation that is not part of the aquifer test response.

Measured and simulated drawdown west of the well field, at MW-6 (Fig. 6.30), is shown on Figure 6.39. The measured data shown on the figure consist of the highest water level measured each day; actual water levels in MW-6, an actively-used pumping well, fluctuate over tens of feet as the pump starts and stops. The data shown on the figure correspond to the water level measured each morning, just before the pump was started.

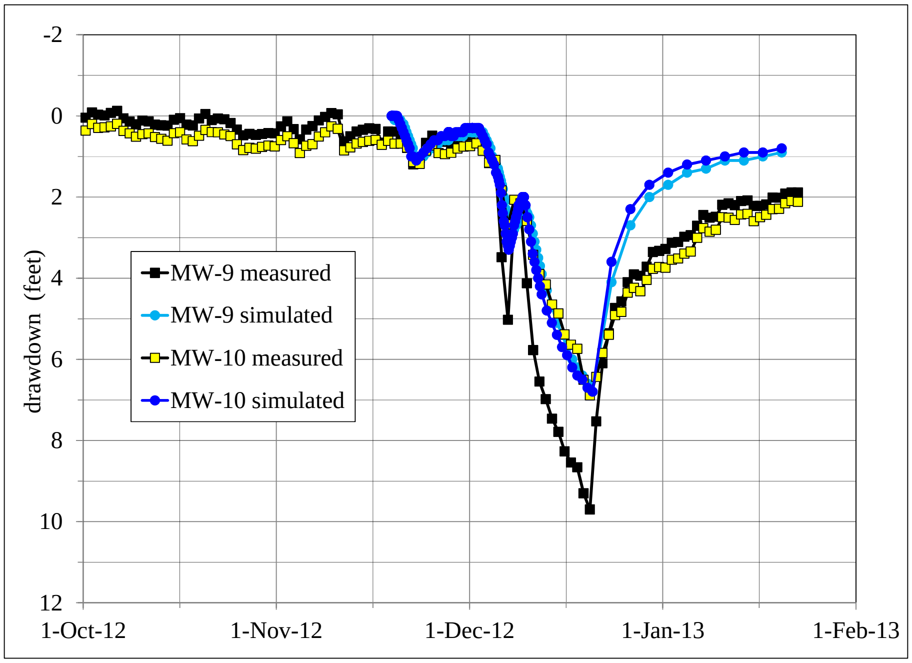


Figure 6.36. Measured and simulated water-level hydrographs in MW-9 and MW-10.

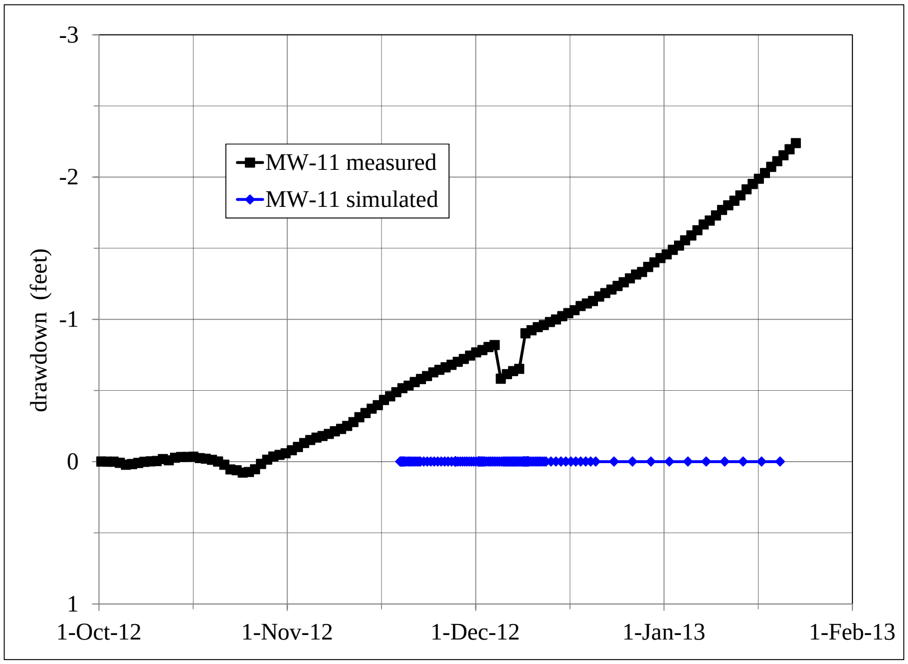


Figure 6.37. Measured and simulated water-level hydrographs in MW-11.

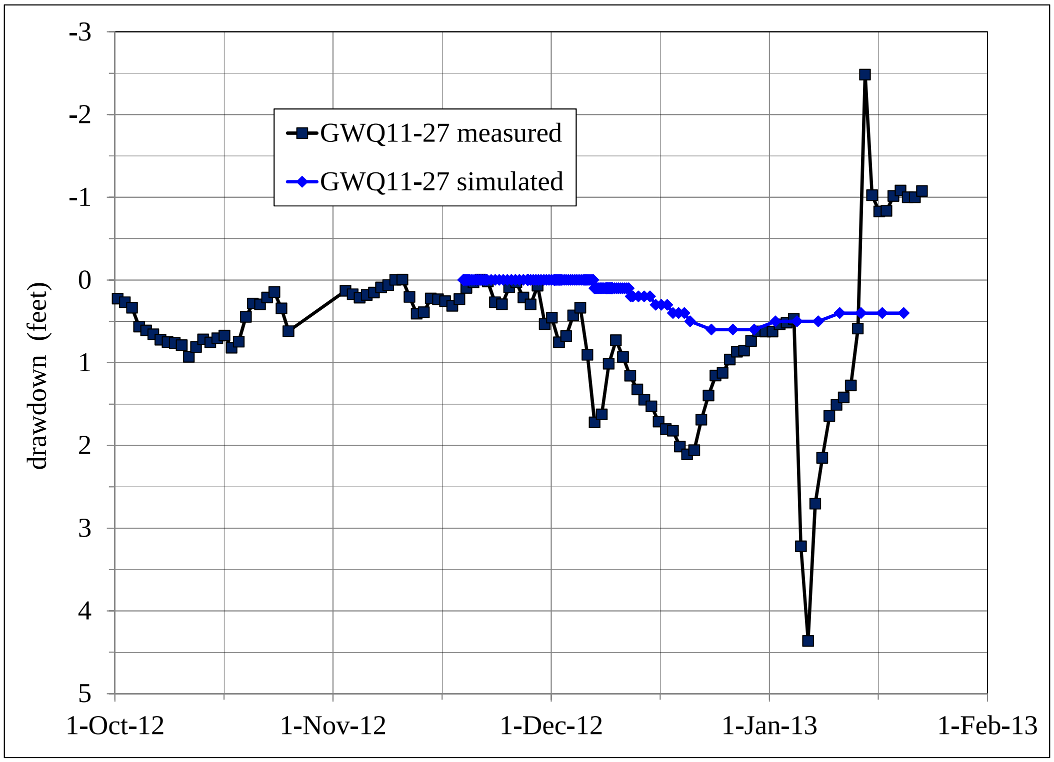


Figure 6.38. Measured and simulated water-level hydrographs in GWQ11-27.

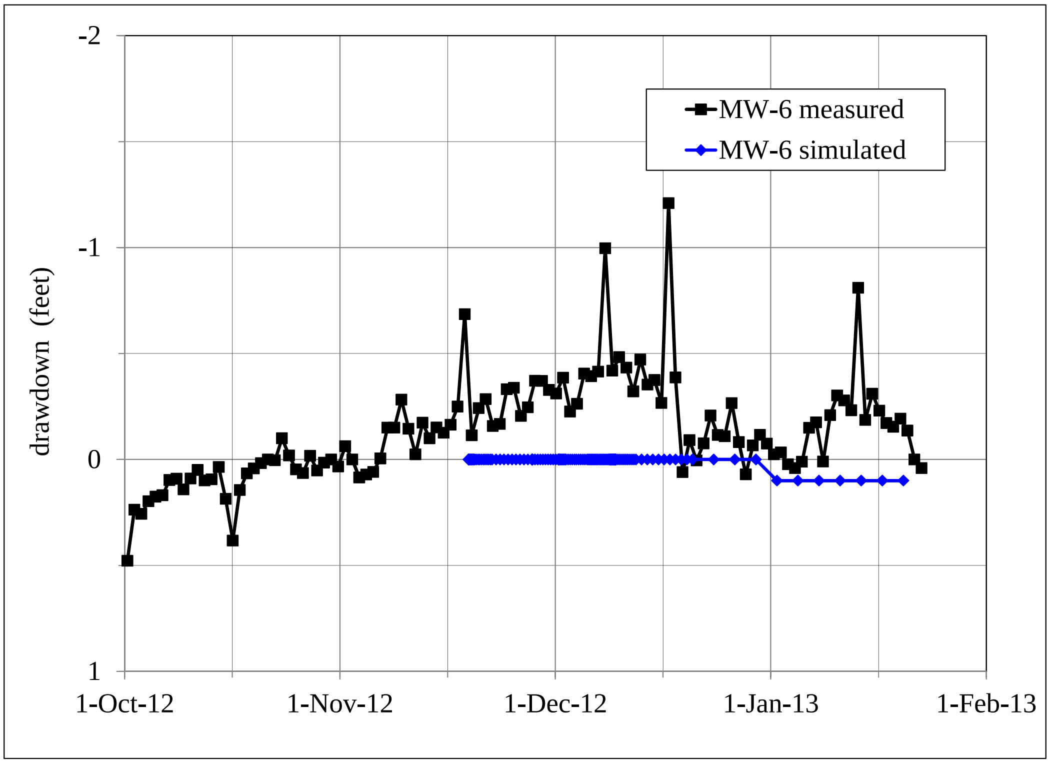


Figure 6.39. Measured and simulated water-level hydrographs in MW-6.

7.0 SENSITIVITY OF MODEL RESULTS

The sensitivity of model results to different parameters is discussed below.

First, the sensitivity of calibration results to model parameters is presented. These indicate which parameters are known with more confidence, or better constrained by data, and which are more unknown or uncertain. This helps to define a range of plausible values for each parameter.

Then the sensitivity of model projection results, within the plausible range of values for different parameters, is evaluated, to indicate a probable range of results. This quantifies the level of uncertainty in the model predictions and defines a range of likely outcomes.

7.1 Sensitivity of Calibration Results

The sensitivity of results to changes in model parameters was investigated during development of the model, in order to improve model calibration. An example of this is given on Figure 7.1, showing the simulation of the 2012 aquifer test for different modeled levels of vertical anisotropy in the Palomas Graben.

The results suggest important vertical flow upward into the strata from which the wells pump. The sediments filling the Palomas Graben are therefore modeled as an isotropic unit, with equal horizontal and vertical permeability (Table 6.1).

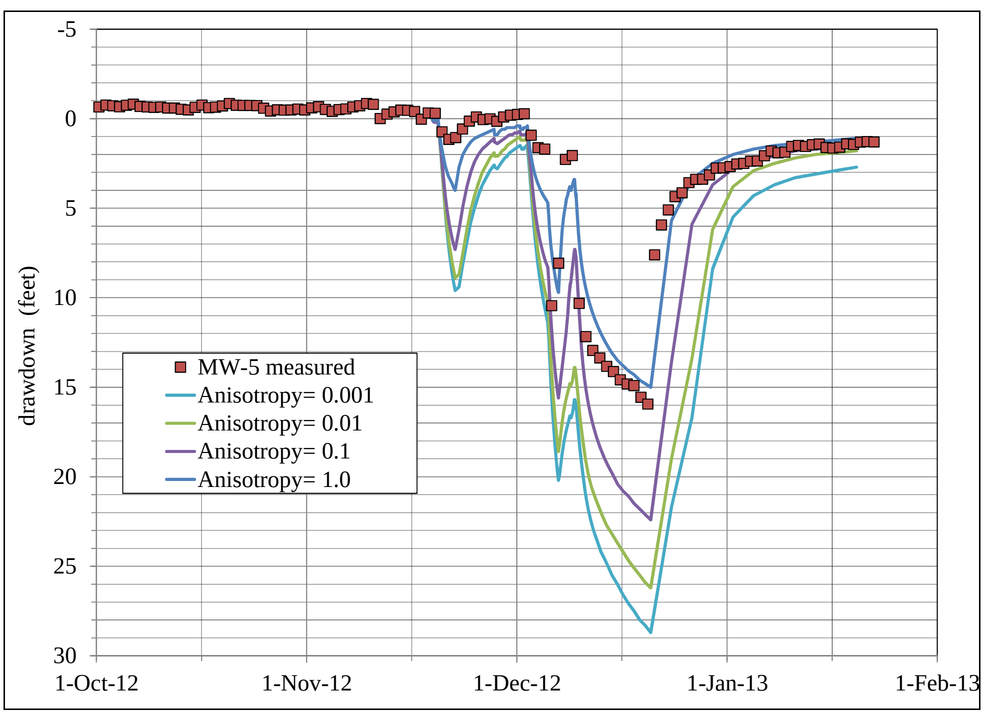


Figure 7.1. Simulated aquifer-test drawdown in well MW-5 for different vertical anisotropy values.

A related example is shown on Figure 7.2, showing the simulation of the 2012 aquifer test for different horizontal permeability of the Palomas Graben. Results show improved calibration for higher permeability. The final modeled permeability was 10 ft/d for the strata in which the well field is completed, with a total aquifer transmissivity of 20,000 ft^2/d (Table 6.1).

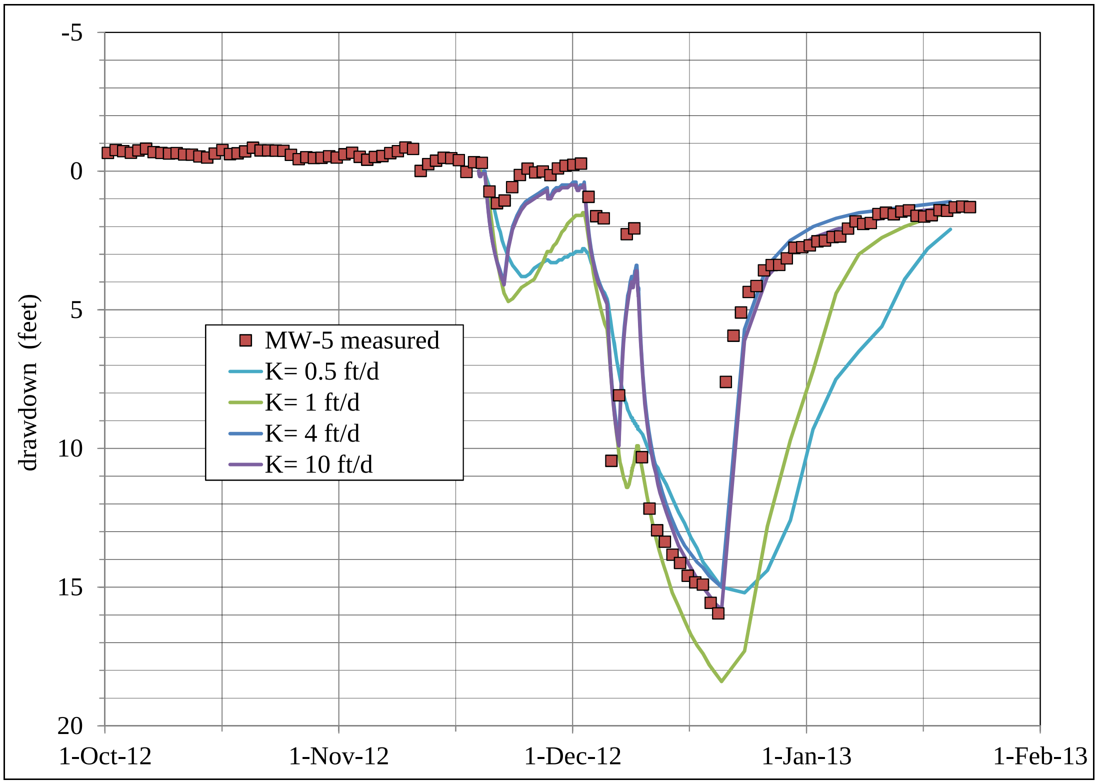


Figure 7.2. Simulated aquifer-test drawdown in well MW-5 for different hydraulic conductivity values.

Another example tests the conceptual model of a linearly extensive Palomas Graben. Figure 7.3 presents simulated 2012 aquifer test drawdown at observation well MW-5, with and without the north-south (GHB) boundary conditions in the Palomas Graben. The model calibration suggests that, if there were no significant north-south flow path in the graben, there would have been more aquifer test drawdown, with slower water-level recovery.

Based on the aquifer test results and model calibration, the Palomas Graben appears to be a linear feature of significant north-south extent; the aquifer test drawdown was characteristic of the response of a semi-infinite linear feature of finite width.

Based on the sensitivity results above, the transmissivity and vertical anisotropy of the highly-transmissive Palomas Graben are considered to be relatively well-known parameters, whose range of possible values is constrained by data.

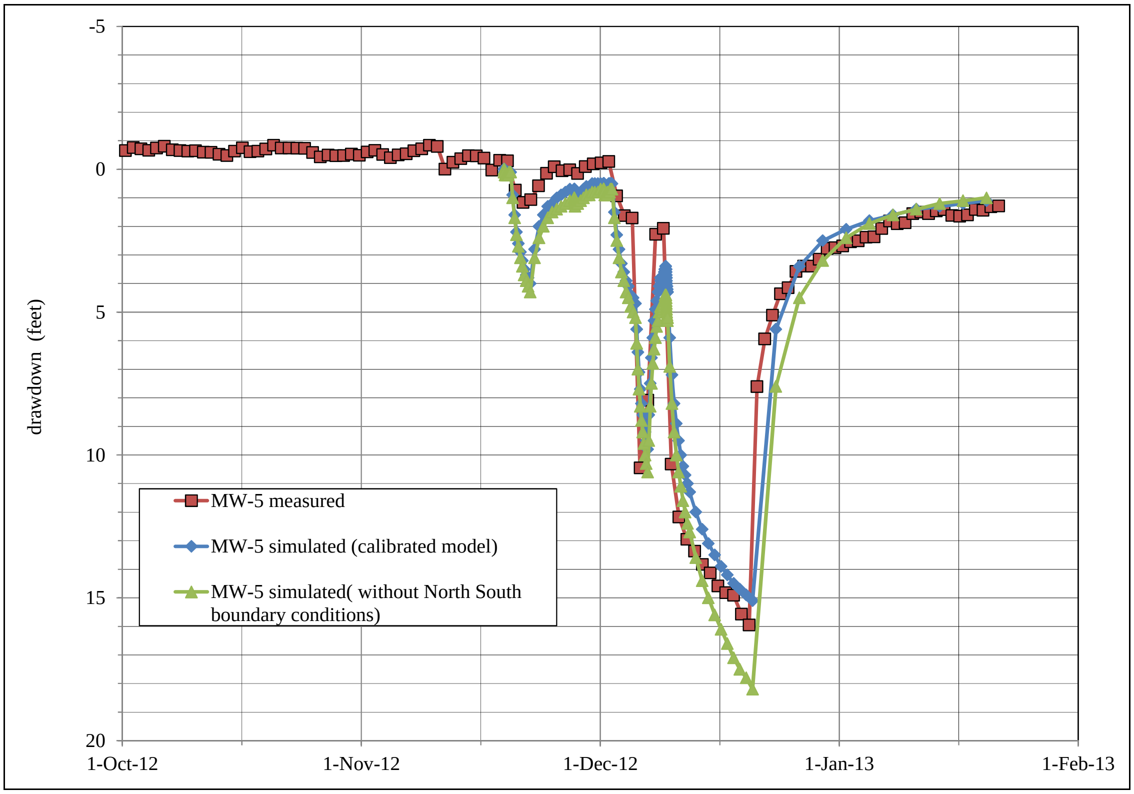


Figure 7.3. Simulated aquifer-test drawdown in well MW-5
with and without Palomas Graben boundary conditions

The hydraulic characteristics of the faults bounding the Palomas Graben are also reasonably known:

- The east bounding fault is weakly resistant to flow (Table 6.2). Based on model calibration, the resistance is not greater than simulated. The east bounding fault could be simulated with zero resistance (and compensating reduced transmissivity east of the graben), with little effect on calibration or projection results.

- The west bounding fault is strongly resistant to flow (Table 6.2). This resistance is important to overall model calibration (Fig. 6.10) and to aquifer test calibration. Simulating greater resistance (smaller conductance on Table 6.2) across the already low-permeability fault makes little difference to calibration or projection results. Simulating less resistance to the west degrades the model calibration and slightly attenuates the projected effects east of the graben.

Away from the Palomas Graben, the properties of the SFG aquifer are less well-known. However, based on aquifer test results and model calibration information the SFG aquifer along Animas Creek (Fig. 6.2) is identified to be similarly transmissive (Table 6.1).

The properties of the alluvial aquifer along Animas Creek are not known in detail, but the alluvium can be assumed to be conductive and to have substantial storage capacity. Measured historical water levels at MW-9, MW-10 and MW-11, results of the 1994 MW-9 pumping test (Fig. 5.13), and results of the 2012 well field pumping test (Fig. 6.37), all show that the alluvial aquifer does not respond readily to pumping in the underlying SFG aquifer.

To summarize the constraints on parameters:

1. Properties of the SFG sediments in the Palomas Graben are reasonably well-known based on calibration to aquifer test results. The graben aquifer is relatively transmissive both horizontally and vertically.

2. Properties of the SFG sediments along Animas Creek are somewhat known based on aquifer test results and other model calibration. The SFG aquifer along Animas Creek is also relatively transmissive.

3. Properties of the alluvial aquifer along Animas Creek are somewhat known, based on overall model calibration and on general material properties. Multiple aquifer test results (Sections 5.2.2, 5.2.3, and 5.2.4) indicate that the alluvial aquifer is substantially isolated from the SFG aquifer.

The above constraints narrow the plausible ranges of the main model result (the projection of groundwater drawdown and surface discharge reduction, resulting from proposed operation of the well field). The sensitivity of this result to variation of model parameters within plausible ranges is discussed below.

7.2 Sensitivity of Projection Results

The sensitivity of model projections to unknown parameters is of importance in evaluating the effects of the proposed project. Because model projections are reported separately, this report does not present results of specific projections. The general sensitivity of all projection scenarios to unknown parameters is discussed here.

The main effects of the project would be associated with pumping of the well field, including groundwater drawdown and surface discharge changes. The high-transmissivity features of the Palomas Graben and the SFG aquifer along Animas Creek largely control the pattern of groundwater drawdown and the effects on discharge. The projected groundwater drawdown spreads throughout the high-transmissivity features, and magnitude of drawdown is proportional to the total volume of water pumped. The discharge effects develop over the life of mine and dissipate over a similar period.

This basic result is controlled by the known high-transmissivity features. Variations of aquifer parameters for these features, within plausible ranges, do not change the basic result, and can only marginally affect the shape and size of the drawdown cone and the timing of the discharge changes. This was confirmed during model calibration by comparing the results of different preliminary projection scenarios, using different preliminary model versions.

While the basic result is insensitive to changes in aquifer parameter values, variation in the model boundary conditions controlling groundwater discharge to the Rio Grande Basin (MODFLOW module GHB) can have more effect. The conductance of the GHB boundaries (Sec. 6.3.1) were adjusted both up and down one order of magnitude, and results of a sample projection compared to results obtained using the calibrated model.

An increase in the already-large conductance does not substantially change model results; the GHB boundaries are simulated with sufficiently large conductance that they function essentially as constant-head boundary conditions, maintaining a constant water level along the east edge of the model domain.

A decrease in GHB conductance, however, reduces simulated discharge to the Rio Grande system, and increases simulated discharge to the Animas Creek and Percha Creek systems. Projected effects on discharge to the Rio Grande system are smaller, and projected effects on discharge to the Animas Creek and Percha Creek systems are larger. Total discharge and total effect on discharge are unchanged.

In summary, the aquifer properties near the well field are relatively well-known, due to the 2012 aquifer test. The aquifer properties farther away do not substantially affect the size or shape of the predicted groundwater drawdown cone, or its rate of dissipation. The identified high-transmissivity units govern the propagation of groundwater drawdown and the resulting water balance effects.

Reasonable variation in boundary condition parameters such as GHB conductance do not substantially change the overall projected effects, but can affect the predicted distribution of those effects between groundwater discharge to the Rio Grande system and discharge to the Animas Creek and Percha Creek systems.

8.0 CONCLUSIONS

A numerical model of groundwater flow in and around Copper Flat, near Hillsboro, New Mexico was developed and calibrated based on previously available information and on new studies of the system. The calibrated model will be used to project the effects, to groundwater and surface water, of the proposed development of the Copper Flat mine.

First, the climate and meteorology, hydrology and water balance, and geology and hydrogeology, of the study area were summarized. Then a conceptual model of the hydrological and hydrogeological system was presented. Important hydrogeological features are the high-transmissivity Palomas Graben and a high-transmissivity zone along the axis of Animas Creek.

Next, the data available to confirm and calibrate the model were presented. Extensive information is available, from previous studies and previous mine operations, and from new studies including the 2012 extended well field test and the 2011 pit-area pressure-injection testing. The large amount of information has allowed development of a model that can reliably project effects of future development.

Next the numerical model was presented, including model structure, inputs and calibration. The model accurately represents the conceptual model and accurately reproduces the calibration data, particularly the results of the 2012 extended well field pumping test. As a result the model is considered suitable for use in projecting the effects of future well field pumping.

Finally the sensitivity of model results to unknown parameters was evaluated. The existing information, including the 2012 aquifer test, characterizes the main SFG aquifer units and narrows the range of parameter uncertainty in the vicinity of the well field. Sensitivity of the primary model projection results, groundwater drawdown and surface discharge changes due to well field pumping, is low.

The calibrated model will be used to generate projections related to the results and effects of mine development. Projections will be generated as required and reported separately. Results of interest include the following:

- Groundwater drawdown due to water-supply pumping, for selected mine development scenarios
- Effects on surface discharge to the Las Animas Creek and Rio Grande systems
- Long-term post-mining residual groundwater drawdown and effects to surface discharge
- Potential ground subsidence due to groundwater drawdown
- Open pit dewatering rates and groundwater drawdown in bedrock
- Post-mining open-pit water level and water balance
- Down-gradient migration of potential leakage from tailings and waste rock storage facilities

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APPENDICES

Appendix A.

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hgeomatters@qwestoffice.net

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Appendix B.

Well Construction Diagrams

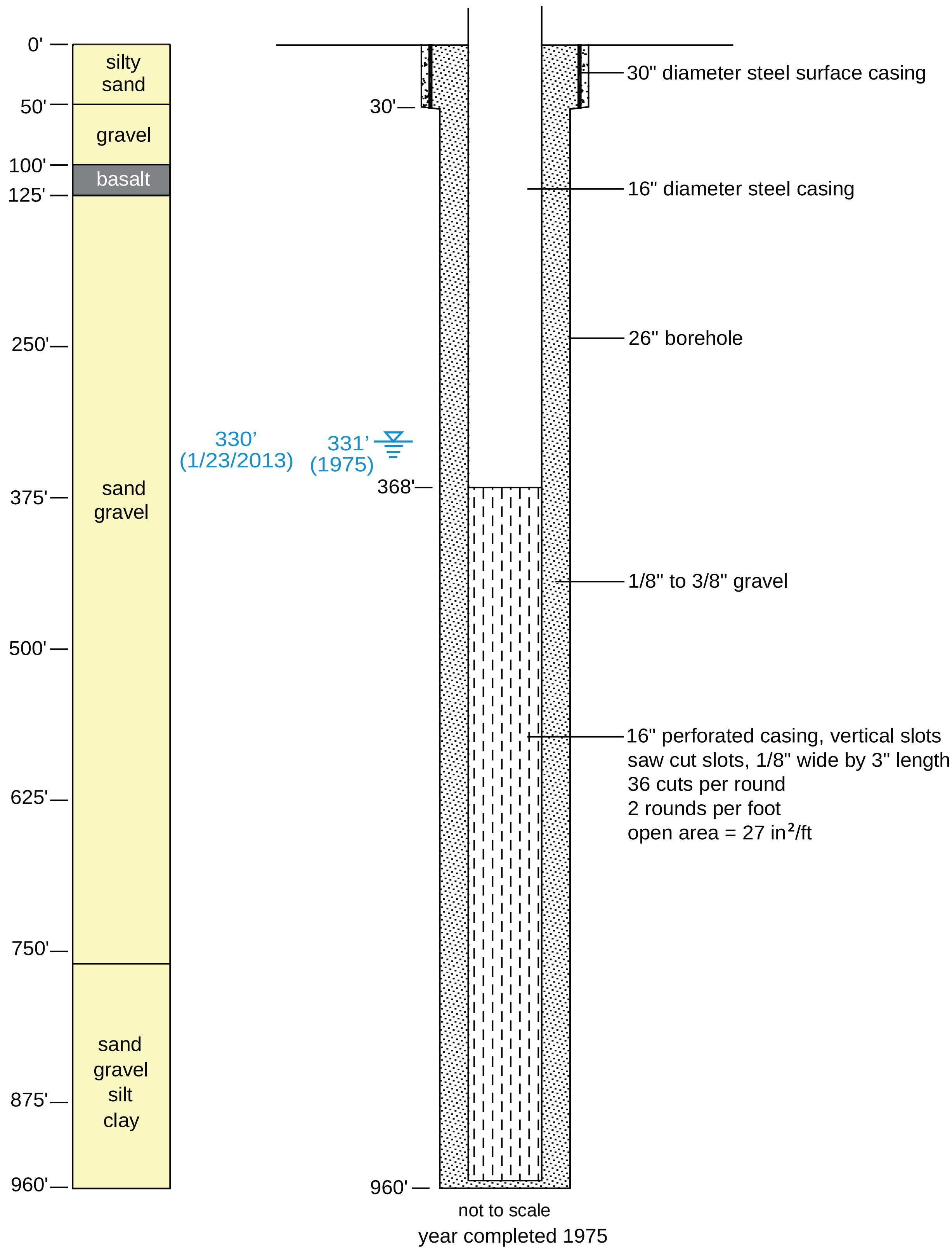


Figure B1. Well completion diagram for LRG-4652 (PW-1), Copper Flat Mine, Sierra County, New Mexico.

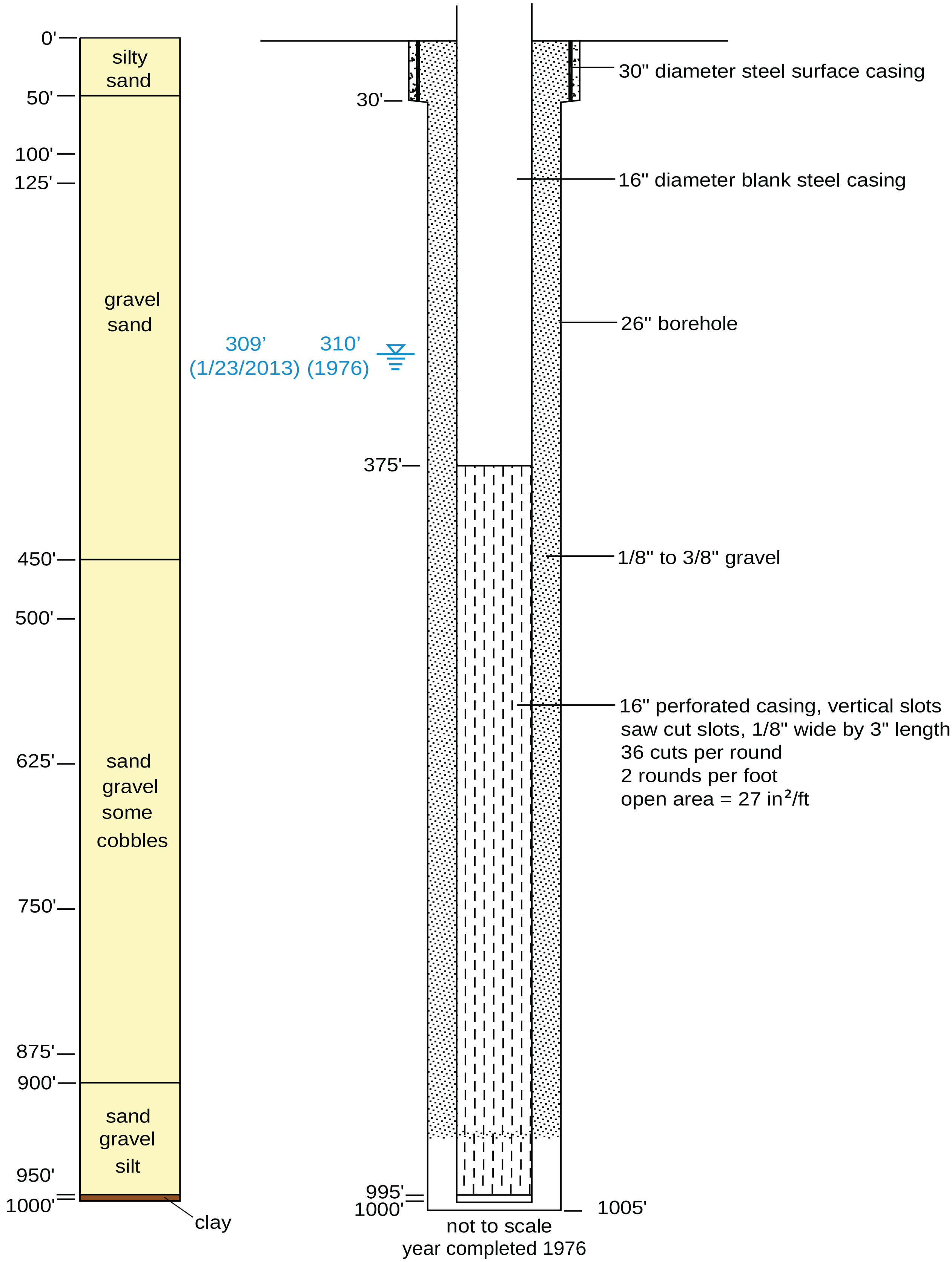


Figure B2. Well completion diagram for LRG-4652-S (PW-2), Copper Flat Mine, Sierra County, New Mexico.

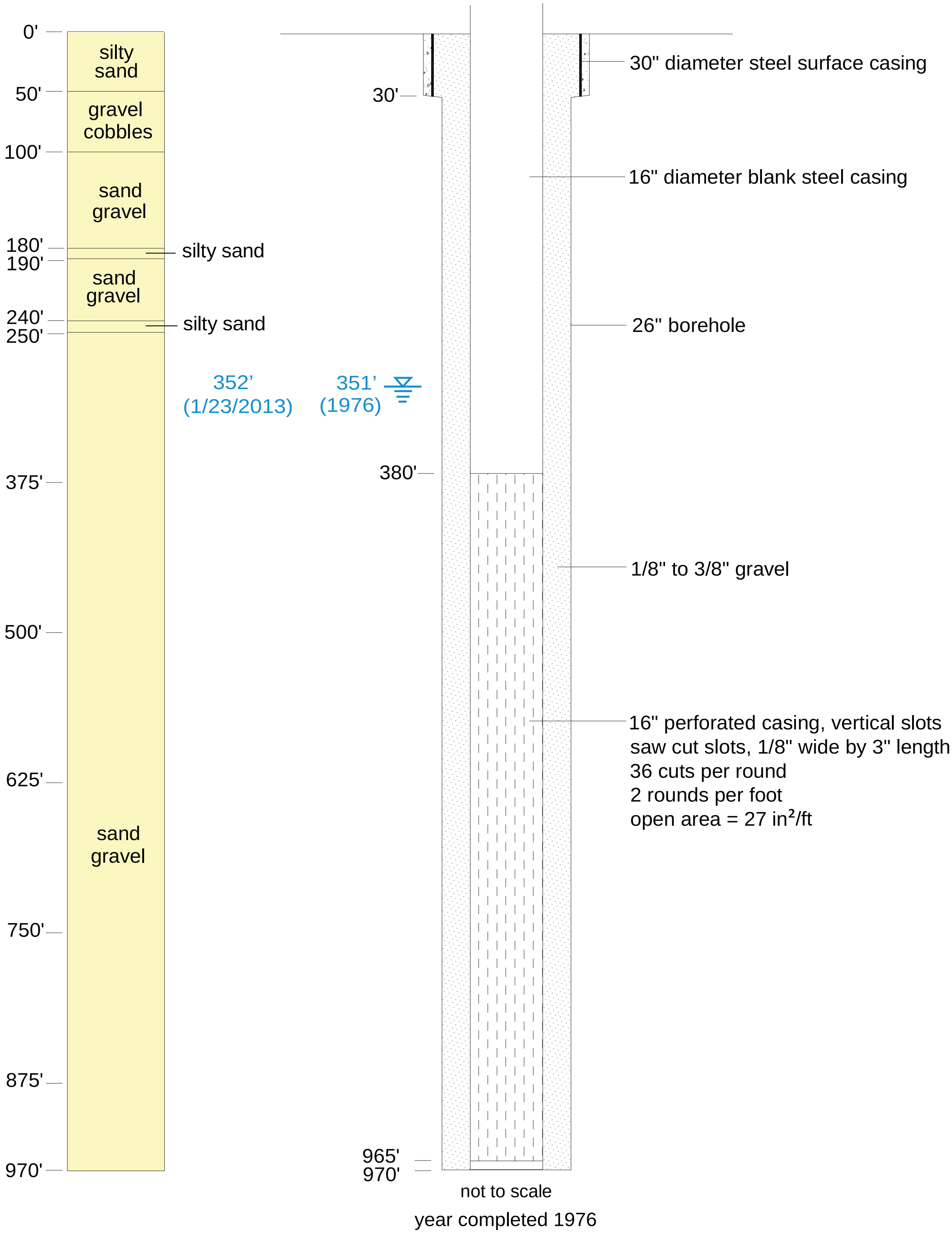


Figure B3. Well completion diagram for LRG-4652-S-2 (PW-3), Copper Flat Mine, Sierra County, New Mexico.

8-21-2013; DA/PW

JOHN SHOMAKER & ASSOCIATES, INC.

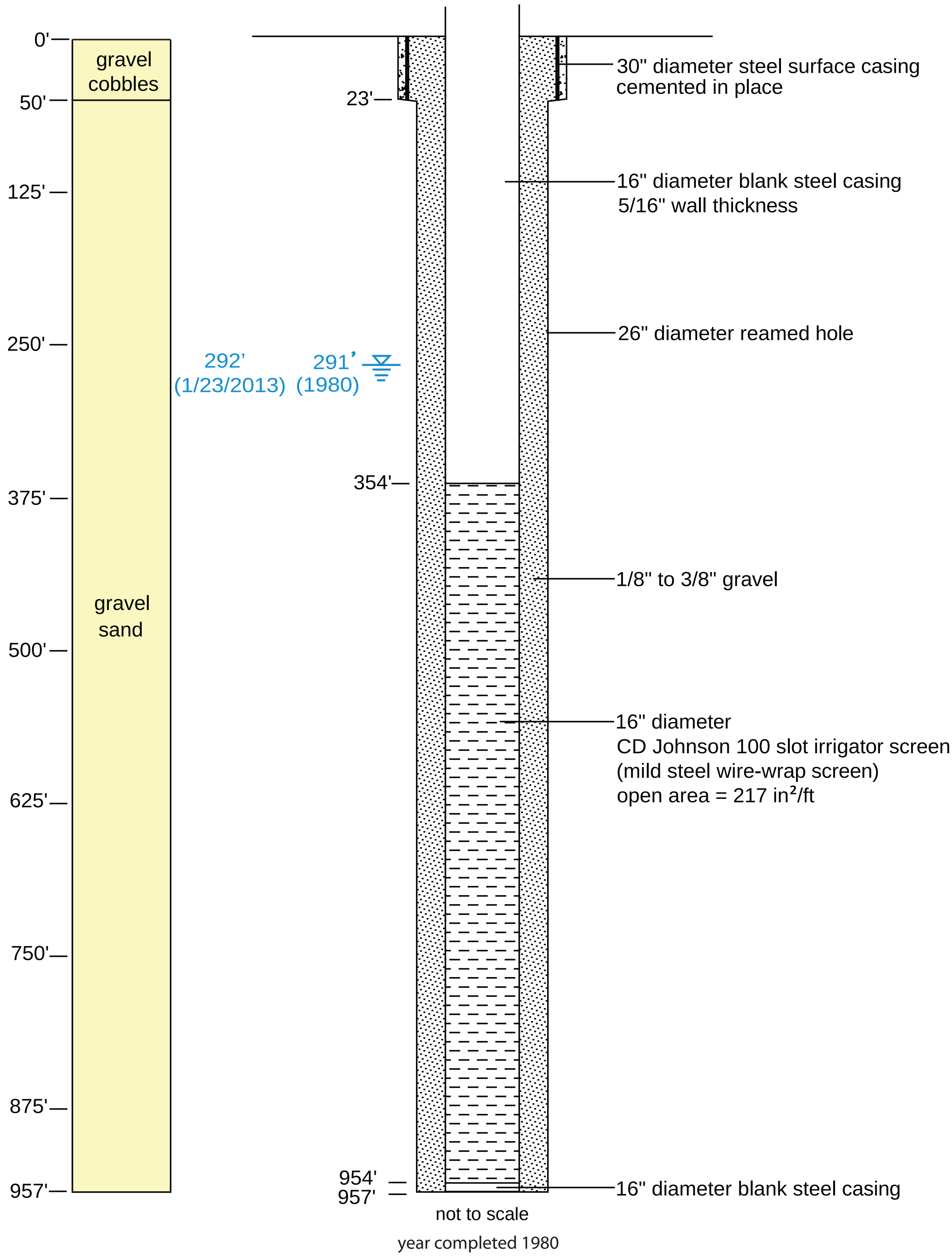


Figure B4. Well completion diagram for LRG-4652-S-3 (PW-4), Copper Flat Mine, Sierra County, New Mexico.

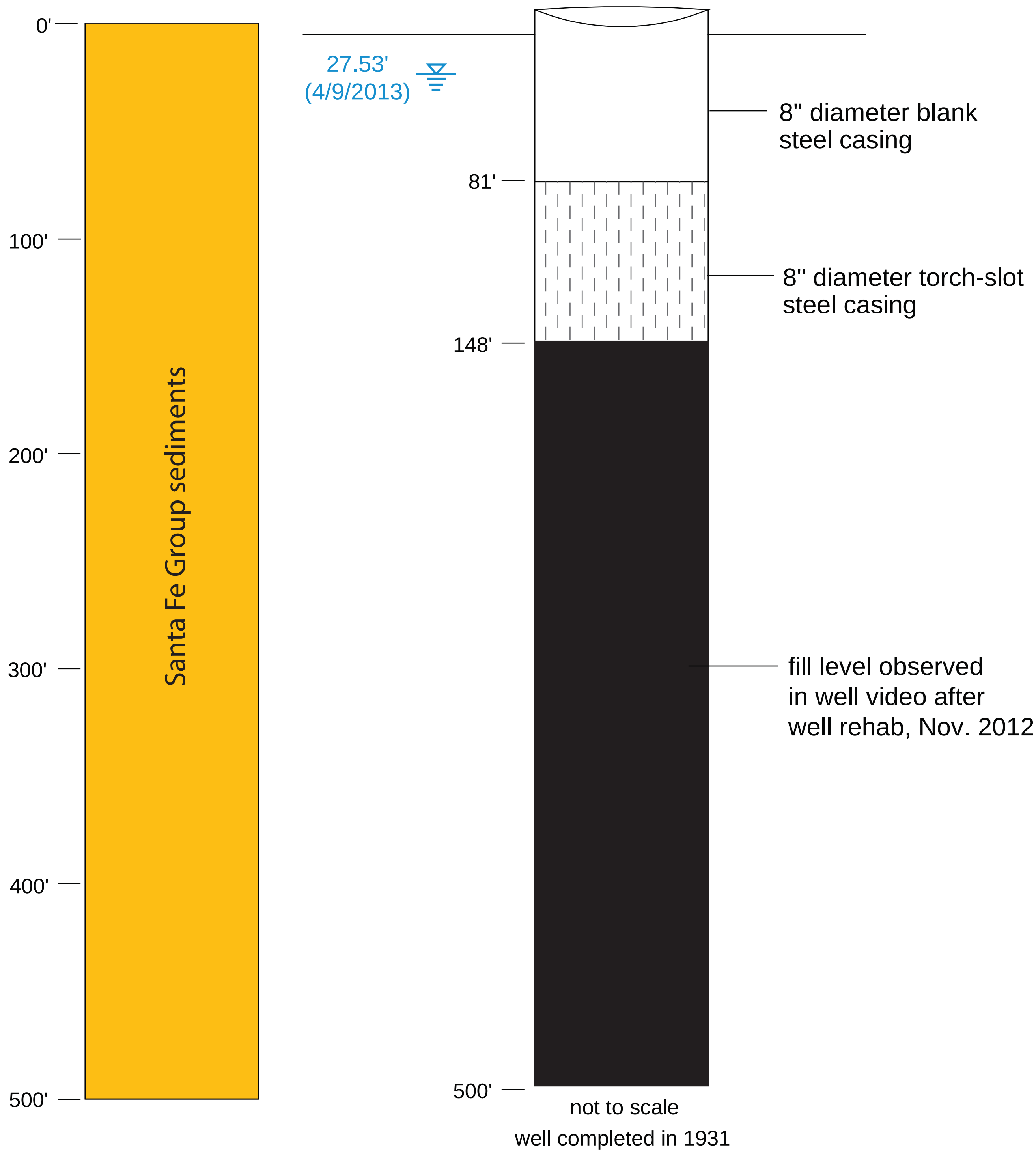


Figure B5. Well completion diagram for LRG-4652-S-4 (GWQ-8), Copper Flat Mine, Sierra County, New Mexico.

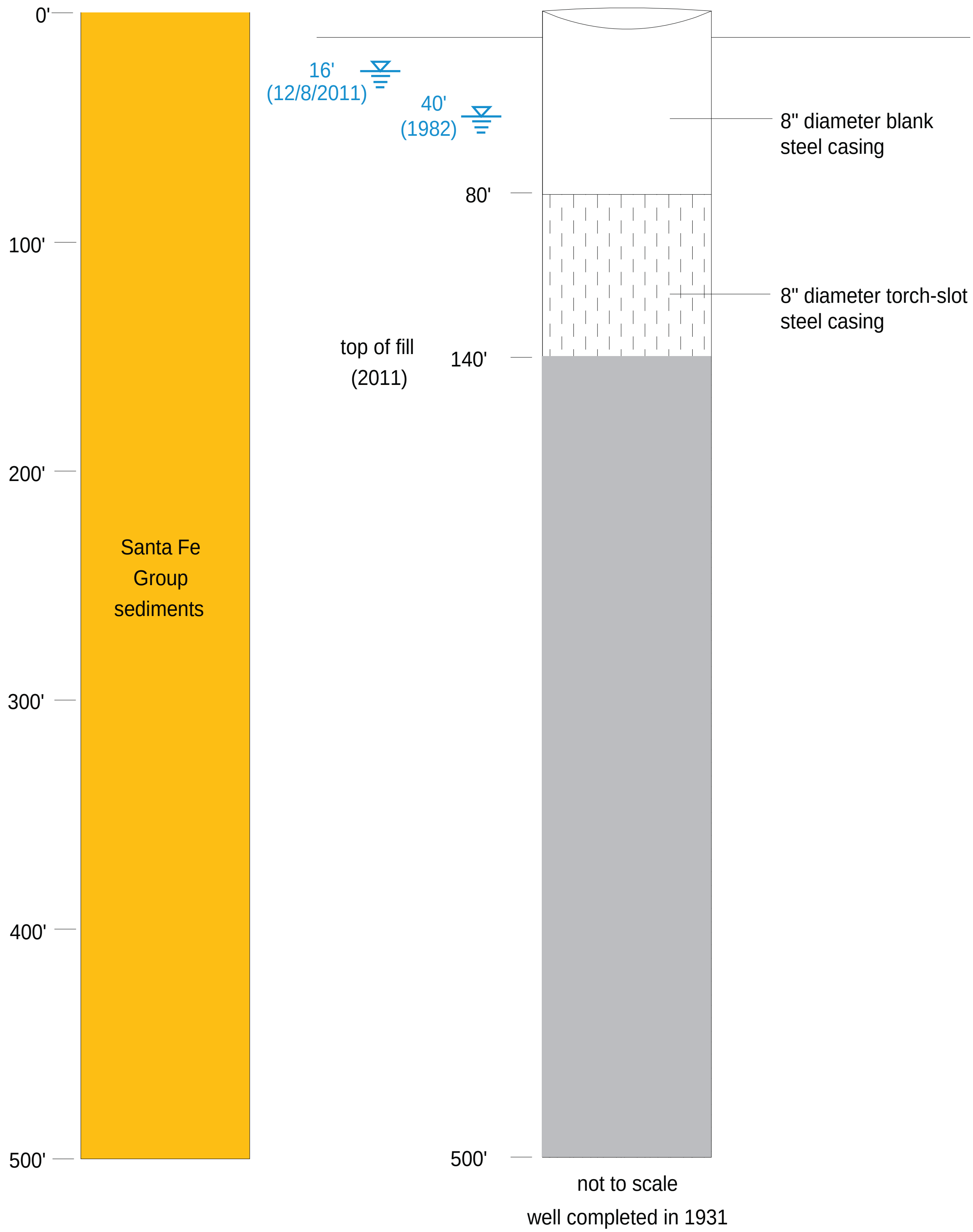


Figure B6. Well completion diagram for LRG-4652-S-5 (McCravery-Grayback), Copper Flat Mine, Sierra County, New Mexico.

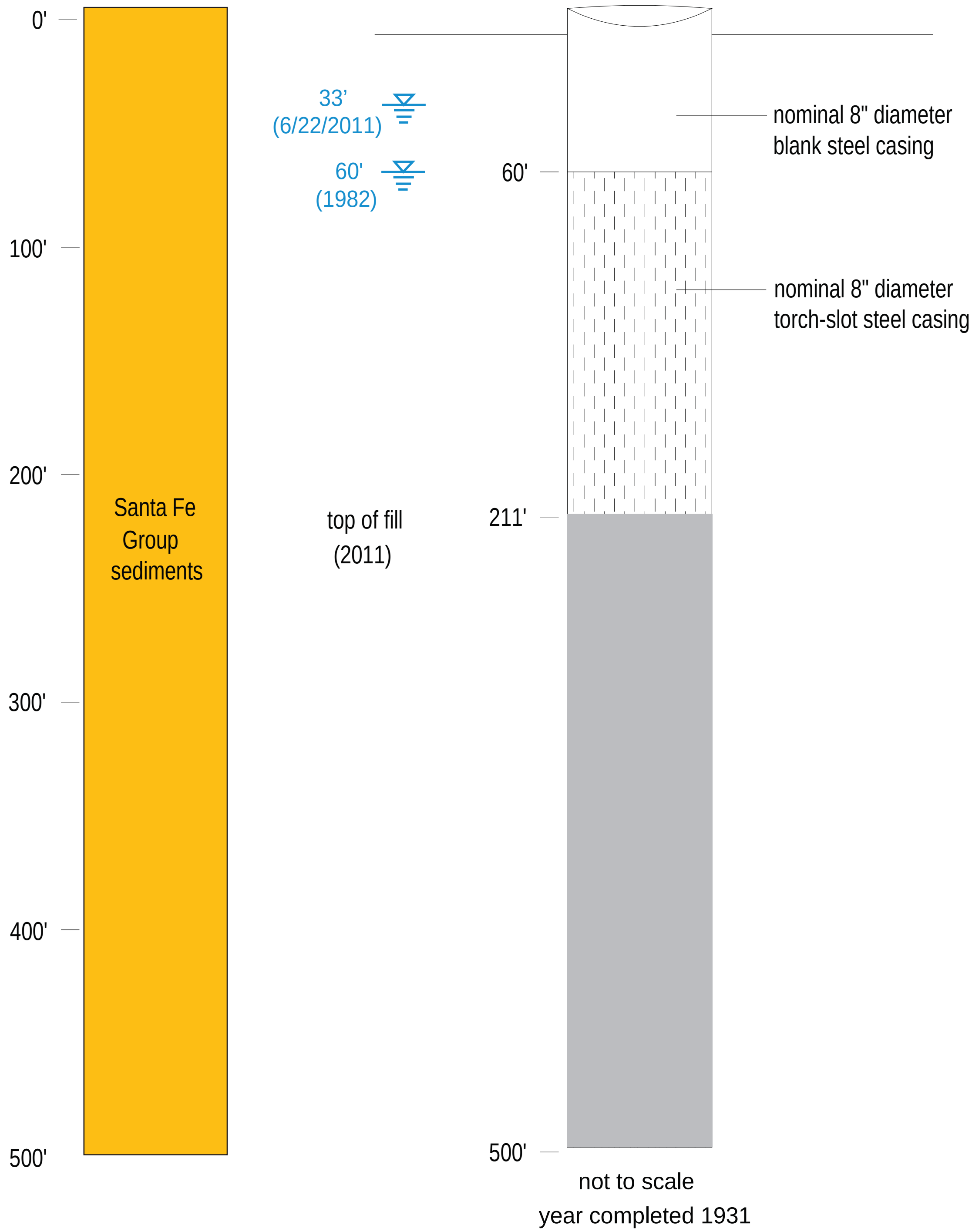


Figure B7. Well completion diagram for LRG-4652-S-6 (GWQ-2), Copper Flat Mine, Sierra County, New Mexico.

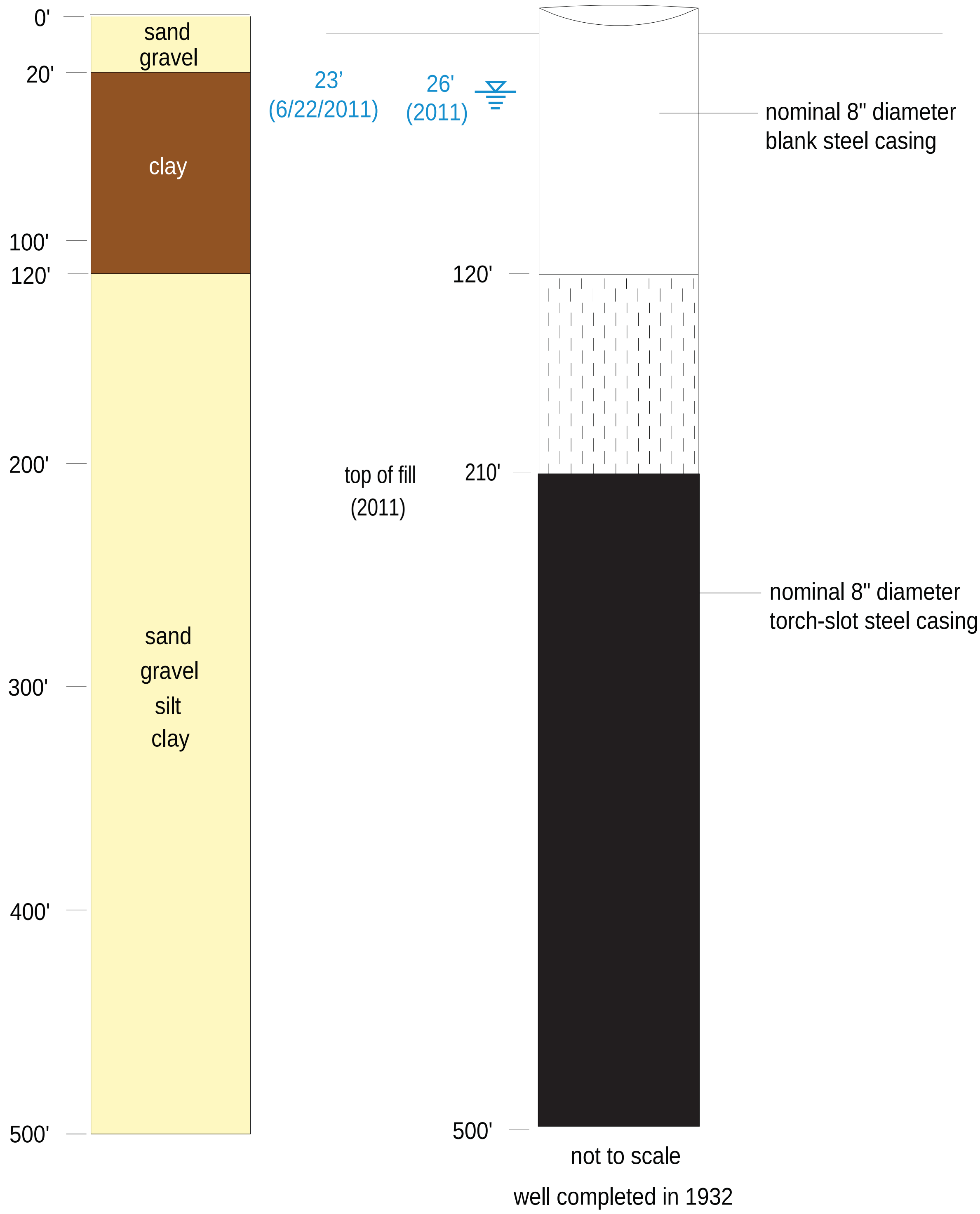


Figure B8. Well completion diagram for LRG-4652-S-7 (Irwin Well), Copper Flat Mine, Sierra County, New Mexico.

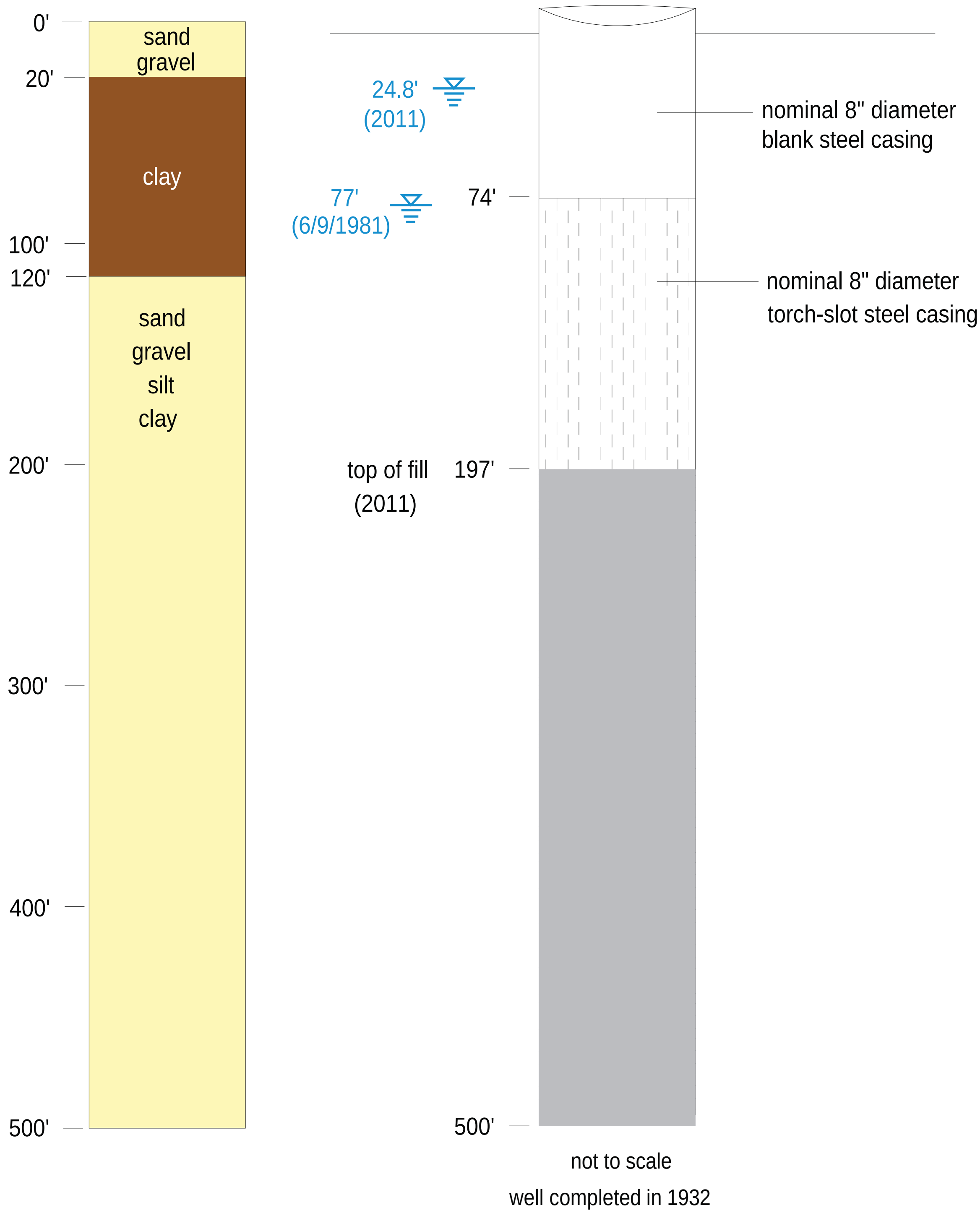


Figure B9. Well completion diagram for LRG-4652-S-8 (GWQ-7, Office Well), Copper Flat Mine, Sierra County, New Mexico.

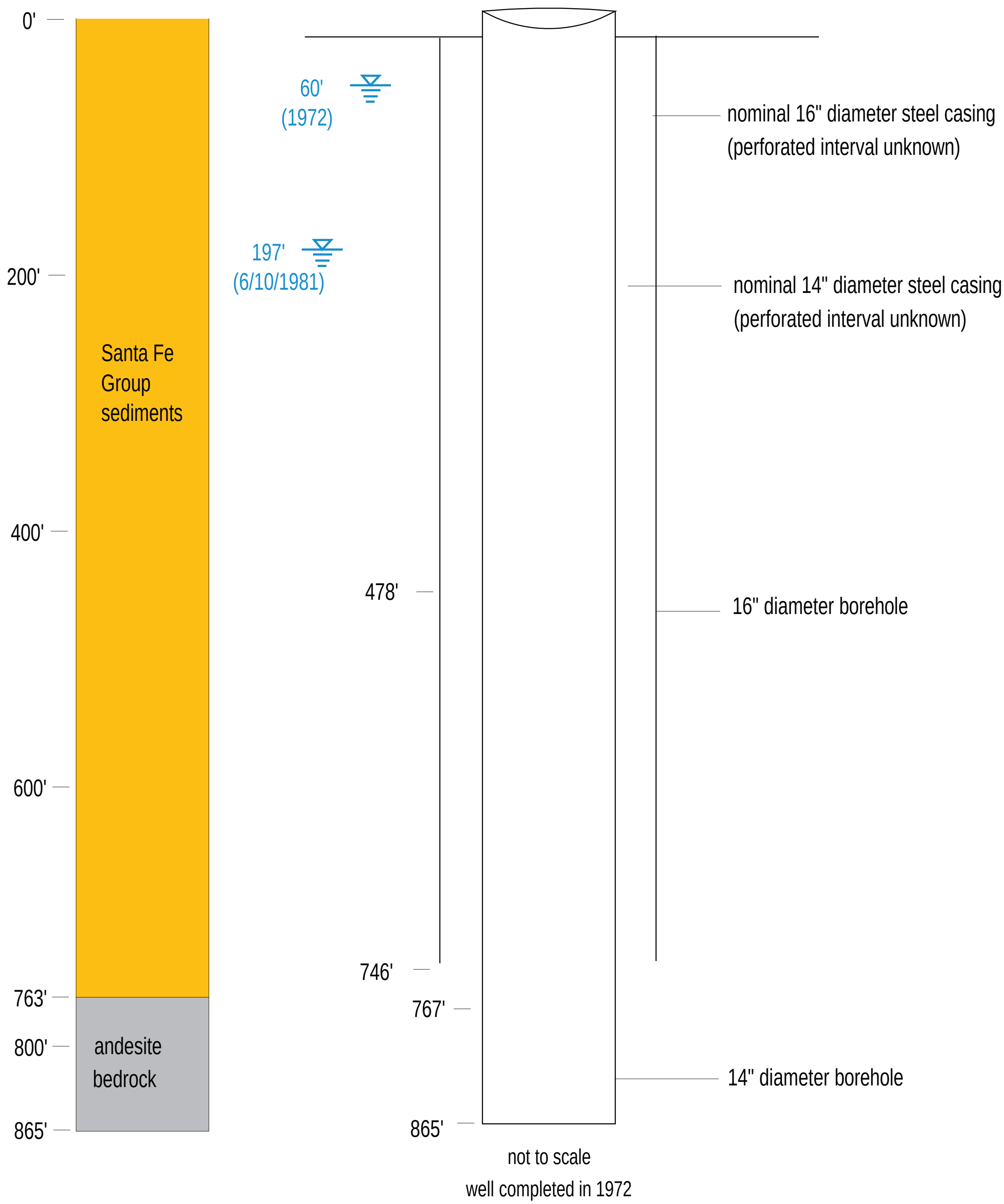


Figure B10. Well completion diagram for LRG-4652-S-9 (GWQ-9, South Inspiration, Well IDW-1), Copper Flat Mine, Sierra County, New Mexico.

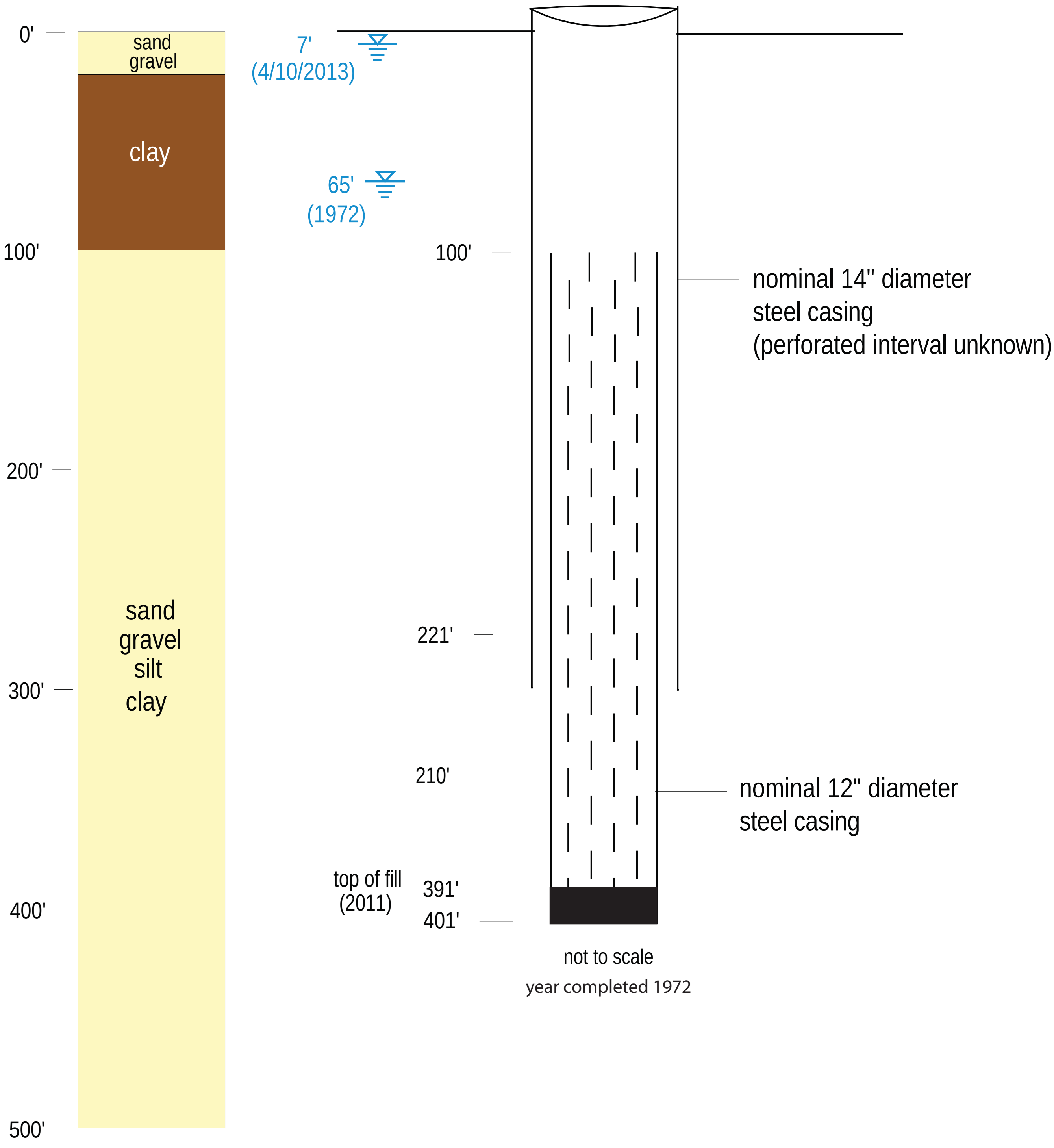


Figure B11. Well completion diagram for LRG-4652-S-10 (GWQ-1, North Inspiration, Well IDW-2, S-10), Copper Flat Mine, Sierra County, New Mexico.

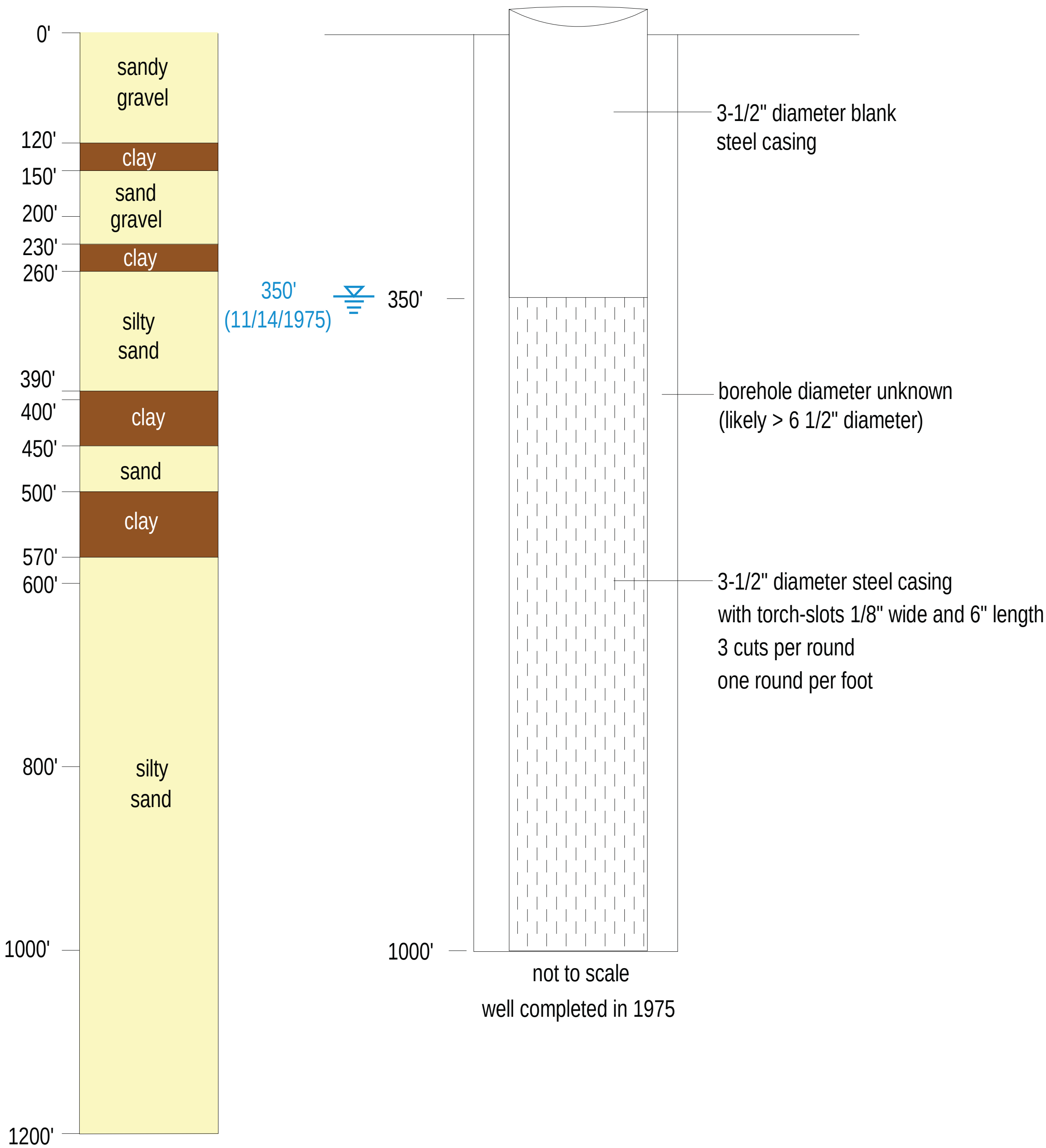


Figure B12. Well completion diagram for LRG-4652-S-11 (MW-1), Copper Flat Mine, Sierra County, New Mexico.

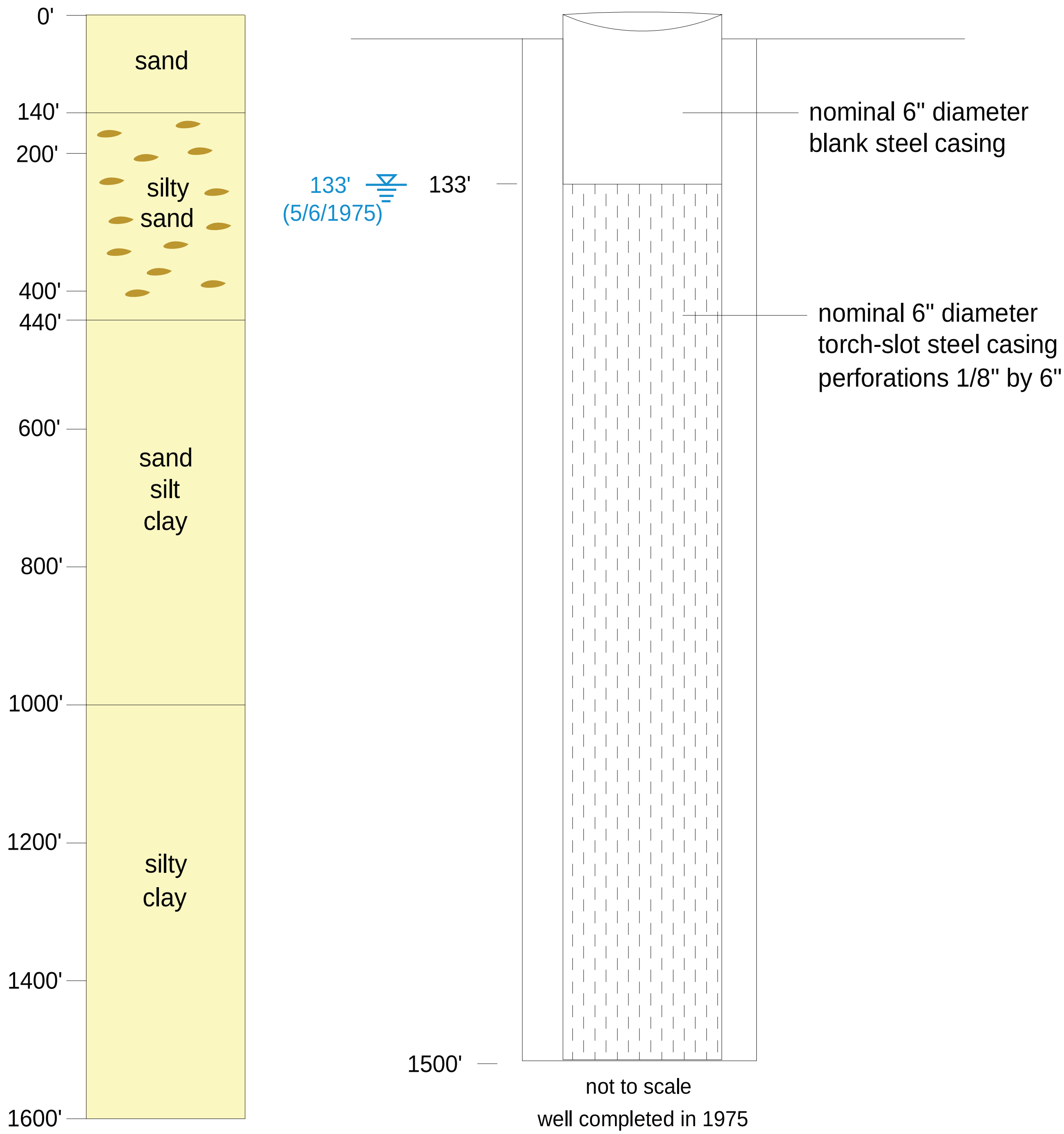


Figure B13. Well completion diagram for LRG-4652-S-12 (MW-2), Copper Flat Mine, Sierra County, New Mexico.

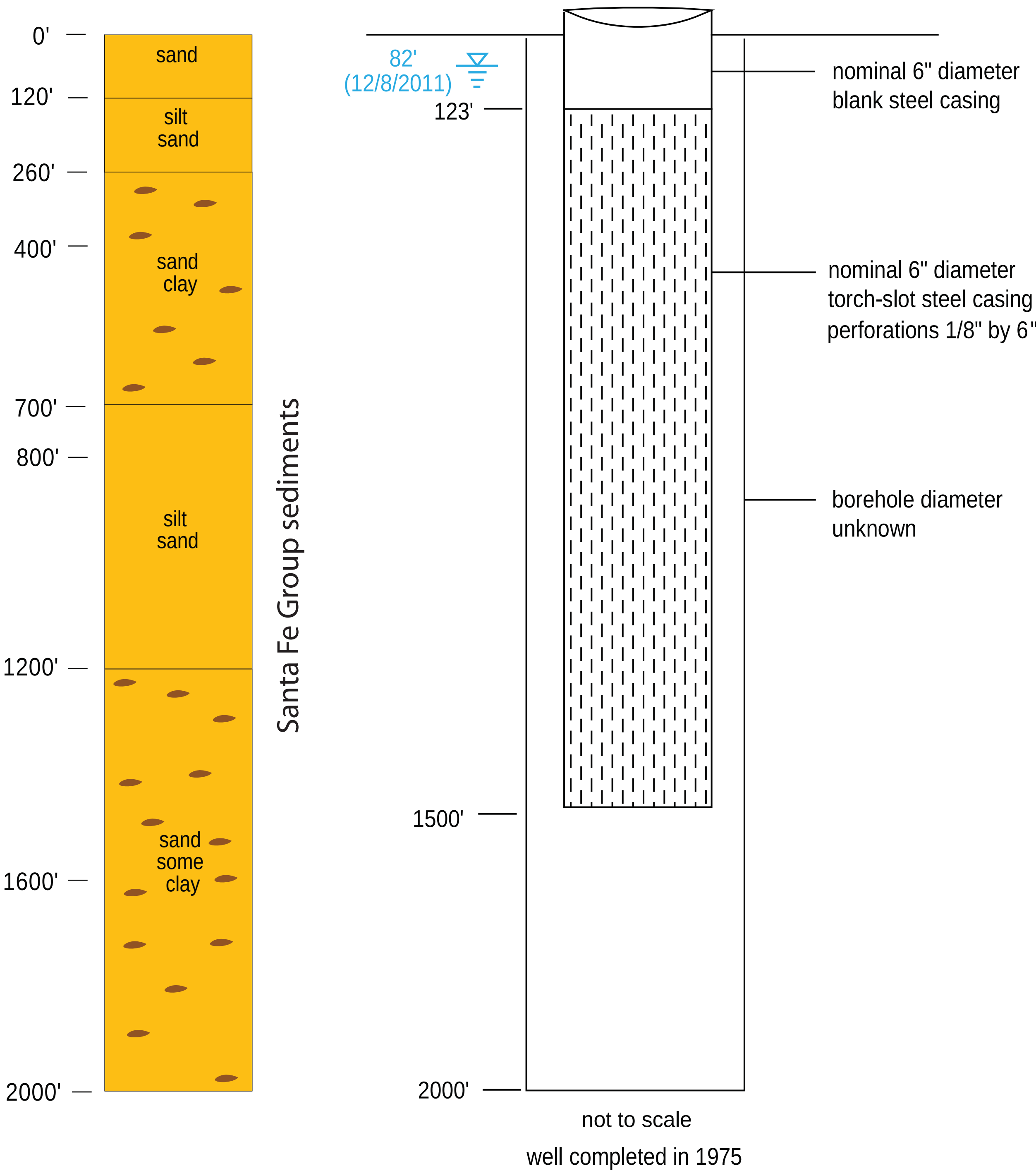


Figure B14. Well completion diagram for LRG-4652-S-13 (MW-4), Copper Flat Mine, Sierra County, New Mexico.

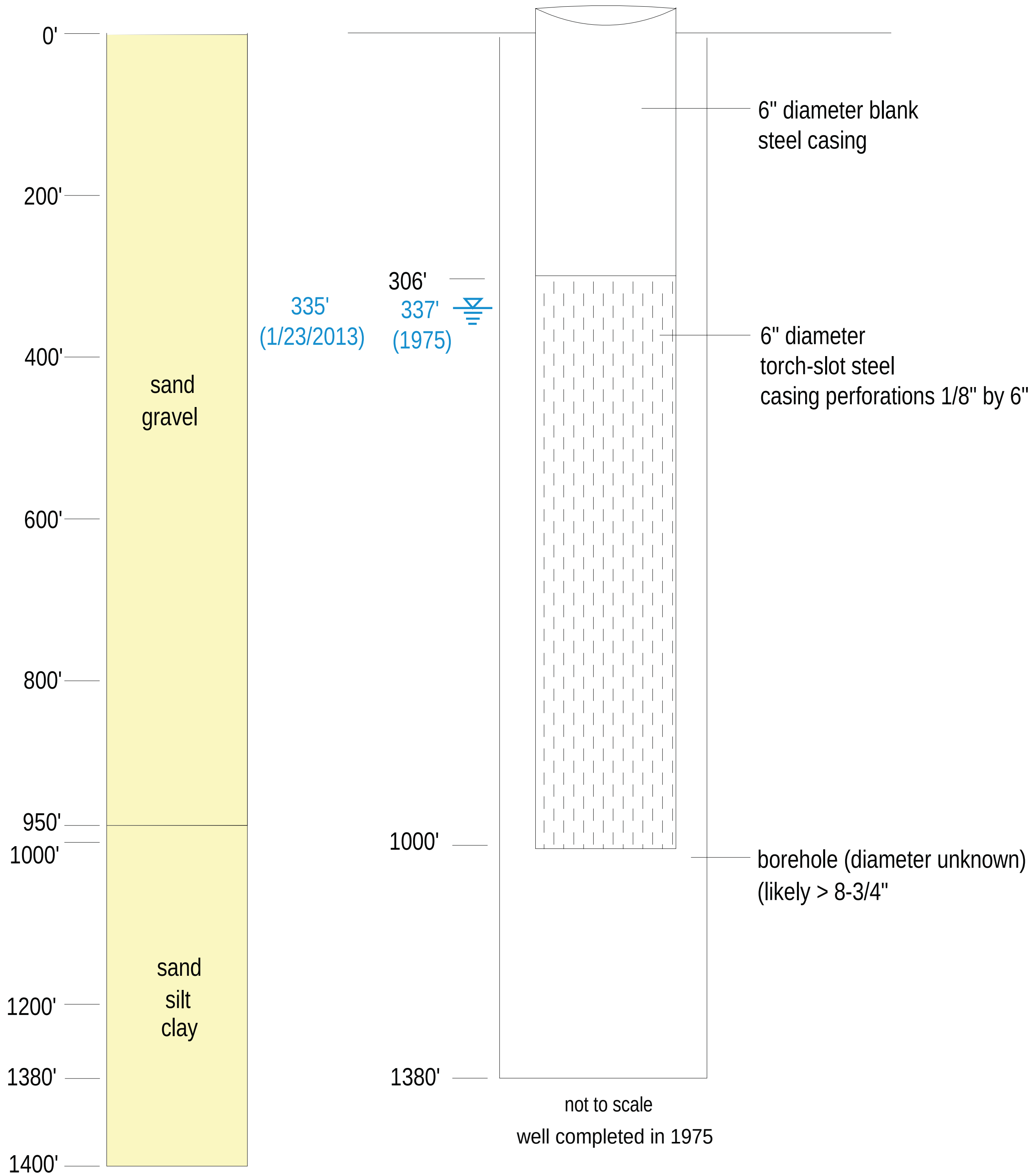


Figure B15. Well completion diagram for LRG-4652-S-14 (MW-5),
Copper Flat Mine, Sierra County, New Mexico.

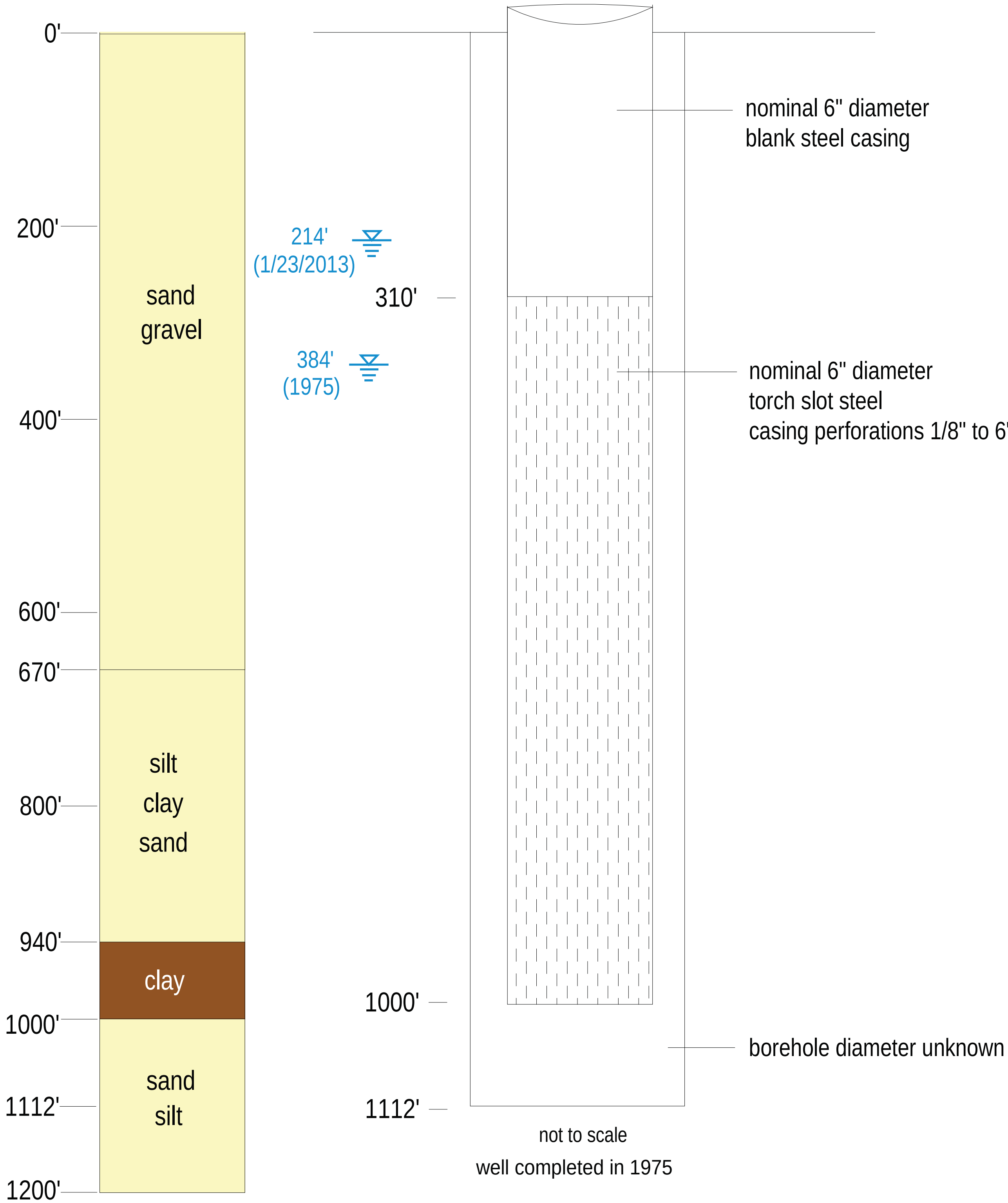


Figure B16. Well completion diagram for LRG-4652-S-15 (MW-6), Copper Flat Mine, Sierra County, New Mexico.

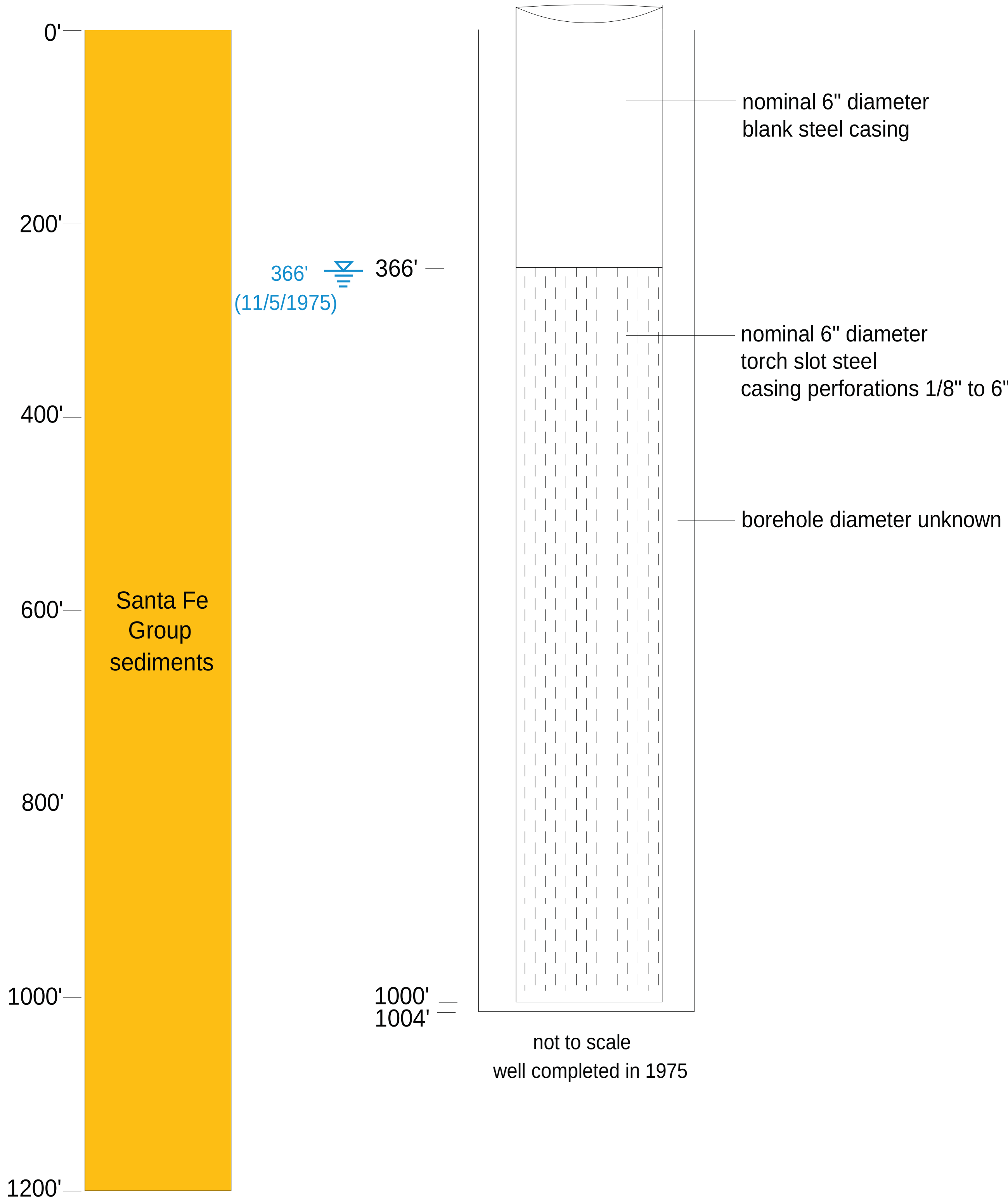


Figure B17. Well completion diagram for LRG-4652-S-16 (MW-8), Copper Flat Mine, Sierra County, New Mexico.

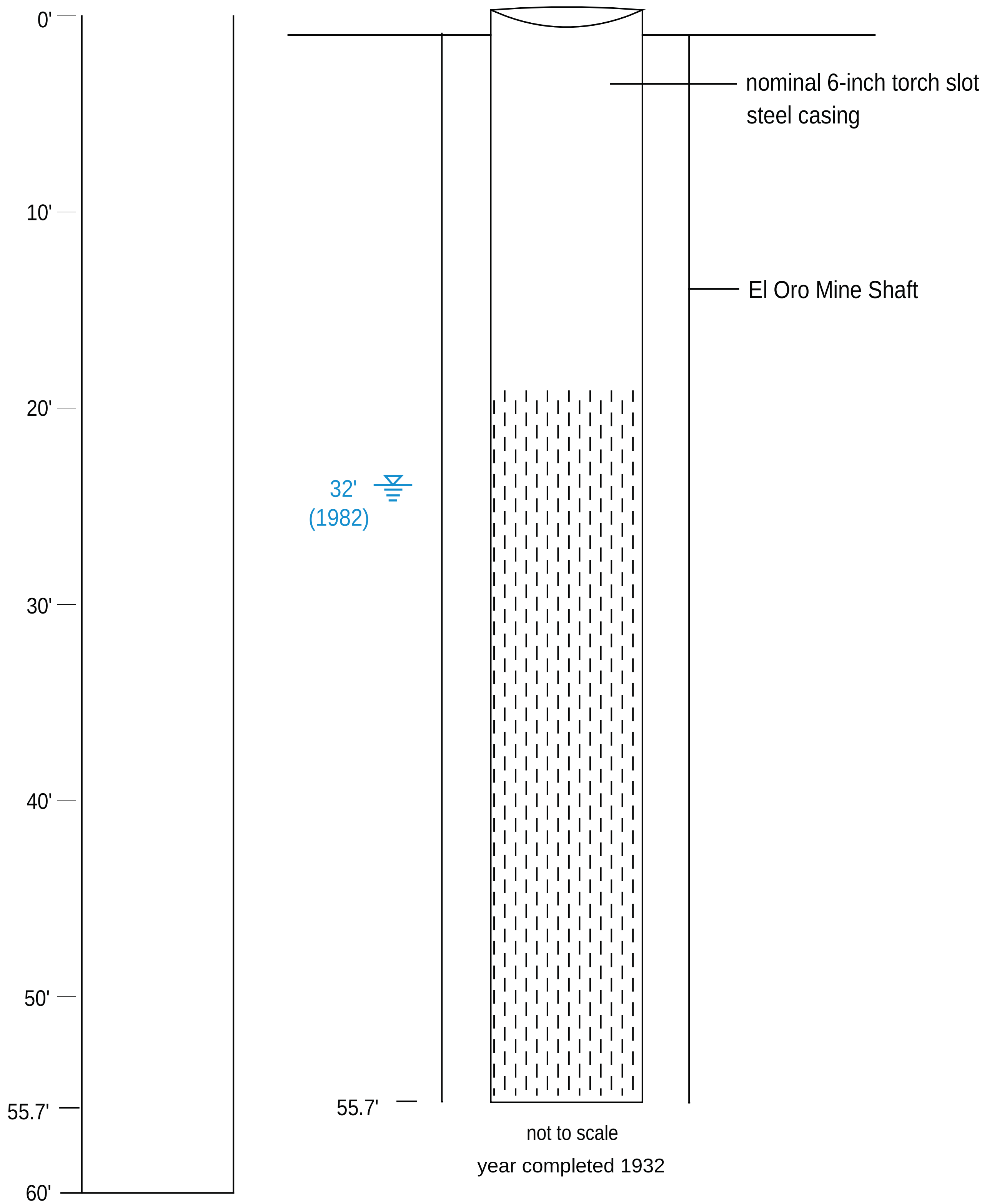


Figure B18. Well completion diagram for LRG-4654 (Old El Oro, Dolores), Copper Flat Mine, Sierra County, New Mexico.

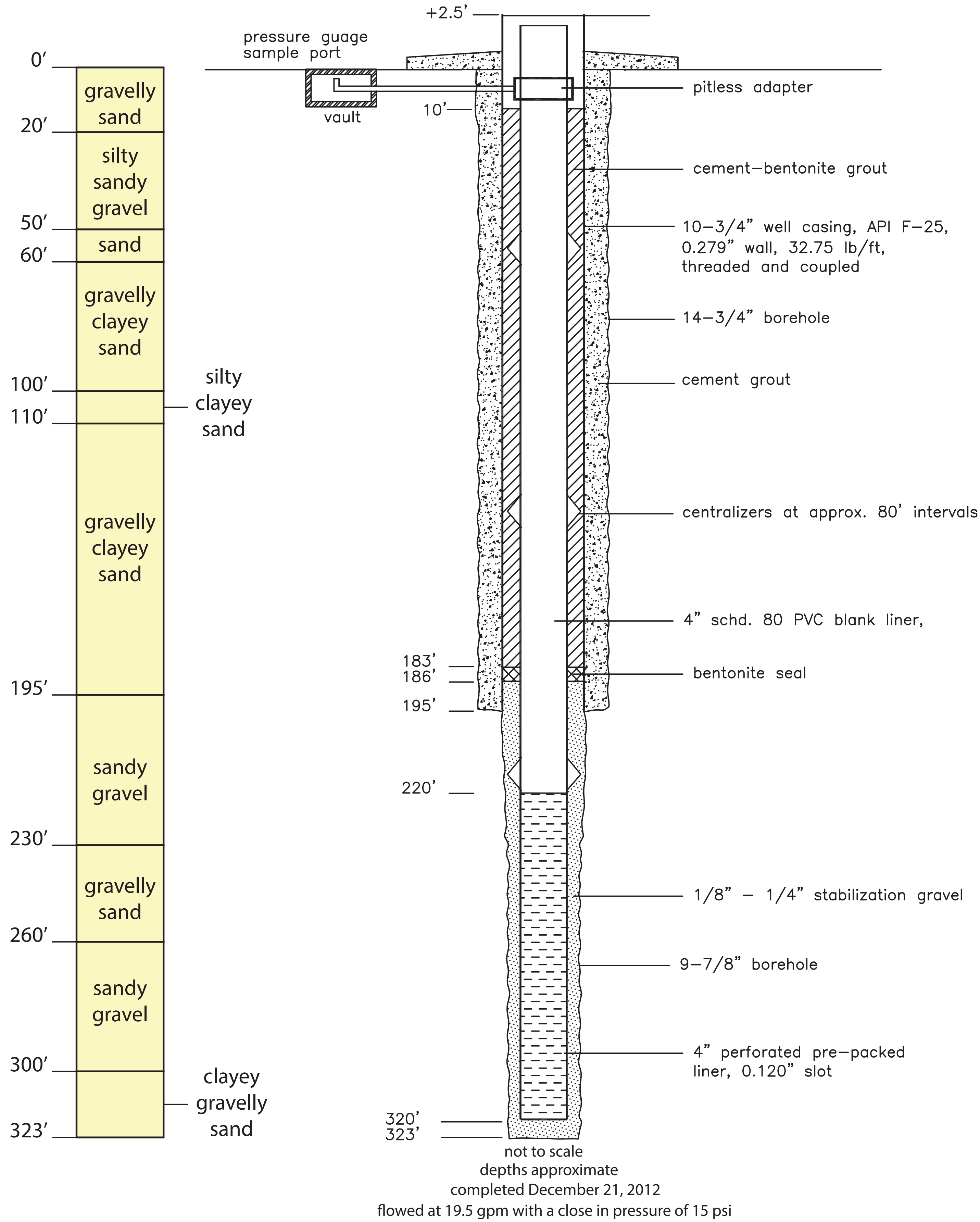
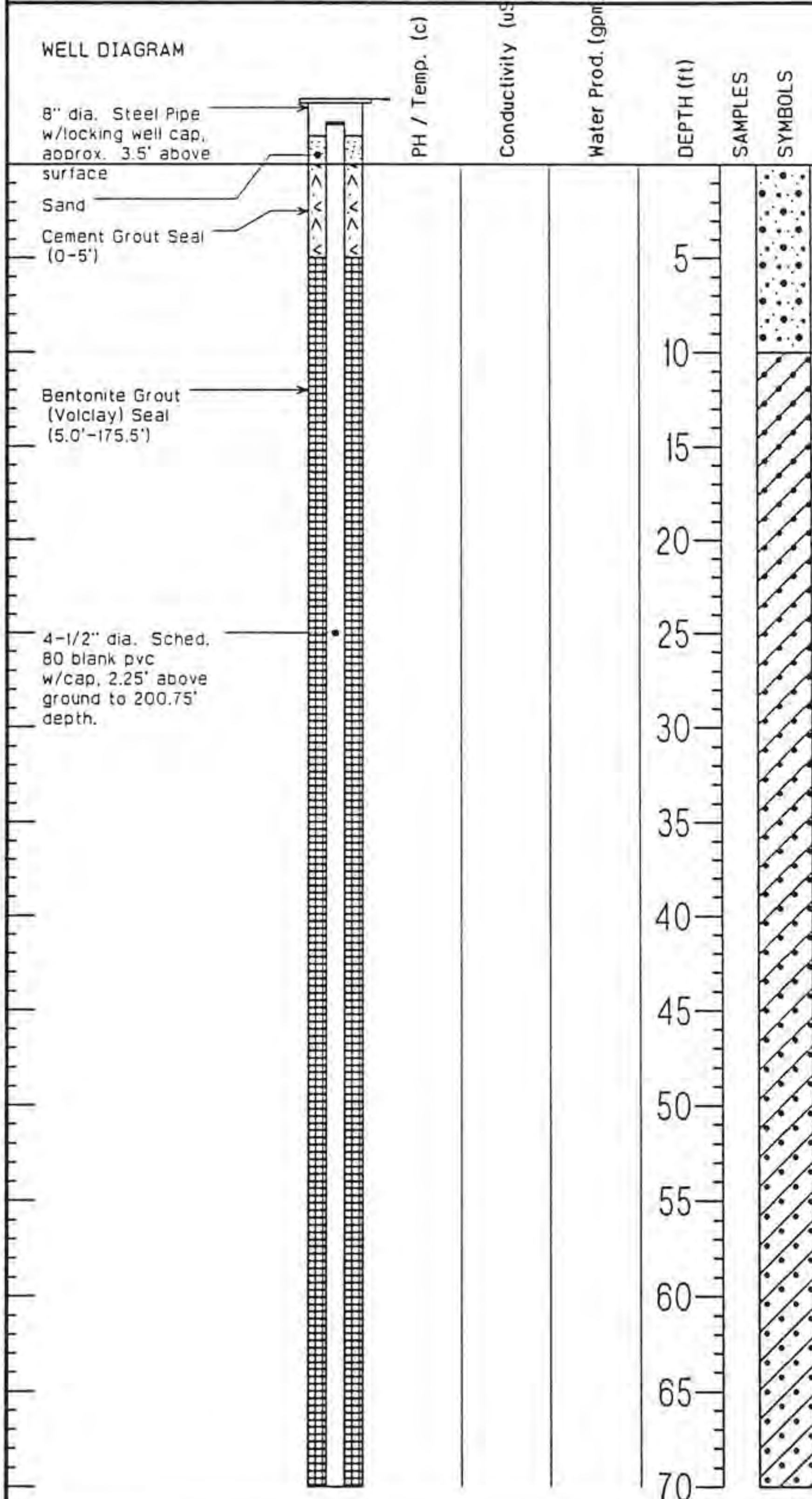


Figure B19. Well completion diagram for GWQ-11-27 (LA 00228 POD 1), Copper Flat Mine, Sierra County, New Mexico

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-9



MATERIALS DESCRIPTION

0-10', Soil/gravel, dark brown, w/abundant, silt, sand, cobbles/pebbles, wet @ 8'

7.75', ENCOUNTERED GROUNDWATER

10'-30', Alluvial gravels, varying amounts of silt/clay, sand & silt, abundant pebbles/cobbles very poorly sorted, Oxidized, wet

30'-40', Gravel, brown-slightly red brown, within clayey matrix very poorly sorted, min.-mod. sand, Oxidized, wet

40'-48', Gravel, as above with less clay/silt matrix.

48'-52', Gravel, brown-red brown within clay/silt matrix, min.-mod. sand very poorly sorted, wet.

52'-53.5', Gravel, as at 40'-48', relatively clean

53.5'-65', Gravel, brown-red brown, moderate-abundant clay/silt matrix, minor sand, very poorly sorted; wet

65'-75', clay, dark red-brown, w/min.-mod. sand & pebbles, no cobbles, moist-wet, very smooth drilling

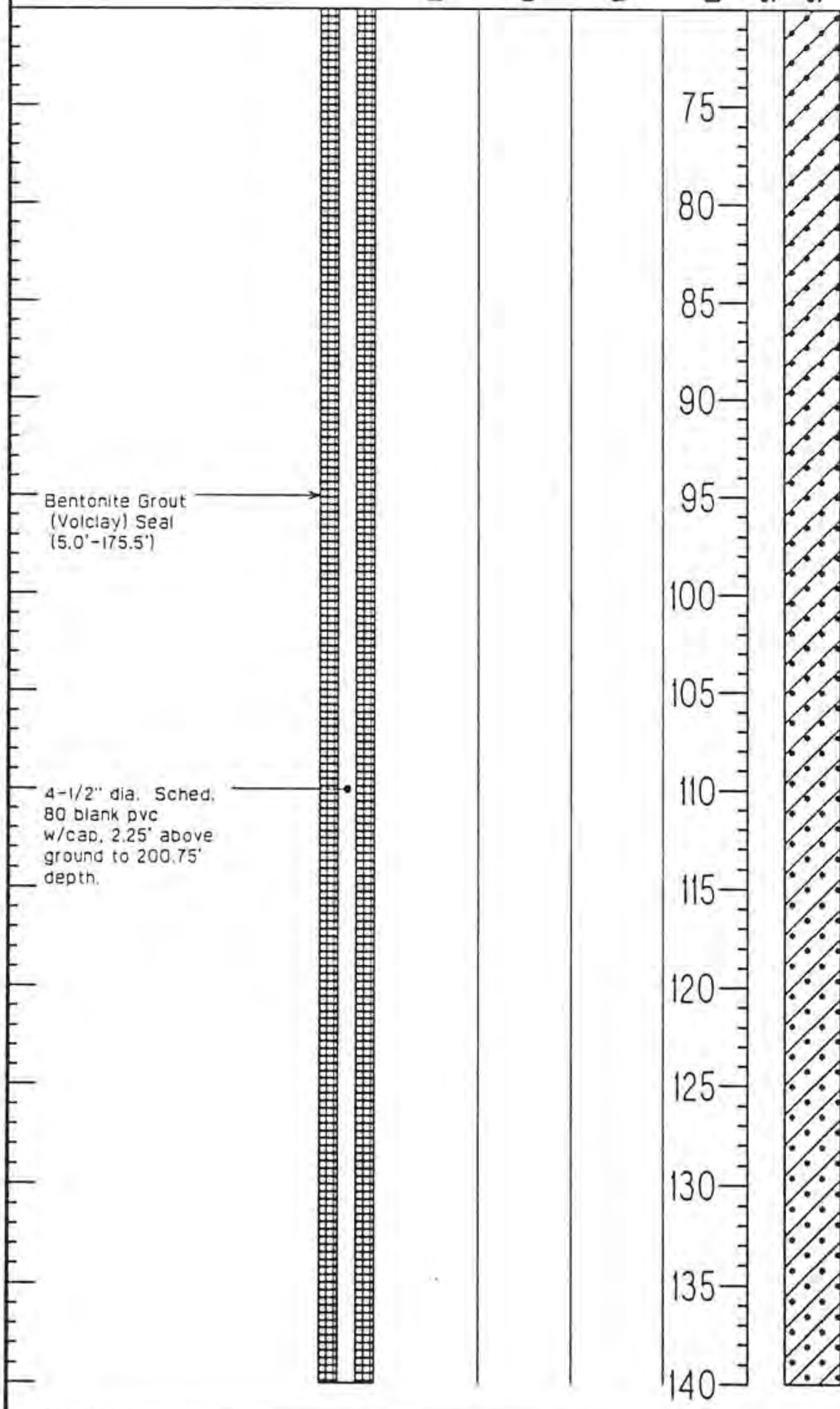
PROJECT Copper Flat - Hillsboro, N.M.
LOCATION N713191.10, E603249.22 N.M. S.P.C.
JOB NUMBER 68607 (ref: 68607M9)
GEOLOGIST C.W.
DRILL RIG Air Rotary

DRILLING COMPANY Beylik Drilling
DATE DRILLED 09/20/94 - 09/26/94
SURFACE ELEVATION 4440.14
TOTAL DEPTH OF HOLE 252.50 Feet
WATER LEVEL Static, from TOC on 11/7/94: 71.05 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-9

WELL DIAGRAM	PH / Temp. (c)	Conductivity (uS/m)	Water Prod. (gpm)	DEPTH (ft)	SAMPLES	SYMBOLS	MATERIALS DESCRIPTION



75'-80', Gravel, very clayey/silty matrix, red-brown, trace-min. sand, very poorly sorted, wet

80'-112', Gravel, light-med brown-grey brown, min.-mod. cl y/silt, min.-mod. sand, wet. Very clayey zone @ 80'-82'.

112'-114', Gravel, med. brown-red brown in clayey matrix, min.-mod. sand, wet.

114'-117', Gravel, dark brown-red brown, min.- mod. clay/silt, trace sand, wet.

117'-118', As at 114-117 with abundant clay/silt.

118'-125', Gravel, med. red brown, min.-mod. clay/silt matrix, trace-min. sand, Oxidized.

125'-130', Gravel, dark brown-red brown, abundant clay/silt matrix, min. sand, Oxidized

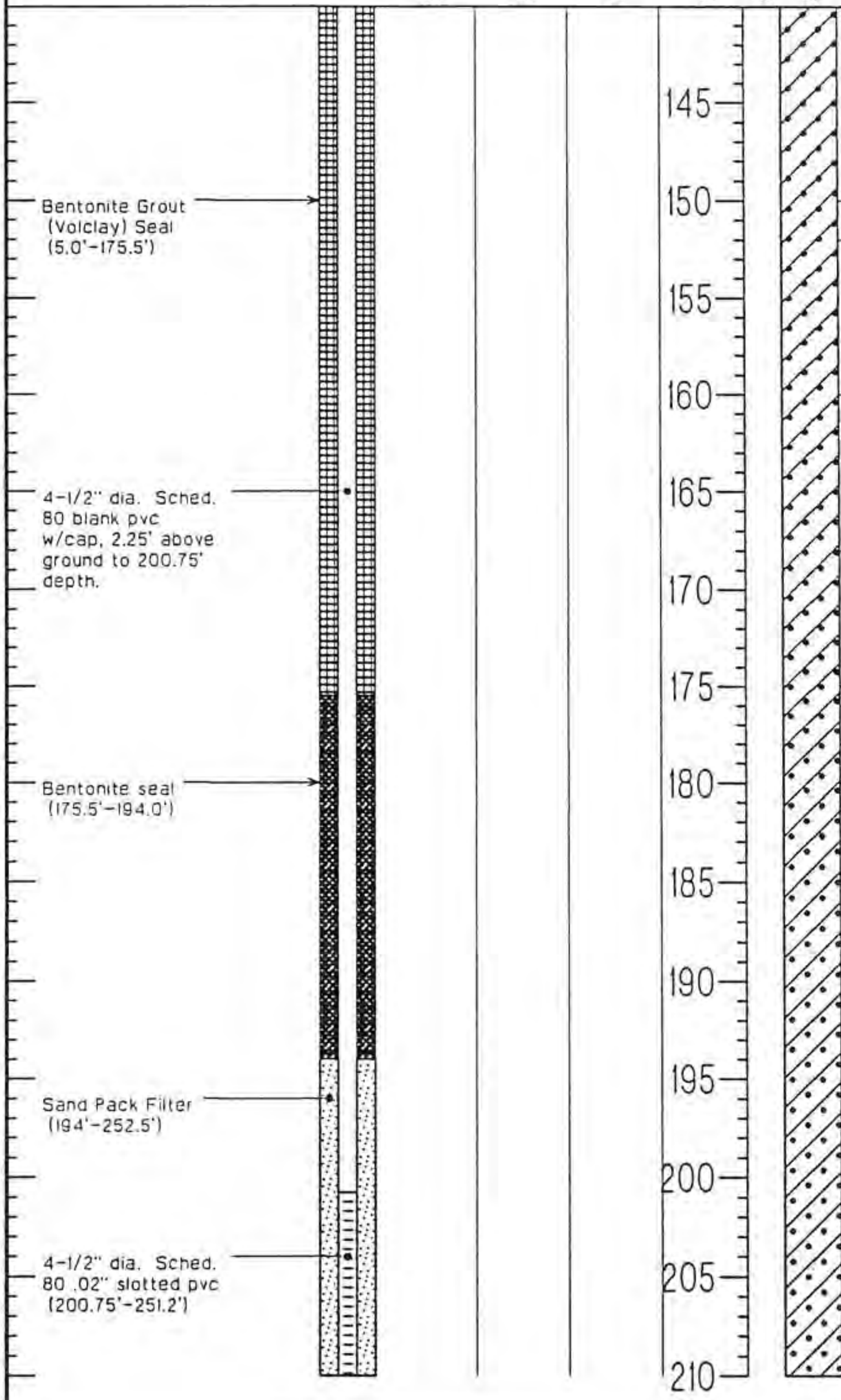
130'-150', Gravel, med. red brown, mod. silt/clay matrix, very poorly sorted, Oxidized.

PROJECT: Copper Flat - Hillsboro, N.M.	DRILLING COMPANY: Beylik Drilling
LOCATION: N713191.10, E603249.22 N.M. S.P.C.	DATE DRILLED: 09/20/94 - 09/26/94
JOB NUMBER: 68607 (ref: 68607M9)	SURFACE ELEVATION: 4440.14
GEOLOGIST: C.W.	TOTAL DEPTH OF HOLE: 252.50 Feet
DRILL RIG: Air Rotary	WATER LEVEL: Static, from TOC on 11/7/94: 71.05 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-9

WELL DIAGRAM | PH / Temp. (c) | Conductivity (uS/m) | Water Prod. (gpm) | DEPTH (ft) | SAMPLES | SYMBOLS | MATERIALS DESCRIPTION



MATERIALS DESCRIPTION

130'-150', Gravel, med. red brown, mod. silt/clay matrix, very poorly sorted, Oxidized.

150'-152', Gravel as above w/abundant clay/silt matrix.

152'-160', Gravel, med. red brown, mod. clay/silt matrix material (less than @ 150-152)

160'-168', Gravel, dark red brown, abundant clay/silt matrix

168'-175', Gravel, medium brown-red brown, min.- mod. clay/silt matrix (most of matrix material washed out of cuttings)

175'-176', Sand in clay/silt matrix, med-very coarse, minor pebbles.

176'-178', Gravel, dark grey brown - red brown, w/min. - mod. clay/silt matrix, wet w/mod. sand.

178'-180', Gravel, brown-red brown, mod. sand, mod.-abundant clay/silt, Oxidized.

180'-192', Gravel, red brown, min.- mod. sand, min.- mod. clay/silt matrix, wet.

192'-202', Gravel, dark brown-red brown, mod.- abundant clay/silt matrix.

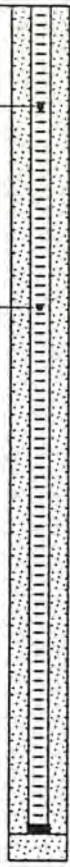
202'-253', Gravel, light-red brown, w/mod. sand, abundant pebbles/cobbles, min.- mod. clay/silt matrix, very poorly sorted, Oxidized, very uniform throughout zone, wet.

PROJECT: Copper Flat - Hillsboro, N.M.	DRILLING COMPANY: Beylik Drilling
LOCATION: N713191.10, E603249.22 N.M. S.P.C.	DATE DRILLED: 09/20/94 - 09/26/94
JOB NUMBER: 68607 (ref: 68607M9)	SURFACE ELEVATION: 4440.14
GEOLOGIST: C.W.	TOTAL DEPTH OF HOLE: 252.50 Feet
DRILL RIG: Air Rotary	WATER LEVEL: Static, from TOC on 11/7/94: 71.05 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-9

WELL DIAGRAM



4-1/2" dia. Sched. 80 .02" Slotted PVC (200.75'-251.2')

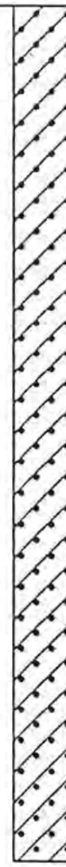
Sand Pack Filter (194'-252.5')

Depth (ft)	PH / Temp. (c)	Conductivity (uS/m)	Water Prod. (gpm)
230	7.93 / 20	250	23
	8.07 / 21	240	24
235	8.42 / 22	250	20
240	8.23 / 22	230	100
252.5	7.83 / 22	330	30 - 40

DEPTH (ft): 215, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280

SAMPLES

SYMBOLS



MATERIALS DESCRIPTION

202'-253', Gravel, light-red brown, w/mod. sand, abundant pebbles/cobbles, min.-mod. clay/silt matrix, very poorly sorted, Oxidized, very uniform throughout zone, wet.

Total depth = 252.5'

Total depth = 252.5'

WELL DEVELOPMENT DATA

DATE: Oct. 6, 1994

FLOW: 50 gpm

TIME (hrs.): 1.5

PROJECT Cooper Flat - Hillsboro, N.M.

LOCATION N713191.10, E603249.22 N.M. S.P.C.

JOB NUMBER 68607 (ref: 68607M9)

GEOLOGIST C.W.

DRILL RIG Air Rotary

DRILLING COMPANY Beylik Drilling

DATE DRILLED 09/20/94 - 09/26/94

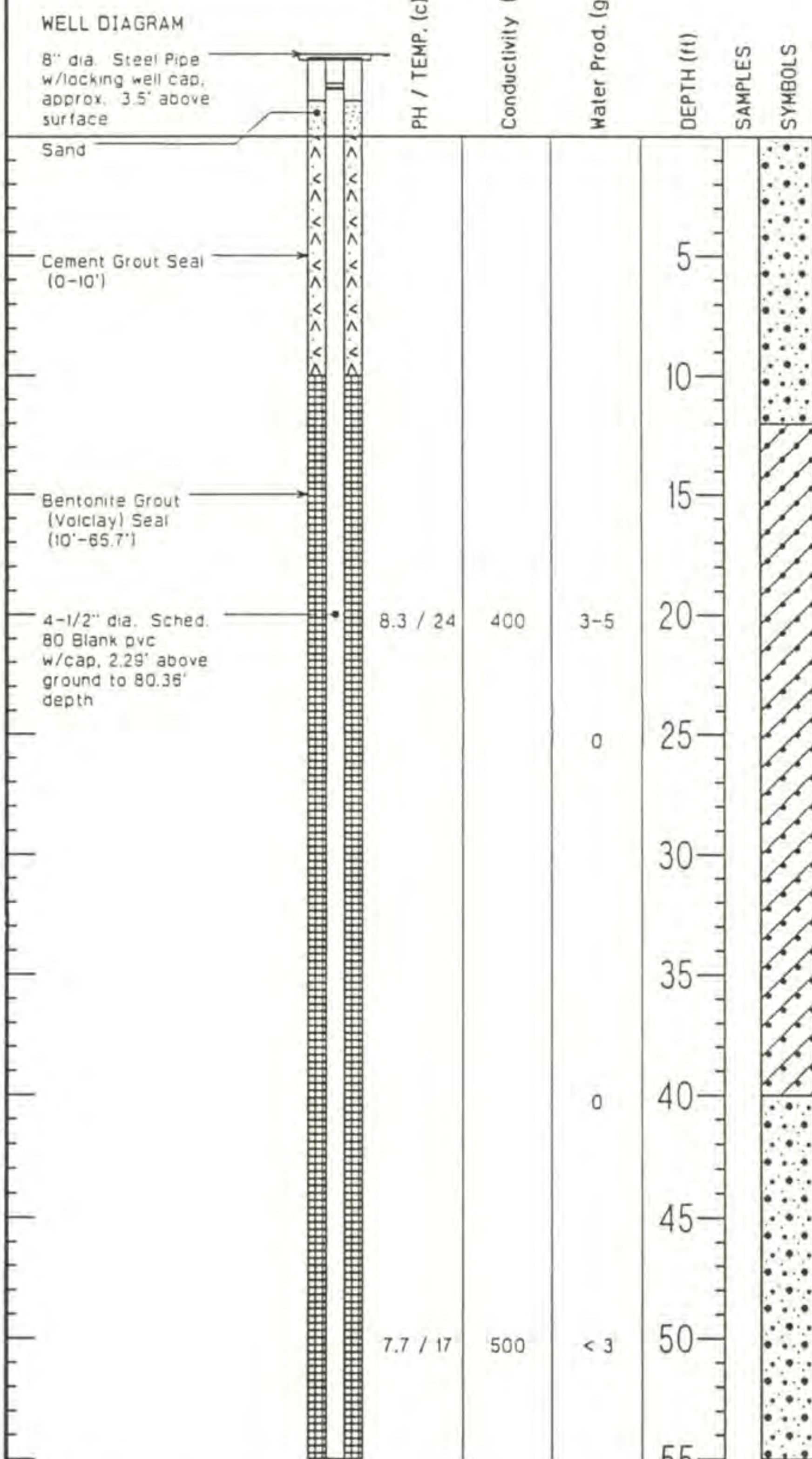
SURFACE ELEVATION 4440.14

TOTAL DEPTH OF HOLE 252.50 Feet

WATER LEVEL Static, from TOC on 11/7/94: 71.05 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-10



DEPTH (ft)	PH / TEMP. (c)	Conductivity (uS/m)	Water Prod. (gpm)
20	8.3 / 24	400	3-5
25			0
40			0
50	7.7 / 17	500	< 3

MATERIALS DESCRIPTION

0 - 12', Gravelly soil, dark brown w/abundant cobbles & pebbles, and moderately abundant sand, silt soil, very poorly sorted, Oxidized, dry to 7.75'

Groundwater encountered @ 7.75'

12'-22', Gravel - medium brown-light red brown, min-mod clay/silt, Oxidized, wet

22'-24', Red-brown, abundant cobbles/pebbles, min-mod sand, abundant silt, Oxidized, no water

24-34.5', clay, brown-red brown, min pebbles, min-mod cobbles, "dry"

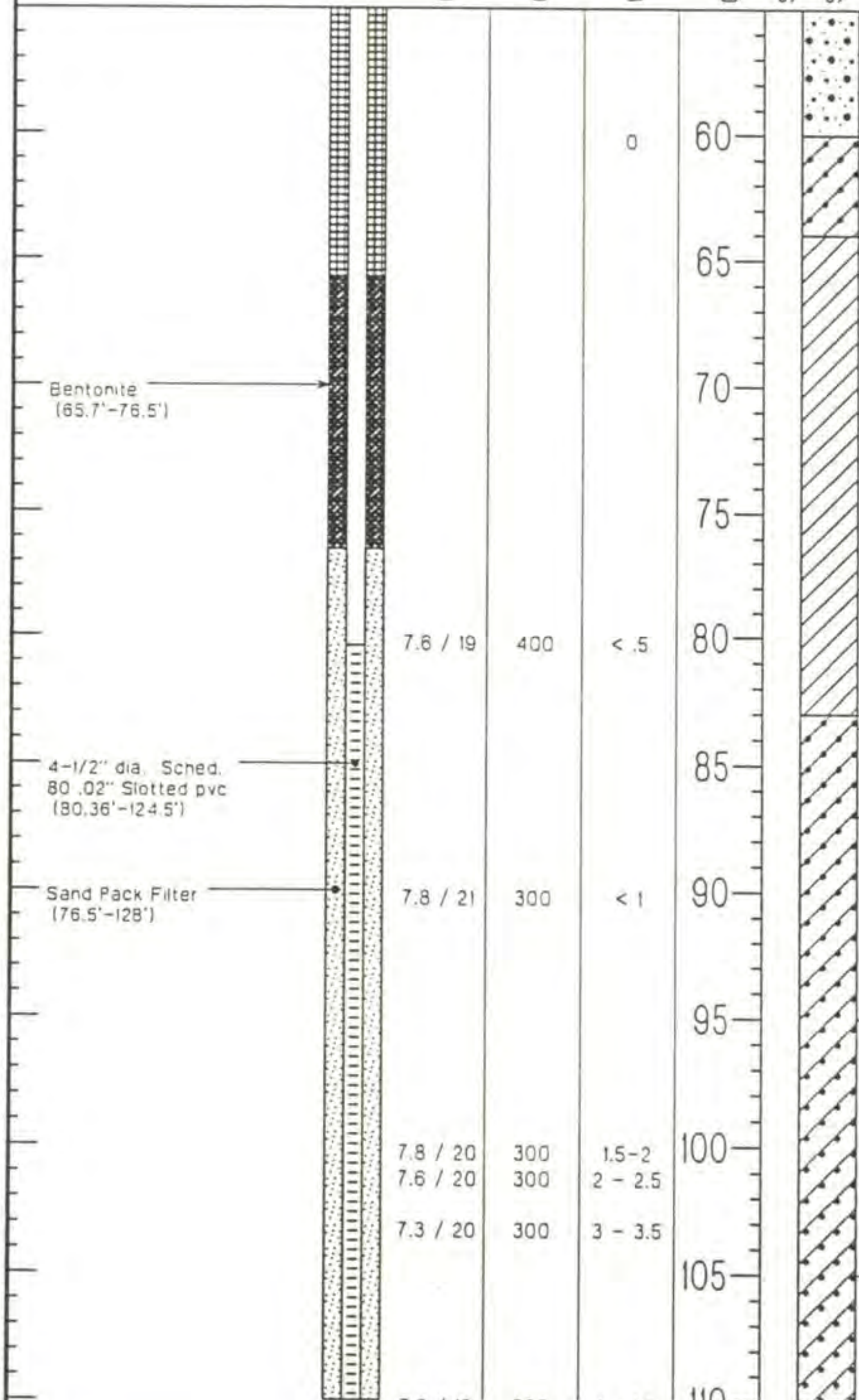
34.5-40', Gravel, grey brown, abundant brown-red brown clay/silt, Oxidized, "dry", tr-min sand

40-60', Gravel: med brown-red brown, abundant cobbles/pebbles, min-mod med-very coarse sand, "dry", Oxidized

PROJECT Copper Flat - Hillsboro, N.M.
LOCATION N719968.25, E636740.99 N.M. S.P.C.
JOB NUMBER 68607 (ref: 68607M10)
GEOLOGIST CW
DRILL RIG Air Rotary
DRILLING COMPANY Beylik Drilling
DATE DRILLED 10/94
SURFACE ELEVATION 4439.27
TOTAL DEPTH OF HOLE 128.0 Feet
WATER LEVEL Static, from TOC on 11/7/94: 70.625 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-10



PH / TEMP. (c)	Conductivity (uS/m)	Water Prod. (gpm)	DEPTH (ft)
		0	60
7.6 / 19	400	< .5	80
7.8 / 21	300	< 1	90
7.8 / 20	300	1.5-2	100
7.6 / 20	300	2 - 2.5	
7.3 / 20	300	3 - 3.5	
7.8 / 19	300	1 - 1.5	110

MATERIALS DESCRIPTION

40'-60', Gravel: med brown-red brown, abundant cobbles/pebbles, min-mod med-very coarse sand, "dry", Oxidized

60-64', Gravel, med brown, within clay/silt matrix, WET (not saturated)

64-78', Clay med brown-grey brown, w/some red brown zones, min-mod sand, wet (not saturated) does not produce water on drilling

78-83', Clay, as above w/slight increase in cobbles/pebbles & trace water

83-83.5', Gravel, medium brown-grey brown w/clay/silt matrix, produces 2-3 gpm water on drilling

83.5-87', Gravel, medium brown-red brown, abundant clay/silt matrix, mod sand, Oxidized

87-95', Gravel: medium brown, abundant clay/silt matrix produces 1/2-1 gpm on drilling

95-105', Gravel - medium brown - w/abundant clay/silt, mod-abundant sand, 1 1/2-2 gpm water when blowing

105-115', Gravel - medium brown-grey brown, abundant clay/silt matrix, minor sand, produces 1 1/2-2 gpm on drilling

PROJECT: Copper Flat - Hillsboro, N.M.	DRILLING COMPANY: Beylik Drilling
LOCATION: N719968.25, E636740.99 N.M. S.P.C.	DATE DRILLED: 10/94
JOB NUMBER: 68607 (ref: 68607M10)	SURFACE ELEVATION: 4439.27
GEOLOGIST: CW	TOTAL DEPTH OF HOLE: 128.0 Feet
DRILL RIG: Air Rotary	WATER LEVEL: Static, from TOC on 11/7/94: 70.625 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-10

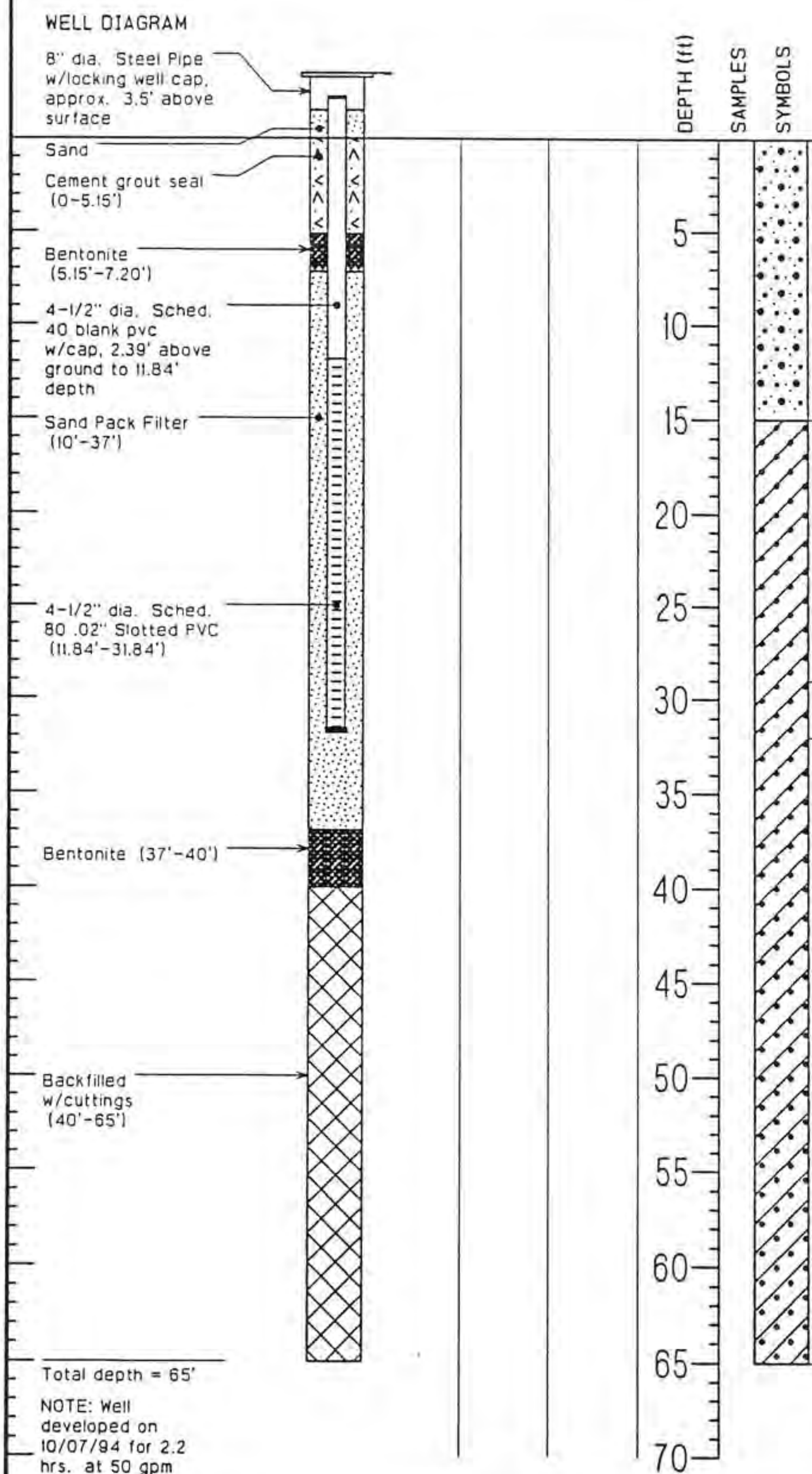
WELL DIAGRAM	PH / TEMP. (c)	Conductivity (uS/m)	Water Prod. (gpm)	DEPTH (ft)	SAMPLES	SYMBOLS	MATERIALS DESCRIPTION
	7.6 / 19	300	< .5				105-115', Gravel - medium brown-grey brown, abundant clay/silt matrix, minor sand, produces 1 1/2-2 gpm on drilling
4-1/2" dia. Sched. 80 .02" Slotted pvc (80.36'-124.5')				115			115-128, Gravel - medium brown-grey brown, abundant clay/silt matrix, mod-abundant sand, produces less than 1 gpm on drilling
Sand Pack Filter (76.5'-128')	7.9 / 19.5	300	< .5	120			
	7.8 / 20.5	300	< 1	125			
Total depth = 128'							Total depth = 128'
				130			
NOTE: Well developed 10/07/94 for 2.25 hrs. at 25 to 30 gpm				135			
				140			
				145			
				150			
				155			
				160			
				165			

PROJECT Copper Flat - Hillsboro, N.M.
LOCATION N719968.25, E636740.99 N.M. S.P.C.
JOB NUMBER 68607 (ref: 68607M10)
GEOLOGIST CW
DRILL RIG Air Rotary

DRILLING COMPANY Beylik Drilling
DATE DRILLED 10/94
SURFACE ELEVATION 4439.27
TOTAL DEPTH OF HOLE 128.0 Feet
WATER LEVEL Static, from TOC on 11/7/94: 70.625 Feet

Steffen Robertson and Kirsten
Engineering and Environmental Consultants

LOG OF MONITORING WELL MW-11



MATERIALS DESCRIPTION

0-15', Soil and gravel, dark brown, abundant cobbles, min.- mod. sand, wet @ 15'.

15'-29', Gravel: med. dark brown, silty soil matrix w/mod. clay, wet.

29'-32', Clay/silt, med. dark brown, moist - damp, (not saturated) abundant cobbles/pebbles, min.- mod. sand.

32'-65', Clay, as above but "dry"

Total depth = 65'

PROJECT Copper Flat - Hillsboro, N.M.	DRILLING COMPANY Beylik Drilling
LOCATION N713751.31, E603378.24 N.M. S.P.C.	DATE DRILLED 10/11/94
JOB NUMBER 68607 (ref: 68607MI1)	SURFACE ELEVATION 4439.48
GEOLOGIST CW	TOTAL DEPTH OF HOLE 65 Feet
DRILL RIG Air Rotary	WATER LEVEL Static, from TOC on 11/7/94: 10.65 Feet

Appendix C1.

Initial PW- Well Pumping Tests, 1975-1980

BD - 1
P.G.D. - 1
NB - 1
MHM - 1

Water Development Corporation
CONSULTANTS IN WATER RESOURCES

RECEIVED
FEB 19 1976
QUINTANA

3938 SANTA BARBARA AVENUE
TUCSON, ARIZONA 85711

PHONE: 602-326-1133
CABLE: WADEVCO, TUCSON

February 17, 1976

W. E. S.
FEB 20 1976

Mr. W. E. Saegart , President
Quintana Minerals Corporation
2475 North Jack Rabbit Avenue
Tucson, Arizona 85705

Dear Bill:

The purpose of this letter is to give a brief summary of the test results for the three production wells drilled for Quintana's Copper Flat Project.

Production Well No. 1 was tested for 70 hours at 1,500 gpm. Initial static water level was 331.8 feet. The final pumping water level was 381.6 feet giving a drawdown of 49.8 feet and a specific capacity of 30.1 gpm per foot of drawdown. Water levels were measured in MW-5 during the test on Production Well No. 1. At the end of 70 hours of pumping the decline in MW-5 amounted to 9.10 feet.

Production Well No. 2 was tested for 72 hours at a discharge rate of 2,020 gpm. Static water level at the beginning of the test was 310.4 feet and the final pumping water level was 413.7 feet giving a drawdown of 103.3 feet and a specific capacity of 19.6 gpm per foot of drawdown. During the test on Production Well No. 2 water levels were measured in MW-5 and Production Well No. 1. During the 72 hours of pumping the decline in MW-5 amounted to 3.82 feet and the decline in Production Well No. 1 amounted to 4.93 feet.

Production Well No. 3 was tested at a rate of 1,500 gpm for 72 hours Initial static water level was 350.8 feet and the final pumping water level was 454.2 feet. Drawdown amounted to 103.4 feet giving a specific capacity of 14.5 gpm per foot of drawdown. Water levels were measured in MW-5, MW-6, and Production Wells 1 and 2 during the test on Production Well No. 3. After 72 hours of pumping the declines were 2.07 feet in Production Well No. 1, 1.46 feet in Production Well No. 2, 2.04 feet in MW-5, and 0.51 feet in MW-6. Prior to and during the early stage of the test water levels were rising in MW-6. As MW-6 had recently been used to supply water for drilling the data for MW-6 are not considered valid.

In terms of specific capacity, Production Well No. 1 is the best well and we consider that this well could be operated at a discharge in the range of 1,800 to 2,000 gpm if necessary. We could not test it at this rate due to pump limitations and for the subsequent tests a larger pump was installed. Well No. 2 is the next best well. At a discharge rate of 2,020 gpm entrained air was beginning to appear in this well and we consider that a more reasonable pumping rate for this well would be in the range of 1,600 to 1,800 gpm. Well No. 3 was producing considerable entrained air at 1,500 gpm and we recommend that, unless necessary, this well not be pumped at a rate in excess of 1,000 to 1,200 gpm. During development this well had a specific capacity of about 20 gpm per foot of drawdown at 1,000 gpm.

The source of entrained air encountered in Production Wells 2 and 3 is from cascading water coming through the perforations and falling to the pumping water level. The deeper the pumping water level is below the top of the perforations the greater the amount of entrained air. We anticipated that this would be a problem in all of the production wells but due to the excellent specific capacity of Production Well No. 1 there was no entrained air at a discharge rate of 1,500 gpm. With a higher discharge rate it is considered likely that some air will appear in the discharge of this well.

The only guaranteed way to eliminate all entrained air from a well discharge is to install blank casing to a depth greater than the anticipated pumping water level. Due to the lenticular nature of the water bearing materials and the indication from the geophysical logs that some of the more productive materials were the shallower sediments, this would result in a substantial reduction in discharge and specific capacity. Thus, if maximum quantity of water is desired, it becomes necessary to produce some entrained air also. By going to deep pump settings a portion of the entrained air can be forced out of the water before it reaches the pump intake.

We are presently preparing a basic-data report on the production wells and an interpretive report related to the effect of operating the well field for a sustained period of time using aquifer coefficients as calculated from the test data. Based on raw data from the well tests we consider at the present time that the existing well field has the following range of capacity:

62,4

Production Well No. 1	1,800 gpm to 2,000 gpm
Production Well No. 2	1,600 gpm to 1,800 gpm
Production Well No. 3	1,000 gpm to 1,200 gpm
Total	4,400 gpm to 5,000 gpm

Upon completion of our calculations related to well interference and long-term operation of the well field it may be necessary to modify the above figures. The modification, if necessary, is not considered likely to be substantial. Final selection of pumps and rates at which to operate each well should be delayed until reasonably accurate figures for mill water requirements are available.

Sincerely yours,

Don

Donald K. Greene

DKG/cm

2374

GPM x 60 x 24 x 60% = GPD

1 FT = 43,560 ft²/ACRE x 7.5 GAL/FT³

326,700 GAL/AC-FT.

6700 GPM x 60 x 24 x 60% x 3

2,112,912,000 GPY Allowed.

6467 AC-FT/YR.

PW 1
PW 2
PW 3

BASIC-DATA REPORT
QUINTANA MINERALS CORPORATION
COPPER FLAT PROJECT
PRODUCTION WELLS,
HILLSBORO, NEW MEXICO

By
D. K. Greene and L. C. Halpenny

Tucson, Arizona
April 1976

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FIGURES

BASIC-DATA REPORT

QUINTANA MINERALS CORPORATION
COPPER FLAT PROJECT PRODUCTION WELLS
HILLSBORO, NEW MEXICO

By

D. K. Greene and L. C. Halpenny

GENERAL INFORMATION

A total of three production wells have been drilled to furnish the water supply for ore processing and other uses at the Copper Flat Project. Locations of the wells are shown on Figure 1 and legal descriptions are as follows:

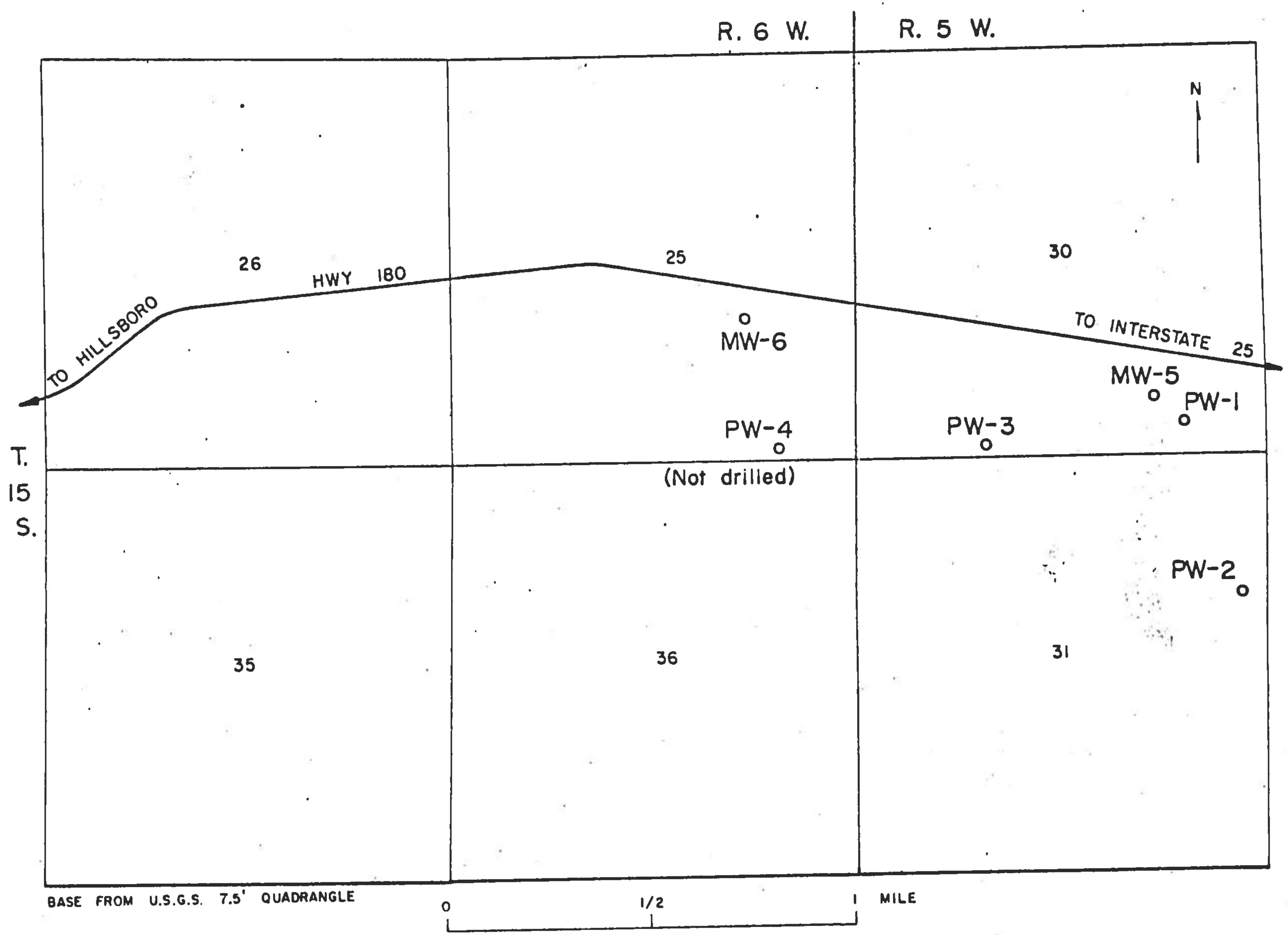

FIGURE 1.--MAP OF A PORTION OF TOWNSHIP 15 SOUTH, RANGES 5 AND 6 WEST, SIERRA COUNTY, NEW MEXICO, SHOWING LOCATIONS OF PRODUCTION WELLS AND MW-5 AND MW-6.

Production Well No. 1 (PW-1) SW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$, Sec. 30, T. 15 S., R. 5 W.

Production Well No. 2 (PW-2) NE$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$, Sec. 31, T. 15 S., R. 5 W.

Production Well No. 3 (PW-3) SW$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$, Sec. 30, T. 15 S., R. 5 W.

The well field is located approximately 7.5 miles east of the proposed concentrator site and it will be necessary to pipe water this distance.

The wells were drilled by B. C. & M. Drilling, Inc. of Mesa, Arizona using reverse air rotary equipment, during the period December 1975-January 1976. Prior to start of drilling 30 feet of 30-inch diameter, 5/16-inch wall thickness, surface pipe was installed and cemented in at each site using an auger rig. During this phase of work a site for a fourth production well (PW-4) (see Figure 1) was prepared. This site was not drilled.

The general procedure in constructing the production wells was to drill a 26-inch diameter hole in one pass, install a 16-inch, 5/16-inch wall thickness, blank and perforated casing assembly with centering guides approximately every 100 feet, gravel pack the annular space with 1/8 to 3/8-inch gravel, and develop the well with the drilling rig by jetting and washing with the compressor. The perforations were vertical saw-cut slots 1/8-inch wide by 3-inches long with 36 cuts per round and two rounds per foot. Total open area amounted to about 27 square inches per foot.

Details on depth drilled, casing installed, etc., for each of the three production wells are as follows:

Production Well No. 1

Depth drilled	960 feet
Casing installed	
Blank	0 to 368 feet
Perforated	368 to 951 feet
Gravel installed	109 yards
Rig development time	33.5 hours
Gravel slippage during rig development	41 feet

Production Well No. 2

Depth drilled	1,005 feet
Casing installed	
Blank	0 to 376 feet
Perforated	376 to 995 feet
Gravel installed	116 yards
Rig development time	28 hours
Gravel slippage during rig development	43 feet

Production Well No. 3

Depth drilled	970 feet
Casing installed	
Blank	0 to 380 feet
Perforated	380 to 965 feet
Gravel installed	116 yards
Rig development time	35.5 hours
Gravel slippage during rig development	17 feet

Following completion of rig development each well was further developed and then tested with a diesel powered turbine pump supplied by Western Pump and Supply Company of Deming, New Mexico. Data obtained during this phase of the investigation are included in the following sections of this report along with logs and water analyses for each production well.

Quintana Minerals Corporation

2475 NORTH JACK RABBIT AVENUE
TUCSON, ARIZONA 85705

602/622-4801

Bob Donegan
Property Manager

FILE MEMORANDUM

TO: W. E. Saegart
P. G. Dunn
M. W. Hood

April 26, 1976

Hillsboro-Copper Flat
Water Wells

FROM: B. G. Donegan

Following are corrected elevations for the water wells given by Gordon McLain in telephone conversation today:

	PW 1	4693
	PW 2	4670
	PW 3	4717
(Proposed)	PW 4	4745
	MW 5	4700

The above are based on QMC elevation datum.

Bob Donegan

BD/ln

Hillsboro - Water
Extra file copies

Water Development Corporation

CONSULTANTS IN WATER RESOURCES

3938 Santa Barbara Avenue
Tucson Arizona 85711

Phone 602-326-1133
Cable WADEVCO Tucson

May 16, 1977

Mr. W. F. Saegart - President
Quintana Minerals Corporation
2475 North Jack Rabbit Avenue
Tucson, Arizona 85705

Re: Copper Flat Project, effect of pumping from wells

Dear Mr. Saegart:

In reply to your request for our opinion on the hydrology of the area of the Copper Flat Project water well field and the effect of pumping for 15 years from that well field, we submit the following information as an addendum to the opinions given in our April 1976 report entitled "Report on development of ground-water supply for Quintana Minerals Corporation Copper Flat Project, Hillsboro, New Mexico":

Extent of Cone of Depression

The aquifer characteristics of the Santa Fe Formation in the vicinity of the well field were developed from extended pumping of Production Wells 1, 2, and 3, and in our opinion are as follows:

Coefficient of transmissivity:	100,000 gal/day/ft
Long-term coefficient of storage:	0.10 dimensionless

The aquifer is less permeable westward toward the mountain front, based on data from test holes drilled during the exploration phase of the water well-field development program. The change toward finer-grained materials westward is gradual. No sharp barrier was found. The mathemathics of evaluating behavior of aquifers are amenable to analysis when a "negative barrier" of impermeable bedrock, or partially permeable materials occurs in one direction or more from a center of well pumping. However, for a gradational change in one or more directions it is necessary to assume the change is abrupt and is at a specified distance from the center of pumping. For this well field we have assumed that at a distance of one mile west of the center of pumping there is an abrupt change in the coefficient of transmissivity from 100,000 gpd/ft on the east side of a north-south line to 20,000 gpd/ft on the west side. The method for evaluating the effect upon water levels in an aquifer of a complete or partial line barrier is to assume the existence of an "image well" at a site on a line from the center of pumping perpendicular across the barrier, at a distance from the center of pumping equal to twice the distance from the center of pumping to the barrier.

We have made calculations of the drawdowns in water level in the Santa Fe aquifer along a north-south line through the center of pumping. These calculations are based on withdrawal of water from the well field during the first year at 6,000 gpm and for the next 14 years at 2,000 gpm. The calculations include the effect of the partial negative barrier westward. The results of the calculations are as follows:

Distance From the Center of Pumping (ft)	Decline of Water Levels in the Santa Fe Formation: After 1 Year (ft)	After 15 Years (ft)
5,000	13.6	18.5
10,000	5.4	13.7
20,000	.3	7.6
30,000	--	4.5
40,000	--	2.6
50,000	--	1.4
60,000	--	.6
70,000	--	.3
100,000	--	--

Decline of water levels eastward from the center of pumping would be less than the preceding tabulated figures because the effects of the assumed barrier decrease eastward.

Source of Recharge for Santa Fe Aquifer

The data given in our 1976 report include sea-level elevations of the water table (p. 18) and a discussion of the various factors affecting the water levels as determined (p. 19-21). The gradient of the water table as indicated by the water levels discussed in the report is clearly downward from west to east toward the Rio Grande, flattening eastward from about 200 feet per mile near the mountain front, decreasing to about 100 feet per mile and then to about 10 feet per mile in the vicinity of the well field. The eastward down-gradient direction of the water table indicates that ground water in the Santa Fe Formation is moving eastward, which in turn indicates that the sources of ground-water recharge are to the west. The north-south alignment of the water table contours indicates that the recharge is fairly uniform and is not concentrated in one place. In the western United States, hydrologic investigations during the past half century have indicated that ground-water recharge from rain falling directly on the desert floors is not great but that runoff in desert washes and mountain-front recharge are the major factors in replenishing the ground-water supply. In our opinion, the sources of recharge for the Santa Fe aquifer in the vicinity of the well field are infiltration of runoff from desert flood flows in Greyback Arroyo, Greenhorn Arroyo, Las Animas Creek, and Percha Creek plus mountain-front recharge.

Effect Upon Water Levels Along Animas Creek

Our April 1976 report discusses the fact that water levels in wells in the valley of Animas Creek are shallower than water levels in deep wells in the Santa Fe Formation by about 80 to 150 feet (p. 21-22). We consider that, although Las Animas Creek is a source of recharge to the Santa Fe Formation aquifer system, the low vertical permeability in the upper part of the Santa Fe Formation slows down the vertical percolation and permits existence of a perched shallow water table in the permeable younger sediments of the ancestral Las Animas Creek.

When water is moving vertically downward underground, the hydraulic head that is a component of that movement is 100 percent, one foot per foot. The factor that controls the downward rate of movement is the permeability of the materials through which the water is moving. If the upper portion of the Santa Fe Formation were highly permeable, all water in the younger alluvium along Las Animas Wash would readily sink, leaving the Las Animas Creek sediments dry and causing a higher water level in the underlying Santa Fe deposits.

Because of the existence of this blanket of finer-grained sediments between the coarse materials underlying Las Animas Creek and the permeable facies of the Santa Fe Formation from which the well field will produce, a water-level decline of about 18 feet in the Santa Fe Formation beneath the axis of Las Animas Creek after 15 years of pumping is not likely to lower water levels in shallow wells tapping the younger Las Animas Creek shoestring aquifer. The vertical gradient cannot increase above 100 percent and that is the gradient now, based on the data collected during the investigation in 1975-1976.

The chapter on quality of water in our 1976 report indicated a difference in chemical character exists between the shallow ground water along Las Animas Creek and the deeper ground water in the Santa Fe Formation (p. 24 and 27, Fig. 10 on p. 26). This confirms our opinion that there is not a direct connection between ground water in the two aquifer systems.

Subsurface Channels Within Santa Fe Formation

Geological field work during the course of our investigation in 1975-1976 indicated the existence of a coarser facies within the uppermost part of the Santa Fe Formation along an axis roughly from north-northwest to south-southeast visible in the canyon walls of Las Animas Creek and Lower Percha Creek. The Quintana well field is situated within this zone. The uppermost visible coarse-grained portion of the formation is underlain by a finer-grained zone which in turn is underlain by a coarser zone. The Quintana wells produce from the lower coarse zone. It is not known whether the trend of this lower coarse zone also is northwest-southeast. We have found no geological nor hydrological evidence of an "underground stream" trending in any direction. Instead the data indicate the well field is situated in a more permeable zone within the Santa Fe Formation, with ground water movement from west to east.

Were there to exist an underground stream along an axis from north-northwest to south-southeast, with recharge from a source somewhere to the north-northwest, pumping from the well field would not affect water levels upgradient beyond about 13 miles as shown in the tabulation set forth in a preceding part of this letter.

Respectfully submitted,
Water Development Corporation

By ______________________________
Leonard C. Halpenny, President

PRODUCTION WELL NO. 1
CUTTING LOG

(Prepared by B. Y. Kim, Geologist, Quintana Minerals Corporation)

Depth From (ft)	To	Pebble	Granule	Coarse Sand	Medium Sand	Fine Sand	Silt and Clay
30	50				30%	60%	10%
50	70	40%	50%	10%			
70	90	Minor	70%-80%	20%-30%	Minor	Minor	Minor
90	110	60%	30%	10%			
110	140	Minor	40%	40%	10%	5%	5%
140	160	60%	30%	10%			
160	180	20%	70%	10%			
180	200		Minor	20%	30%	30%	20%
200	220	10%	50%	40%			
220	240		Minor	20%	30%	20%	30%
240	250		60%	30%	Minor	5%	5%
250	270			Minor	10%-20%	40%	40%-50%
270	290	20%	40%	35%	Minor	Minor	5%
290	300		Minor	20%	30%	20%	30%
300	340		60%	30%	Minor	5%	5%
340	360		Minor	20%	20%	30%	30%
360	620	Minor	40%-70%	10%-30%	Minor	5%-15%	5%-15%
620	640		5%	5%	20%	30%	40%
640	660		40%	40%	Minor	10%	10%-20%
660	670	30%	40%	20%			10%
670	760	20%	40%	20%	Minor	5%	15%
760	770		5%	5%	20%	30%	40%
770	790	20%	40%	20%	Minor	5%	15%
790	800		Minor	10%	20%	40%	30%
800	960		40%-60%	10%-30%	5%	5%	20%

Well cuttings 360-620 feet generally uniform with coarse material (0.5mm) 60%-90%.

A few peanut-sized gravel at 880-890 feet with less amount of fine material; marked increase of fine material at 910-920 feet.

PRODUCTION WELL NO. 1
CUTTING LOG
(continued)

The following size ranges have been established from Wentworth Scale for classification of clastic sedimentary rock. The above log has been done by visual estimation according to the scale.

Pebble	Above 4 mm
Granule	2 mm - 4 mm
Coarse Sand	Very coarse - 1 mm - 2 mm Coarse - 0.5 mm - 1 mm (1/2 mm - 1 mm)
Medium Sand	0.25 mm - 0.5 mm (1/4 mm - 1/2 mm
Fine Sand	Fine - 0.125 mm - 0.25 mm (1/4 mm 1/8 mm) Very fine - 0.0625 mm - 0.125 mm (1/8 mm - 1/16 mm)
Silt and Clay	Less than 0.0625 mm (less than 1/16 m

PRODUCTION WELL NO. 1
DRILLERS LOG

Depth From (ft)	To	Sample Description
30	45	Fine silt.
45	50	Sand and silt.
50	55	Very hard rock.
55	90	Sand and rock.
90	105	Gravel and trace of clay.
105	115	Basalt, sand, little clay.
115	125	Basalt, sand.
125	135	Sand, clay, and some basalt.
135	155	Sand and rock.
155	165	Rock and some sand.
165	175	Small gravel and sand.
175	185	Clay with 5% sand.
185	195	Clay with 25% sand, some gravel.
195	206	Clay with gravel, 5% sand.
206	216	Gravel pediment with sand.
216	218	Clay.
218	222	Gravel pediment with 5% sand.
222	245	Clay.
245	255	Sand with cobbles, very hard.
255	265	Clay with 2% sand.
265	275	Sandy clay.
275	285	Sand and gravel.
285	295	Gravel and sand.
295	305	Sand and gravel with 80% clay.
305	315	Sand, gravel, and clay.
315	320	Gravel and clay.
320	325	Gravel, rock, and clay.
325	335	Basalt and rock.
335	340	Gravel and rock.
340	345	Clay and gravel.
345	355	Clay.
355	360	Clay and sand.
360	375	Sand and rock.
375	390	Sand, gravel, and clay.
390	406	Sand, rock, and clay.
406	415	Clay, sand, and gravel.
415	435	Sand and gravel.

PRODUCTION WELL NO. 1
DRILLERS LOG
(continued)

Depth From - To (ft)	Sample Description
435 - 445	Sand and some gravel.
445 - 469	Sand and little clay.
469 - 475	Sand and rock.
475 - 495	Pediment gravels, some sand.
495 - 505	Clay, 20% gravel.
505 - 525	Clay and gravel.
525 - 555	Sand and gravel.
555 - 565	Sand and 80% clay.
565 - 575	Sand, gravel, and some clay.
575 - 585	Sand and gravel.
585 - 590	Clay, sand, and gravel.
590 - 595	Sand and gravel.
595 - 605	Gravel and clay.
605 - 615	Clay, sand, and gravel.
615 - 620	Gravel and sand.
620 - 625	Sand.
625 - 630	Sand, gravel, 90% clay.
630 - 635	Clay.
635 - 645	Sand, 95% clay.
645 - 655	Sand, 35% clay.
655 - 665	Clay 50%, sand 50%.
665 - 675	Coarse sand 35%, gravel 35%, clay 30%.
675 - 685	Coarse sand, gravel.
685 - 709	Coarse sand 50%, gravel 20%, clay 30%.
709 - 715	Coarse sand 50%, gravel 10%, clay 40%.
715 - 725	Coarse sand 70%, gravel 20%, clay 10%
725 - 765	Gravel, clay, and sand.
765 - 785	Clay and gravel.
785 - 797	Sand, gravel, and clay.
797 - 805	Clay, sand, and gravel.
805 - 815	Sand 75%, gravel 10%, clay 15%.
815 - 835	Sand, gravel, and clay.
835 - 845	Sand 80%, gravel 15%, clay 5%.
845 - 850	Sand, clay, and gravel.
850 - 858	Sand and clay.
858 - 860	Clay and sand.
860 - 875	Sand.
875 - 888	Sand, some clay.

PRODUCTION WELL NO. 1
DRILLERS LOG
(continued)

Depth From	To (ft)	Sample Description
888	895	Sand, gravel, and clay.
895	905	Sand and clay.
905	917	Sand and gravel.
917	935	Clay 85%, gravel 5%, sand 10%.
935	947	Clay, gravel, and sand.
947	960	Clay, sand, and gravel.

PRODUCTION WELL NO. 1

DEVELOPMENT DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-18-75	09:48	329.3		Measuring with sounder. Measuring point top of 3/4-inch tube 1.65 feet above top of surface pipe. Surface pipe approximately 0.2 feet above land surface.
	10:00			Pump on. Eight-inch pump with bowls set at 550 feet. Discharge pipe 10-inch, orifice 6-inch.
	10:01	357.9		Decreasing RPM.
	10:02	348.9	370	Muddy, silty.
	10:03	345.3	395	
	10:04	344.4	370	Trace of sand.
	10:12	346.3	395	Clearing some.
	10:13			Increased RPM.
	10:14	350.0	500	
	10:15	350.6	500	Some mud, silt, trace of sand.
	10:20	352.1	500	
	10:27	352.4	500	
	10:44	353.1	500	Clearing.
	10:55			Surge.
	10:58			Lowering impellers.
	11:00			Pump on.
	11:05	350.3	500	Some color.
	11:12			Fairly clear, surge twice.
	11:18		760	Muddy, silty, no sand.
	11:19	358.8		
	11:25	360.8	760	Considerable color, silty.
	11:40	362.3	773	Clearing.
	11:45			T = 76^{o} F, K = 350 micromhos.
	11:50	362.7	773	Fairly clear, surge twice.
	11:56			Silty.
	11:58		760	Clearing.
	12:00	356.9	760	

PRODUCTION WELL NO. 1

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-18-75	12:15	358.7	760	Fairly clear.
	12:22	359.0	760	T = 76° F, K = 340+ micromhos.
	12:23			Surge twice.
	12:30			Little mud and silt.
	12:33			Clearing.
	12:35	355.9	760	Fairly clear.
	12:40			Surge twice.
	12:47			Some color, no sand.
	12:50			Clearing.
	13:19	356.7	760	Surge twice.
	14:07	356 2	760	Clear, surge twice.
	14:15			Little color.
	14:18	353.1	760	Clear.
	14:20			Surge, change to 8-inch orifice.
	14:27			Pump on.
	14:29			Some color, no sand.
	14:30	358.4	1,040	
	14:35	361.6		
	14:52	363.7	1,060	Slight color.
	14:58	364.2	1,060	Surge.
	15:05			Fair amount of color, silt, no sand.
	15:08			Clearing.
	15:10	362.1	1,040	T = 76° F, K = 350 micromhos.
	15:30	363.8	1,050	Surge.
	15:35			Fair amount of color, silt.
	15:40			Clearing.
	15:58	361.8	1,030	Clear, surge twice.
	16:03			Some color, silt.
	16:28	363.5	1,060	Clear, surge twice.
	16:33			Some color, silt.
	16:37			Clearing.
	17:00	362.8	1,050	

PRODUCTION WELL NO. 1

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-18-75	17:05	378.6	1,500	Some color, no sand.
	17:10			Considerable color, silt.
	17:13	382.5	1,471	Lot of color, silt, $<$ 0.1 cc/l sand.
	17:19	382.2	1,438	
	17:28	382.6	1,421	
	17:38	382.5	1,404	Surge.
	17:45			Some color, silt.
	18:00	387.0	1,500	Surge twice.
	18:30		1,500	Surge.
	19:00		1,500	Surge.
	19:30		1,500	Surge.
	19:50	386.0	1,500	
	20:10			Surge twice.
	20:15		1,500	Some color.
	20:38	385.1	1,500	Clear, surge.
	21:07	383.6	1,493	Clear, surge twice.
	21:12			Some color, no sand.
	21:38	382.0	1,486	T = 76^{o} F, K = 340 micromhos, clear, surge twice.
	21:45			Some color.
	22:20	381.2	1,493	Clear, surge twice.
	22:25			Some color.
	23:04	381.2	1,507	Clear, surge twice.
	23:10			Some color, silt.
	23:35	379.9	1,500	Clear, surge twice.
	23:40			Some color.
12-19-75	00:05	378.9	1,493	Clear, surge twice.
	00:10			Little color.
	00:30	378.4	1,493	Clear, surge twice.
	00:34	375.1	1,500	
	00:55	378.9	1,500	Clear, surge twice.
	01:05	375.7	1,500	Clear.
	01:40	378.6	1,500	Clear, surge twice.
	02:10	377.8	1,500	Clear, surge twice.

PRODUCTION WELL NO. 1

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-19-75	02:40	377.4	1,493	Clear, surge twice.
	03:10	377.0	1,500	Clear, surge twice.
	03:40	376.6	1,486	Clear, surge twice.
	04:10	376.3	1,493	Clear, surge twice.
	04:45	376.3	1,500	Clear, surge twice.
	05:15	375.7	1,493	Clear, surge twice.
	05:45	376.1	1.500	Clear, surge twice.
	06:15	376.6	1,500	Clear, surge twice.
	06:45	376.6	1,500	Clear, surge twice.
	07:00	377.0	1,500	Clear, surge twice.
	07:05			Very little color.
	07:30	376.0	1,493	Clear.
	07:35			T = 76^{o} F, K = 340 micromhos.
	08:28	376.0	1,500	Clear.
	08:29			Increase RPM.
	08:30	380.9	1,641	
	08:32			Some color.
	08:33			Clearing.
	08:45	382.1	1,641	Clear, surge.
	08:50			Some color, then clear.
	09:00	381.5	1,634	Clear.
	09:15	381.9	1,634	Clear.
	09:18			T = 76^{o} F, K = 340 micromhos.
	09:30	382.2	1,627	
	09:50	382.5	1,627	Clear.
	10:00			Pump off.
	10:01	338.4		
	10:02	338.1		
	10:03	339.8		
	10:04	339.3		
	10:05	338.6		
	10:06	338.3		
	10:07	337.8		

PRODUCTION WELL NO. 1

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-19-75	10:08	337.5		
	10:09	337.2		
	10:10	336.8		
	10:15	335.7		
	10:20	335.0		
	10:30	334.1		
	10:38	333.4		
	12:09	330.4		
	13:18	329.8		
	14:03	329.5		
	15:40	329.1		
	15:47	332.77		Measured with chain.

PRODUCTION WELL NO. 1

TEST DATA

cofpw1.wk1

time (min) C6..c98
WL d6..d98
MW-5 WL e6..e98

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-20-75	08:00	331.82		Measured with chain. Same measuring point as for development.
	09:22	331.82		Measured with chain.
	09:32	331.8		Set sounder at 331.8.
	11:00	331.8 −1.85 = 330.0 GL		Pump on. Same setting as for development.
	11:01	360.8	1,500	
	11:02	363.5	1,500	
	11:03	365.9	1,500	
	11:04	367.2	1,500	
	11:05	367.9	1,500	
	11:06	368.5	1,500	Clear.
	11:07	369.2	1,500	
	11:08	369.7	1,500	
	11:09	370.1	1,500	
	11:10	370.2	1,500	
	11:12	370.8	1,500	
	11:14	371.1	1,500	
	11:16	371.4	1,500	
	11:18	371.8	1,500	
	11:20	372.0	1,500	
	11:25	372.6	1,500	
	11:30	373.3	1,500	
	11:35	373.7	1,500	
	11:40	374.1	1,500	
	11:50	374.7	1,500	
	12:00	375.0	1,500	
	12:15	375.5	1,500	
	12:30	376.0	1,500	
	12:45	376.3	1,500	
	13:00	376.7	1,500	
	13:30	377.4	1,500	
	14:00	377.6	1,500	
	15:00	378.2	1,500	

PRODUCTION WELL NO. 1

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-20-75	16:00	378.6	1,500	Clear.
	17:00	379.2	1,500	
	18:00	379.3	1,500	
	19:00	379.6	1,500	
	20:00	379.9	1,500	
	21:00	380.2	1,500	
	22:00	380.4	1,500 +	Decrease RPM.
	23:00	380.3	1,500	
	24:00	380.4	1,500	
12-21-75	01:00	380.4	1,500	
	01:50			T = 76° F, K = 340 microm-hos.
	02:10	380.4	1,500	
	03:00	380.6	1,500	
	04:00	380.6	1,500	
	05:00	380.8	1,500	
	06:00	380.0	1,486	Increase RPM.
	06:50			T = 76° F, K = 340 microm-hos.
	07:00	381.0	1,500	
	08:00	381.1	1,500	
	09:00	381.4	1,500	
	10:00	381.4	1,500 +	Decrease RPM.
	11:00	381.3	1,500	
	12:00	381.2	1,500	
	13:00	381.3	1,500	
	13:15			T = 76° F, K = 340 microm-hos.
	14:20	381.3	1,500 -	Increase RPM.
	15:00	381.3	1,500	
	16:00	381.2	1,500	
	17:00	381.4	1,500	
	18:00	381.4	1,500	
	19:00	381.4	1,500	
	20:00	381.4	1,500	

PRODUCTION WELL NO. 1

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-21-75	21:00	381.5	1,500	
	22:00	381.7	1,500 +	Decrease RPM.
	23:00	381.4	1,500	
	24:00	381.4	1,500	
12-22-75	02:00	381.5	1,500	
	03:00	381.4	1,500	
	04:00	381.4	1,500	
	05:00	381.7	1,500	
	06:00	381.4	1,486	Increase RPM.
	07:00	381.0	1,500	
	08:00	381.3	1,500	
	09:00	381.4	1,500 +	Decrease RPM.
	10:00	381.4	1,500	
	11:00	381.4	1,500	
	12:00	380.7	1,500 -	Increase RPM.
	13:00	381.1	1,500	
	14:00	381.3	1,500	
	14:30	381.3	1,500	
	15:00	381.4	1,500	
	16:00	381.4	1,500	
	17:00	381.4	1,500	
	18:00	381.6	1,500	
	19:10	381.6	1,500	
	24:00	382.0	1,500	
12-23-75	03:00	381.7	1,500	
	07:00	381.6	1,500	
	08:45	381.6	1,500	T = 76^{o} F, K = 340 micromhos. Collected water samples
	09:00			Pump off.
	09:01	340.9		
	09:02	342.7		
	09:03	342.2		
	09:04	341.6		
	09:05	341.3		
	09:06	341.1		
	09:07	340.2		
	09:18	338.8		
	09:30	337.5		

PRODUCTION WELL NO. 1

TEST DATA

(Observation Well MW-5 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
12-18-75	07:55	335.58	Measured with chain. Measuring point top of 6-inch casing approximately 1 foot above land surface.
	08:10	335.57	Measured with chain. Set sounder with tape mark at 335.57.
	10:00		PW-1 pump on for development.
	10:52	337.15	
	14:48	339.33	
12-19-75	07:40	344.03	
	09:12	344.54	
	10:00		PW-1 pump off.
	10:24	342.18	
	12:06	338.91	
	13:22	338.22	
	14:10	337.95	
	15:32	337.63	
12-20-75	07:43	336.73	Measured with chain. Set sounder with tape mark at 336.73.
	09:46	336.69	
	11:00	336-69	PW-1 pump on for test.
	11:01	336.73	
	11:02	336.90	
	11:03	337.14	
	11:04	337.32	
	11:05	337.52	
	11:06	337.61	
	11:07	337.81	
	11:08	337.89	
	11:09	338.05	
	11:10	338.19	
	11:11	338.31	
	11:12	338.47	
	11:13	338.51	
	11:14	338.62	

PRODUCTION WELL NO. 1

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-20-75	11:15	338.77	
	11:16	338.82	
	11:17	338.93	
	11:18	339.00	
	11:19	339.16	
	11:20	339.19	
	11:23	339.45	
	11:25	339.67	
	11:30	339.89	
	11:35	340.08	
	11:40	340.30	
	11:45	340.41	
	11:50	340.65	
	12:00	341.00	
	12:15	341.30	
	12:30	341.69	
	12:45	341.86	
	13:00	342.18	
	13:30	342.52	
	14:00	342.75	
	15:05	343.18	
	16:05	343.42	
	17:05	343.61	
	18:05	343.74	
	19:05	344.09	
	20:05	344.12	
	21:10	344.24	
	22:10	344.36	
	23:10	344.43	
12-21-75	00:10	344.51	
	01:30	344.54	
	02:00	344.68	
	03:05	344.75	
	04:05	344.81	

PRODUCTION WELL NO. 1

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-21-75	05:05	344.87	
	06:05	344.87	
	07:05	344.83	
	08:05	345.02	
	09:05	345.00	
	10:05	345.02	
	11:05	345.03	
	12:05	345.07	
	13:05	345.06	
	14:15	345.03	
	15:05	345.10	
	16:05	345.10	
	17:05	345.18	
	18:05	345.16	
	19:05	345.16	
	20:05	345.23	
	21:05	345.22	
	22:05	345.25	
	23:05	345.27	
12-22-75	00:05	345.31	
	01:25	345.21	
	02:00	345.52	
	03:05	345.44	
	04:05	345.39	
	06:05	345.37	
	07:05	345.32	
	08:05	345.38	
	09:05	345.52	
	10:05	345.54	
	11:05	345.58	
	13:10	345.54	
	14:10	345.54	
	15:05	345.61	
	16:05	345.57	

PRODUCTION WELL NO. 1

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-22-75	17:05	345.66	
	18:05	345.63	
	19:05	345.58	
12-23-75	00:10	345.70	
	03:10	345.78	
	07:10	345.71	
	08:50	345.79	
	09:00		PW-1 pump cff.
	09:14	344.08	
	09:25	343.20	
	09:45	342.15	

BC LABORATORIES Inc.
OIL - CORES - SOIL - WATER
3016 UNION AVENUE
BAKERSFIELD, CALIFORNIA 93305
Phone (805) 325-7475
J. J. EGLIN, Reg. Chem. Engr.

Submitted By: Water Development Corporation
3839 Santa Barbara Ave.
Tucson, Arizona 85711

Date Reported: 1/16/76
Date Received: 1/8/76
Laboratory No.: 9939

Marked: Quintana No. 1 12/23/75 08:45 T: 76° K: 340

WATER ANALYSIS

Sample Description:

pH	7.8
E.C. Micromhos/cm (K x 10^6) @ 25°C (salinity)	
Resistivity, Ohm M^2/M	

Constituents, P. P. M. (parts per million)

Boron, (B)	
Calcium, (Ca)	22.
Magnesium, (Mg)	2.8
Sodium, (Na)	38.
Potassium, (K)	4.5
Carbonates, (CO_3)	0.
Bicarbonates, (HCO_3)	144.6
Chlorides, (Cl)	16.3
Sulphates, (SO_4)	10.
Nitrate, (NO_3)	3.53
Fluoride, (F)	0.46
Total Iron, (Fe)	
Copper, (Cu)	
Manganese, (Mn)	
Chromium, (Cr)	
Zinc, (Zn)	
Aluminum, (Al)	
Silica, (SiO_2)	
Lithium, (Li)	
Lead, (Pb)	
Phenol	
Sulfides as H_2S	
Total Hardness as $CaCO_3$	
Oil (chloroform extractable)	
Total Dissolved Solids	217. @ 180°F.
Total Suspended Solids	

BC LABORATORIES Inc.

By: J. J. Eglin

PRODUCTION WELL NO. 2
CUTTING LOG

(Prepared by B.Y. Kim, Geologist, Quintana Minerals Corporation)

Depth From	To (ft)	Pebble	Granule	Coarse Sand	Medium Sand	Fine Sand	Silt and Clay
30	40			50%	20%	10%	20%
40	100	Minor	40%-60%	30%-50%			Minor
100	110		40%	10%	10%	20%	20%
110	150		40%	40%	5%	5%	10%
150	160		10%	20%	20%	25%	25%
160	210	Minor	50%-60%	40%-50%			Minor
210	250			10%	20%	30%	40%
250	260	Minor	60%	20%	5%	5%	10%
260	270			10%	20%	40%	30%
270	290	20%	60%	20%			Minor
290	300		10%	30%	20%	20%	20%
300	310	20%	70%	10%			Minor
310	330	Minor	30%	50%	5%	5%	10%
330	370		Minor	20%	20%	30%	30%
370	440		30%	40%	10%	10%	10%
440	450			Minor	30%	50%	20%
450	900	0%-20%	20%-40%	20%-30%	0%-10%	10%-20%	10%-20%
900	910		5%	15%	20%	20%	30%
910	920	20%	50%	Minor	Minor	10%	20%
920	960	Minor	20%-30%	30%-40%	10%	10%-20%	20%
960	970	Minor	50%	30%	Minor	Minor	20%
970	990		20%	20%	10%	20%	30%
990	1005			Minor	Minor	Minor	90%

No sample from 530-540 feet; 20% pebble at 610-620 feet.

Average for the above interval 450-900 feet:

10%	30%	30%	5%	10%	15%

PRODUCTION WELL NO. 2
CUTTING LOG
(continued)

The following size ranges have been established from Wentworth Scale for classification of clastic sedimentary rock. The above log has been done by visual estimation according to the scale.

Pebble	Above 4 mm
Granule	2 mm - 4 mm
Coarse Sand	Very coarse - 1 mm - 2 mm Coarse - 0.5 mm - 1 mm (1/2 mm - 1 mm)
Medium Sand	0.25 mm - 0.5 mm (1/4 mm - 1/2 mm)
Fine Sand	Fine - 0.125 mm - 0.25 mm (1/4 mm - 1/8 mm) Very fine - 0.0625 mm - 0.125 mm (1/8 mm - 1/16 mm)
Silt and Clay	Less than 0.0625 mm (less than 1/16 mm

PRODUCTION WELL NO. 2
DRILLERS LOG

Depth From (ft)	Depth To (ft)	Sample Description
45	65	Sand, rock, and gravel.
65	105	Sand and gravel.
105	115	Clay and sand.
115	125	Sand and gravel.
125	135	Sand, gravel, and clay.
135	145	Sand and gravel.
145	155	Sand, gravel, and clay.
155	165	Clay and gravel.
165	215	Sand and gravel.
215	225	Clay and fine sand.
225	250	Clay and sand.
250	255	Clay and gravel.
255	265	Cobbles, gravel, and sand.
265	275	Clay with 10% rock.
275	285	Gravel and sand.
285	295	Sand and gravel.
295	305	Clay and sand.
305	315	Sand and gravel.
315	325	Sand, gravel, and 2% clay.
325	335	Sand, gravel, and 15% clay.
335	345	Clay.
345	355	Clay and 5% sand.
355	365	Clay, sand, and gravel.
365	375	Clay and fine sand.
375	385	Clay, sand, and gravel.
385	415	Sand, gravel, and clay.
415	435	Sand, gravel, and trace of clay.
435	445	Sand and clay.
445	455	Clay with sand.
455	465	Clay 50%, sand 50%.
465	475	Clay and sand.
475	485	Sand 60%, gravel 35%, clay 5%.
485	495	Sand 90%, clay 10%.
495	505	Sand, clay, and gravel.
505	515	Sandy clay with caliche, gravel.
515	525	Sandy clay with caliche, some gravel.

PRODUCTION WELL NO. 2
DRILLERS LOG
(continued)

Depth From (ft)	To	Sample Description
525	540	Sand and clay.
540	550	Gravel 90%, clay 10%.
550	553	Gravel 70%, clay 30%.
553	555	Gravel 80%, clay 20%.
555	560	Gravel and clay.
560	565	Gravel 60%, clay 40%.
565	575	Sand and gravel.
575	580	Sand 80%, clay 20%.
580	583	Gravel 70%, clay 30%.
583	585	Gravel 80%, clay 20%.
585	590	Clay 70%, sand 30%.
590	600	Rock, clay, and gravel.
600	605	Rock 50%, clay 50%.
605	610	Gravel.
610	613	Gravel 10%, clay.
613	620	Sand, 20% clay.
620	625	Clay and gravel, hard.
625	635	Gravel, 5% clay.
635	640	Rock, 10% clay, and sand.
640	643	Rock, basalt, hard.
643	645	Clay and some sand.
645	675	Gravel 50%, clay 50%
675	701	Clay, sand, and gravel.
701	705	Gravel 65%, clay 35%.
705	710	Gravel 50%, clay 50%.
710	720	Clay 55%, gravel 45%.
720	725	Gravel 60%, clay 40%.
725	735	Gravel 65%, clay 35%.
735	750	Gravel 70%, clay 30%.
750	765	Sand,80%, clay 20%.
765	775	Gravel 80%, clay 20%.
775	789	Gravel 90%, clay 10%.
789	795	Clay, sand, and gravel.
795	800	Sand and clay.
800	805	Clay and sand.
805	835	Sand and gravel, clay 65%.
835	855	Clay, sand, and gravel.

PRODUCTION WELL NO. 2
DRILLERS LOG
(continued)

Depth From (ft)	To	Sample Description
855	865	Gravel.
865	885	Gravel 85%, clay 15%.
885	905	Coarse sand,85%, clay 15%.
905	915	Clay 65%, coarse sand 35%.
915	925	Gravel, sand, and clay, equal amounts.
925	935	Clay 40%, gravel 30%, sand 30%.
935	945	Clay 75%, sand 25%.
945	955	Clay 90%, sand 10%.
955	965	Gravel, sand, clay stringers.
965	975	Gravel and sand, 10% clay.
975	985	Gravel 50%, clay 50%.
985	995	Sand 60%, clay 40%.
995	1005	Clay.

PRODUCTION WELL NO. 2

DEVELOPMENT DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-10-76	12:36	309.4		Measuring with sounder. Measuring point top of 3/4-inch tube 0.95 foot above top of surface pipe. Surface pipe approximately 0.5 foot above land surface.
	12:44	309.4		
	12:45			Pump on. Ten-inch pump with bowls set at 460 feet Discharge pipe 10-inch, orifice 6-inch.
	12:47	331.8	550	Dirty.
	12:48	331.3		
	12:50	331.7		Lot of color, 0.5 cc/l, fine sand, soapy.
	12:58	332.2	550	Color decreasing, 0.1 cc/l fine sand, soapy.
	13:08	333.3	568	Color decreasing, 0.1 cc/l fine sand,
	13:09			Pump off.
	13:11	284.3		
	13:12	305.7		
	13:13	309.7		
	13:14	310.5		
	13:15	310.8		
	13:19	310.6		
	13:20			Pump on.
	13:24	333.0	550	Lot of color, 0.3 cc/l fine sand.
	13:30	333.7	550	Clearing some, 0.1 cc/l fine sand.
	13:40	334.6	559	Muddy, silty.
	14:00		550	Fairly clear, surge once.
	14:07		550	Lot of color, 0.3 cc/l fine sand.

PRODUCTION WELL NO. 2

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-10-76	14:35	332.4	520	Fairly clear, surge once, change to 8" orifice.
	14:42	374.7	1,040	
	14:45			Lot of color, less than 0.1 cc/l sand.
	15:00	351.4	1,016	Fairly clear, surge once.
	15:05			Lot of color, silt, less than 0.1 cc/l fine sand.
	15:30	352.3	1,040	Fairly clear, surge twice.
	15:37			Lot of color, silt, 0.1 cc/l fine sand.
	16:00	351.4	1,040	Fairly clear, surge twice.
	16:08			Lot of color, silt, 0.2 cc/l fine sand.
	16:30	349.8	1,040	Fairly clear, surge twice.
	16:47			Lot of color, silt, 0.3 cc/l fine sand.
	17:00	349.2	1,016	Fairly clear, surge twice.
	17:10	365.9	1,500	Lot of color, silt, 0.1 cc/l fine sand.
	17:30	373.2	1,500	Fairly clear, surge twice.
	17:38			Lot of color, silt, 0.1 cc/l fine sand. T = 74^{o}F, K = 370 micromhos.
	18:00	372.1	1,486	Fairly clear, surge twice.
	18:07			Lot of color, silt.
	18:30	371.9	1,486	Fairly clear, surge twice.
	19:00	371.4	1,486	Surge twice.
	19:30	370.9	1,500	Surge twice.
	20:00	367.4	1,486	Surge twice.
	20:30	369.4	1,500	Fairly clear, surge twice.
	20:35			Less than 0.01 cc/l fine sand.
	21:00	369.1	1,486	Surge twice, straw color, clears quickly.
	21:30	369.0	1,486	Surge twice, slight color.

PRODUCTION WELL NO. 2

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-10-76	22:00	369.0	1,500	Surge twice, clear.
	22:30	369.0	1,486	Surge twice, straw color.
	23:00	368.4	1,486	Surge twice, clear.
	23:30	369.0	1,500	Surge twice, clear.
	24:00	368.4	1,486	Surge twice, straw color. Increase RPM.
01-11-76	00:30	394.6	1,940	Surge twice, some color.
	01:00	395.0	1,928	Surge twice, straw color, clears quickly. Entrained air showing in discharge.
	01:30	395.8	1,928	Surge twice, straw color.
	02:00	396.7	1,928	Surge twice, straw color.
	02:30	397.4	1,928	Surge twice, straw color.
	03:00	398.0	1,928	Surge twice, straw color.
	03:30	399.9	1,928	Surge twice, straw color.
	04:00	400.0	1,920	Surge twice, straw color, clears quickly.
	04:30	399.9	1,928	Surge twice, some color.
	05:00	399.8	1,928	Surge twice, some color.
	05:30	398.1	1,928	Surge twice, some color.
	06:00	397.4	1,928	Surge twice, straw color, clears quickly.
	06:30	400.0	1,970	Surge twice, some color.
	07:00	404.4	1,970	Surge twice, considerable color.
	07:30	400.9	1,940	Fairly clear, surge twice.
	07:37			Some color, silt.
	08:00	398.2	1,920	Clear, surge twice.
	08:06			Some color, clearing within 2 minutes.
	08:30	399.0	1,940	Clear, surge twice
	09:07			Some color, increase RPM.
	09:10		2,115	Clearing.
	09:15	412.0	2,212	More color showing, no sand.
	09:30	419.0	2,200	Clear, surge twice.

PRODUCTION WELL NO. 2

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-11-76	09:37			Some color, clearing in 2 minutes.
	10:00	419.0	2,200	Clear, surge twice.
	10:08			Some color, less than 0.1 cc/l sand. Clearing in 2 minutes.
	10:30	418.7	2,212	Clear.
	10:37			Some color, clearing in 2 minutes, no sand.
	10:40			T = 76° F, K = 350 micromhos.
	11:00	418.0	2,200	Clear, surge twice.
	11:07			Some color, clearing in 2 minutes, no sand.
	11:30	417.6	2,200	Clear, surge twice.
	11:37			Some color, clearing in 2 minutes, no sand.
	12:00	418.7	2,200	Clear, surge twice.
	12:07			Some color, clearing in 2 minutes, no sand.
	12:40	412.7	2,115	Clear.
	12:45			Pump off.
	12:46	321.9		
	12:47	326.5		
	12:48	330.6		
	12:49	330.0		
	12:50	328.9		
	12:51	328.0		
	12:52	327.3		
	12:53	326.5		
	12:54	325.8		
	12:55	325.2		
	13:00	322.8		
	13:05	321.3		
	13:10	320.2		
	13:15	319.3		
	13:51	316.1		
	16:06	312.8		

PRODUCTION WELL NO. 2

cwfpw2.wk1

time = c6..c102
Pwl = d6..d102

TEST DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-12-76	08:46	310.4 – 1.45 = 309.0 GL		Measuring with sounder. Same measuring point as for development.
	09:30			Pump on. Same setting as for development.
	09:31	366.4	2,020	Clear.
	09:32	370.4	2,020	
	09:33	373.9	2,020	
	09:34	376.2	2,020	
	09:35	378.0	2,020	
	09:36	379.6	2,020	
	09:37	380.7	2,020	
	09:38	381.7	2,020	
	09:39	382.6	2,020	
	09:40	383.3	2,020	
	09:45	386.6	2,020	
	09:50	388.8	2,020 +	Decrease RPM.
	09:55	390.3	2,020	
	10:00	391.7	2,020	Entrained air in discharge.
	10:10	393.5	2,020	
	10:20	395.7	2,020	
	10:30	396.3	2,020	
	10:40	397.8	2,020	
	10:50	398.4	2,020	
	11:00	399.1	2,020	
	11:17	400.1	2,020	
	11:30	400.3	2,020	
	11:45	401.1	2,020	
	12:00	401.4	2,020	
	12:15	402.3	2,040	Decrease RPM.
	12:30	401.3	2,020	
	12:45	401.3	2,020	
	13:00	401.3	2,020	
	13:17			T = 75°F, K = 335 micromhos.

PRODUCTION WELL NO. 2

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-12-76	13:30	401.9	2,020	
	14:00	402.9	2,020	
	14:30	402.8	2,020 -	Increase RPM.
	15:00	402.9	2,020	
	16:00	403.7	2,020	
	17:00	404.3	2,020 -	Increase RPM.
	18:00	405.2	2,020	
	19:00	405.1	2,020	
	20:00	405.7	2,020	
	21:00	406.1	2,020	
	22:00	406.8	2,020	
	23:00	407.6	2,020	
	24:00	408.0	2,020	
01-13-76	01:00	408.9	2,020	
	02:00	409.1	2,020	
	03:00	409.2	2,020 +	Decrease RPM.
	04:00	408.5	2,020	
	05:00	409.1	2,020	
	06:00	408.1	2,020 -	Increase RPM.
	07:00	409.3	2,020	
	08:00	409.3	2,020	
	09:00	409.4	2,020	
	10:00	409.4	2,020	
	11:00	409.2	2,020	
	12:00	410.2	2,020	
	13:00	410.6	2,020	
	13:50		2,020 +	T = 76°F, K = 350 micromhos. Decrease RPM.
	14:00	410.0	2,020	
	15:00	410.0	2,020	
	16:00	410.1	2,020	
	17:00	410.2	2,020	
	18:00	411.3	2,020	
	19:00	411.2	2,020	
	20:00	410.1	2,020	

PRODUCTION WELL NO. 2

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-13-76	21:00	410.7	2,020	
	22:00	410.7	2,020	
	23:00	410.7	2,020	
	24:00	411.3	2,020	
01-14-76	01:00	411.4	2,020	
	02:00	411.7	2,020	
	03:00	411.7	2,020	
	04:00	411.5	2,020	
	05:00	411.7	2,020	
	06:00	411.5	2,020 -	Increase RPM.
	07:15	411.9	2,020	
	08:00	412.2	2,020	
	09:00	412.0	2,020	
	10:00	412.0	2,020	
	11:00	412.3	2,020	
	12:00	411.9	2,020	
	13:00	412.2	2,020	
	14:00	411.7	2,020	
	15:00	411.7	2,020	
	16:00	411.7	2,020	
	17:00	411.7	2,020	
	18:00	412.1	2,020	
	19:00	413.3	2,020 +	Decrease RPM.
	20:00	413.3	2,020 +	Decrease RPM.
	20:05			T = 76° F, K = 350 mhos.
	21:00	414.4	2,020	
	22:00	414.6	2,020	
	23:00	414.6	2,020 +	Decrease RPM.
	24:00	414.6	2,020	
01-15-76	01:00	414.0	2,020	
	02:00	414.1	2,020	
	03:00	413.8	2,020	
	04:00	412.8	2,020	
	05:00	412.6	2,020	

PRODUCTION WELL NO. 2

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-15-76	06:00	412.5	2,020	
	07:00	412.5	2,020	
	08:00	413.0	2,020	
	08:30			T = 76° F, K = 350 micromhos. Collected water samples.
	09:00	413.7	2,020	
	09:30			Pump off.
	09:31	325.0		
	09:32	329.9		
	09:33	333.8		
	09:34	333.3		
	09:35	331.9		
	09:36	331.2		
	09:37	330.3		
	09:38	329.6		
	09:39	328.8		
	09:40	328.3		
	09:45	326.2		
	09:50	324.7		
	09:55	323.5		
	10:00	322.6		
	10:10	321.3		
	10:20	320.3		
	10:30	319.5		
	10:45	318.7		
	11:00	318.0		
	11:15	317.4		
	11:30	317.0		
	12:00	316.5		
	12:30	315.9		
	13:00	315.6		
	13:30	315.2		
	14:00	314.8		
	15:00	314.6		

PRODUCTION WELL NO. 2

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-15-76	16:00	314.1		
	17:00	314.0		
	20:00	313.4		
	24:00	313.0		
01-16-76	04:00	312.8		
	08:00	312.5		
	09:45	312.2		
	09:50	312.42		Measured with chain.

PRODUCTION WELL NO. 2.

TEST DATA

(Observation Well PW-1 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-11-76	13:28	333.36	Measured with chain, spotty. Measuring point hole in plate 0.87 foot above top of surface pipe. Surface pipe approximately 0.2 foot above land surface.
	13:35	333.24	Measured with chain, spotty.
	16:00	332.04	Measured with chain. Water level is recovering from development of PW-2.
01-12-76	08:27	330.76	Measured with chain. Set sounder with tape mark at 330.76.
	09:11	330.66	
	09:30		PW-2 pump on for test.
	09:48	330.68	
	10:15	330.99	
	11:10	331.74	
	12:05	332.28	
	13:05	332.52	
	14:05	332.73	
	15:05	332.98	
	16:05	333.05	
	17:05	333.20	
	18:05	333.30	
	19:05	333.58	
	20:05	333.65	
	21:05	333.70	
	22:05	333.78	
	23:05	333.89	
01-13-76	00:05	334.05	
	01:00	333.97	
	02:05	333.96	
	03:05	334.03	
	04:05	334.06	
	05:05	334.10	
	06:08	334.17	
	07:05	334.25	

PRODUCTION WELL NO. 2

TEST DATA

(Observation Well PW-1 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-13-76	08:05	334.38	
	09:05	334.36	
	10:05	334.46	
	11:05	334.51	
	12:05	334.36	
	13:05	334.62	
	15:05	334.55	
	17:07	334.63	
	19:05	334.92	
	21:05	334.98	
	23:05	335.12	
01-14-76	01:05	335.19	
	03:05	335.23	
	05:05	335.27	
	07:20	335.18	
	08:05	335.21	
	09:05	335.24	
	11:05	335.29	
	13;05	335.30	
	15:05	335.29	
	17:05	335.32	
	19:05	335.39	
	21:05	335.44	
	23:05	335.53	
01-15-76	01:05	335.59	
	03:05	335.54	
	05:05	335.52	
	07:05	335.49	
	09:05	335.59	
	09:30		PW-2 pump off.
	10:03	335.39	
	10:33	334.94	
	11:05	334.50	
	11:35	334.25	

PRODUCTION WELL NO. 2

TEST DATA

(Observation Well PW-1 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-15-76	12:05	334.06	
	12:35	333.86	
	13:05	333.68	
	13:35	333:55	
	14:05	333.41	
	15:05	333.24	
	16:05	333.06	
	17:05	332.86	
	20:05	332.72	
01-16-76	00:05	332.44	
	04:05	332.36	
	08:05	332.25	
	10:04	332.01	

PRODUCTION WELL NO. 2

TEST DATA

(Observation Well MW-5 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-11-76	13:45	338.14	Measured with chain. Measuring point top of 6-inch casing approximately 1 foot above land surface.
	15:54	337.57	Measured with chain. Water level is recovering from development of PW-2.
01-12-76	08:00	336.52	Measured with chain. Set sounder with tape mark at 336.52.
	09:15	336.43	
	09:30		PW-2 pump on for test.
	09:52	336.44	
	10:17	336.52	
	11:14	337.02	
	12:07	337.28	
	13:07	337.44	
	14:07	337.60	
	15:07	337.74	
	16:07	337.85	
	17:07	337.98	
	18:07	338.06	
	19:07	338.14	
	20:07	338.23	
	21:07	338.31	
	22:08	338.42	
	23:07	338.47	
01-13-76	00:07	338.51	
	01:37	338.54	
	02:07	338.65	
	03:07	338.70	
	04:07	338.79	
	06:16	338.85	
	07:07	338.91	
	08:07	339.09	
	09:07	339.06	
	10:07	339.13	

PRODUCTION WELL NO. 2

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-13-76	11:07	339.22	
	12:07	339.22	
	13:07	339.23	
	15:07	339.21	
	17:09	339.31	
	19:07	339.45	
	21:07	339.54	
	23:07	339.62	
01-14-76	01:07	339.77	
	03:07	339.73	
	05:07	339.82	
	07:22	339.84	
	08:07	339.86	
	09:07	339.89	
	11:07	339.94	
	13:07	339.93	
	15:10	339.92	
	17:07	339.96	
	19:07	340.03	
	21:07	340.02	
	23:07	340.19	
01-15-76	01:07	340.18	
	03:07	340.21	
	05:07	340.11	
	07:07	340.18	
	09:07	340.25	
	09:30		PW-2 pump off.
	10:05	340.14	
	10:35	339.93	
	11:08	339.70	
	11:37	339.53	
	12:07	339.40	
	12:37	339.25	
	13:07	339.16	

PRODUCTION WELL NO. 2

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-15-76	13:37	338.99	
	14:07	338.94	
	15:07	338.86	
	16:07	338.80	
	17:07	338.55	
	20:05	338.20	
01-16-76	00:07	338.03	
	04:07	337.89	
	08:07	337.72	
	10:19	337.75	

BC
LABORATORIES Inc.
OIL - CORES - SOIL - WATER
3016 UNION AVENUE
BAKERSFIELD, CALIFORNIA 93305
Phone (805) 325-7475
J. J. EGLIN, Reg. Chem. Engr.

ubmitted By: Water Development Corp.
3938 Santa Barbara Ave.
Tucson, Arizona 85711

Date Reported: 2/16/76
Date Received: 2/3/76
Laboratory No.: 10752

Aarked: Quintana #2 1/15/76 08:30 T: 76°F. K: 350

WATER ANALYSIS

Sample Description:

pH ---------------		8.1
E.C. Micromhos/cm (K x 10^6) @ 25°C (salinity)---------		310.
Resistivity, Ohm M^2/M		
Constituents, P. P. M. (parts per million)		
(B) -		
Calcium, (Ca) ----------------		21.
Magnesium, (Mg)----------------		3.4
Sodium, (Na) ----------------		39.
Potassium, (K) ----------------		4.3
Carbonates, (CO_3) ----------------		0.
Bicarbonates, (HCO_3) -------------		153.1
Chlorides, (Cl) ----------------		17.0
Sulphates, (SO_4) ----------------	(-)	5.
Nitrate, (NO_3) ----------------		3.53
Fluoride, (F) ----------------		0.66
Total Iron, (Fe)		
Copper, (Cu)		
Manganese, (Mn)		
Chromium, (Cr)		
Zinc, (Zn)		
Aluminum, (Al)		
Silica, (SiO_2)		
Lithium, (Li)		
Lead, (Pb)		
Phenol		
Sulfides as H_2S		
Total Hardness as $CaCO_3$		
Oil (chloroform extractable)		
Total Dissolved Solids ------------		257. @ 180°F.
Suspended Solids		

BC LABORATORIES Inc.

By J. J. Eglin

PRODUCTION WELL NO. 3
CUTTING LOG

(Prepared by B. Y. Kim, Geologist, Quintana Minerals Corporation)

Depth From - To (ft)	Pebble	Granule	Coarse Sand	Medium Sand	Fine Sand	Silt and Clay
30 - 50		30%	50%	5%	5%	10%
50 - 60	90%	10%				
60 - 80	Minor	60%	20%	Minor	5%	15%
80 - 100	90%	10%				
100 - 180	10%-30%	50%-70%	5%-15%	Minor	5%	10%
180 - 190			Minor	20%	40%	40%
190 - 210	Minor	40%	30%	5%	5%	20%
210 - 220			10%	20%	40%	20%
220 - 240	Minor	50%	40%			10%
240 - 250			10%	20%	40%	30%
250 - 260		50%	40%	Minor		10%
260 - 270		10%	20%	10%	20%	20%
270 - 330	10%-20%	50%-60%	20%	Minor	Minor	10%
330 - 350		10%	30%-40%	0%-10%	20%	30%
350 - 380	0%-10%	40%-50%	30%-40%	Minor	Minor	0%-10%
380 - 390		10%	30%	10%	20%	20%
390 - 450		30%-40%	30%-40%	0%-10%	0%-10%	10%-20%
450 - 460			10%	30%	30%	30%
460 - 760	Minor	20%-40%	20%-30%	0%-10%	10%-20%	10%-30%
(Representative Sample:	Minor	30%	30%	5%	10%	20%)
760 - 830		10%-20%	30%-40%	0%-10%	10%-20%	20%
830 - 910		20%-30%	30%-40%	10%	20%	10%
910 - 970		10%-20%	20%-30%	10%-20%	10%-20%	20%

Peanut-size angular pebbles at 80-100 feet, probably broken pieces from larger boulder.

Sample 120-180 missing.

Pebble-containing samples:
670-680 (20%)
710-720 (10%)
610-620 (5%)

Toward the bottom of the hole, gradual decrease of coarse material (granule and coarse sand) has been noticed.

PRODUCTION WELL NO. 3
CUTTING LOG
(continued)

The following size ranges have been established from Wentworth Scale for classification of clastic sedimentary rock. The above log has been done by visual estimation according to the scale.

Pebble	Above 4 mm
Granule	2 mm - 4 mm
Coarse Sand	Very coarse - 1 mm - 2 mm Coarse - 0.5 mm - 1 mm (1/2 mm - 1 mm)
Medium Sand	0.25 mm - 0.5 mm (1/4 mm - 1/2 mm)
Fine Sand	Fine - 0.125 mm - 0.25 mm (1/4 mm - 1/8 mm) Very fine - 0.0625 mm - 0.125 mm (1/8 mm - 1/16 mm)
Silt and Clay	Less than 0.0625 mm (less than 1/16 mm)

PRODUCTION WELL NO. 3
DRILLERS LOG

Depth From (ft)	To	Sample Description
40	55	Sand 85%, gravel.
55	65	Gravel, 10% sand.
65	75	Gravel, 20% sand.
75	165	Sand and gravel.
165	185	Sand 70%, gravel 25%, clay 5%.
185	195	Clay.
195	200	Sand, 5% clay.
200	205	Clay.
205	215	Sand, 50%, gravel 45%, clay 5%.
215	225	Clay, 10% sand.
225	235	Sand 55%, gravel 40%, clay 5%.
235	250	Sand and gravel.
250	255	Sand, 80% clay.
255	265	Sand and gravel, 5% clay.
265	275	Sand, 70% clay.
275	339	Sand and gravel.
339	345	Clay 80%, sand 20%.
345	355	Clay 75%, sand 20%, gravel 5%.
355	369	Sand 90%, gravel 10%.
369	375	Clay 60%, gravel 30%, sand 10%.
375	385	Sand 65%, clay 25%, gravel 10%.
385	399	Clay 60%, sand 40%.
399	405	Sand 90%, clay 10%.
405	415	Sand 50%, gravel 50%.
415	425	Sand 50%, gravel 40%, clay 10%.
425	429	Sand, gravel, and clay.
429	435	Gravel 65%, sand 30%, clay 5%.
435	455	Sand, gravel, and clay.
455	465	Clay and little sand.
465	475	Clay, gravel, and sand.
475	495	Gravel 60%, sand 20%, clay 20%.
495	505	Sand and gravel.
505	525	Sand 50%, clay 50%.
525	535	Gravel 50%, sand 50%.
535	545	Sand 65%, clay 25%, gravel 10%.
545	555	Sand 50%, clay 50%.
555	565	Sand, 30% clay.

PRODUCTION WELL NO. 3
DRILLERS LOG
(continued)

Depth From (ft)	To	Sample Description
565	575	Sand and gravel.
575	590	Sand, gravel, and clay.
590	595	Sand and gravel, some clay.
595	605	Sand, gravel, and clay.
605	615	Sand and gravel, some clay.
615	625	Sand and gravel, 70% clay.
625	655	Sand and gravel.
655	665	Sand 70%, clay 30%.
665	675	Sand 85%, gravel 10%, clay 5%.
675	685	Gravel 60%, sand 20%, clay 20%.
685	699	Sand 50%, gravel 25%, clay 25%.
699	705	Sand 50%, gravel 48%, clay 2%.
705	715	Gravel 45%, coarse sand 45%, clay 10%.
715	728	Sand 80%, gravel 10%, clay 10%.
728	745	Sand, gravel, and clay.
745	756	Sand 85%, clay.
756	817	Sand, gravel, and clay.
817	835	Clay 80%, gravel 10%, sand 10%.
835	847	Sandy clay 98%, gravel 2%.
847	855	Sand 70%, gravel 30%.
855	865	Sand 80%, gravel 15%, clay 5%.
865	878	Clay 55%, gravel 35%, sand 10%.
878	895	Sand, gravel, and clay.
895	905	Sand and gravel.
905	945	Gravel 50%, sand 30%, clay 20%.
945	955	Clay 50%, sand 30%, gravel 20%.
955	965	Clay 95%, sand 5%.
965	970	Clay 90%, sand 10%.

PRODUCTION WELL NO. 3

DEVELOPMENT DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-22-76	12:54	350.6		Measuring with sounder. Measuring point top of 3/4-inch tube 0.95 feet above top of surface pipe. Surface pipe approximately 1 foot above land surface.
	13:00			Pump on. Ten-inch pump with bowls set at 500 feet. Discharge pipe 10-inch, orifice 6-inch.
	13:02	391.8	520	
	13:03	390.1		Dirty, lot of color.
	13:04	389.7	520	
	13:05	389.3		
	13:07	390.1	520	Lot of color, silt, 0.5 cc/l sand and silt.
	13:10	390.6		
	13:15	390.9	520	Clearing, less than 0.1 cc/l sand.
	13:20			Surge.
	13:25			Some color and silt, less than 0.1 cc/l fine sand.
	13:30	391.2	520	Clearing.
	13:36			Fairly clear, surge twice.
	13:44			Considerable color, 0.2 cc/l fine sand.
	13:47	386.4	520	
	13:55	388.6	520	Fairly clear, surge twice.
	14:05			Some color, silt.
	14:15	385.4	520	Fairly clear, surge twice.
	14:23			Some color, silt, less than 0.1 cc/l fine sand.
	14:30	383.3	520	Fairly clear, surge twice.
	14:37			Some color, silt, 0.1 cc/l fine sand.

PRODUCTION WELL NO. 3

DEVELOPMENT DATA (continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-22-76	14:45	382.0	520	Fairly clear, surge twice.
	14:58			Some color, silt, less than 0.1 cc/l fine sand.
	15:00	380.4	520	Fairly clear, silt, surge twice.
	15:08			Some color, no sand.
	15:15	379.4	520	Fairly clear, surge twice.
	15:30	378.4	520	Fairly clear, surge twice.
	15:45	377.9	520	Fairly clear, surge twice.
	16:00	377.7	520	Fairly clear, surge twice.
	16:15	377.6	520	Fairly clear, surge twice.
	16:30	377.4	520	Fairly clear, surge twice, change to 8-inch orifice.
	16:33			Pump on, increase RPM.
	16:35	402.7	1,000	Considerable color, 0.1 cc/l fine sand.
	16:40	403.0	1,000	
	16:45	403.8	1,000	Fairly clear, surge twice.
	16:53			Considerable color, silt, 0.1 cc/l fine sand.
	17:00	403.8	1,000	Fairly clear, surge twice.
	17:07			Considerable color, silt, 0.1 cc/l fine sand.
	17:10			T = 76° F, K = 370 microm-hos.
	17:15	403.1	1,000	Fairly clear, surge twice.
	17:22			Considerable color, silt, 0.1 cc/l fine sand.
	17:30	402.5	1,000	Fairly clear, surge twice.
	17:37			Considerable color, silt, 0.1 cc/l fine sand.
	17:45	401.4	1,000	Fairly clear, surge twice.
	17:52			Some color, silt, 0.15 cc/l fine sand.
	18:00	402.0	1,000	Fairly clear, surge twice.
	18:07			Some color, silt, 0.15 cc/l fine sand.

PRODUCTION WELL NO. 3

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-22-76	18:15 18:22	400.6	1,000	Fairly clear, surge twice. Some color, silt, 0.1 cc/l fine sand.
	18:30 18:37	399.7	1,000	Fairly clear, surge twice. Some color, silt, 0.1 cc/l fine sand.
	18:45 18:52	399.7	1,000	Fairly clear, surge twice. Some color, silt, less than 0.1 cc/l fine sand.
	19:00 19:08	399.4	1,000	Fairly clear, surge twice. Some color, silt, less than 0.1 cc/l fine sand.
	19:15 19:22	399.2	1,000	Fairly clear, surge twice. Some color, silt, 0.1 cc/l fine sand.
	19:30 19:37	398.3	1,000	Fairly clear, surge twice. Some color, silt, 0.1 cc/l fine sand.
	19:45 19:52	398.4	1,000	Fairly clear, surge twice. Some color, silt, less than 0.1 cc/l fine sand.
	20:00	398.6	1,000	Fairly clear, surge twice, increase RPM.
	20:07	428.5	1,500	Considerable color, 0.1 cc l fine sand.
	20:09	438.7		
	20:15	446.6	1,500	Dirty, 0.1 cc/l fine sand, considerable entrained air in discharge.
	20:30 20:37	447.0	1,486	Clearing, surge twice. Lot of color, silt, 0.2 cc/l fine sand.
	20:45 20:52	443.9	1,455	Fairly clear, surge twice. Lot of color, silt, 0.2 cc.l fine sand.

PRODUCTION WELL NO. 3

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-22-76	21:00	446.1	1,500	Fairly clear, surge twice.
	21:07			Lot of color, silt, 0.1 cc/l fine sand.
	21:15	444.8	1,500	Fairly clear, surge twice.
	21:22			Lot of color, silt, less than 0.1 cc/l fine sand.
	21:30	444.1	1,500	Fairly clear, surge twice.
	21:37			Lot of color, silt.
	21:45	441.1	1,471	Fairly clear, surge twice.
	21:53			Considerable color, silt, less than 0.1 cc/l fine sand.
	22:00	442.0	1,486	Fairly clear, surge twice.
	22:30	446.6	1,500	Fairly clear, surge twice.
	23:00	446.5	1,500	Fairly clear, surge twice.
	23:30	446.9	1,486	Fairly clear, surge twice.
	23:38			Considerable color, silt, no sand.
	24:00	446.4	1,500	Fairly clear, surge twice.
01-23-76	00:07			Lot of color, silt, no sand.
	00:30	446.9	1,500	Fairly clear, surge twice.
	00:38			Lot of color, silt, no sand.
	01:00	447.0	1,500	Fairly clear, surge twice.
	01:07			Lot of color, silt.
	01:30			Engine stopped, broken throttle linkage.
	01:36			Throttle repaired, second surg
	01:40			Lot of color, silt, no sand.
	02:00	447.1	1,500	Fairly clear, surge twice.
	02:07			Lot of color, silt, no sand.
	02:30	447.2	1,500	Fairly clear, surge twice.
	03:00	447.8	1,500	Fairly clear, surge twice.
	03:37		1,500	
	04:00	448.0	1,500	Fairly clear, surge twice.
	04:07		1,500	
	04:30	447.4	1,500	Fairly clear, surge twice.

PRODUCTION WELL NO. 3

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-23-76	04:37		1,500	
	05:00	447.2	1,500	Fairly clear, surge twice.
	05:07		1,500	
	05:30	447.3	1,500	Fairly clear, surge twice.
	05:37		1,500	
	06:00	449.3	1,500	Fairly clear, surge twice.
	06:07		1,500	
	06:30	447.4	1,500	Fairly clear, surge twice.
	06:37		1,500	Considerable color, silt, no sand.
	07:00	447.4	1,500	Clear, surge twice, increase RPM.
	07:09	463.1	1,809	Fairly dirty, 0.3 cc/l fine sand.
	07:11	470.2	1,809	Fairly dirty, lot of entrained air.
	07:15			Ohmmeter fluctuating badly. Starts at 460 feet.
	07:31		1,641	Manometer ± 1 inch, well is not surging.
	07:33			Fairly clear, surge twice.
	08:30	454.7	1,669	Clear, Ohmmeter and Manometer fluctuating, surge twice.
	08:32			Some color, silt, no sand.
	09:00	452.1	1,543	Clear, surge twice.
	09:08			Some color, silt, no sand.
	09:10			Engine stopped, broken throttle linkage.
	09:15			Throttle repaired.
	09:30	453.1	1,613	Clear, surge twice, reduce RP
	10:02			Little color, silt, no sand.
	10:04		1,500	
	10:30	448.2	1,515	Clear, reduce RPM.
	11:00	448.0	1,500	

PRODUCTION WELL NO. 3

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-23-76	11:11			T = 76° F, K = 360 microm-hos.
	11:30	448.0	1,500	Clear.
	11:58	448.4	1,500	Clear.
	12:00			Pump off.
	12:01	421.1		
	12:02	396.3		
	12:03	365.2		
	12:04	354.0		
	12:05	354.2		
	12:16	352.7		
	12:15	352.1		

PRODUCTION WELL NO. 3

TEST DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-24-76	07:46	350.8		Measuring with sounder. Same measuring point as for development.
	08:59	350.8 -1.95 = 348.9 GL		
	09:00			Pump on. Same setting as for development.
	09:01	421.4	1,500	
	09:02	424.6	1,500	Some color.
	09:03	428.2	1,500	
	09:04	431.1	1,500	
	09:05	432.6	1,500	Clear.
	09:06	433.5	1,500	
	09:07	434.5	1,500	
	09:08	435.6	1,500	
	09:09	436.2	1,500	
	09:10	436.9	1,500	
	09:11	437.6	1,500	
	09:12	437.8	1,500	
	09:13	438.0	1,500	
	09:14	438.5	1,500	
	09:15	439.0	1,500	
	09:16	440.0	1,515	Decrease RPM.
	09:17	439.6	1,500	
	09:18	439.6	1,500	
	09:19	439.8	1,500	
	09:20	440.0	1,500	
	09:25	441.0	1,500	
	09:30	441.6	1,500	
	09:35	441.9	1,500	
	09:40	442.0	1,500	
	09:50	443.4	1,500	
	10:00	443.5	1,500	
	10:15	444.5	1,500 -	Increase RPM.
	10:30	445.0	1,500	Considerable entrained air in discharge.
	10:45	445.9	1,500	

PRODUCTION WELL NO. 3

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-24-76	11:00	446.0	1,500 +	Decrease RPM.
	11:30	446.6	1,500	
	12:00	446.6	1,500	
	12:03			T = 76°, K = 360 microm-hos.
	12:30	448.4	1,500	
	13:00	449.5	1,500	
	13:30	449.0	1,500 -	Increase RPM.
	14:00	449.1	1,500	
	15:00	448.7	1,500 +	Decrease RPM.
	16:00	448.9	1,500	
	17:00	449.8	1,515	Decrease RPM.
	18:00	448.4	1,486	Increase RPM.
	19:00	499.4	1,500	
	20:00	450.4	1,500	
	21:00	450.9	1,500	
	22:00	451.5	1,500	
	23:00	451.8	1,500	
	24:00	452.2	1,500	
01-25-76	01:00	452.2	1,500	
	02:00	452.2	1,500	
	03:00	452.4	1,500	
	04:00	452.4	1,500	
	05:00	452.7	1,500	
	06:00	453.0	1,500	
	07:00	453.7	1,500	
	08:00	452.3	1,500	
	09:00	451.7	1,486	Increase RPM.
	10:00	452.4	1,500	
	11:00	452.4	1,500	
	12:00	453.0	1,500 -	Increase RPM.
	12:25	453.2	1,500	
	12:36	453.2	1,500	Changed sounders.
	13:00	453.86	1,500	
	14:00	454.83	1,500 +	Decrease RPM.

PRODUCTION WELL NO. 3

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-25-76	14:40			T = 76°, K = 360 microm-hos.
	15:00	452.50	1,500	
	16:00	452.59	1,500	
	17:00	453.81	1,500	
	18:00	454.26	1,500	
	19:00	453.73	1,500	
	20:00	454.16	1,500	
	21:00	455.38	1,500	
	22:00	456.12	1,500 +	Decrease RPM.
	23:00	456.36	1,500	
	24:00	456.46	1,500	
01-26-76	01:00	455.86	1,500	
	02:01	455.71	1,500	
	03:00	455.76	1,500	
	04:00	455.71	1,500	
	05:00	455.66	1,500	
	06:00	455.46	1,500	
	07:00	455.56	1,500 +	Decrease RPM.
	08:00	454.49	1,500	
	09:00	454.86	1,500	
	10:00	455.40	1,500	
	11:00	455.34	1,500	
	12:00	455.50	1,500	
	13:00	455.80	1,500	
	13:40		1,500 +	Decrease RPM.
	14:00	455.77	1,500	
	15:00	455.76	1,500	
	16:00	456.87	1,500	
	17:00	455.70	1,500	
	18:00	455.42	1,486	Increase RPM.
	19:00	456.19	1,500 -	Increase RPM.
	20:00	457.03	1,500	
	21:00	457.14	1,500	
	22:00	457.14	1,500	

PRODUCTION WELL NO. 3

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
01-26-76	23:00	457.31	1,500	
	24:00	457.0	1,500	
01-27-76	01:00	456.96	1,500	
	02:00	456.98	1,500	
	03:00	455.66	1,500	
	04:00	455.96	1,500	
	05:00	455.96	1,500	
	06:05	457.66	1,500	
	07:00	455.26	1,500	
	08:00	453.71	1,500	
	08:50			T = 76°, K = 360 micromhos. Collected water samples.
	08:55	454.16	1,500	
	09:00			Pump off.
	09:01	337.06		
	09:02	346.23		
	09:03	356.86		
	09:04	356.38		
	09:05	356.46		
	09:06	356.35		
	09:07	356.09		
	09:08	355.90		
	09:09	355.72		
	09:10	355.54		
	09:15	354.84		
	09:20	354.32		
	09:25	354.02		
	09:30	353.80		
	09:40	353.53		
	09:50	353.32		
	10:00	352.98		
	10:15	352.89		
	11:00	352.49		
	18:44	351.24		
01-28-76	07:42	350.66		

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well PW-1 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-22-76	11:49	330.91	Measured with chain, Measuring point hole in plate over casing 0.87 foot above top of surface pipe. Surface pipe approximately 0.2 foot above land surface.
	13:00		PW-3 pump on for development.
01-23-76	10:55	331.94	Measured with chain.
	12:00		PW-3 pump off.
01-24-76	08:13	330.77	Measured with chain. Set sounder with tape mark at 330.77.
	09:00		PW-3 pump on for test.
	09:10	330.77	
	09:30	330.87	
	09:45	330.96	
	10:00	330.98	
	10:15	331.10	
	10:35	331.10	
	11:05	331.22	
	11:55	331.33	
	13:12	331.42	
	14:15	331.45	
	15:15	331.51	
	16:15	331.55	
	17:18	331.62	
	18:23	331.67	
	20:13	331.77	
	22:13	331.85	
01-25-76	00:13	331.96	
	02:13	332.11	
	04:13	332.11	
	06:15	332.13	
	08:15	332.08	
	10:15	332.15	
	12:15	332.13	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well PW-1 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-25-76	14:15	332.11	
	16:12	332.15	
	18:15	332.21	
	20:15	332.27	
	22:50	332.36	
01-26-76	00:30	332.37	
	02:30	332.38	
	06:30	332.49	
	08:28	332.58	
	10:13	332.74	
	12:17	332.72	
	14:11	332.67	
	16:10	332.66	
	18:15	332.68	
	20:05	332.70	
01-27-76	00:10	332.74	
	02:15	332.76	
	05:55	332.78	
	08:20	332.84	
	09:00		PW-3 pump off.
	10:35	332.44	
	18:55	331.73	
01-28-76	08:06	331.47	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well PW-2 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-22-76	11:58	309.93	Measured with chain. Measuring point hole in plate above casing 0.7 foot above top of surface pipe. Surface pipe approximately 0.5 foot above land surface.
	13:00		PW-3 pump on for development.
01-23-76	10:45	310.31	Measured with chain.
	12:00		PW-3 pump off.
01-24-76	08:31	309.67	Measured with chain. Set sounder with tape mark at 309.67.
	09:00		PW-3 pump on for test.
	09:05	309.67	
	09:25	309.67	
	09:40	309.67	
	09:55	309.71	
	10:10	309.74	
	10:25	309.75	
	10:40	309.77	
	11:00	309.81	
	11:50	309.84	
	13:16	309.89	
	14:20	309.91	
	15:20	309.94	
	16:20	309.98	
	17:24	310.02	
	18:30	310.07	
	20:16	310.12	
	22:16	310.18	
01-25-76	00:16	310.22	
	02:16	310.27	
	04:18	310.31	
	06:20	310.40	
	08:20	310.42	
	10:20	310.46	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well PW-2 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-25-76	12:20	310.46	
	14:20	310.43	
	16:16	310.43	
	18:20	310.48	
	20:20	310.55	
	23:00	310.67	
01-26-76	00:35	310.65	
	02:35	310.72	
	06:35	310.83	
	08:33	310.90	
	10:17	311.01	
	12:23	311.00	
	14:15	310.92	
	16:15	310.96	
	18:20	310.99	
	20:10	311.01	
01-27-76	00:15	311.04	
	02:20	311.11	
	06:00	311.12	
	08:25	311.13	
	09:00		PW-3 pump off.
	10:40	311.04	
	19:00	310.65	
01-28-76	08:17	310.43	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well MW-5 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-22-76	11:41	336.67	Measured with chain. Measuring point top of 6-inch casing approximately 1 foot above land surface.
	13:00		PW-3 pump on for development.
01-23-76	11:03	337.68	Measured with chain.
	12:00		PW-3 pump off.
01-24-76	07:57	336.52	Measured with chain. Set sounder wit- tape mark at 336.52.
	09:00		PW-3 pump on for test.
	09:13	336.52	
	09:34	336.64	
	09:50	336.70	
	10:04	336.71	
	10:24	336.77	
	10:36	336.83	
	11:07	336.91	
	11:57	337.01	
	13:10	337.07	
	14:12	337.11	
	15:12	337.14	
	16:12	337.24	
	17:15	337.29	
	18:20	337.33	
	20:08	337.42	
	22:08	337.49	
01-25-76	00:08	337.53	
	02:08	337.60	
	04:08	337.67	
	06:10	337.76	
	08:10	337.76	
	10:10	337.83	
	12:10	337.82	
	14:10	337.79	
	16:10	337.90	
	18:10	337.82	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well MW-5 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-25-76	20:10	337.94	
	22:50	338.01	
01-26-76	00:25	338.03	
	02:25	338.06	
	06:25	338.17	
	08:25	338.26	
	10:10	338.28	
	12:12	338.29	
	14:09	338.28	
	16:08	338.30	
	18:10	338.34	
	20:00	338.39	
01-27-76	00:05	338.41	
	02:10	338.42	
	05:50	338.43	
	08:10	338.56	
	09:00		PW-3 pump off.
	10:30	338.18	
	18:50	337.41	
01-28-76	07:54	337.10	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well MW-6 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
01-22-76	12:22	386.84	Measuring with sounder. Inside of casing too wet to use chain. Measuring point top of 6-inch casing approximately 1 foot above land surface. MW-6 was used to supply drilling water for drilling production wells.
	13:00		PW-3 pump on for development.
01-23-76	10:14	386.67	
	12:00		PW-3 pump off.
01-24-76	07:34	386.41	
	09:00		PW-3 pump on for test.
	09:20	386.41	
	11:06	386.40	
	12:08	386.38	
	13:04	386.33	
	14:07	386.33	
	15:07	386.33	
	16:07	386.32	
	17:09	386.35	
	18:09	386.34	
	20:05	386.32	
	22:05	386.29	
01-25-76	00:05	386.32	
	02:05	386.35	
	04:05	386.39	
	06:05	386.43	
	08:05	386.49	
	10:05	386.53	
	12:05	386.50	
	14:05	386.47	
	16:05	386.41	
	18:05	386.46	
	20:05	386.54	
	22:24	386.63	

PRODUCTION WELL NO. 3

TEST DATA

(Observation Well MW-6 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
01-26-76	00:15	386.64	
	02:15	386.63	
	06:20	386.74	
	08:20	386.80	
	10:06	386.82	
	12:07	386.82	
	14:05	386.78	
	16:04	386.79	
	18:05	386.77	
	19:56	386.84	
	24:00	386.86	
01-27-76	02:05	386.87	
	05:45	386.88	
	08:05	386.92	
	09:00		PW-3 pump off.
	10:10	386.87	
	18:38	386.81	
01-28-76	07:29	386.77	

BC LABORATORIES Inc.
OIL - CORES - SOIL - WATER
3016 UNION AVENUE
BAKERSFIELD, CALIFORNIA 93305
Phone (805) 325-7475
J. J. EGLIN, Reg. Chem. Engr.

Submitted By: Water Development Corp.
3938 Santa Barbara Ave.
Tucson, Arizona 85711

Date Reported: 2/16/76
Date Received: 2/3/76
Laboratory No.: 10753

Marked: Quintana #3 1/27/76 08:50 T: 76°F. K: 360

WATER ANALYSIS

Sample Description:

pH	8.0
E.C. Micromhos/cm (K x 10^6) @ 25°C (salinity)	330.
Resistivity, Ohm M^2/M	

Constituents, P. P. M. (parts per million)

(B)	
Calcium, (Ca)	22.5
Magnesium, (Mg)	2.7
Sodium, (Na)	44.
Potassium, (K)	5.1
Carbonates, (CO_3)	0.
Bicarbonates, (HCO_3)	158.0
Chlorides, (Cl)	24.1
Sulphates, (SO_4)	(-) 5
Nitrate, (NO_3)	2.60
Fluoride, (F)	0.64
Total Iron, (Fe)	
Copper, (Cu)	
Manganese, (Mn)	
Chromium, (Cr)	
Zinc, (Zn)	
Aluminum, (Al)	
Silica, (SiO_2)	
Lithium, (Li)	
Lead, (Pb)	
Phenol	
Sulfides as H_2S	
Total Hardness as $CaCO_3$	
Oil (chloroform extractable)	
Total Dissolved Solids	243. @ 180°F.
Suspended Solids	

BC LABORATORIES Inc.

By: J. J. Eglin

WATER DEVELOPMENT CORPORATION

BASIC-DATA REPORT
QUINTANA MINERALS CORPORATION
COPPER FLAT PROJECT
PRODUCTION WELL NO. 4,
HILLSBORO, NEW MEXICO

By
D. K. Greene and L. C. Halpenny

Tucson, Arizona
December 1980

BASIC-DATA REPORT

QUINTANA MINERALS CORPORATION
COPPER FLAT PROJECT PRODUCTION WELL NO. 4, HILLSBORO, NEW MEXICO

By

D. K. Greene and L. C. Halpenny

GENERAL INFORMATION

A fourth production well (PW-4) has been drilled to assist in furnishing the water supply for ore processing and other uses at the Copper Flat Project. Location of PW-4 along with PW-1, PW-2, and PW-3, is shown on Figure 1. The legal description of PW-4 is as follows:

NW$\frac{1}{4}$ SW$\frac{1}{4}$ NE$\frac{1}{4}$, Sec. 31, T. 15 S., R. 5 W.

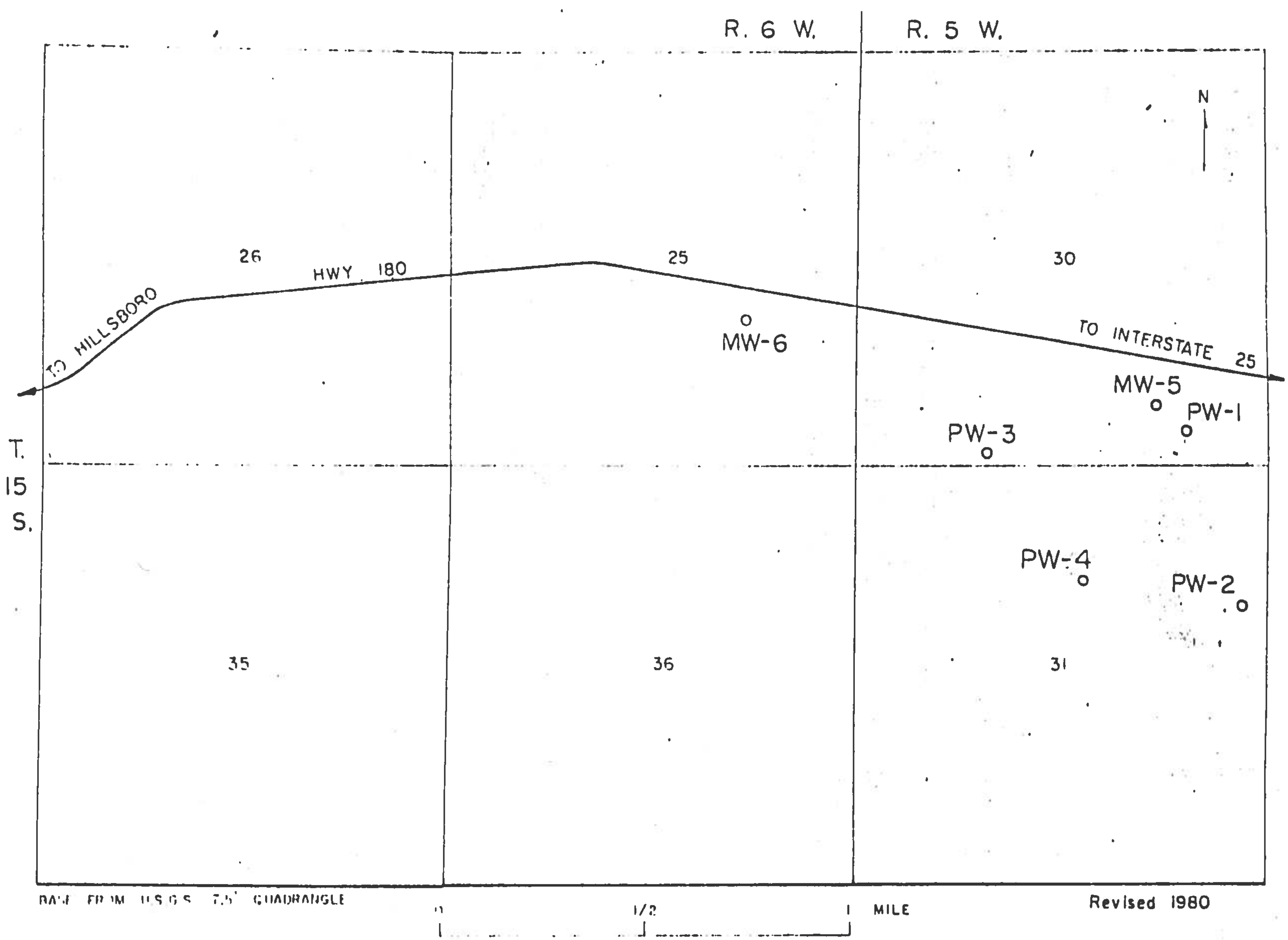

FIGURE 1.--MAP OF A PORTION OF TOWNSHIP 15 SOUTH, RANGES 5 AND 6 WEST, SIERRA COUNTY, NEW MEXICO, SHOWING LOCATIONS OF PRODUCTION WELLS AND MW-5 AND MW-6.

PW-4 was drilled by R. L. Guffey, Inc., Drilling Contractors of Las Cruces, New Mexico using rotary equipment and the conventional method of drilling. Considerable difficulty was encountered in drilling the upper 100 feet of hole due to boulders. A 12-inch pilot hole was drilled through this section and down to 400 feet. From 400 feet a 9-7/8-inch pilot hole was drilled to bottom depth of 957 feet. Following pilot hole drilling a 23-foot joint of 30-inch diameter surface pipe was set and cemented in place. The hole was then reamed to an ultimate diameter of 26 inches to a depth of 954 feet. An 18-inch pilot bit extended ahead of the 22-inch bit giving a hole diameter of 18-inches from 954 to 957 feet.

The hole was cased with 16-inch OD, 5/16-inch wall thickness, blank casing and 16-inch OD Johnson 100 slot Irrigator Screen. Open area in the Irrigator Screen amounts to 217 square inches per lineal foot. A 3-foot section of 16-inch OD, 5/16 inch wall thickness, blank casing was welded to the bottom of the Irrigator Screen. This section of casing is tapered on the bottom end. The annular space was gravel packed with 1/8 to 3/8-inch gravel and the well was developed with the drilling rig by washing, jetting, and bailing.

Details on depth drilled, casing installed, etc., for PW-4 are as follows:

Depth drilled	957 feet
Casing installed	
Blank	0 to 354 feet
Screen	354 to 954 feet
Blank	954 to 957 feet
Gravel installed	110 yards
Rig development time	39 hours
Gravel slippage during rig development	55 feet

Upon completion of rig development the well was further developed and tested with a diesel powered turbine pump furnished by Western Pump and Supply Company of Deming, New Mexico. Data obtained during this phase of work are included in the following sections of this report along with logs for the well.

PRODUCTION WELL NO. 4
DRILLER'S LOG

(Prepared by R. L. Guffey, Inc. Drilling Contractors)

Depth From (ft)		To	Sample Description
0	-	23	Boulder gravel some clay
23	-	38	Hard black rock stks, clay
38	-	56	Stks. hard black rock gravel boulder some clay
56	-	73	Gravel some boulders and clay
73	-	96	Gravel and clay with boulders
96	-	156	Clay and gravel stks gravel
156	-	198	Gravel some sand with clay and clay stks.
198	-	233	Gravel and sand stks of red clay
233	-	275	Clay (red) stks gravel
275	-	281	Sand sandy clay
281	-	293	Clay stks gravel embedded in clay
293	-	309	Gravel some sand stks clay
309	-	407	Sand small gravel stks clay (sandy)
407	-	422	Clay stks gravel calcareous and sand
422	-	446	Clay some gravel embedded
446	-	532	Gravel and sand some clay stks
532	-	560	Gravel (larger) with clay
560	-	610	Gravel sand with some clay
610	-	764	Gravel some (clean) with clay stks, drilled tight
764	-	783	Gravel, gravel embedded in clay
783	-	805	Gravel some sand with clay
805	-	825	Gravel and clay (Bentonite)
825	-	835	Gravel clean with sand
835	-	877	Clay with gravel embedded
877	-	896	Gravel clean some clay lens
896	-	925	Gravel fine with sand (some clean)
925	-	957	Gravel embedded in clay

PRODUCTION WELL NO. 4

WADEVCO LOG

Depth From (ft)	To	Sample Description
0	20	Angular fragments of boulders which are exposed at land surface, 1/4" to 1/2" +.
20	30	Angular fragments of boulders, 1/4" to 1/2" +. Small amount of medium to coarse sand.
30	40	Angular fragments of boulders, 1/4" to 1/2" +.
40	50	Angular rock fragments, 1/8" to 1/4". Some silt and very fine sand.
50	70	Angular rock fragments, 1/4" to 1/2" +.
70	90	Angular rock fragments, 1/8" to 1/2" +. Some fine to medium sand.
90	100	Angular rock fragments, 1/8" to 1/2" +.
100	110	Angular rock fragments, 1/8" to 1/2" +. Some silt and clay.
110	120	Primarily angular rock fragments, 1/8" to 1/2". Few fragments are rounded.
120	130	Primarily angular rock fragments, 1/4" to 1/2". Several fragments of clay with embedded sand and gravel.
130	140	Angular rock fragments, ± 1/8". Some medium to very fine sand, silt, and clay.
140	160	Angular rock fragments, 1/8" to 1/4". Some medium to very fine sand, silt, and clay.
160	170	Angular rock fragments, 1/8" to 1/4". Some coarse to very fine sand.
170	180	Angular rock fragments, ± 1/8". Some coarse to very fine sand.
180	200	Medium to very coarse sand and gravel up to 1/8". Some silt.
200	220	Angular rock fragments, ± 1/8". Some coarse to very fine sand.
220	230	Angular rock fragments, 1/8" to 1/4". Some very coarse to fine sand.
230	240	Angular rock fragments, ± 1/8". Some very coarse to fine sand.
240	250	Angular rock fragments, 1/8" to 1/4". Some very coarse to fine sand.

PRODUCTION WELL NO. 4

WADEVCO LOG
(continued)

Depth From (ft)	To	Sample Description
250	260	Angular rock fragments, 1/8" to 1/4". Some very coarse to fine sand and silt. Several fragments of clay ± 1/8".
260	280	Angular rock fragments, ± 1/8". Some very coarse to fine sand.
280	300	Angular rock fragments, 1/8" to 1/4". Some very coarse to fine sand.
300	310	Angular rock fragments, 1/8" to 1/4". Some very coarse to fine sand. Several clay fragments ± 1/8".
310	330	Gravel up to ± 1/8" with fine to very coarse sand. Several rock fragments ± 1/4". Several clay fragments ± 1/8".
330	340	Medium to very coarse sand with gravel up to 1/8". Few angular rock fragments ± 1/4".
340	360	Fine to very coarse sand and gravel. Some silt.
360	390	Very coarse sand and gravel. Some fine to medium sand.
390	400	Very coarse sand and gravel. Some fine to medium sand. Few small fragments of clay.
400	420	Angular rock fragments 1/4" to 1/2". Some medium to very coarse sand and gravel.
420	450	Very coarse sand and gravel to ± 1/8". Few rock fragments ± 1/4". Some medium to coarse sand.
450	460	Very coarse sand and gravel to ± 1/8". Some medium to fine sand. Few fragments of clay. Some silt.
460	490	Very coarse sand and gravel to ± 1/8". Some medium to fine sand.
490	500	Very coarse sand and gravel to ± 1/8". Some medium to fine sand. Several fragments of black vesicular material with sand grains embedded in some vesicles.
500	530	Very coarse sand and gravel to ± 1/8". Some medium to fine sand.
530	560	Angular rock fragments, 1/8" to 1/2" with fine to very coarse sand. Some silt.

PRODUCTION WELL NO. 4

WADEVCO LOG
(continued)

Depth From (ft)	To	Sample Description
560	590	Very coarse sand and gravel to ± 1/8". Fair number of angular rock fragments in 1/4" to 1/2" range. Several fragments of clay up to 1/2". Some silt.
590	620	Very coarse sand and gravel up to ± 1/8". Some medium to very fine sand and silt.
620	700	Very coarse sand and gravel up to ± 1/8". Some medium to fine sand.
700	730	Medium to very coarse sand with some gravel up to ± 1/8". Some fine sand and silt.
730	740	Medium to very coarse sand with some gravel up to ± 1/8". Some fine sand, silt, and clay fragments.
740	750	Medium to very coarse sand with some gravel up to ± 1/8".
750	760	Coarse to very coarse sand with some gravel up to ± 1/8". Some fine to medium sand.
760	780	Coarse to very coarse sand with some gravel up to ± 1/8". Some fine to medium sand. Several fragments of clay.
780	800	Very coarse sand and gravel up to ± 1/8". Some medium to fine sand.
800	810	Coarse to very coarse sand with some gravel up to ± 1/8". Some fine to medium sand. Few fragments of clay.
810	820	Very coarse sand and gravel up to ± 1/8". Several angular rock fragments ± 1/4". Some fine to medium sand and silt.
820	840	Very coarse sand and gravel up to ± 1/8". Some fine to medium sand.
840	850	Medium to very coarse sand and gravel up to ± 1/8". Several rock fragments ± 1/4". Silt and numerous fragments of clay.
850	870	Very fine to medium sand and silt with fragments of clay. Some coarse to very coarse sand with gravel up to ± 1/8".

PRODUCTION WELL NO. 4

WADEVCO LOG
(continued)

Depth From (ft)	To	Sample Description
870	880	Coarse to very coarse sand and gravel up to ± 1/8". Some fine to medium sand.
880	900	Coarse to very coarse sand. Some fine to medium sand.
900	910	Very fine to coarse sand.
910	920	Very fine to medium sand with some coarse sand.
920	957	Samples missing. Refer to Driller's Log.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
11-30-80	16:15	290.82		Measured with chain. Measuring point top of 3/4-inch pipe 0.86 foot above top of surface pipe. Surface pipe approximately 0.5 foot above land surface.
12-01-80	07:35	290.87		Measured with chain.
	07:50	290.9		Measuring with sounder.
	09:50	290.9		
	10:15			Pump on. Ten-inch pump to 350-feet. Eight inch pump 350 to 550 feet. Top of 13.5 inch bowls set at 550 feet. Discharge pipe 10-inch. Orifice 7-inch.
	10:16	326.6		
	10:17	309.4	550	
	10:20	309.2		
	10:21	309.2	550	
	10:24		550	Lot of mud. 2.5 cc/l fine to very fine sand.
	10:25	309.5		
	10:28		550	Clearing some. 0.3 cc/l fine to very fine sand.
	10:30	309.4		
	10:38	309.4		
	10:40			Fairly clear. Slight mud color. < 0.1 cc/l very fine sand.
	10:44		550	Fairly clear. < 0.1 cc/l very fine sand.
	10:45	309.7		
	10:47			Surge once.
	10:52			Lot of mud. 1.5 cc/l medium to very fine sand.
	10:55			Lot of mud. 2.5 cc/l fine to very fine sand.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-01-80	10:56	310.6		
	11:05	310.7		Lot of mud. < 0.1 cc/l very fine sand.
	11:11		550	Clearing some. < 0.1 cc/l very fine sand.
	11:12	310.7		
	11:19			Fairly clear. < 0.1 cc/l very fine sand.
	11:20			Surge once.
	11:25		550	Lot of mud. 2.5 cc/l fine to very fine sand.
	11:27			Still lot of mud. 1.0 cc/l fine to very fine sand.
	11:29	310.5		
	11:32			Less mud. <0.1 cc/l very fine sand.
	11:38	310.6		
	11:40		550	Less mud. < 0.1 cc/l very fine sand.
	11:49			Fairly clear. Surge once.
	11:54		550	Lot of mud. 1.3 cc/l fine to very fine sand.
	11:56			Lot of mud. 0.9 cc/l fine to very fine sand.
	11:58			Lot of mud. 0.15 cc/l fine to very fine sand.
	12:00	310.9	550	
	12:11		550	Still muddy. < 0.1 cc/l very fine sand.
	12:15			Fairly clear. Surge once.
	12:19		812	Lot of mud. 1.5 cc/l medium to very fine sand.
	12:21			Lot of mud. 0.5 cc/l fine to very fine sand.
	12:23	324.1		
	12:27		812	Still muddy. < 0.1 cc/l fine to very fine sand.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-01-80	12:32	324.7		
	12:34			Fairly clear. Surge once.
	12:37			Lot of mud. 0.6 cc/l medium to very fine sand.
	12:38			Lot of mud. 1.2 cc/l fine to very fine sand.
	12:40		812	Lot of mud. 0.3 cc/l fine to very fine sand.
	12:34	324.0		
	12:52	324.4		
	12:53			Fairly clear. < 0.1 cc/l very fine sand.
	12:54			Surge twice.
	12:59			Lot of mud. 1.0 cc/l fine to very fine sand.
	13:00			Lot of mud. 0.6 cc/l fine to very fine sand.
	13:01		812	Lot of mud. 0.1 cc/l fine to very fine sand.
	13:03			Still muddy. 0.1 cc/l fine to very fine sand.
	13:12	323.8		
	13:15			Fairly clear. Surge twice.
	13:21			Lot of mud. 1.5 cc/l medium to very fine sand.
	13:23		812	Lot of mud. 0.1 cc/l fine to very fine sand.
	13:27			Still muddy. < 0.1 cc/l fine to very fine sand.
	13:29	323.1		
	13:31			Fairly clear. Surge twice.
	13:36			Lot of mud. 1.0 cc/l medium to fine sand.
	13:38			Lot of mud. 0.9 cc/l very fine sand and silt.
	13:47	322.5	812	Fairly clear. Surge twice.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-1-80	13:53		812	Lot of mud. 1.5 cc/l medium to very fine sand.
	13:55			Lot of mud. 0.15 cc/l fine to very fine sand.
	13:59		812	Still some mud. < 0.1 cc/l very fine sand.
	14:02	321.8		
	14:03			Fairly clear. Surge twice.
	14:08			Lot of mud. 0.5 cc/l medium to very fine sand.
	14:10		812	Lot of mud. 0.2 cc/l very fine sand and silt.
	14:18	321.2		
	14:20		812	Clearing some.
	14:22			Fairly clear. Surge twice.
	14:27		1,001	Lot of mud. 0.3 cc/l medium to very fine sand.
	14:28			Lot of mud. 0.3 cc/l medium to very fine sand.
	14:30			Still muddy. 0.1 cc/l very fine sand.
	14:32	329.0		
	14:40	329.8	1,001	
	14:41			Fairly clear. Surge twice.
	14:46			Lot of mud. 0.6 cc/l medium to very fine sand.
	14:48			Lot of mud. 0.1 cc/l very fine sand and silt.
	14:58	329.2	1,001	
	14:59			Fairly clear. Surge twice.
	15:04			Considerable mud and color. 0.5 cc/l medium to very fine sand.
	15:06		1,001	Considerable mud and color. 0.1 cc/l very fine sand.
	15:14	328.2	1,001	

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-01-80	15:15			Fairly clear. Surge twice.
	15:20			Considerable mud and color. 0.2 cc/l medium to fine sand.
	15:22		1,001	Considerable mud and color. 0.1 cc/l very fine sand.
	15:29	327.8	1,001	
	15:30			Fairly clear. Surge twice.
	15:35			Considerable mud and color. 0.2 cc/l fine to very fine sand.
	15:37			Considerable mud and color. < 0.1 cc/l very fine sand.
	15:44	327.2	1,001	
	15:45			Fairly clear. Surge twice.
	15:50			Considerable mud and silt. 0.2 cc/l medium to very fine sand.
	15:52			Considerable mud and silt. 0.1 cc/l very fine sand and silt.
	15:59	326.5	1,001	
	16:00			Fairly clear. Surge twice.
	16:05			Considerable mud and silt. 0.1 cc/l fine to very fine sand.
	16:07			Considerable mud and silt. 0.1 cc/l very fine sand and silt.
	16:14	326.2	1,001	
	16:15			Fairly clear. Surge twice.
	16:17			Considerable mud and silt. 0.2 cc/l fine to very fine sand.
	16:19			Considerable mud and silt. 0.1 cc/l very fine sand and silt.
	16:29	326.1	1,001	
	16:30			Fairly clear. Surge twice.
	16:35		1,251	Lot of mud and silt. 0.2 cc/l fine to very fine sand.
	16:44	335.9		
	16:45			Fairly clear. Surge twice.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-01-80	16:50			Lot of mud and color. 0.15 cc/l fine to very fine sand.
	16:52			Lot of mud and silt. < 0.1 cc/l very fine sand.
	16:59	335.9	1,251	
	17:00			Fairly clear. Surge twice.
	17:29	336.7	1,251	
	17:30			Fairly clear. Surge twice.
	17:35			Lot of color. 0.1 cc/l very fine sand.
	17:44	335.5	1,251	
	17:45			Fairly clear. Surge twice.
	17:59	335.4	1,251	Surge twice.
	18:00		1,404	Changed to 8-inch orifice.
	18:05	337.9	1,404	Fairly clear.
	19:00	341.2		Surge twice. Some color 0.1 cc/l very fine sand.
	19:15	339.9	1,370	Some color. 0.1 cc/l very fine sand.
	19:39	339.6	1,370	Surge twice. Some color.
	19:43		1,404	Some color. 0.2 cc/l very fine sand.
	20:00	339.9	1,387	Surge twice.
	20:05		1,404	Clear, then some color.
	20:30	339.5	1,370	Clearing.
	20:35		1,529	Clear, then some color.
	21:00	346.9	1,543	Some color. Surge twice.
	21:07			T = 76°F; K = 360 micromhos. < 0.1 cc/l very fine sand.
	21:30	346.7	1,500	Clearing. Surge twice.
	21:37			Clear, then color. < 0.1 cc/l very fine sand.
	22:03	345.9	1,500	Clear. Surge twice.
	22:10		1,529	Clear, then some color. 0.1 cc/l very fine sand.
	22:30	345.2	1,529	Clearing. Very little color. Surge twice.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-01-80	23:07		1,613	Color, clearing fast. No sand.
12-02-80	01:00	348.3	1,585	Clear. Surge twice.
	01:07		1,613	Color, < 0.1 cc/l very fine sand.
	01:30	346.5	1,557	Clear. Surge twice.
	01:37	[illegible]	1,613	Some color. Clearing fast. < 0.1 cc/l very fine sand.
	02:00	345.0	1,529	Clear. Surge twice.
	02:05		1,613	Clear, then some color. < 0.1 cc/l very fine sand.
	02:35	350.2	1,627	Clear. Surge twice.
	02:40		1,697	Clear, then color. < 0.1 cc/l very fine sand.
	03:30	352.6	1,697	Clear. Surge twice.
	03:35			Color. Clearing. No sand. T = 76°F; K = 380 micromhos.
	04:00	352.7	1,711	Surge twice.
	04:07			Color. No sand.
	04:30	352.3	1,711	Surge twice.
	04:37		1,791	Clear, then some color. No sand.
	05:30	355.9	1,791	Clear. Surge twice.
	05:37		1,791	Some color. No sand.
	06:00	356.2	1,791	Clear. Surge twice.
	06:07		1,791	Color. No sand.
	06:30	356.9	1,795	
	07:10	356.2	1,791	Clear. Surge twice.
	07:15		1,865	Color. No sand.
	07:24	357.4	1,865	Clear. Surge twice.
	07:30			Color. No sand.
	07:31			Starting to clear.
	07:42	358.3	1,865	Clear. Surge twice.
	07:48			Color. No sand.
	07:52	357.2	1,865	Clear. Surge twice.
	07:57			Color. No sand.
	07:59			Clearing.
	08:05			Surge twice.

PRODUCTION WELL NO. 4

DEVELOPMENT DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-02-80	08:11			Color. No sand.
	08:15	357.0	1,865	Surge twice.
	08:21		2,005	Color. No sand.
	08:23		1,975	Clear.
	08:25	359.2		
	08:28		1,975	Clear. Surge twice.
	08:31		1,975	Slight color.
	08:32			Clearing.
	08:34			Clear.
	08:35	359.0	1,975	
	08:36			Reduced rpm.
	08:39	355.7	1,809	Clear.
	08:48			T = 76°F; K = 380 micromhos.
	08:53	356.8		
	09:23	357.6	1,823	Clear.
	09:40	357.5	1,809	Clear. No sand.
	09:55	357.6	1,809	Clear. No sand.
	10:05	357.7	1,808	Clear. No sand.
	10:15			Pump off.
	10:16	292.2		
	10:17	299.7		
	10:18	299.4		
	10:19	298.9		
	10:20	298.4		
	10:32	295.7		
	10:45	295.2		

PRODUCTION WELL NO. 4

TEST DATA

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-03-80	07:25	291.75		Measured with chain. Same measuring point as for development.
	07:30	291.7 -1.36 = 290.3 GL		Measuring with sounder.
	07:45	291.7		
	08:00			Pump on. Same setting as for development.
	08:01	337.8	1,711	Some color.
	08:02	341.9		Some color. Trace of sand.
	08:03	343.4	1,711	Clearing. No sand.
	08:04	344.4		
	08:05	344.9	1,711	
	08:06	345.5		Slight mud color. Few grains of sand.
	08:07	345.9		
	08:08	346.3	1,711	
	08:09	346.5		Clear. No sand.
	08:10	346.7	1,711	
	08:11	346.9		
	08:12	347.2		
	08:13	347.6		
	08:14	347.6	1,711	
	08:15	347.6		
	08:16	347.6		
	08:17	348.0		
	08:18	348.2	1,711	Clear. No sand.
	08:19	348.3		
	08:20	348.3		
	08:21	348.4		
	08:22	348.5	1,711	
	08:24	348.8		
	08:26	348.9		
	08:28	348.9		
	08:30	349.0		
	08:32	349.0		
	08:34	349.2	1,711	

PRODUCTION WELL NO. 4

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-03-80	08:36	349.6		
	08:38	349.7		
	08:40	349.7		
	08:44	349.9		Clear. No sand.
	08:46	349.9	1,711	
	08:48	350.1		T = 76°F; K = 380 micromhos.
	08:50	350.3		
	08:52	350.3		
	08:54	350.4		
	08:56	350.5	1,711	
	08:58	350.7	1,711 +	Decreased rpm slightly.
	09:00	350.6		
	09:05	350.4		
	09:10	350.6		
	09:15	351.1	1,725	Decreased rpm slightly.
	09:20	351.0	1,711 +	Decreased rpm slightly.
	09:25	351.0		
	09:30	351.1		
	09:35	351.2	1,711 +	Decreased rpm slightly.
	09:40	351.2	1,711	
	09:50	351.3	1,711	
	10:00	351.5	1,711	
	10:10	351.5	1,711	
	10:20	351.8	1,711 +	Decreased rpm slightly.
	10:30	351.7	1,711 +	Decreased rpm slightly.
	10:40	351.7	1,711	
	10:50	351.9	1,711	
	11:00	351.8	1,711 -	Increased rpm slightly.
	11:20	351.9	1,711	
	11:30	352.3	1,711	
	11:45	352.3	1,711 +	Decreased rpm slightly.
	12:00	352.3	1,711	
	12:15	352.5	1,711 +	Decreased rpm slightly.
	12:30	352.4	1,711	
	13:00	352.7	1,711	

PRODUCTION WELL NO. 4

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-03-80	13:30	352.7	1,711	
	14:00	352.8	1,711	
	14:30	352.8	1,711	
	15:00	353.0	1,711	
	15:30	353.0	1,711	
	16:00	353.2	1,711	
	16:05			T = 76°F; K = 380 micromhos.
	16:30	353.3	1,711	
	17:00	353.4	1,711	
	17:30	353.4	1,711	
	18:00	353.5	1,711	
	18:30	353.4	1,711	
	19:00	353.4	1,711	
	19:30	353.4	1,711	
	20:00	353.9	1,711 +	Decreased rpm slightly.
	20:30	353.7	1,711	
	21:00	353.4	1,697	Increased rpm slightly.
	21:30	353.6	1,711	
	22:00	353.9	1,711	
	22:30	353.8	1,711	
	23:00	353.8	1,711	T = 76°F; K = 380 micromhos.
	23:30	354.1	1,711	
12-04-80	00:00	354.5	1,711	
	00:30	354.6	1,711	
	01:00	354.9	1,711	
	01:30	355.0	1,711 +	Decreased rpm slightly.
	02:00	355.3	1,711 +	Decreased rpm slightly.
	02:30	355.5	1,725	Decreased rpm slightly.
	03:00	354.5	1,711	
	03:30	354.5	1,711 +	Decreased rpm slightly.
	04:00	354.3	1,711	
	04:30	354.3	1,711	
	04:46			Engine stopped, wire to fuel pump solenoid broke.

PRODUCTION WELL NO. 4

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-04-80	04:50	298.9		
	04:51	298.7		
	04:52	298.3		
	04:53	298.1		
	04:54	297.9		
	04:55	297.7		
	04:56	297.6		Pump back on.
	05:00	348.7	1,711	
	05:22	352.8	1,711	
	05:30	353.1	1,711	
	06:00	353.7	1,711	
	06:30	354.0	1,711 +	Decreased rpm slightly.
	07:00	353.7	1,711	
	07:30	353.9	1,711	
	07:45			T = 76°F; K = 380 micromhos. Collected samples.
	07:55	353.4	1,711	
	08:00			Pump off.
	08:01	283.1		
	08:02	299.0		
	08:03	299.8		
	08:04	299.4		
	08:05	299.1		
	08:06	298.7		
	08:07	298.5		
	08:08	298.3		
	08:09	298.0		
	08:10	297.8		
	08:11	297.6		
	08:12	297.5		
	08:13	297.4		
	08:14	297.2		
	08:15	297.2		
	08:20	296.7		
	08:25	296.2		
	08:30	296.0		

PRODUCTION WELL NO. 4

TEST DATA
(continued)

Date	Hour	Depth to Water (ft)	Discharge (gpm)	Remarks
12-04-80	08:35	295.8		
	08:40	295.5		
	08:45	295.5		
	08:50	295.2		
	08:55	295.1		
	09:00	295.0		
	09:10	294.9		
	09:20	294.6		
	09:30	294.5		
	09:40	294.4		
	09:50	294.3		
	10:00	294.2		
	10:15	294.0		
	10:30	293.8		
	10:45	293.8		
	11:00	293.7		
	11:30	293.5		

PRODUCTION WELL NO. 4

TEST DATA

(Observation Well PW-1 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
11-17-80	11:35	329.04	Measured with chain. Measuring point hole in plate over casing 0.87 foot above top of surface pipe. Surface pipe approximately 0.2 foot above land surface.
11-30-80	15:08	328.76	Measured with chain.
	15:28		Set wire with tape mark at 328.76.
12-01-80	08:09	328.68	
	10:15		PW-4 on for development.
	17:18	329.24	
12-02-80	02:15	330.21	
	09:07	330.70	
	10:15		PW-4 off.
12-03-80	07:25	329.44	
	08:00		PW-4 on for test.
	08:28	329.49	
	09:00	329.71	
	09:20	329.82	
	09:35	329.90	
	09:50	329.94	
	10:10	330.02	
	10:25	330.06	
	10:45	330.13	
	11:25	330.24	
	11:40	330.26	
	12:40	330.42	
	13:40	330.51	
	14:40	330.61	
	15:40	330.68	
	16:40	330.76	
	17:40	330.86	
	19:10	330.95	
	20:10	331.06	
	21:10	331.13	
	22:10	331.43	
	23:10	331.22	

PRODUCTION WELL NO. 4

TEST DATA
(Observation Well PW-1 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-04-80	00:10	331.24	
	01:10	331.25	
	02:10	331.30	
	03:10	331.33	
	04;10	331.34	
	05:10	331.29	
	06:10	331.32	
	07:10	331.39	
	08:00		PW-4 off.
	08:45	331.21	
	09:00	331.14	
	09:15	331.07	
	09:30	331.00	
	10:15	330.85	
	10:30	330.78	
	11:10	330.67	

PRODUCTION WELL NO. 4

TEST DATA

(Observation Well PW-2 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
11-17-80	11:50	307.46	Measured with chain. Measuring point hole in plate over casing 0.90 foot above top of surface pipe. Surface pipe approximately 0.5 foot above land surface.
11-30-80	15:40	307.29	Measured with chain.
	15:55		Set wire with tape mark at 307.29.
12-01-80	08:15	307.32	
	10:15		PW-4 on for development.
	17:22	307.97	
12-02-80	02:25	309.74	
	06:50	310.40	
	09:15	310.71	
	10:15		PW-4 off.
12-03-80	07:32	308.79	
	08:00		PW-4 on for test.
	08:33	308.94	
	09:05	309.10	
	09:25	309.18	
	09:40	309.23	
	09:55	309.31	
	10:15	309.42	
	10:30	309.49	
	10:50	309.57	
	11:30	309.71	
	11:45	309.77	
	12:45	310.01	
	13:45	310.13	
	14:45	310.35	
	15:45	310.52	
	16:45	310.73	
	17:45	310.92	
	19:15	311.17	
	20:15	311.30	
	21:15	311.46	

PRODUCTION WELL NO. 4

TEST DATA
(Observation Well PW-2 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-03-80	22:15	311.58	
	23:15	311.67	
12-04-80	00:15	311.76	
	01:15	311.83	
	02:15	311.91	
	03:15	311.98	
	04:15	312.07	
	05:15	312.04	
	06:15	312.17	
	07:15	312.22	
	08:00		PW-4 off.
	08:50	312.01	
	09:05	311.93	
	09:20	311.82	
	09:35	311.74	
	10:20	311.44	
	10:35	311.33	
	11:30	311.10	

PRODUCTION WELL NO. 4

TEST DATA

(Observation Well PW-3 Water Levels)

Date	Hour	Depth to Water (ft)	Remarks
11-17-80	11:10	353.22	Measured with chain. Measuring point hole in plate over casing 1.3 feet above surface pipe. Surface pipe approximately 1 foot above land surface.
11-30-80	14:23	352.92	Measured with chain.
	14:55		Set wire with tape at 352.92.
12-01-80	08:03	352.80	
	10:15		PW-4 on for development.
	17:13	353.18	
12-02-80	02:15	353.93	
	06:44	354.20	
	09:00	354.29	
	10:15		PW-4 off.
12-03-80	07:39	353.43	
	08:00		PW-4 on for test.
	08:23	353.47	
	08:55	353.64	
	09:30	353.77	
	09:45	353.79	
	10:00	353.83	
	10:20	353.86	
	10:35	353.91	
	11:20	353.98	
	11:35	354.01	
	12:35	354.06	
	13:35	354.12	
	14:35	354.16	
	15:35	354.24	
	16:35	354.28	
	17:35	354.34	
	19:05	354.41	
	20:05	354.48	
	21:05	354.57	
	22:05	354.59	
	23:05	354.65	

PRODUCTION WELL NO. 4

TEST DATA
(Observation Well PW-3 Water Levels)
(continued)

Date	Hour	Depth to Water (ft)	Remarks
12-04-80	00:05	354.63	
	01:05	354.65	
	02:05	354.68	
	03:05	354.69	
	04:05	354.74	
	05:05	354.67	
	06:05	354.74	
	07:05	354.78	
	08:00		PW-4 off.
	08:55	354.60	
	09:10	354.55	
	09:25	354.51	
	10:10	354.40	
	10:25	354.37	
	10:45	354.31	

Appendix C2.

MW-9 Pumping Test, 1994

APPENDIX C

LAS ANIMAS CREEK

PUMPING TEST

Prepared for:

Steffen Robertson and Kirsten, Inc.
1755 E. Plumb Lane, Suite 241
Reno, NV 89502

Prepared by:

Adrian Brown Consultants, Inc.
155 South Madison Street, Suite 230
Denver, Colorado 80209-3013
(303)-399-9630

September 12, 1996
Report 1356A/960912

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1. INTRODUCTION

Water supply for the Copper Flat project is to be drawn from Santa Fe Formation alluvium in the valley of the Rio Grande. Water is to be removed from four wells approximately one mile north of the Las Animas Creek valley. This valley contains a shallow aquifer and an intermittent stream, which supply water for a wide range of agricultural and water supply activities, as well as support a major stand of deciduous trees.

In order to evaluate the extent to which the stream flow and the water in the shallow aquifer may be affected by the drawdown from the nearby pumping wells, a major pumping test was designed and performed in Animas Creek. This test comprised the installation of a pumping well in the main Santa Fe aquifer, located some 200 feet below the ground surface in the valley. Water was pumped from this well to create a drawdown which would simulate the drawdown expected from the production pumping. The response to this pumping was monitored in one well completed at the top of the saturated section in the Santa Fe formation, at a depth of approximately 80 feet. In addition, the response of the overlying Las Animas Creek shallow aquifer was monitored by one specially completed shallow monitor well, as well as a total of seven other shallow private wells in the area. The pumping test was performed in October, 1994. This appendix presents the test approach, test results, and an interpretation of the results.

2. APPROACH

The pumping test was performed in the Las Animas Creek Valley at the point closest to the mine's water supply wells, as shown in Figure 1. The test location geology comprises 20-60 feet of reworked gravels which form a recent alluvium layer, overlying several thousand feet of Santa Fe Group gravels, sands, and silts.

A number of nearby private wells draw water from the Las Animas Creek alluvium, most are less than 100 feet deep, tapping the recent alluvium. Water levels in these wells are typically within a few feet of ground surface, and appear to be associated with stream levels (when the stream flows). This aquifer provides groundwater for domestic and stock watering wells in the area. Several wells are completed at approximately 100 feet or greater. These wells display a chemical signature distinct from the alluvial well water and a water level about 50 feet lower than the shallow wells.

Las Animas Creek is an intermittent stream. The stream was flowing when sampled in August 1994, but was not flowing at the time of the pumping test in October 1994. Water quality is generally good.

3. TEST ARRANGEMENT

Figure 2 shows the locations of the three wells which were installed for the test. Details of each well are provided in Attachment 1. The three wells were completed as follows:

1. Pumping well MW-9. The pumping well is MW-9. This well is drilled to a depth of 252.5 feet through the Las Animas Creek alluvium into the Santa Fe Formation. It is open to the formation from 194 feet to total depth. The well was screened with 4 ½ inch Schedule 80

slotted PVC, and cased with 4 ½ inch Schedule 80 blank PVC pipe. The well was fitted with a 100 gpm submersible pump.

2. Monitor well MW-10. MW-10 is located approximately 50 feet east of MW-9. It was drilled to a depth of 125 feet, and screened between 76.5 feet and total depth in the Santa Fe alluvium.

3. Monitor well MW-11. MW-11 is located approximately 50 feet southeast of MW-9. MW-11was initially drilled to a depth of 65 feet. After logging the hole, it was backfilled to a depth of 37 feet, sealed with bentonite, and screened from 7 to 37 feet BGS with a gravel pack.

Figure 3 shows the generalized geology of the three wells. The initial water levels are shown for reference.

In addition to these three wells, the test was monitored by measuring water levels in nearby domestic, irrigation, and water supply wells. The wells used were as follows:

Well Name	Location Relative to MW-9	Drilling method	Approx. Depth (ft)
Irwin House- “Birdie”	250 feet southwest	Hand dug	40
Irwin Yard- “Concrete”	150 feet due south	Hand dug	30
Exten	1250 feet west	Hand dug	25
Nicholson	1350 feet east	Hand dug	25
Cox	2200 feet east	Drilled	112
Darling	2700 feet east	Hand dug	25
PW-1	3400 feet south	Drilled	1000

4. TEST RESULTS

4.1 Pre-test activities

Prior to the test, all wells were measured daily for 17 days, to establish a trend for groundwater levels (if any).

4.2 Pumping Test Operation

The test was operated by starting the pump generator on October 13, 1994 at 12:30 p.m. Initially water was discharged to a location approximately 200 feet from the well. It was discovered that this location was too close to the monitor wells, as the water level began to rise slightly in MW-11. The test was temporarily shut down on October 14 from 13:32 to 16:30 to change the location of the discharge, with the new discharge point being located approximately one mile from the pumping well. During operating periods, the pumped flow rate averaged 90 gpm. Flows are shown on Figure 4. The test ended at 09:00 on October 17. Water levels were measured every day for 12 days following the test.

Water levels were monitored using water level sounders, which were calibrated against each other to the nearest one hundredth foot. Reading frequency depended on the changes in the levels; pre- and post-test levels were generally read daily, while test rates ranged from hourly to once per shift. Results of water level monitoring are presented in Attachment 2.

4.3 Rainfall event

On October 14, a nearby rain gauge measured 1 inch of rain in 2.5 hours in the Las Animas Creek drainage basin. The creek began to flow, and water levels in the wells changed in response to the rain and the flow.

5. RESULTS

5.1 Flows

Flows from the pumped well (MW-09) were recorded using a flow meter. The results are presented in Figure 4. The flow fluctuated somewhat, with an average flow rate of 90 gpm.

5.2 Heads

Heads were measured in all project wells, but were measured more frequently in the three main wells installed for the project. The results are as follows:

1. MW-09. The initial water level elevation in the pumping well was approximately 4,375 feet. The response of MW-9 to pumping is indicated in Figure 5. As can be seen, drawdown was rapid and reversible, and reached approximately 24 feet at the end of the test. Specific capacity of the well was 3.75 gpm/ft.
2. MW-10. The initial water level elevation in the deeper of the two monitor wells was 4,376 feet, about the same as the pumping well. The response to the pumping is indicated in Figure 6. A drawdown of approximately 1 foot was recorded at the well, although it is possible that this value was affected by the rainfall which occurred late in the test.
3. MW-11. The initial water elevation in the shallowest well, completed in the Las Animas Creek alluvium, was 4,435 feet, approximately 60 feet higher than the two deeper wells. The response of the level in MW-11 during the test is presented in Figure 7 (note very expanded vertical scale on this graph). The rise in water level after the start of the test on October 14 is due to the local discharge of water on the ground nearby. There is no evidence that pumping in MW-9 effected a head change in MW-11 at any time during the test; the level in the well was falling prior to the test, and continued to fall after it.

In addition to monitoring the three main wells, a total of seven other wells were monitored. All were relatively shallow, and all were near the pumping well. Figure 9 presents a magnified view of the pumping test wells' head responses. The general trend of these well results is as follows:

1. a small rise for the first few days after pumping began
2. a return to the previous rate of decrease after the rise.

Prior to the pumping test, the "Birdie" shallow aquifer well was falling at 0.02 ft/day. After the discharge incident, the rate of decline remained the same. There is no identifiable evidence of any impact on these wells of the drawdown created by MW-09.

5.3 PW-1 Response

To check if there was any effect of the drawdown in the extraction wells, pumping well PW-1 was monitored. This well is located 3500 feet to the south of MW-9. The water level elevation in this well was 4375 feet for the period during which the test was run. During the test, the water level in PW-1 did not change in any way attributable to MW-9.

6. ANALYSIS OF RESPONSES

6.1 MW-09 response

The hydraulic characteristics of the aquifer tapped by MW-09 have been estimated by a variety of non-equilibrium methods, using the Aqtesolve Package (Gerahty and Miller, 1995). Three approaches were used to analyze the first 24 hour drawdown period, with the following results (Figure 10, Figure 11, and Figure 12):

Method	Cooper-Jacob	Theis	Hantush	Average
Transmissivity (ft^2/min)	0.6086	0.5779	0.5666	0.5700
Storage Coefficient	3.3×10^{-5}	6.1×10^{-5}	7.3×10^{-5}	5×10^{-5}
Horizontal hydraulic conductivity (ft/yr)	6,400	6,075	5,960	6,000
Vertical hydraulic conductivity (ft/yr)	n/a	n/a	60	60

The Hantush analysis is particularly interesting, as the fit is good between the observed and the predicted behavior. In this analysis, it is assumed that there is leaky flow through an aquitard (on the bottom or top of the aquifer, or both). The vertical hydraulic conductivity of the leaky aquitards can be estimated from the response. The value obtained is 60 ft/yr. The vertical to horizontal anisotropy ratio obtained for the test is 100:1.

In summary, it would appear that MW-09 is located in a material with a hydraulic conductivity of approximately 6,000 ft/yr, with a storage coefficient of 5×10^{-5}, and a ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity of 100:1. These values are very similar to the calibrated values which have been used in the modeling (Appendix D).

6.2 Las Animas Creek aquitard conductivity

The conductivity of the aquitard below the Las Animas Creek alluvium can be estimated by consideration of the head difference in the aquifer. The vertical head gradient between MW-11 (completed in the Las Animas Creek alluvium) and MW-10 (completed in the Santa Fe Formation) can be computed as follows: 60'?

Head difference MW-10 to MW-11 = 23 feet

Thickness of low permeability layer = 50 feet

Head gradient = 23/50 = 0.46

This is a substantial vertical gradient. From modeling, it appears that there is approximately 13 miles of Las Animas Creek bottom land, with an average width of 2,000 feet. The total flow down the valley appears to be in the order of 2,000 gpm. If half of the water were to seep from the upper alluvium to the lower through the low permeability layer between the two wells above, then the hydraulic conductivity would have to be:

evidence? but in the lower part, it seeps up!

$$K = Q/iA$$

where: K = hydraulic conductivity (ft/yr)

Q = flow (1,000 gpm or 70×10^6 cuft/yr)

i = hydraulic gradient = 0.46

A = flow area (5 square miles or 150×10^6 square feet)

Applying the values produces a vertical hydraulic conductivity estimate of 1.0 ft/yr, or about 10^{-6} cm/sec. This is the vertical conductivity of a clayey material.

6.3 Water Chemistry

As a part of the evaluation, water chemistry was sampled from the test wells. The results are included in the data presented in Appendix E. The chemistry of the water is summarized below:

Parameter	Units	MW-9	MW-10	MW-11	PW-1
TDS	mg/L	190	310	314	217
HCO_3	mg/L	149	262	263	144
SO_4	mg/L	12	25	21	10
Ca	mg/L	12	59	63	22
Na	mg/L	54	29	23	38
Mg	mg/L	1	8	10	n/a

The chemistry of wells MW-10 and MW-11 are very similar, indicating that the water in the upper portion of the Santa Fe aquifer is provided by seepage from the overlying Las Animas Creek alluvium through a low permeability layer to the MW-10 level. Conversely, the chemistry of MW-9 differs from MW-10 and MW-11, and is very similar to PW-1. This suggests MW-9 comprises underflow beneath Las Animas Creek, not flow from it.

6.4 Conceptual Model

Based on the observations from the Las Animas Creek pump test a conceptual flow model of this system has been developed and quantified:

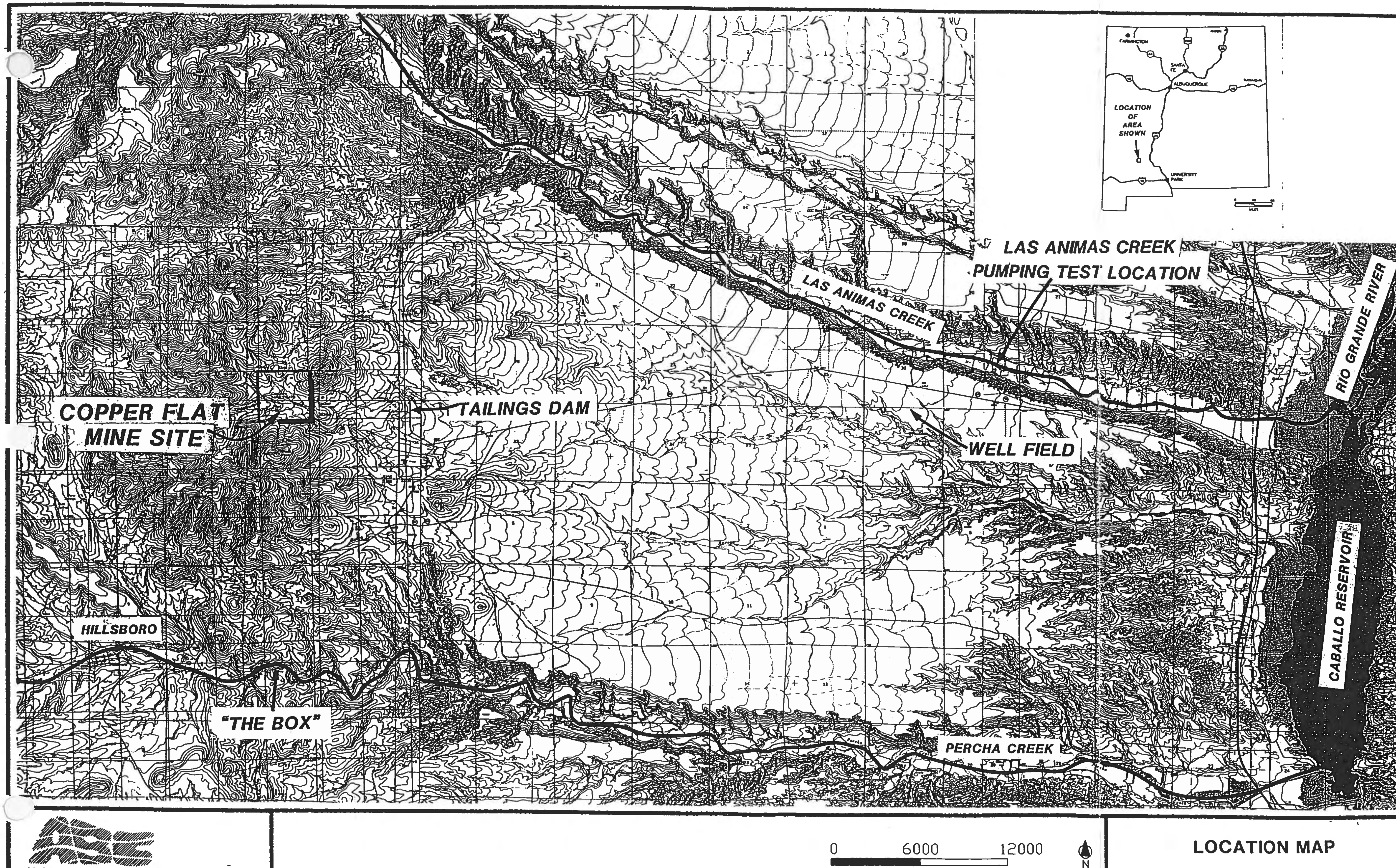
1. Water flows along Las Animas Creek, filling the associated alluvial aquifer.
2. Water leaks from the Las Animas Creek alluvial aquifer through the underlying clayey material. Analysis of this flow and the head gradient identified in the test produces a vertical hydraulic conductivity of 1 ft/yr.
3. This infiltrating water then meets with, and mixes with, water in the main Santa Fe aquifer. This aquifer is made up of relatively high permeability material, with a lateral hydraulic conductivity of about 6,000 ft/yr. The vertical permeability of this material is approximately 100 times less than its effective horizontal conductivity.

This system provides the explanation as to why the Las Animas alluvium remains saturated; the low conductivity of the underlying clayey material is sufficiently low to prevent water from leaving the alluvium, even under the strong vertical head which exists through the layer.

7. CONCLUSIONS

The Las Animas Creek alluvial system pump test has established that the creek and the associated alluvium is prevented from leaving the valley by a low permeability zone beneath the alluvial aquifer. This zone is estimated to have an hydraulic conductivity of no more than 1 ft/yr. The lower material in the Santa Fe aquifer is comprised of layers of high horizontal hydraulic conductivity materials (K = 6,000 ft/yr) and layers of low vertical conductivity aquitards (K = 60 ft/yr, or 1/100 of the horizontal conductivity).

While there is some evidence to suggest that the material between the Las Animas Creek alluvium is unsaturated (Attachment 1) the testing data does not provide a demonstration of a widespread unsaturated material beneath the creek bed.

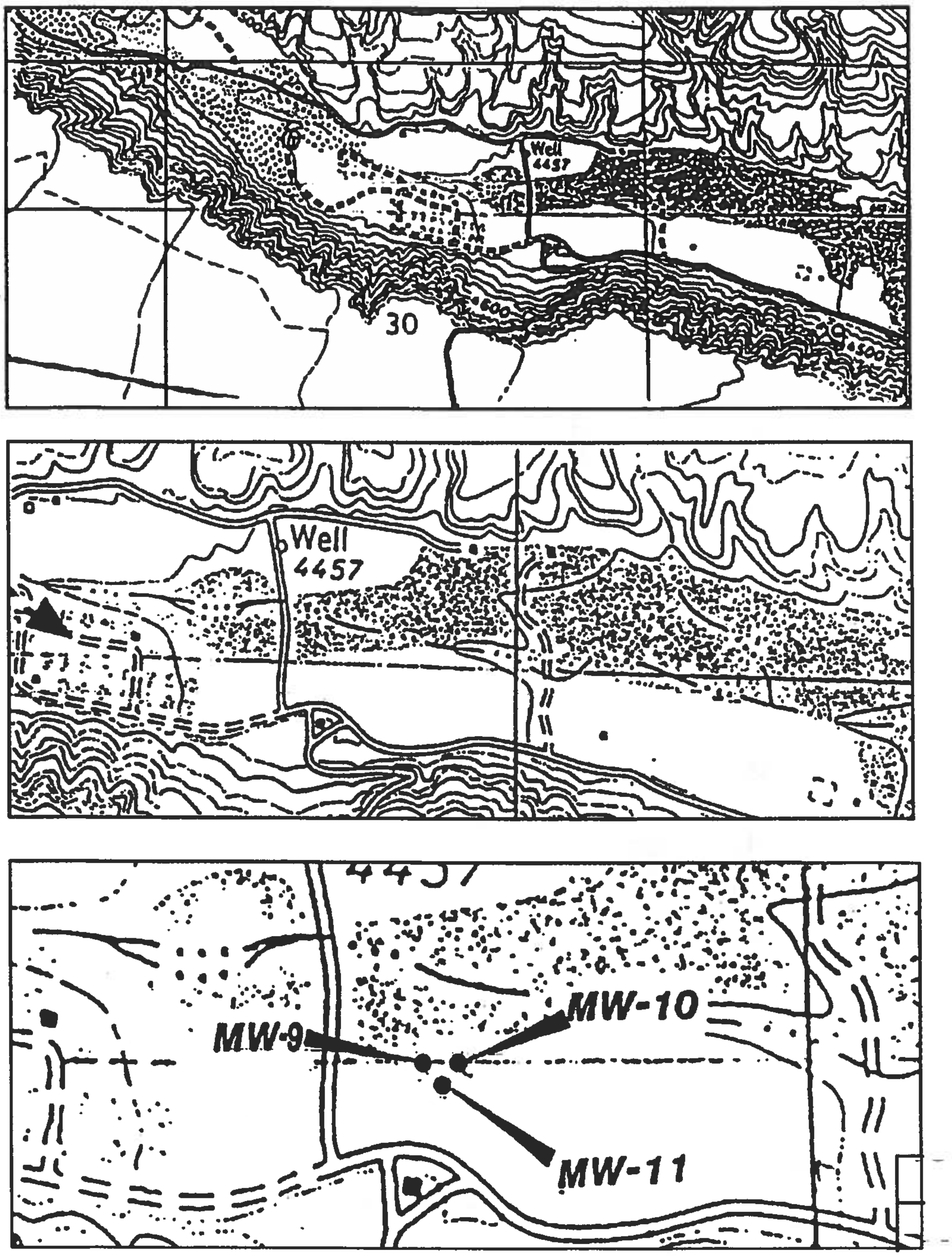


ADRIAN BROWN CONSULTANTS, INC.

LOCATION MAP

Figure 1

Figure 2 Pump test location map



1" = 2000'

1" = 1000'

1" = 500'

Figure 3 Generalized geology of pumping test wells

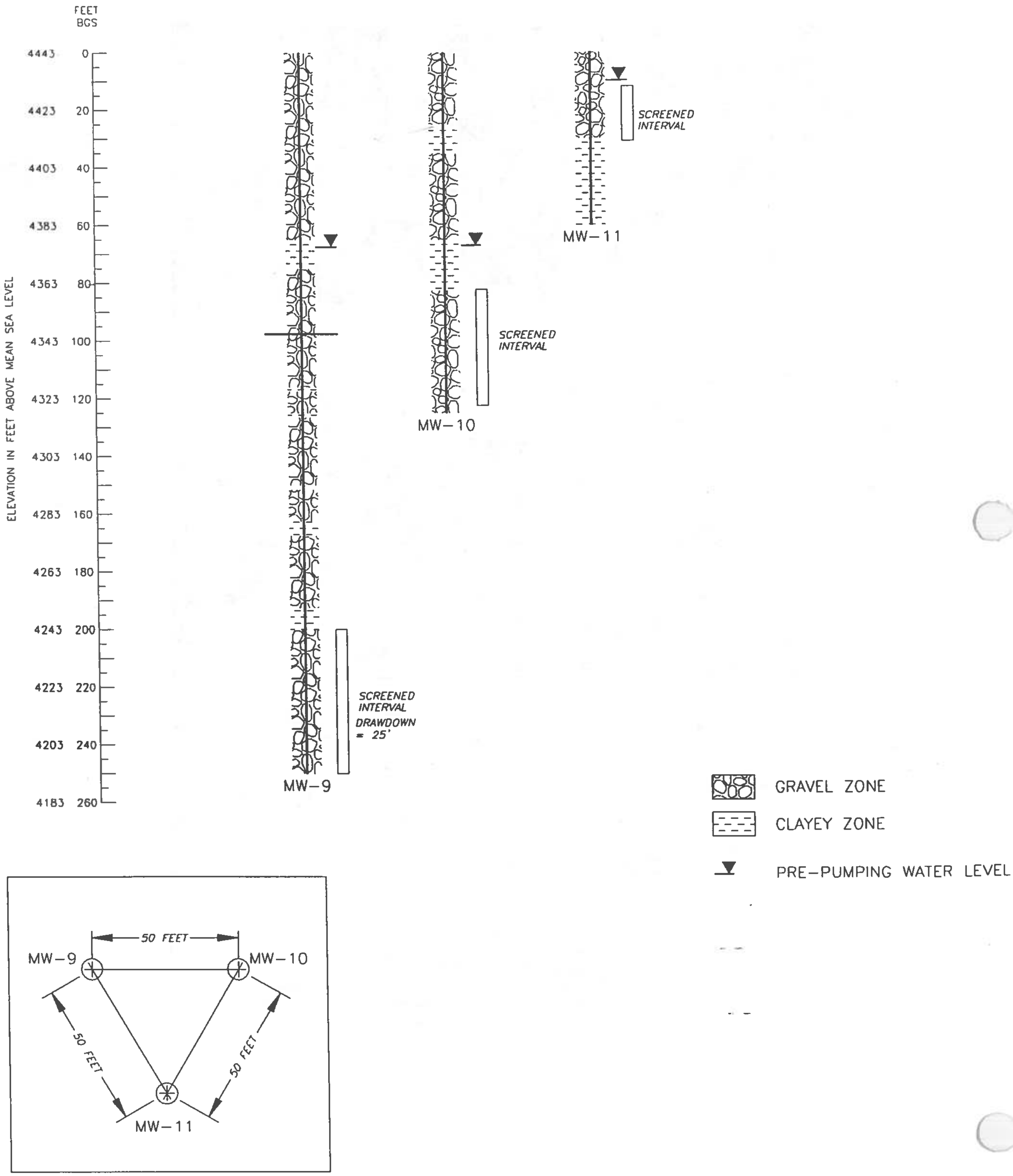


Figure 4 Flow from MW-9

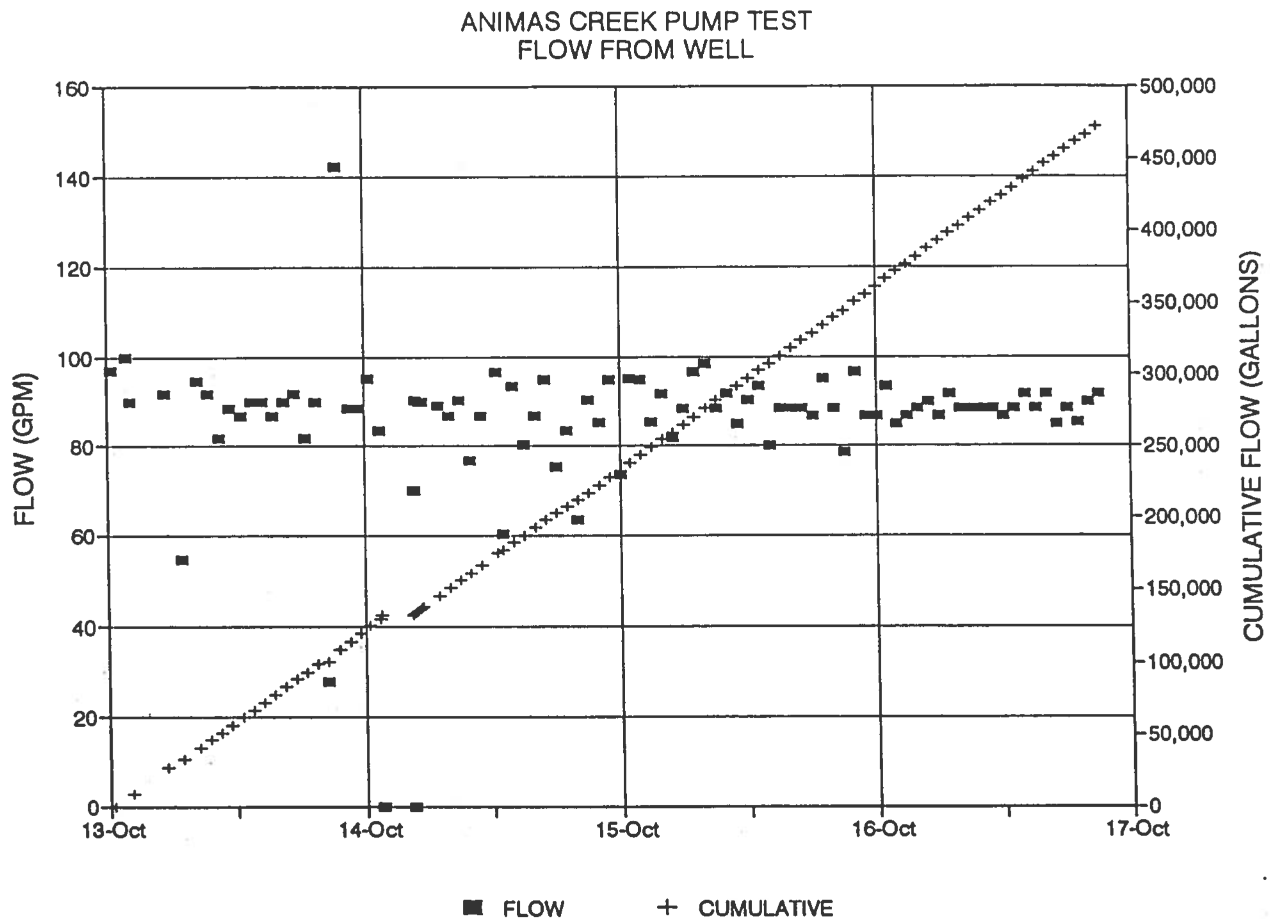


Figure 5 Drawdown in MW-9

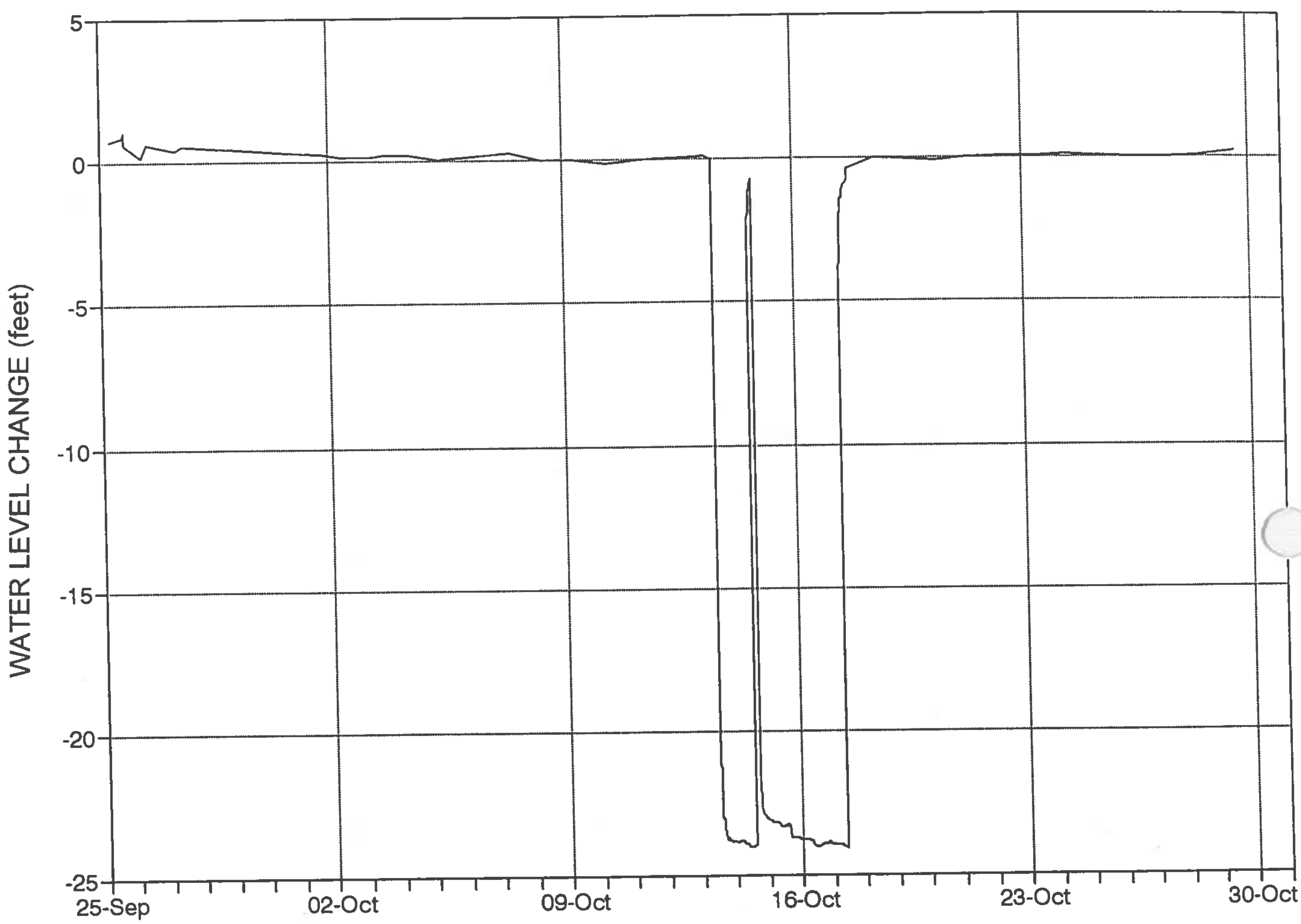


Figure 6 Drawdown in MW-10

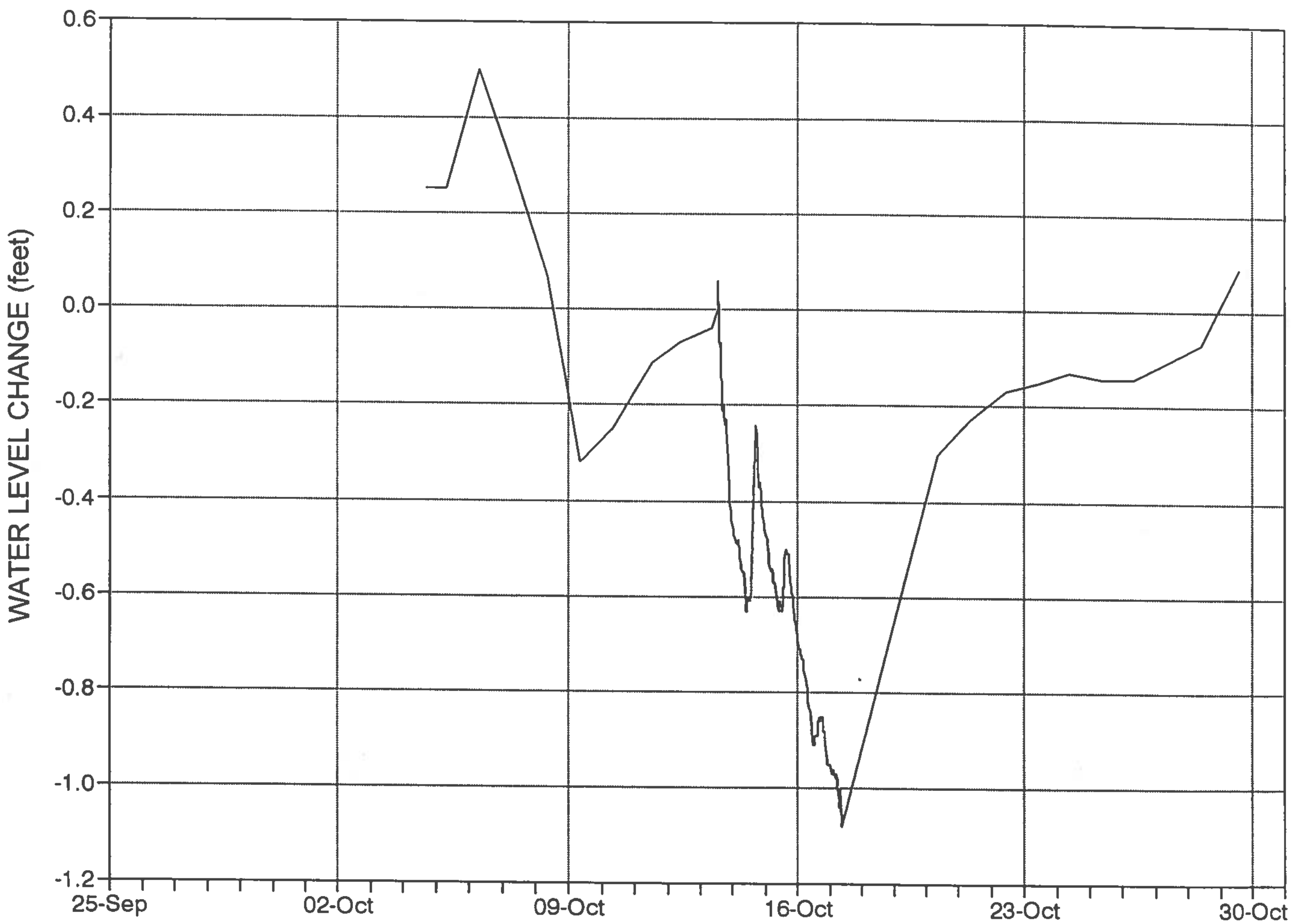


Figure 7 Drawdown in MW-11

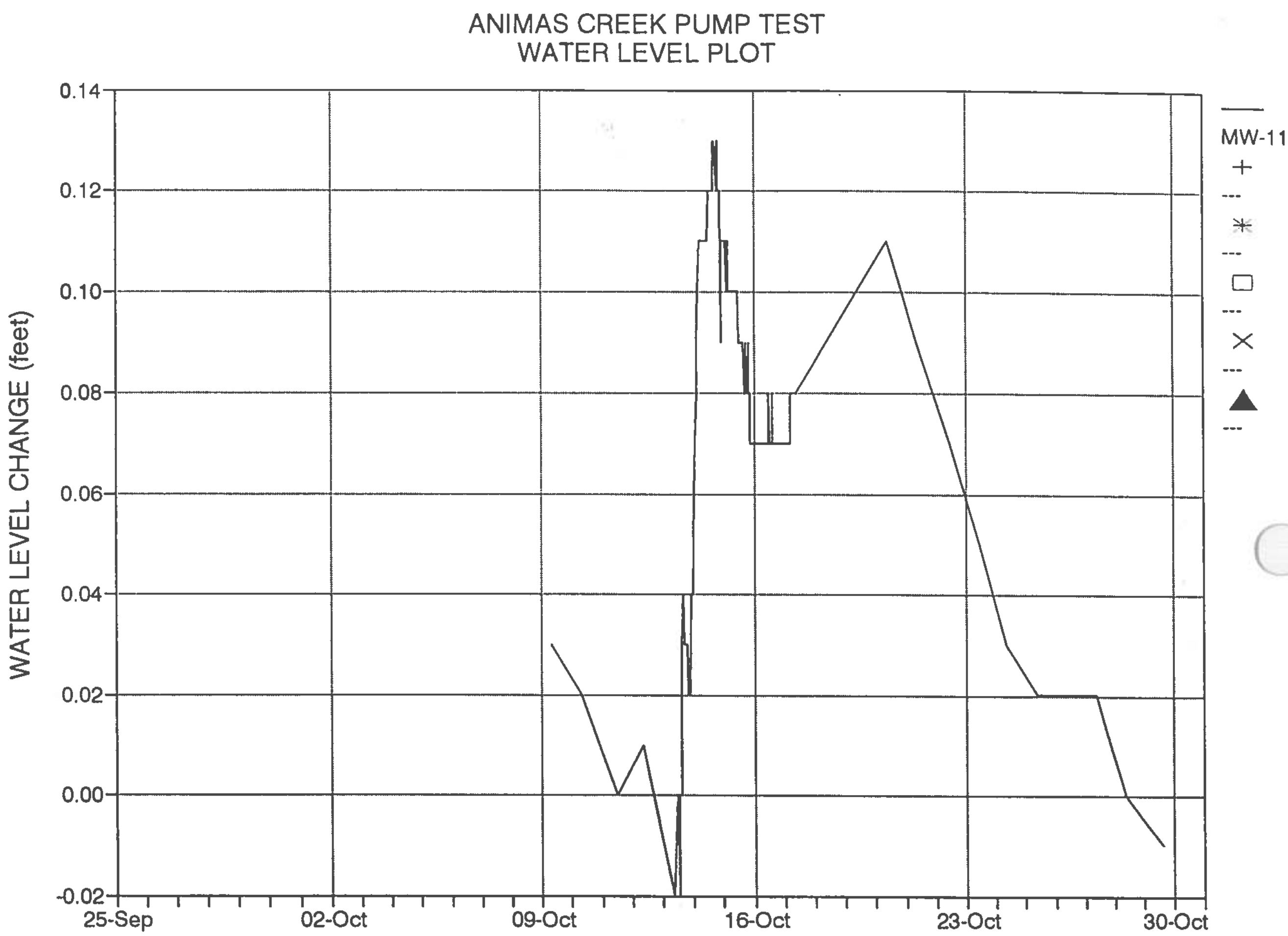


Figure 8 Water elevations in test wells

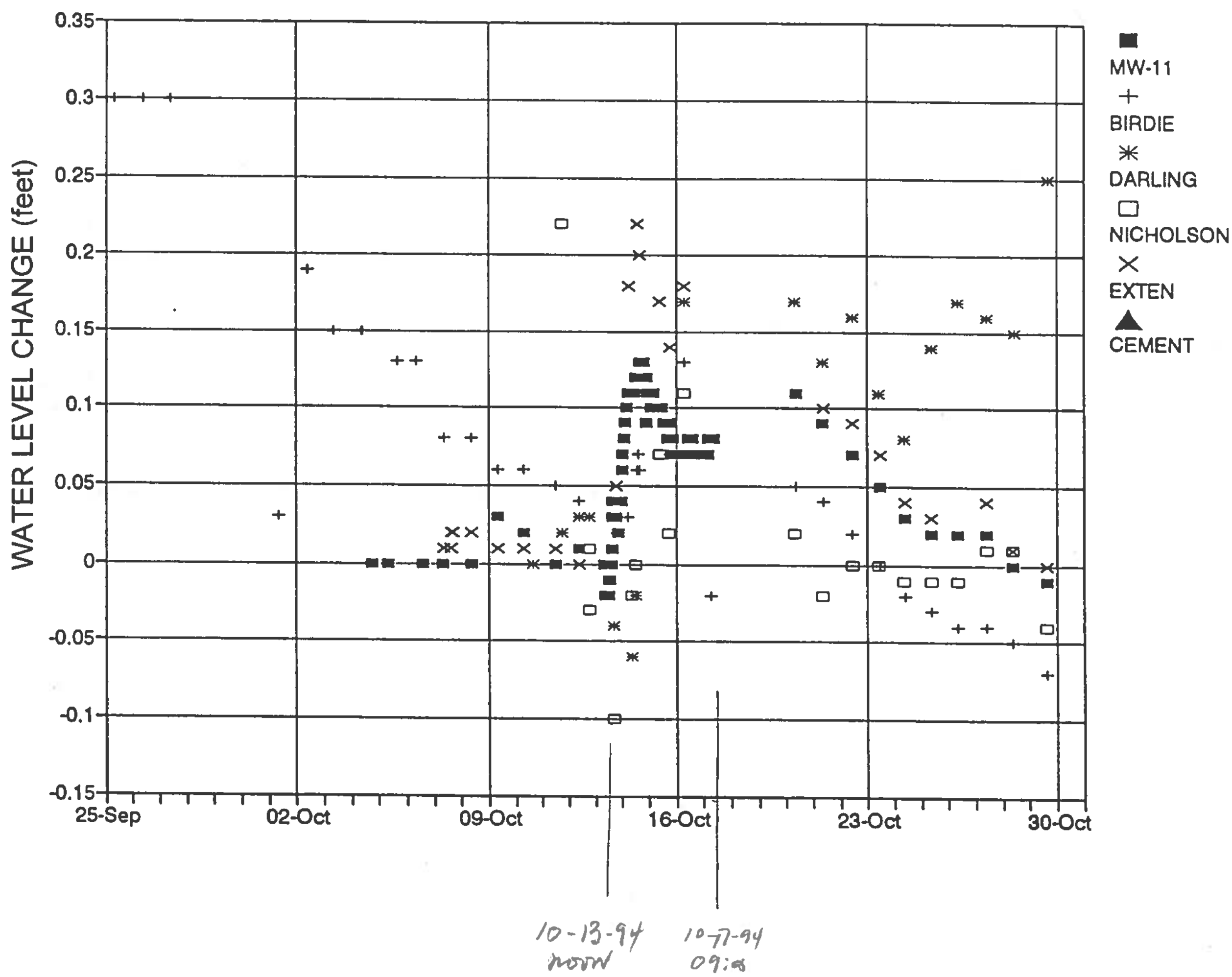


Figure 9 Head changes for test wells

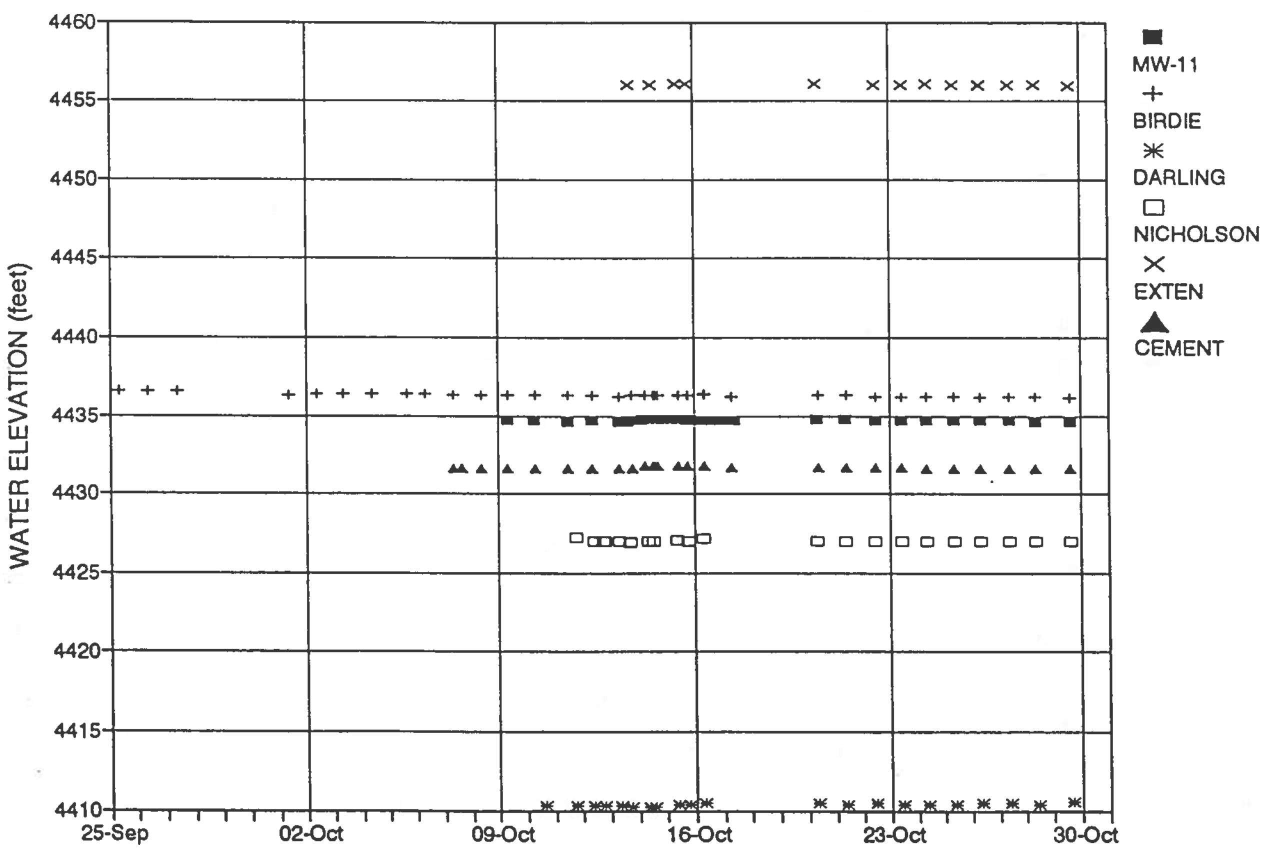


Figure 10 Cooper- Jacob drawdown analysis plot

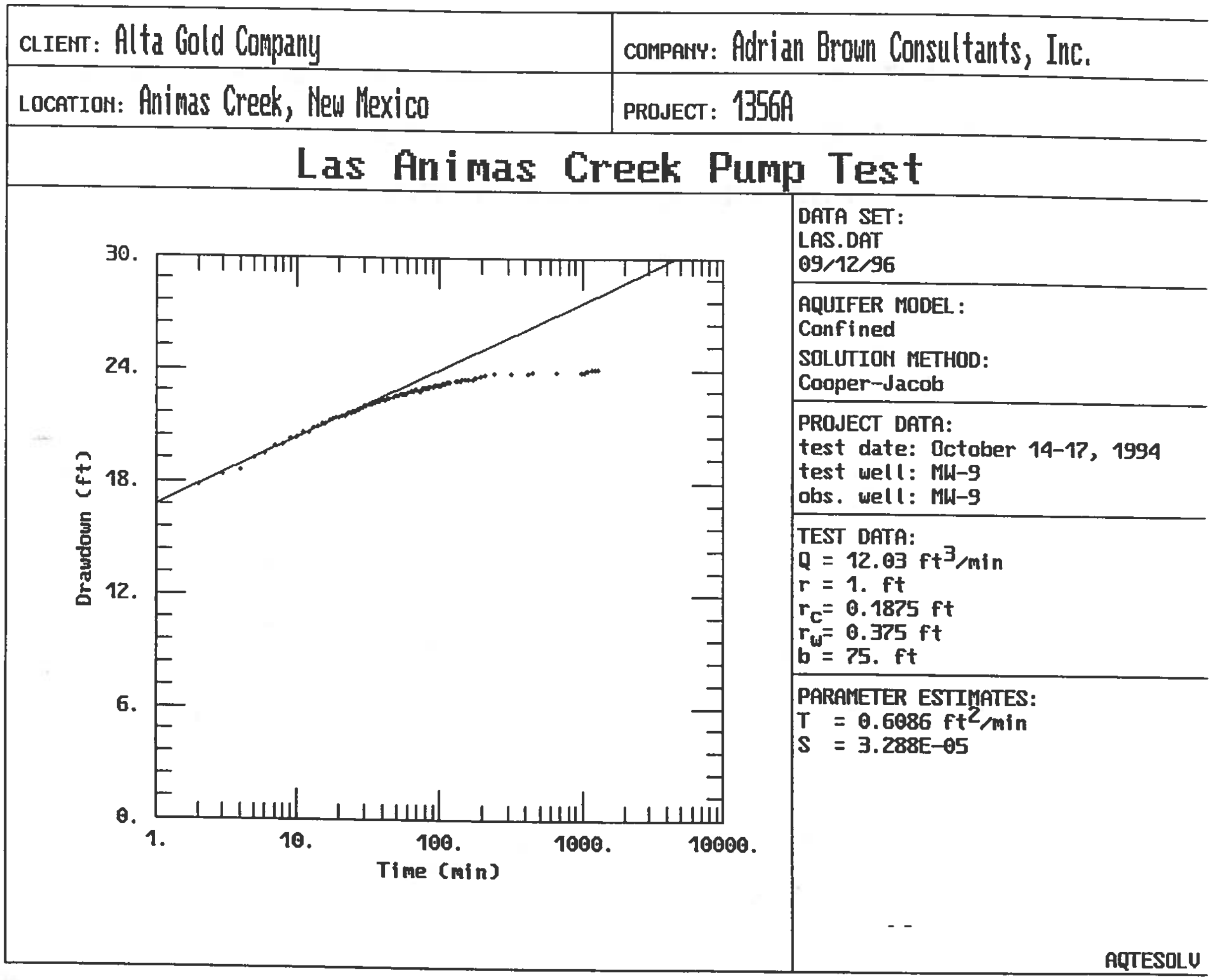
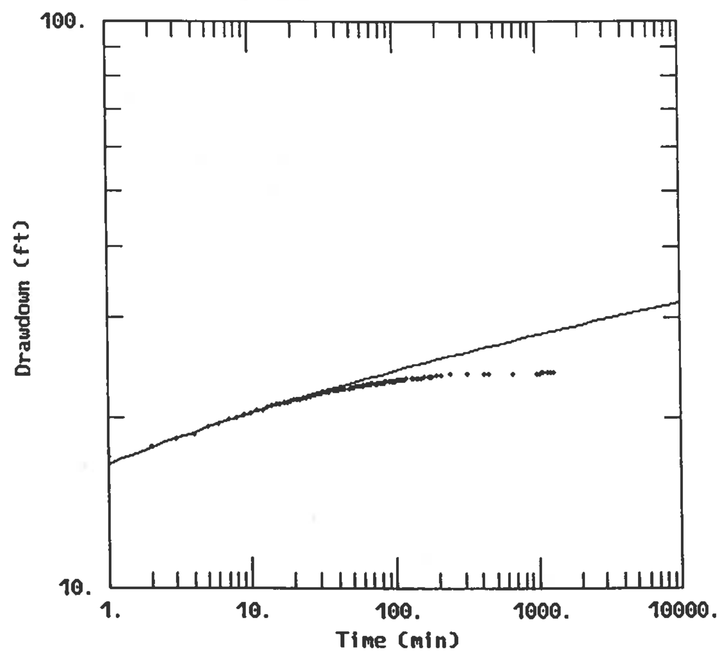


Figure 11 Theis drawdown analysis plot

CLIENT: Alta Gold Company	COMPANY: Adrian Brown Consultants, Inc.
LOCATION: Animas Creek, New Mexico	PROJECT: 1356A

Las Animas Creek Pump Test



DATA SET:
LAS.DAT
09/12/96

AQUIFER MODEL:
Confined

SOLUTION METHOD:
Theis

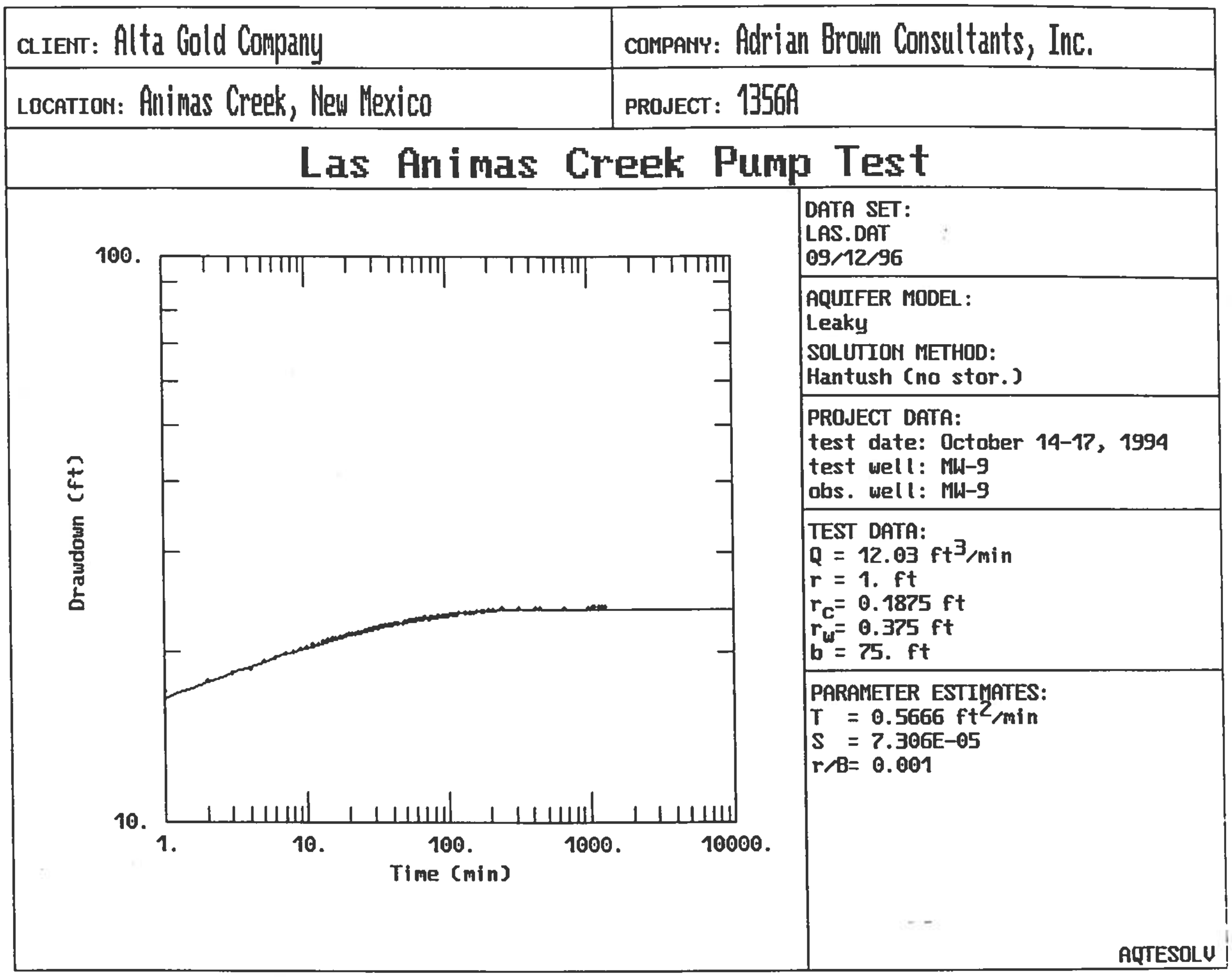
PROJECT DATA:
test date: October 14-17, 1994
test well: MW-9
obs. well: MW-9

TEST DATA:
Q = 12.03 ft^3/min
r = 1. ft
r_c= 0.1875 ft
r_w= 0.375 ft
b = 75. ft

PARAMETER ESTIMATES:
T = 0.5779 ft^2/min
S = 6.098E-05

AQTESOLV

Figure 12 Hantush leaky aquifer drawdown analysis plot



Appendix C3.

TSF-Area Pumping Test, 1994

APPENDIX G
TAILINGS DAM AREA PUMPING TEST

Prepared for:

Steffen Robertson and Kirsten
1755 East Plumb Lane, Suite 241
Reno, Nevada 89502

Prepared by:

Adrian Brown Consultants, Inc.
155 South Madison Street, #230
Denver, Colorado 80209

September 9, 1996
Project #1356A

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ATTACHMENTS

G.1 INTRODUCTION

A seven-day aquifer test was conducted in the vicinity of the tailings dam of the Copper Flat Mine, to determine the hydraulic characteristics of the aquifer(s) in this area. This section describes the pump test activities, and includes a discussion of the selection of the pumping well and observation wells, schedule of operations, operation of the test, water discharge and water quality issues. The aquifer test analysis is summarized in Section G.4 of this report.

An understanding of the site-specific geology is critical to the interpretation of the pumping test results. The deposits in the vicinity of the tailings dam are comprised of relatively recent sands and gravel contained within a clay/silt matrix, all of which overlie the Santa Fe Group sediments, which are similar in nature. A distinctive clay/silty clay unit is found at depths ranging from approximately 10 to 30 feet below ground surface and ranges in thickness from 25 to over 100 feet. This clay/silty clay unit, characterized by a distinctive red to red-brown color and dry to slightly moist with uniform composition and consistency, provides an effective hydrologic barrier between the upper alluvial sediments and those representing the Santa Fe Group.

Volcanic rocks (basalt and/or rhyolite) were commonly encountered above the clay unit during the drilling of the project boreholes. One borehole (GWQ94-16), however, encountered basalt beneath the clay. Unlike the clay observed in other boreholes, the clay/silty clay in GWQ94-16 was uncharacteristically thinner and was accompanied by significant amounts of gravel and moisture. Based on the gravelly nature of the clay, the relative superposition in the borehole, and the eastward dip of the sediments, the relatively shallow clay/silty clay located above the basalt in borehole GWQ94-16 may actually be reworked material from an upgradient clay source which was deposited over the basalt. The stratigraphy observed in all other boreholes clearly indicates that basalt and/or rhyolite was flowed out above the thick clay unit.

The alluvial units above and below the clay unit are similar in nature, although the gravel unit below the clay contains more matrix material. Because of the abundant matrix material, the lower unit is more poorly sorted and the lower aquifer has a lower permeability in those zones where clay or silty clay predominate.

G.2 WELL SELECTION

One pumping well and 13 observation wells were employed during the aquifer test. Figure G-1 shows the well locations and Table G-1 presents pertinent information for each of the wells used for data collection.

G.2.1 Pumping Well

Well GWQ94-17 was drilled and completed in October 1994. The borehole was drilled to a total depth of 158 feet and the well is screened from 120-150 feet below ground surface. Static water level in the well is on the order of 3 feet below ground surface. Well GWQ94-17 was chosen for pumping for the following reasons:

1. Central location relative to observation wells.
2. Casing diameter (4") was sufficient for pump installation.
3. Discharge water could be easily routed to discharge point.
4. Sulfate concentrations were low enough to pump without concern of immediately exceeding discharge standards.
5. Screened in a horizon of suitable water production.
6. Screen located beneath the red clay aquitard that separates the shallow aquifer from the underlying aquifer.

Discharge water from GWQ94-17 was piped through 600 feet of 3-inch layflat vinyl pipe that passed under the county road through a corrugated-steel culvert to a concrete sump. The sump is connected by an underground concrete culvert to a concrete-lined pit, located approximately 1500 feet southwest of the pumping well. Figure G-2 shows a schematic of the system.

G.2.2 Observation Wells

Observation wells were selected based on their proximity to the pumping well, their screened intervals, and their potential to exhibit a response in water levels during the pumping test.

The nearest observation well, GWQ94-13, is located 190 feet west-southwest of the pumping well, and is screened from 75 to 105 feet below ground surface. Observation well GWQ94-14, located 390 feet east-southeast of the pumping well, is screened from 127.5 to 157.5 feet. Observation well GWQ94-15 is 713 feet southeast of the pumping well, and is screened from 112 to 142 feet. Well GWQ94-16 is among the shallowest observation wells (screened from 25 to 45 feet below ground surface) and is located 423 feet southwest of pumping well GWQ94-17. The deepest observation well, GWQ94-20, is screened from 288 to 338 feet, and is located 264 feet northwest of the pumping well. Observation well GWQ94-21 has separate completions at

213-263 feet (A) and 285-315 feet (B), and is located 621 feet east of the pumping well.

Limited completion information was available for the six observation wells installed prior to the 1994 field program. Observation well GWQ-11 is located approximately 405 feet southwest of the pumping well and is completed to a depth of 76 feet. Observation wells NP-2 and NP-5 are located approximately 1130 and 735 feet south-southwest of the pumping well, and have total depths of 110 and 41 feet, respectively. Observation well IW-1 has a total depth of 67 feet and is located 239 feet west of the pumping well. Observation well IW-2, 248 feet northwest of the pumping well, is completed to 45 feet.

Water levels in wells GWQ94-18 and GWQ94-19 were not monitored during the pumping test since both wells were dry or nearly dry.

G.3 AQUIFER TEST

G.3.1 Aquifer Pumping Test Operations

Well GWQ94-17 was pumped for a total of 78.14 hours, starting at 10:50 on Tuesday, November 8, 1994 and ending at 16:58 on Friday, November 11, 1994. The average flow rate during the test was 23 gpm. The flowrate was not sufficient to activate the inline flowmeter at the wellhead, so flowrate was measured at the concrete sump discharge point approximately hourly using a bucket and stopwatch. The flowrate remained steady throughout the test until the pump was shut off.

G.3.2 Monitoring

Water level changes during the pumping portion of the aquifer test were monitored manually for wells GWQ94-17, GWQ-11, GWQ94-15, GWQ94-16, GWQ94-21A, GWQ94-21B, NP-2, NP-3, NP-5, IW-1, and IW-2 using an electronic water level sounder. The remaining wells (GWQ94-13, GWQ94-14, and GWQ94-20) were monitored automatically, during the pumping portion of the aquifer test, using pressure transducers attached to data logging units. Manual readings were collected every 5 to 10 minutes for about the first hour, every 15 to 20 minutes for the next 3 to 4 hours, and at least hourly for the remainder of the test. Automatic pressure transducer readings were collected every minute during the pumping period.

During the recovery portion of the test, water levels were measured at 5-minute intervals in wells GWQ94-14 and GWQ94-13 using pressure transducers. The pressure transducer that was set in GWQ94-20 during the pumping period of the test was transferred to GWQ94-21A for the recovery test. Water level recovery was also monitored in the pumping well at 5-minute intervals, using a pressure transducer. Recovery was monitored for 2.5 days, from 16:58 on Friday, November 11, 1994 to approximately 16:00 on Sunday, November 13.

A summary of these monitoring activities is presented in Figure G-3. The pre-pumping static water level data and aquifer test water level data are presented in the Attachments A-5 and G-2, respectively. A major storm event occurred, in which 6.5 inches of rain were gauged at the tailings dam from the morning of November 11, 1994 to the evening of November 12, 1994 (Irwin, personal communication). This recharge event may have affected the recovery of the water levels in the observation wells.

G.3.3 Observations

G.3.3.1 Pumping Well GWQ94-17

Well GWQ94-17 was pumped at a rate of 23 gpm for a total of 78.14 hours. The steady-state drawdown of 125 feet was acheived in 31 minutes of pumping. The plot of drawdown versus time, presented in Figure G-4, indicates that the pump operated continuously during the test.

G.3.3.2 Discharge

The well discharged a total of just under 108,000 gallons into the concrete-lined pit, located approximately 1500 feet south-southwest of the pumping well. Observation well NP-2, located approximately 50 feet from the northwest corner of the pit, was monitored during the test to determine whether the concrete pit was leaking and if so, how much effect it had on the local groundwater table. The water levels in NP-2 during the test period are shown in Figure G-5, and do not exhibit effects from leakage. However, the drop in water level in the concrete pit after the pump was shut off indicated that the pit leaked approximately 5000 gallons/day.

G.3.3.3 Water Quality

The quality of the discharge water was monitored periodically during the test. Sulfate ranged from a low of 180 mg/l to a high of 360 mg/l, with concentrations peaking eight hours into the test and decreasing as the test progressed. Temperature readings were affected by the sun incidence on the discharge pipe and were not representative of the groundwater temperature. The pH of the water stabilized at approximately 7.4 and the conductivity ranged from a low of 990 μS to a high of 1110 μS. Water quality parameters measured at the discharge pipe are summarized in Table G-2.

G.3.4 Test Results

G.3.4.1 Shallow Aquifer System

The shallow aquifer system hosts numerous wells, including the shallow (<80 feet) monitoring wells near the tailings dam.

None of the shallow observation wells monitored during the pumping test showed a response to pumping at GWQ94-17, indicating that in this area there is no hydraulic connection between the upper, shallow alluvial aquifer and the lower aquifer in the Santa Fe Group. The plots of drawdown in the observation wells versus time during the pumping test are presented in Attachment G-1. The shallow observation wells are IW-1, IW-2, NP-5, GWQ-11, and GWQ94-16.

G.3.4.2 Santa Fe Group Aquifer System

Two types of response were observed in the Santa Fe Group aquifer system due to stressing by pumping at GWQ94-17. Theis type responses were demonstrated at wells GWQ94-13, GWQ94-14, GWQ94-21A, GWQ94-21B and NP-3. An attenuated response was demonstrated at observation well GWQ94-15, in the form of a slower, flatter drawdown curve.

The response in observation well GWQ94-20 was influenced by recharge of the well following development on November 3, 1994. The well is completed in a low-permeability zone and is slow to equilibrate following pumping/development. Therefore, data collected from GWQ94-20 during the pumping test are considered invalid for analysis purposes. The water level plots versus time for all other monitoring wells observed during the aquifer test are shown in the Attachment G-1.

G.3.4.3 Bedrock Flow System

Although no deep bedrock wells were installed or monitored during this study, some knowledge of the deep bedrock system is discernible through investigation of the local geology of the area. Water that enters the various limestone beds of the upper Paleozoic rocks in the north-trending Animas Uplift moves downdip along bedding plane and solution openings until it reaches the zone of saturation, then moves laterally along the strike of permeable strata toward points of discharge in the principal stream valleys, which in this case are Las Animas Creek and Seco Creek (Davies and Spiegel, 1967).

G.4 ANALYSIS AND INTERPRETATION

The transmissivity of the aquifer appears to be approximately 1400 gpd/ft with a storage coefficient of 2.5 x 10^{-4}, based on a Theis analysis, and is representative of a confined aquifer of moderate permeability. Plots from the Theis evaluation are presented in Figures G-6 and G-7. The estimated efficieny of the pumping well, GWQ94-17, is approximately 25% based on the drawdown in the pumping well versus the water levels in the observation wells. This suggests that the aquifer is sufficiently tight to create large head losses in the formation as the groundwater flows radially into the wellbore. Additional well losses could be caused by the well design and completion.

The aquifer test did not positively identify any fixed-head or no-flow boundaries. The test did confirm that wells that penetrate the clay layer are hydraulically connected to the pumping well. Response of those observation wells were, in general, well-modeled by a Theis-type response. Wells that are completed above the confining clay layer (shallow aquifer) were not affected by the pumping activity at GWQ94-17.

Well GWQ94-14 displayed an unusually quick response and more rapid drawdown possibly indicating the presence of a higher permeability paleo-channel that connects GWQ94-14 to GWQ94-17.

In addition to performing an integrated, detailed Theis analysis on the suite of observation wells, data from individual observation wells were analyzed using the aquifer test analysis software package, AQTESOLV (Geraghty and Miller, Inc.). Table G-3 presents the transmissivity and storativity values derived using various methods, and the plots of drawdown versus time are included in Attachment G-1.

Table G-1 Observations Wells Used During the Tailings Dam Area Aquifer Test

WELL ID	TD (feet)	ELEV. (toc) QMC[3]	r (feet)	TOP OF SCREEN (feet bgs)	BOTTOM OF SCREEN (feet bgs)	SCREEN LENGTH (feet)	PIPE DIAM. (in.)	STATIC WATER LEVEL (feet btoc) 11/7/94
GWQ-11	76	5174.87	≈405	na	na	na	3	17.04
GWQ94-13	112	5179.05	190	75	105	30	4.5	8.02
GWQ94-14	158	5171.41	390	127.5	157.5	30	4.5	1.585
GWQ94-15	148	5161.64	713	112	142	30	4	0.63
GWQ94-16	48	5176.02	423	25	45	20	4	18.23
GWQ94-17[1]	158	5176.97	0	120	150	30	4	5.32
GWQ94-20	340	5181.97	264	288	338	50	4.5	20.315
GWQ94-21A	320	5171.28	621	213	263	50	2	4.58
GWQ94-21B	320	5170.79	621	285	315	30	2	3.945
NP-2	110	5171.38	≈1130	na	na	na	2	29.46
NP-3	79.3[2]	5178.42	≈239	na	na	na	2	7.07
NP-5	41.2[2]	5177.45	≈735	na	na	na	2	19.67
IW-1	67[2]	5177.68	239	na	na	na	4	20.55
IW-2	45	5186.54	438	na	na	na	4	33.585

[1] Pumping well
[2] Measured prior to groundwater sampling
[3] Elevations relative to project datum (Quintana Minerals Corp.)
TD = total depth of borehole
r = distance to the pumping well (feet)
bgs = below ground surface
toc = top of casing
btoc = below top of casing
na = information not available

Table G-2 Summary of Water Quality during Pumping of GWQ94-17

DATE	TIME	TEMPERATURE (deg-C)	pH	CONDUCTIVITY (um/cm)	SULFATE CONCENTRATION (mg/l)
11/8/94	12:14	21	7.4	1110	225
11/8/94	13:22	21	7.4	1050	180
11/8/94	15:15	19.5	7.4	1050	210
11/8/94	17:25	19	7.4	1030	350
11/8/94	18:10	18	7.4	1030	360
11/9/94	07:18	--	7.3	1050	300
11/9/94	12:24	--	7.3	1020	240
11/9/94	14:35	--	7.3	990	250
11/9/94	13:57	--	7.3	1010	240
11/10/94	12:40	--	7.4	1030	280
11/10/94	14:35	--	7.4	1000	220

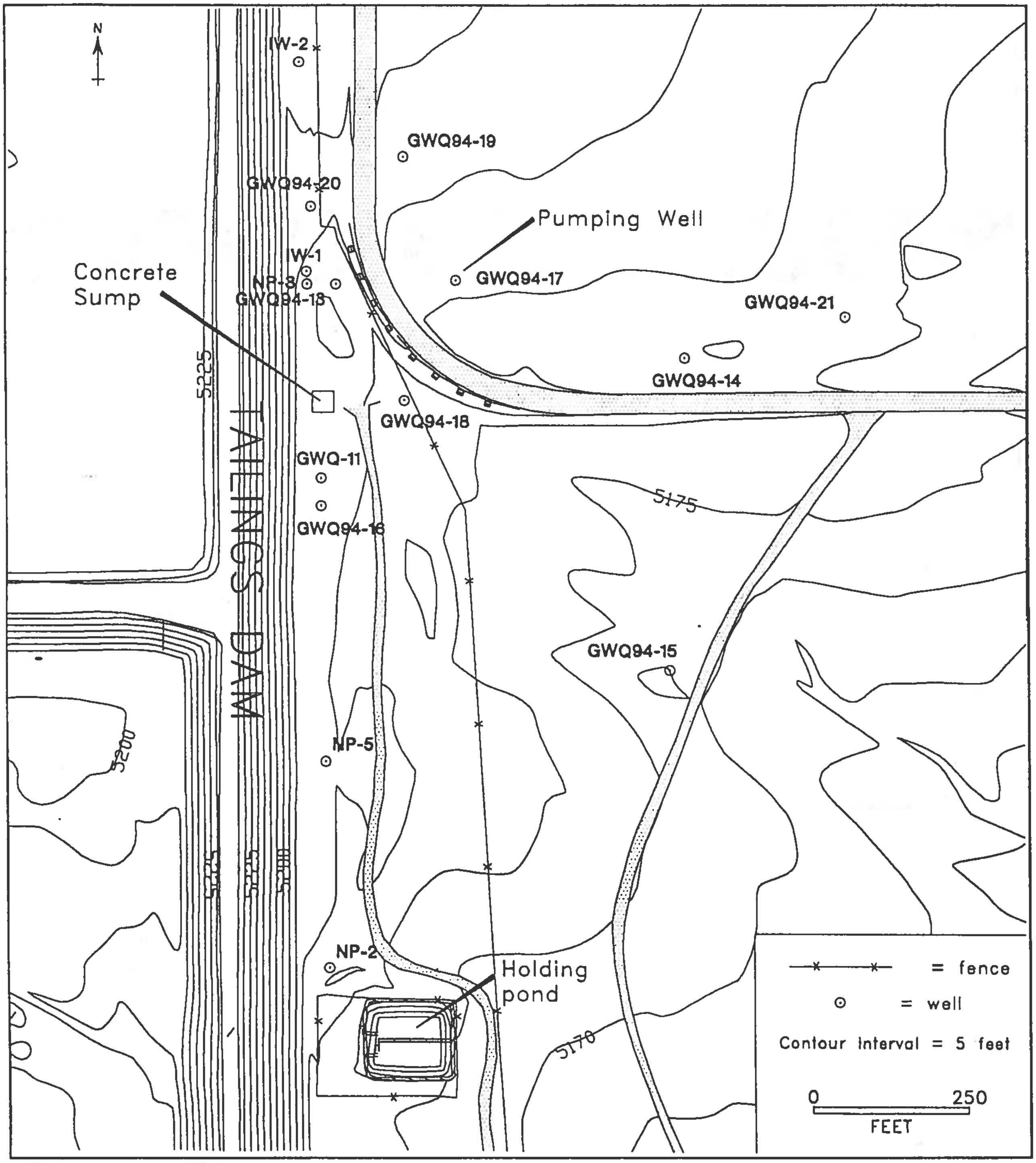


Figure G-1 Well location map for tailings dam area pumping test

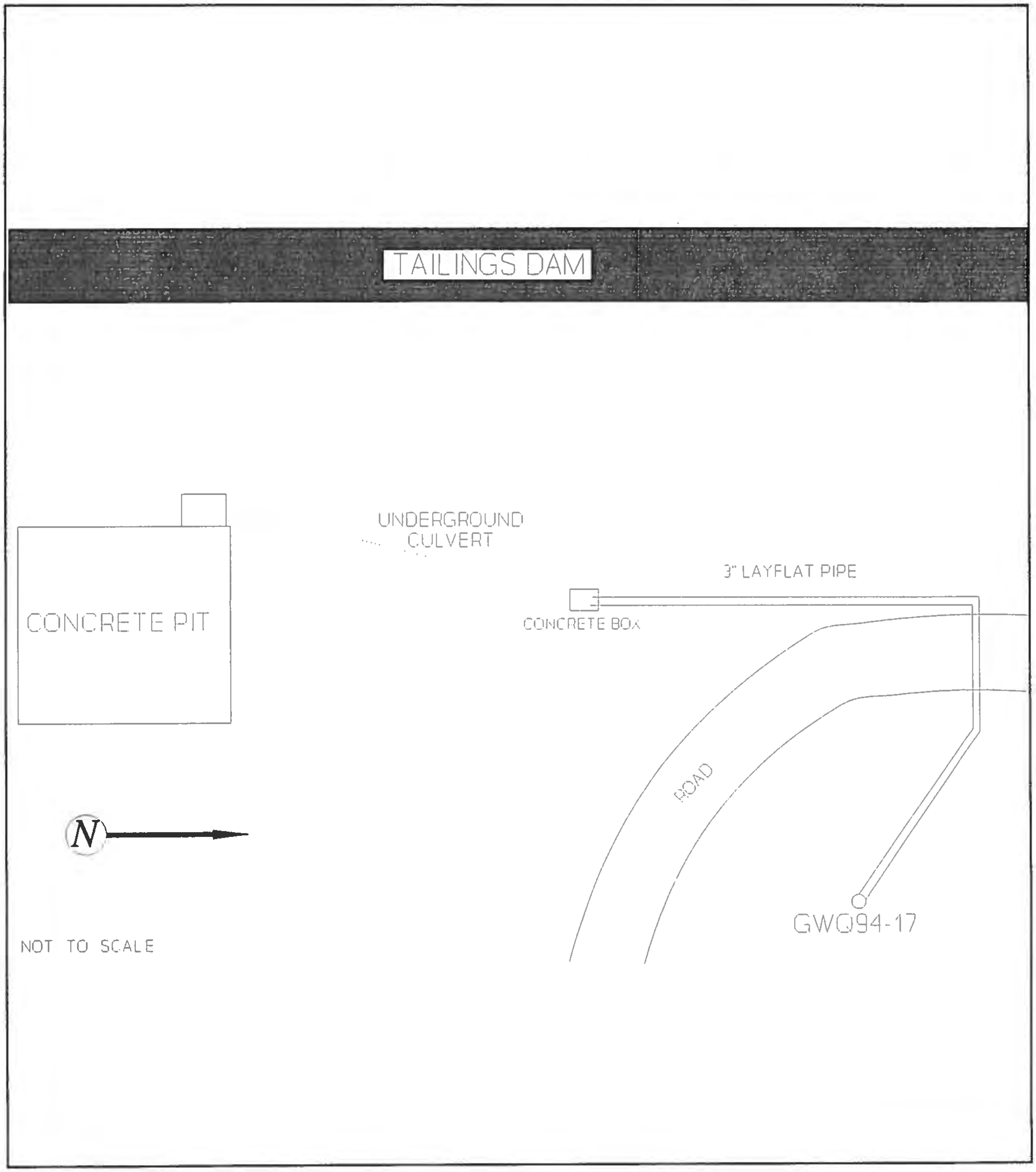


Figure G-2 Schematic of pumping test system

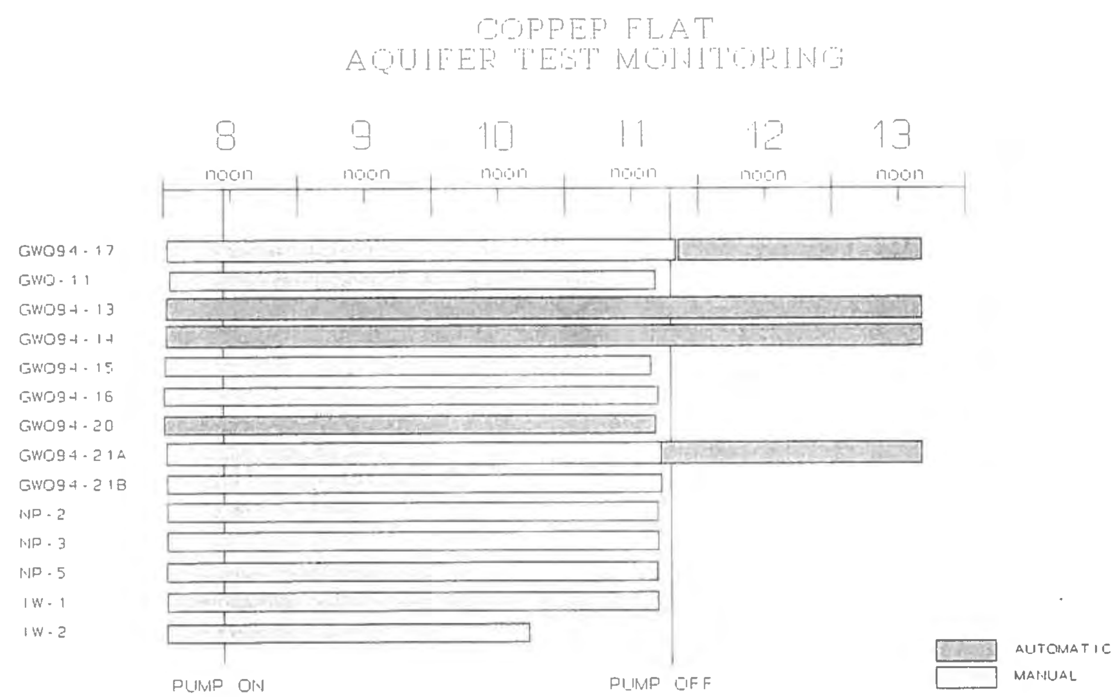
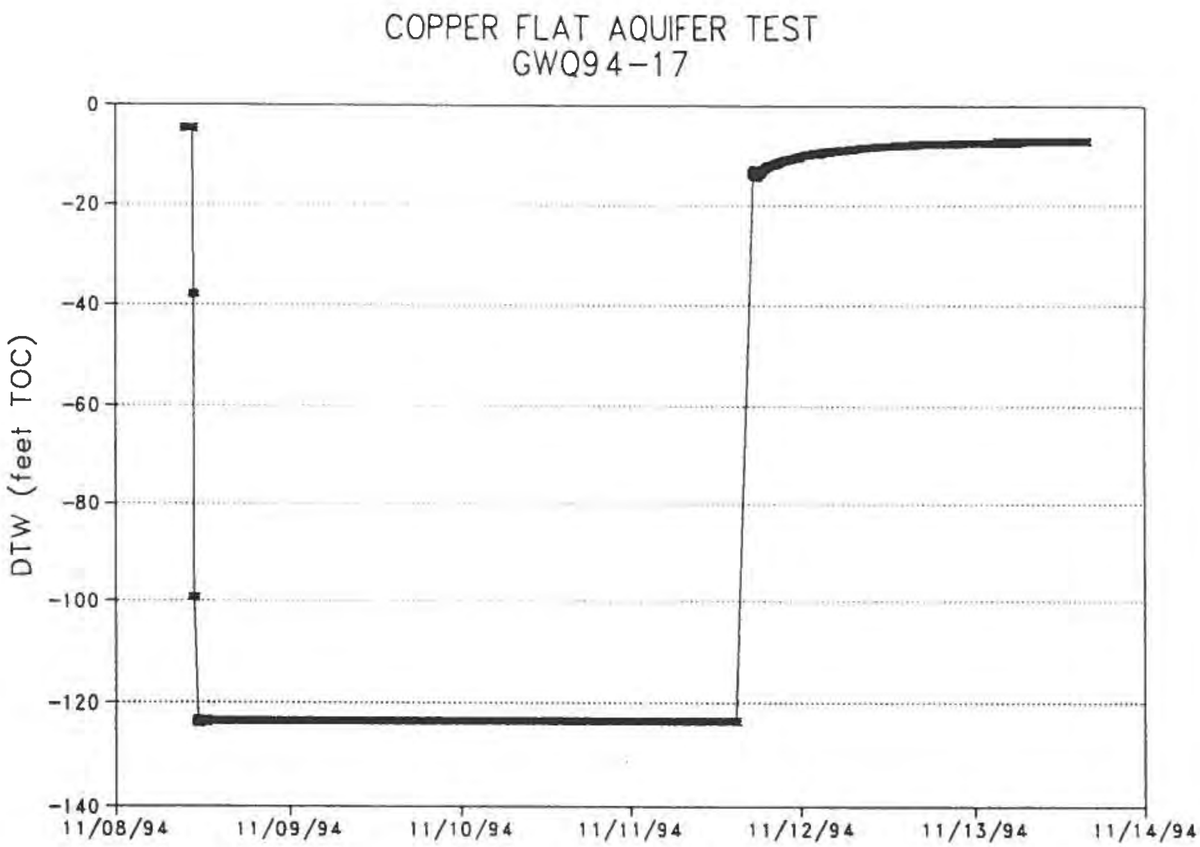


Figure G-3 Copper Flat tailings dam aquifer test monitoring


COPPER FLAT AQUIFER TEST
GWQ94-17
DTW (feet TOC)
0
-20
-40
-60
-80
-100
-120
-140
11/08/94
11/09/94
11/10/94
11/11/94
11/12/94
11/13/94
11/14/94

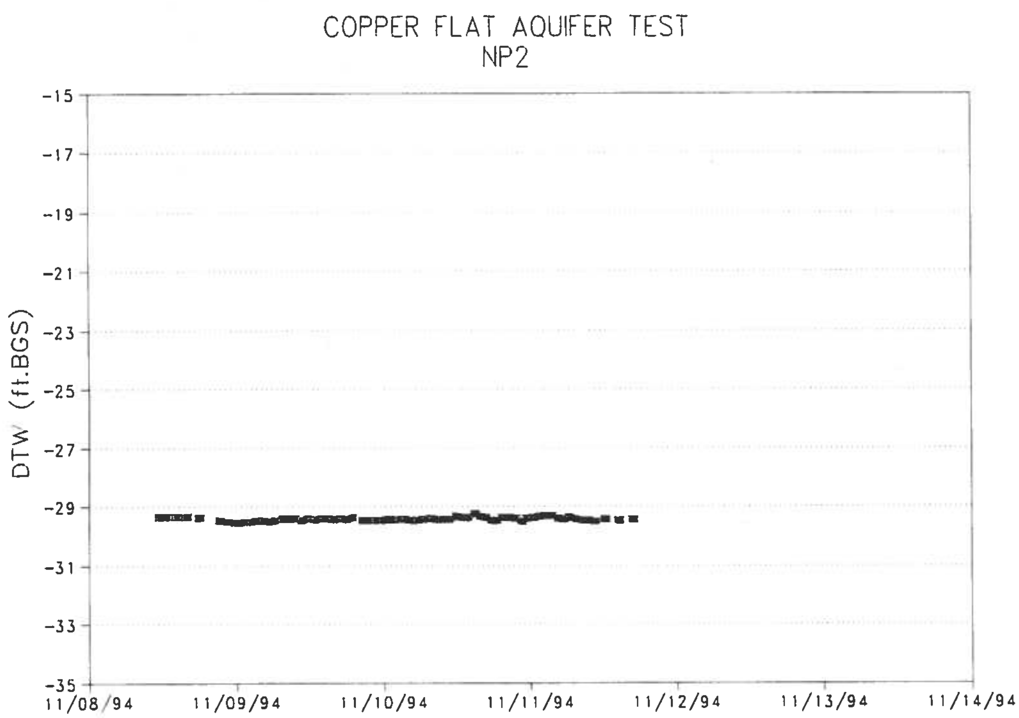


Figure G-5 Water levels in observation well NP-2

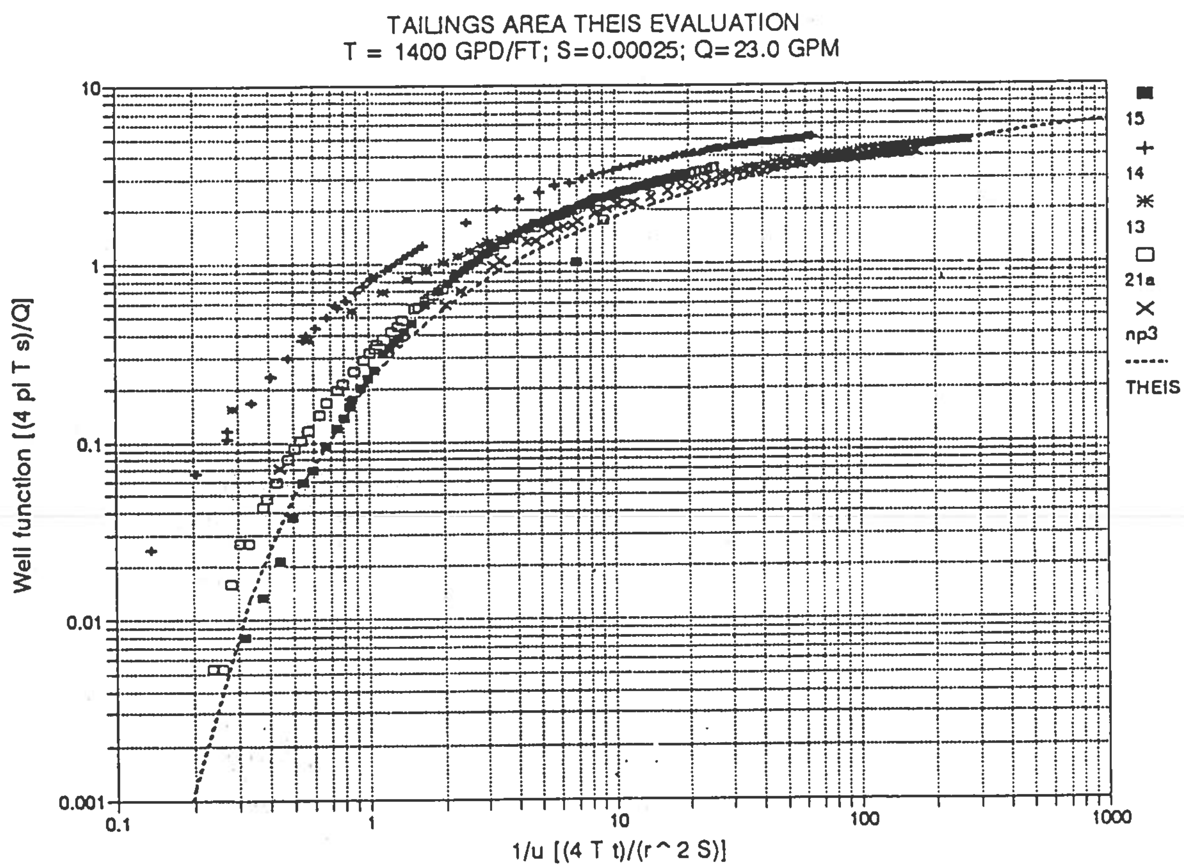


Figure G-6 Theis evaluation for tailings dam area pumping test, T=1400 gpd/ft

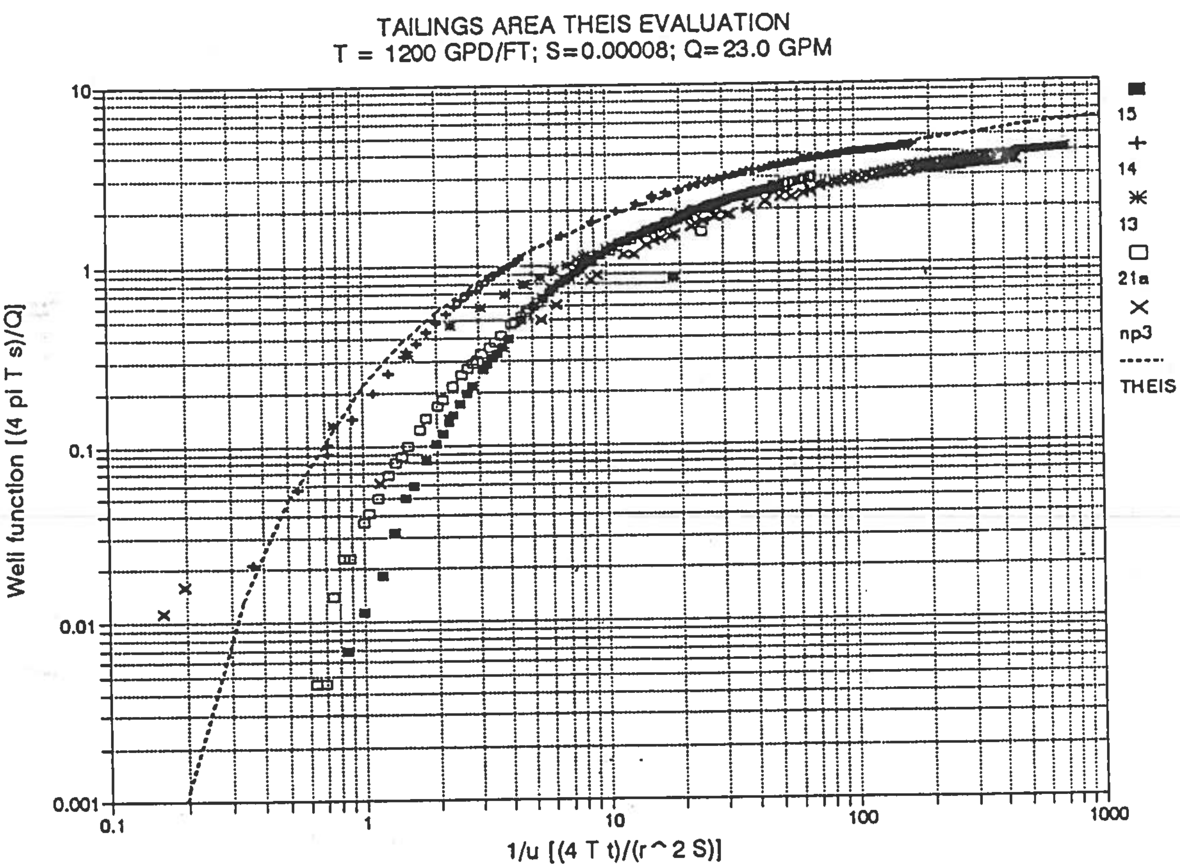


Figure G-7 Theis evaluation for tailings dam area pumping test, T=1200 gpd/ft

Table G-3 Aquifer Test Analysis Results

WELL ID	SOLUTION	TRANSMISSIVITY (gpd/ft)	STORATIVITY
GWQ94-13	Theis	1658	1.1×10^{-4}
	Jacob-Cooper straight-line	1540	1.2×10^{-4}
GWQ94-14	Theis	1148	8.1×10^{-5}
	Jacob-Cooper straight-line	1177	6.9×10^{-5}
GWQ94-15	Theis	1259	1.5×10^{-4}
	Hantush - leaky con. w/o storage	1168	1.7×10^{-4}
	Jacob-Cooper straight-line	1299	1.3×10^{-4}
GWQ94-21A	Theis	1147	1.7×10^{-4}
	Jacob-Cooper straight-line	1272	1.4×10^{-4}
GWQ94-21B	Theis	1068	2.8×10^{-4}
	Jacob-Cooper straight-line	1086	2.4×10^{-4}
Integrated Approach[1]	Theis	1400	2.5×10^{-4}

[1]See text and Figures B-6 and B-7

Appendix C4.

2012 Aquifer Test Results

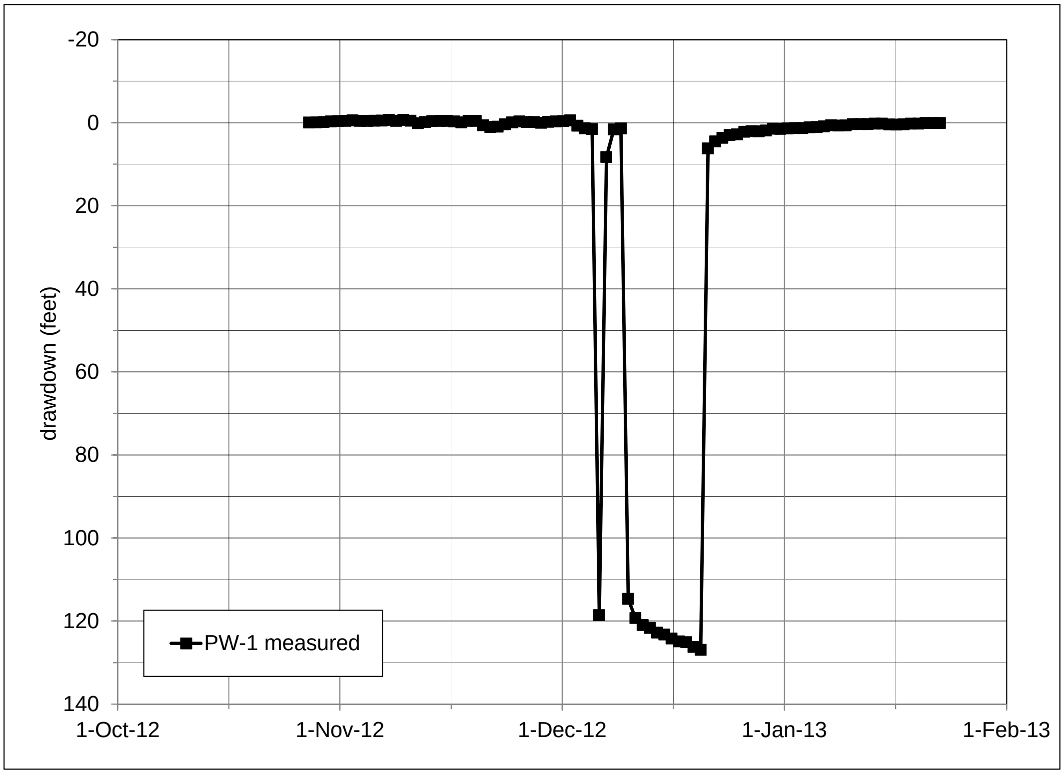


Figure C4-1. Aquifer test hydrograph PW-1.

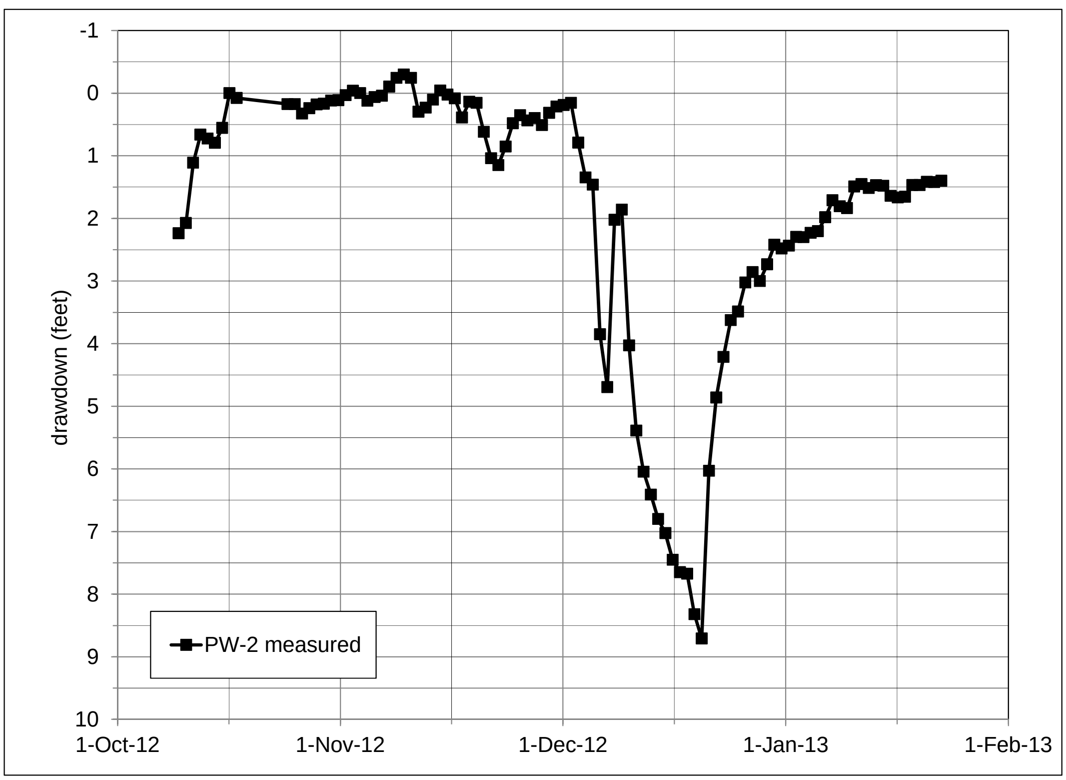


Figure C4-2. Aquifer test hydrograph PW-2.

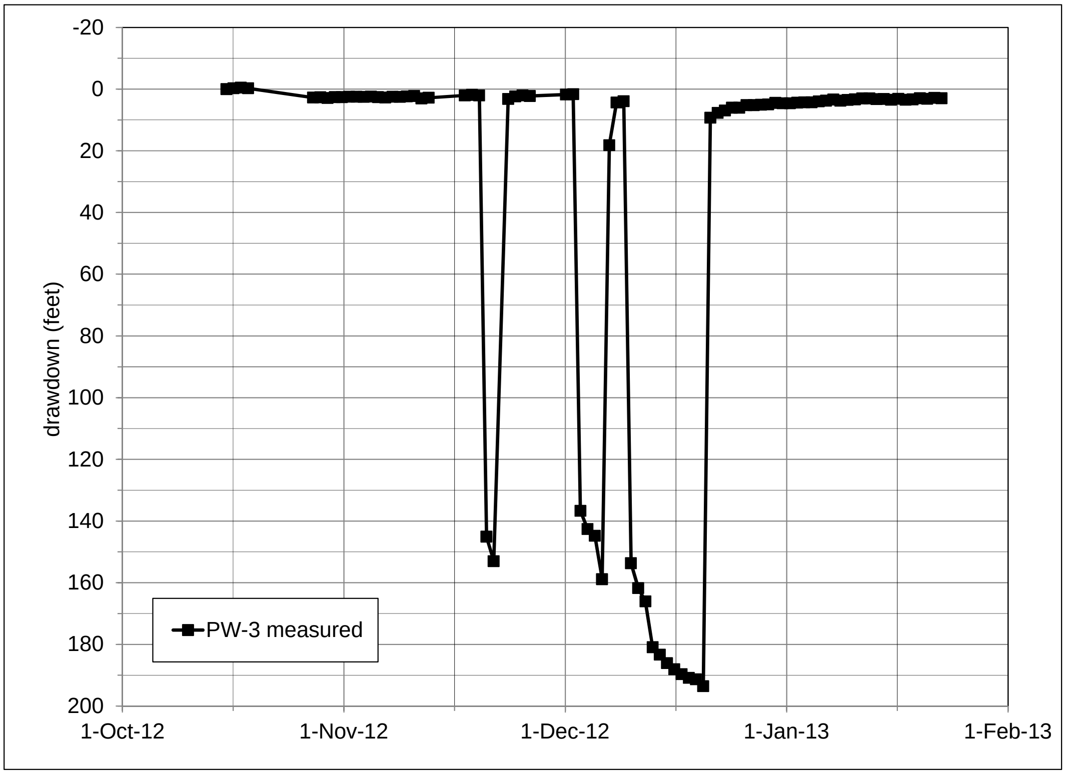


Figure C4-3. Aquifer test hydrograph PW-3.

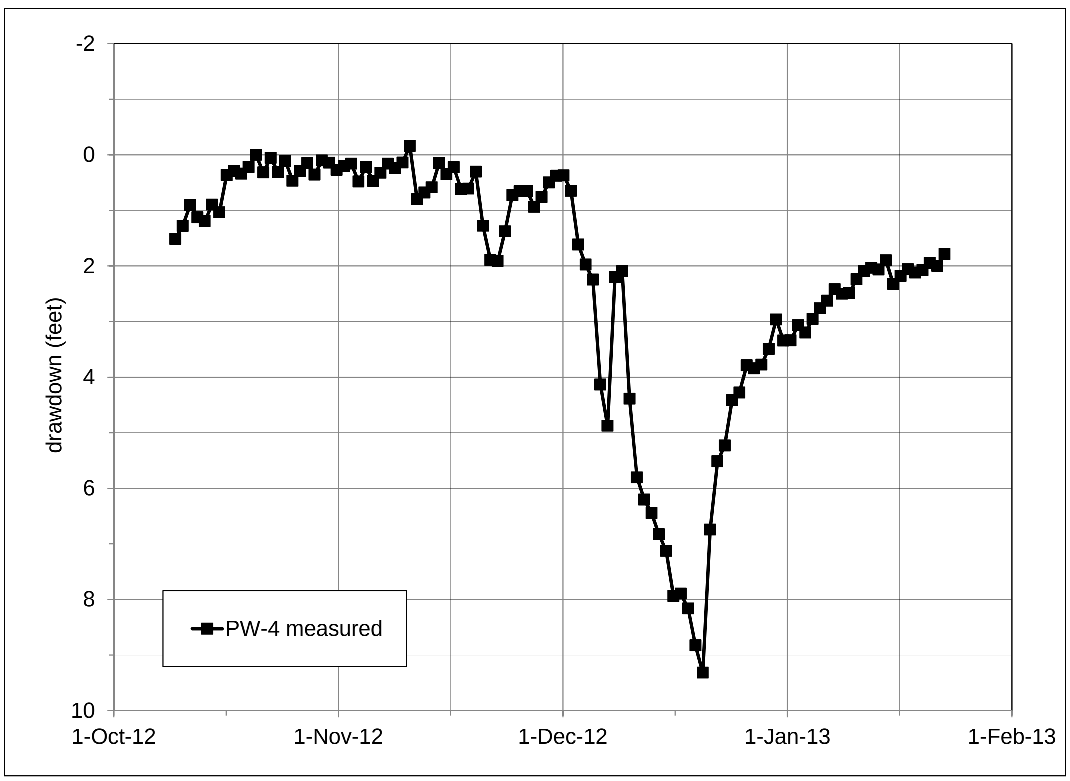


Figure C4-4. Aquifer test hydrograph PW-4.

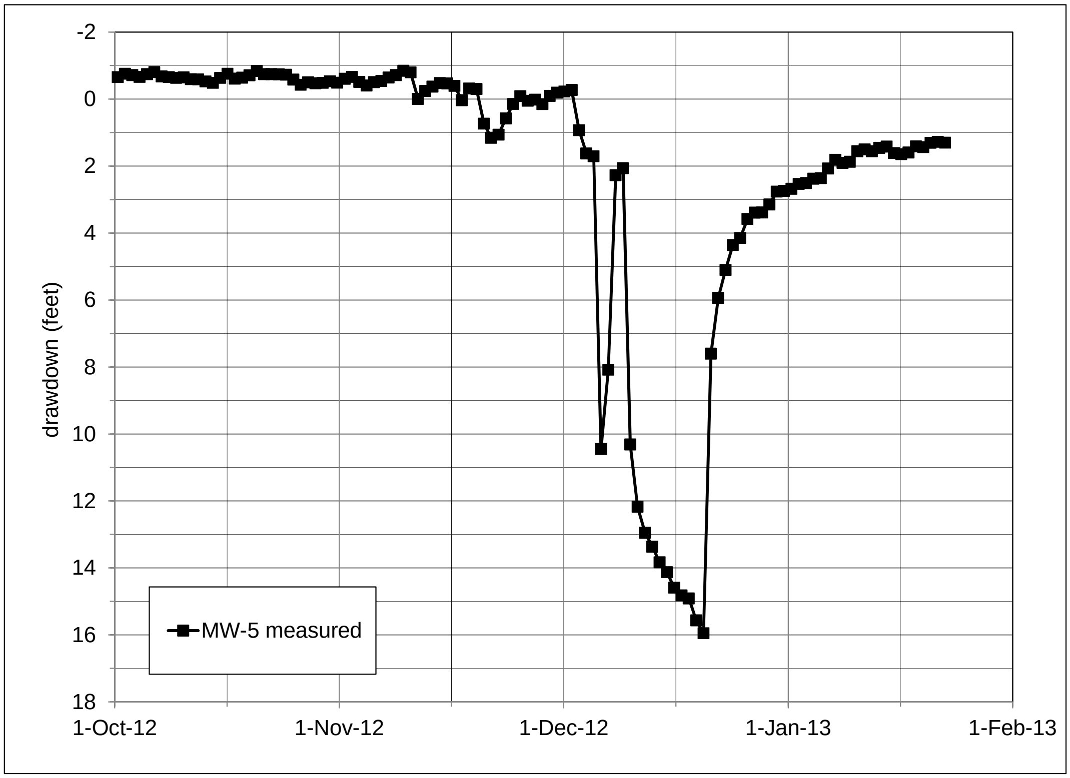


Figure C4-5. Aquifer test hydrograph MW-5.

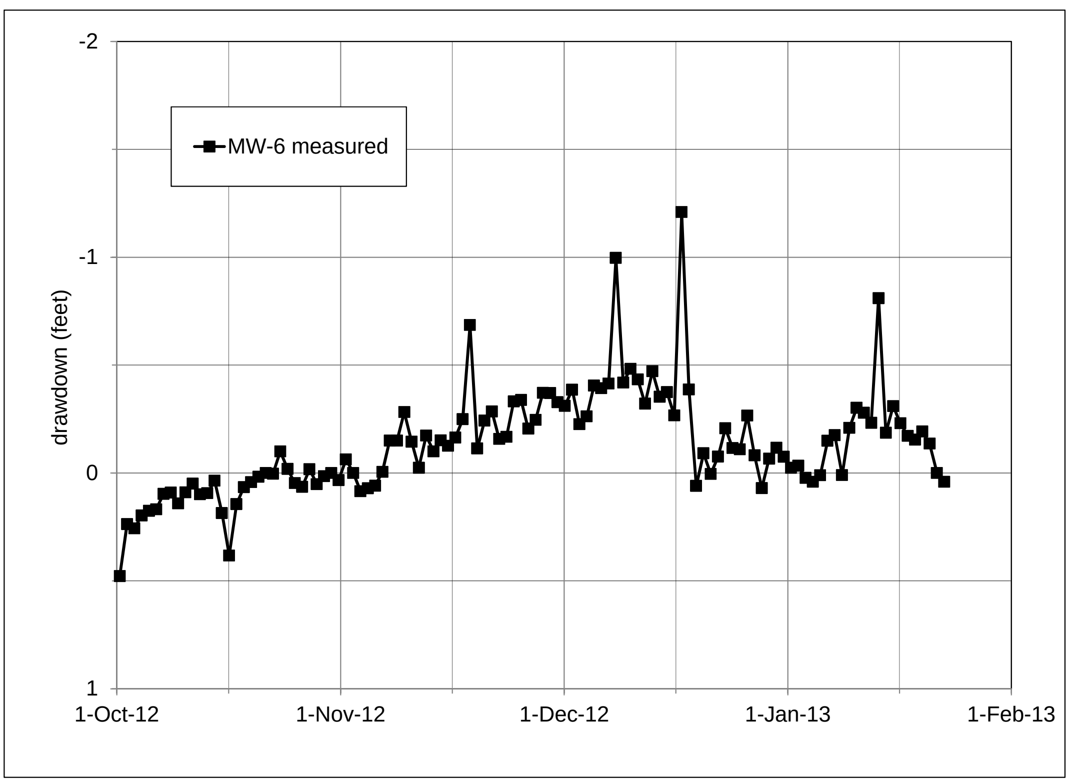


Figure C4-6. Aquifer test hydrograph MW-6.

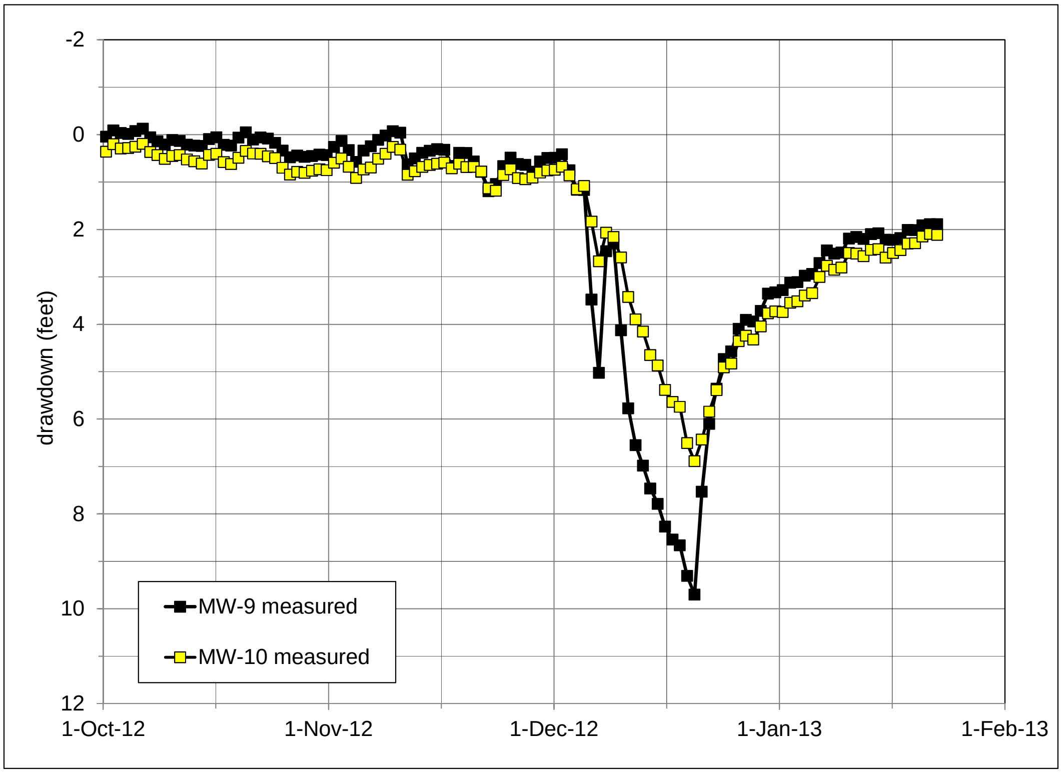


Figure C4-7. Aquifer test hydrograph MW-10.

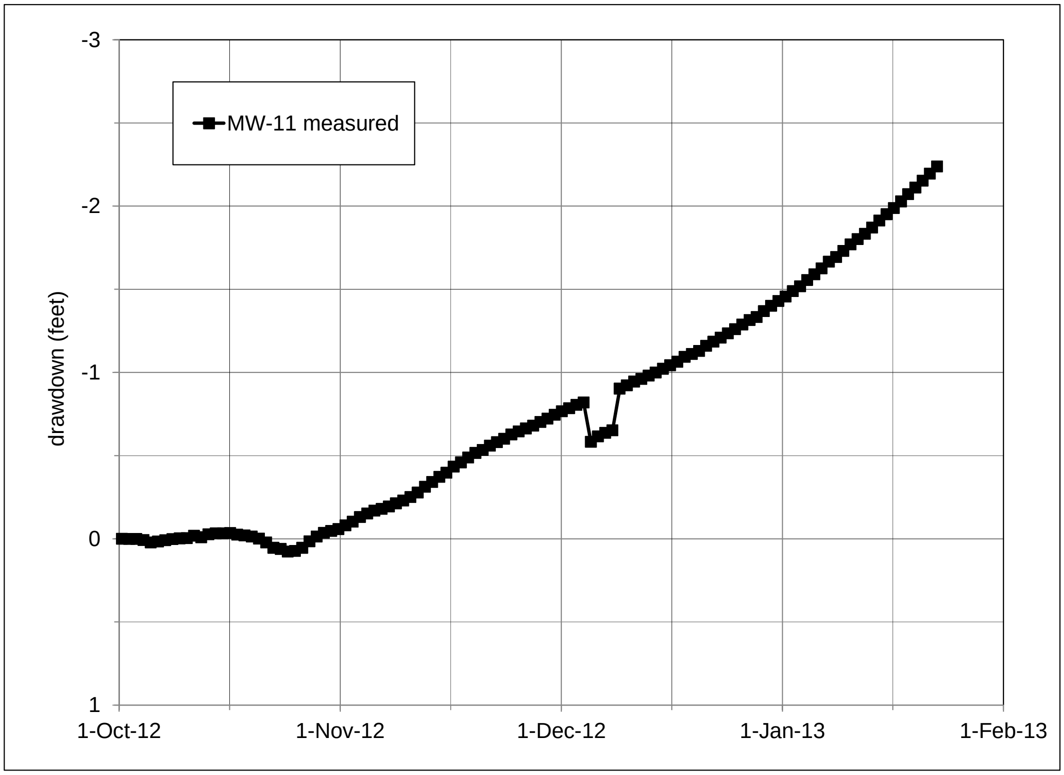


Figure C4-8. Aquifer test hydrograph MW-11.

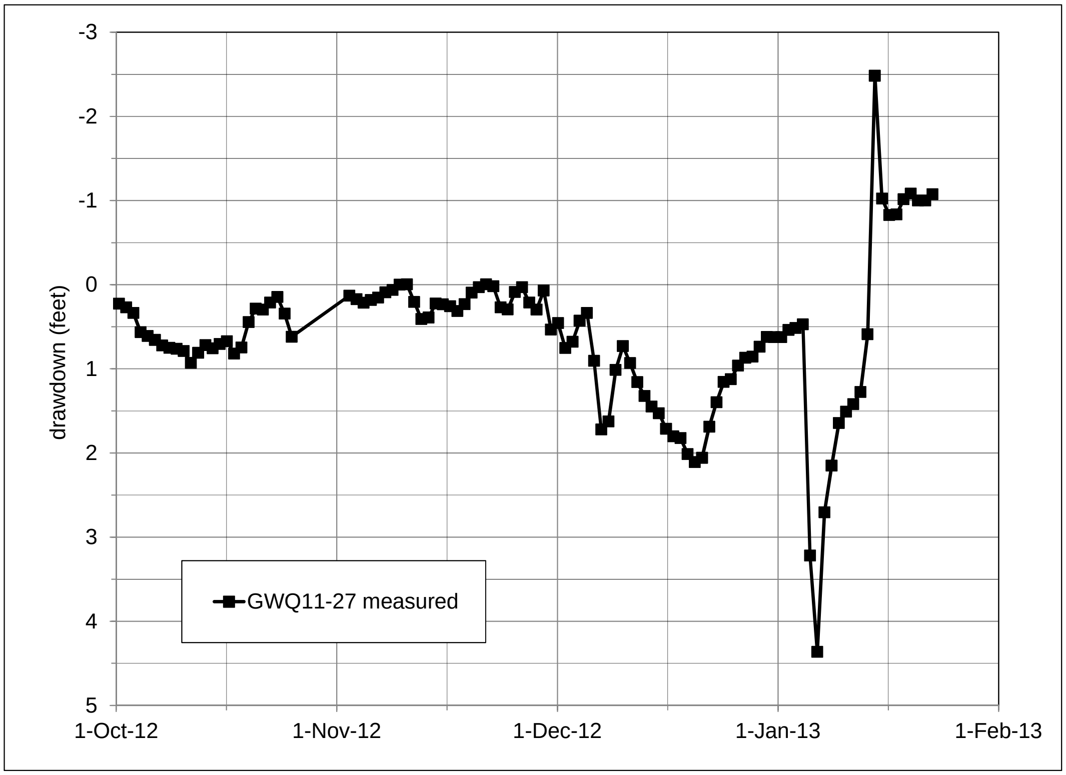


Figure C4-9. Aquifer test hydrograph GWQ11-27.

Appendix C5.

Pit Area Pressure-Injection Tests, September 2011

ESTIMATED HYDRAULIC CONDUCTIVITY OF PRESSURE-INJECTION TEST ZONES BOREHOLES GWQ 5-R, GWQ 11-24, AND GWQ 11-25 COPPER FLAT MINE SIERRA COUNTY, NEW MEXICO

by

John W. Shomaker, Ph.D.

JOHN SHOMAKER & ASSOCIATES, INC.
Water-Resource and Environmental Consultants
2611 Broadbent Parkway NE
Albuquerque, New Mexico 87107
505-345-3407
www.shomaker.com

prepared for

New Mexico Copper Corporation
2425 San Pedro NE
Albuquerque, New Mexico 87110

September 2011

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TABLE

ILLUSTRATIONS

(follow text)

APPENDIX

(follow illustrations)

Basic data for pressure-injection tests

ESTIMATED HYDRAULIC CONDUCTIVITY OF PRESSURE-INJECTION TEST ZONES BOREHOLES GWQ 5-R, GWQ 11-24, AND GWQ 11-25 COPPER FLAT MINE, SIERRA COUNTY, NEW MEXICO

INTRODUCTION

Pressure-injection tests were conducted during drilling of three boreholes (later reamed and completed as monitor wells), New Mexico Copper GWQ 5-R, GWQ-11-24, and GWQ-11-25. One zone was tested in GWQ 5-R, and three zones were tested in each of the other two boreholes. The tests were carried out between July 27 and August 31, 2011. Test equipment was provided and operated by the drilling contractor, WDC Exploration. Jeffrey J. Kelsch of John Shomaker & Associates recorded the data. Figure 1 is a map showing the locations.

The locations, logs and descriptions of the three monitor wells may be found in other reports. Well GWQ 5-R is completed in Cretaceous-age andesite, in the SE/4 NE/4 NW/4, Sec. 36, T. 15 S., R. 7 W. GWQ 11-24 and GWQ 11-25 are completed in Cretaceous-age intrusive rocks, in the SE/4 NE/4 NW/4 of Sec. 35, and the SW/4 NE/4 SW/4 of Sec. 26, respectively, of T. 15 S., R. 7 W.

TEST METHOD AND INTERPRETATION

The tests were conducted using a variation on the standard Lugeon test (Lugeon, 1933; Houlsby, 1976), for estimating average hydraulic conductivity of rock masses. In each of the three vertical, 3-3/4-in. boreholes, one or more zones were isolated between the bottom of the hole as it was at the time of the test, and a packer run on 1-in. standard-pipe tubing. In all but one case (GWQ 5-R), the test zone was below the water table and the rock mass was saturated at the beginning of the test.

For most of the tests, a Moyno progressing-cavity pump, reportedly rated at 10 gpm maximum flow and 350 psi maximum pressure, was used to inject water. One test employed a centrifugal pump, which was then replaced by the Moyno pump. The lengths of the test zones ranged from 36 ft to 48 ft, as indicated in Table 1 below. The injection rate was metered as clear water was pumped through the tubing into the open interval of the borehole at constant pressure, in 10-minute steps, first at increasing pressure and then at decreasing pressure. Basic data from the tests are given in the Appendix. In most cases, three series of measurements, at the same injection-pressure steps, were taken.

Injection rate was measured with a new, calibrated meter. Pressure in the tubing was measured with a 4-1/2-in.-dial, 0-300 psi, NIST certified gauge with 10-psi increments. Data were recorded each minute during each 10-minute pumping step.

The standard Lugeon test method is based on a sequence of five, 10-minute measurements of injection rate, three at increasing pressure, followed by two at decreasing pressure. The procedure for this project differed from the standard method in that many more measurements were made, with smaller increments of pressure between them, as suggested by Quiñones-Rozo (2010). This variation provides data for a more complete interpretation. In all cases, the higher pressures in the sequence of steps exceeded the fracture-gradient pressure at the depth of the open interval of the borehole, and existing fractures were dilated as water was pumped into them, or new fractures were created.

For each step, total head above the pre-test water level in the borehole was calculated as the sum of the gauge pressure in the tubing, the height of the gauge above ground level, and the depth to the static water level in the borehole, less the friction loss in the tubing at the specific injection rate. The friction loss was calculated by the standard Hazen-Williams formula with a constant for steel pipe of 100.

Hydraulic conductivity was calculated using the Lugeon relationship, which is empirically defined as the conductivity required for maintenance of an injection rate of 1 liter per minute per meter of open interval in the borehole, under a reference water pressure of 10 bars. One Lugeon unit is equivalent to 1.3×10^{-5} cm/sec, 0.03685 ft/day (Fell et al., 2005). For convenience, the calculations were made in terms of total added head in pounds per square inch (psi), and injection rates in gallons per minute (gpm).

Plots of injection rate versus total head above the pre-test water level in the borehole, and of apparent hydraulic conductivity (permeability) against total head, are given in Figures 1 through 12 for the tests in which the pumping rate was measurable.

RESULTS AND CONCLUSIONS

GWQ 5-R

One injection zone, from the bottom of the packer at 64 ft to the bottom of the borehole at 100 ft, was tested. Although the hole was almost full of fluid at the time of the test, later water-level measurements indicate that the natural static water level is about 48 ft. No flow was measured until the total head above the water level at the beginning of the test (5.6 ft below land surface, probably more than 40 ft above the natural water level) had reached more than 200 ft of water (87 psi; see Fig. 1). The injection rate was small, but increased rapidly, above that pressure. In a pressure step at 120 psi gauge pressure, fluid began to move up the hole above the packer, and the well began to flow, indicating that the packer seal had failed. An attempt was made to complete the test, but only very small injection rates could be maintained and it is clear from Figure 1 that any measurable fluid injected was entering dilated fractures. The test interval took no more fluid at declining pressures after the total head fell below about 340 ft of water, at about 110 psi gauge pressure.

The apparent hydraulic conductivity (permeability) was calculated at zero for the steps up to a head of about 200 ft of water, and then rose rapidly at higher pressures (Fig. 2). All of the measured injection that did occur was undoubtedly into fractures dilated by the high test pressures, and the actual hydraulic conductivity (permeability) is extremely low. This conclusion is reinforced by the fact that, at the beginning of the test, the water level in the borehole was 5.6 ft below land surface, even though later measurements in the completed well indicate that the hole would have been dry to a depth of 48 ft. No attempt was made to replicate the test.

Table 1. Summary of hydraulic conductivity (permeability) estimates

borehole and zone	depth interval, ft	apparent permeability		
		Lugeon units	cm/sec	ft/day
GWQ 5-R, Zone 1	64-100	~0	~0	~0
GWQ 11-24, Zone 1	100-147	0.5	7×10^{-6}	0.02
GWQ 11-24, Zone 2	150-197	2.3	3.0×10^{-5}	0.085
GWQ 11-24, Zone 3	204-251	3.8	4.9×10^{-5}	0.14
GWQ 11-25, Zone 1	100-148	~0	~0	~0
GWQ 11-25, Zone 2	150-198	2.2	2.9×10^{-5}	0.081
GWQ 11-25, Zone 3	207-251	2.0	2.6×10^{-5}	0.074

GWQ 11-24, Zone 1

This zone extended from the packer, at 100 ft, to 147 ft. Three series of injection tests were conducted, the first two with a centrifugal pump and the third with the Moyno positive-displacement pump. Plots of injection rate against total head are shown on Figure 3. In Series 1, the injection rates at increasing pressure were close to a line passing through the origin of the graph (Fig. 1), indicating that dilation of fractures was not significant until total head exceeded 200 ft or more, and the apparent permeability (Fig. 2) was roughly constant at around 0.5 Lugeon units (7×10^{-6} cm/sec, or 0.02 ft/day). Late in the first series, above total heads of around 210 ft of water, with about 75 psi gauge pressure, the injection rates began to increase sharply (Fig. 3), and it is probable that dilation of fractures was occurring.

In the subsequent two series of injection measurements, the rates were successively higher at corresponding pressures, and apparent permeability was greater (Fig. 4). In the third series, at the highest injection rates, the decreasing trend of apparent permeability indicates that head loss due to turbulent flow, as water flowed to and entered discrete fractures, played a significant role. The value of around 0.5 Lugeon units (7×10^{-6} cm/sec, or 0.02 ft/day), based on the first series of measurements, is likely to be most nearly representative.

GWQ 11-24, Zone 2

The packer was set at 150 ft and the bottom of the hole was at 197 ft. The injection rates in the first series of measurements were high compared with the other tests (see Fig. 5), but the plot of injection rates against total head does not extrapolate back through the origin. This may be attributable to turbulent-flow losses, or to significant dilation of fractures that occurred, and flow into the rock mass begun, even as the hole was filling and before pressure began to show on the gauge. This seems improbable at such low total heads. Although not reflected in the field notes, a more probable explanation is that some leakage around the packer was occurring.

In the second series of measurements (Fig. 5), the injection rates were directly proportional to total head, and the increasing-pressure plot extrapolates back almost through the origin, suggesting that the packer was sealing properly. Injection rates were somewhat greater during the decreasing-pressure part of the series, which may be attributable to some fracture dilation that occurred at the highest pressures during the increasing-pressure part of the test, and persisted.

The plot of apparent permeability against total head (Fig. 6) shows a steep decline with increasing injection rate for the first series of measurements, which might be indicative of large and increasing influence of turbulent flow, but is more likely a consequence of leakage around the packer as mentioned above. In the second series, in contrast, the apparent permeability is nearly constant, representing nearly laminar-flow conditions, at about 2.3 Lugeon units for increasing pressures. The representative permeability is likely to be 2.3 Lugeon units (3.0 x 10^{-5} cm/sec, or 0.085 ft/day).

GWQ 11-24, Zone 3

In this zone, the packer was set at 204 ft and the bottom of the borehole was at 251 ft. For the first four steps at increasing pressure in the first series of measurements, for total head up to about 170 ft, the injection rates plot approximately on a line that extrapolates back through the origin (Fig. 7), indicating that no fracture-dilation occurred. The apparent-permeability plot, projected back to the value at zero head (Fig. 8) suggests a value of about 0.6 Lugeon units, and a small turbulent-flow effect.

After total head exceeded about 170 ft in the first series of measurement, the injection rate increased markedly (Fig. 7), indicating that a fracture or fractures had opened under the increasing pressure, or more probably in this case, that temporary clogging of a fracture or the skin effect of drilling-fluid solids had been overcome. The pattern of injection rates as the pressures continued to increase and then decrease in the first series of measurements, and the identical pattern in the second and third series of measurements (see Fig. 7), suggest that fracture(s) did not close as the pressure was reduced, and that the initial sharp rise in injection rates during the first series was attributable to clearing of clogging or skin effect.

The plots of injection rate against total head for points representing measurements after the original breakthrough do not, however, extrapolate back through the origin. A loss of about 1.6 gpm, equivalent to about 93 ft of head differential, is indicated. The water level in the well at the beginning of the test, however, compares closely with later measurements, and it is not likely that a difference between the natural head and the head at the beginning of the test would account for the discrepancy. The most likely explanation seems to be that some water leaked around the packer, perhaps through a fracture open at both ends of the packer element.

Figure 8 shows the calculated values of permeability versus total head. Discounting the earliest measurements in Series 1, and assuming that turbulent-flow conditions account for the negative slope of the plot, and also assuming that the leakage around the packer is actually proportional to the injection rate, leads to a projection at zero total head, where no turbulence or leakage would exist, of about 3.8 Lugeon units (4.9×10^{-5} cm/sec, or 0.14 ft/day).

GWQ 11-25, Zone 1

A zone from 100 to 148 ft was isolated between the packer and the bottom of the borehole. No water was measured as being injected into the test zone until the gauge pressure reached 150 psi, representing a total head above the water level in the hole at the beginning of the test of about 375 ft, equivalent to 163 psi. This pressure is far in excess of any probable fracture-gradient pressure at 100 ft, and it seems clear that the hydraulic conductivity of the rock was extremely low before fractures were induced or opened by the injection pressure. The remainder of the test was not considered valid for estimation of permeability.

GWQ 11-25, Zone 2

Zone 2 extended from the packer at 150 ft to the bottom of the hole at 198 ft. Injection rates during the first series of measurements were approximately proportional to total head, except for a relative rise in injection rate at heads above about 240 ft (Fig. 9). In the second and third series of measurements, injection rates increased and became directly proportional to total head, and the plot of injection rate against total head extrapolates back through the origin, with zero flow at zero additional head. Probably this sequence reflects some clearing of clogging by drilling-fluid solids.

The apparent permeability plot (Fig. 10) appears to reflect a decrease in turbulent-flow effects from Series 1 to Series 3. Projection of the apparent permeability for Series-3 measurements back to the value at zero additional head, where no turbulent-flow effect would be seen, suggests a representative permeability of about 2.2 Lugeon units (2.9 x 10^{-5} cm/sec or 0.081 ft/sec).

GWQ 11-25, Zone 3

This zone extended from the packer at 207 ft to the bottom of the hole at 251 ft. The injection rate was approximately proportional to total head at values of head up to about 180 ft during the first series of measurements (Fig. 11), but the plot appears to project back to a rate greater than zero at zero head, suggesting some leakage. At higher pressures, the injection rate increased very sharply, indicating dilation of fractures, and the injection rates at descending values of total head fell below the rates at corresponding heads during the increasing-pressure phase of the test, suggesting that some plugging of fractures had occurred. In the second and third series of measurements, the injection-rate versus total-head plots were very similar, and in each series they were similar for increasing and decreasing rates. The sharp rise in rate indicative of fracture dilation occurred at a higher total head, and projections of the plots pass nearly through the origin.

The apparent-permeability plot (Fig. 12) shows the influence of turbulent flow in all three series. Projection of the low total-head points back to a value at zero total head, suggests that a representative permeability may be about 2.0 Lugeon units (2.6 x 10^{-5} cm/sec or 0.074 ft/day).

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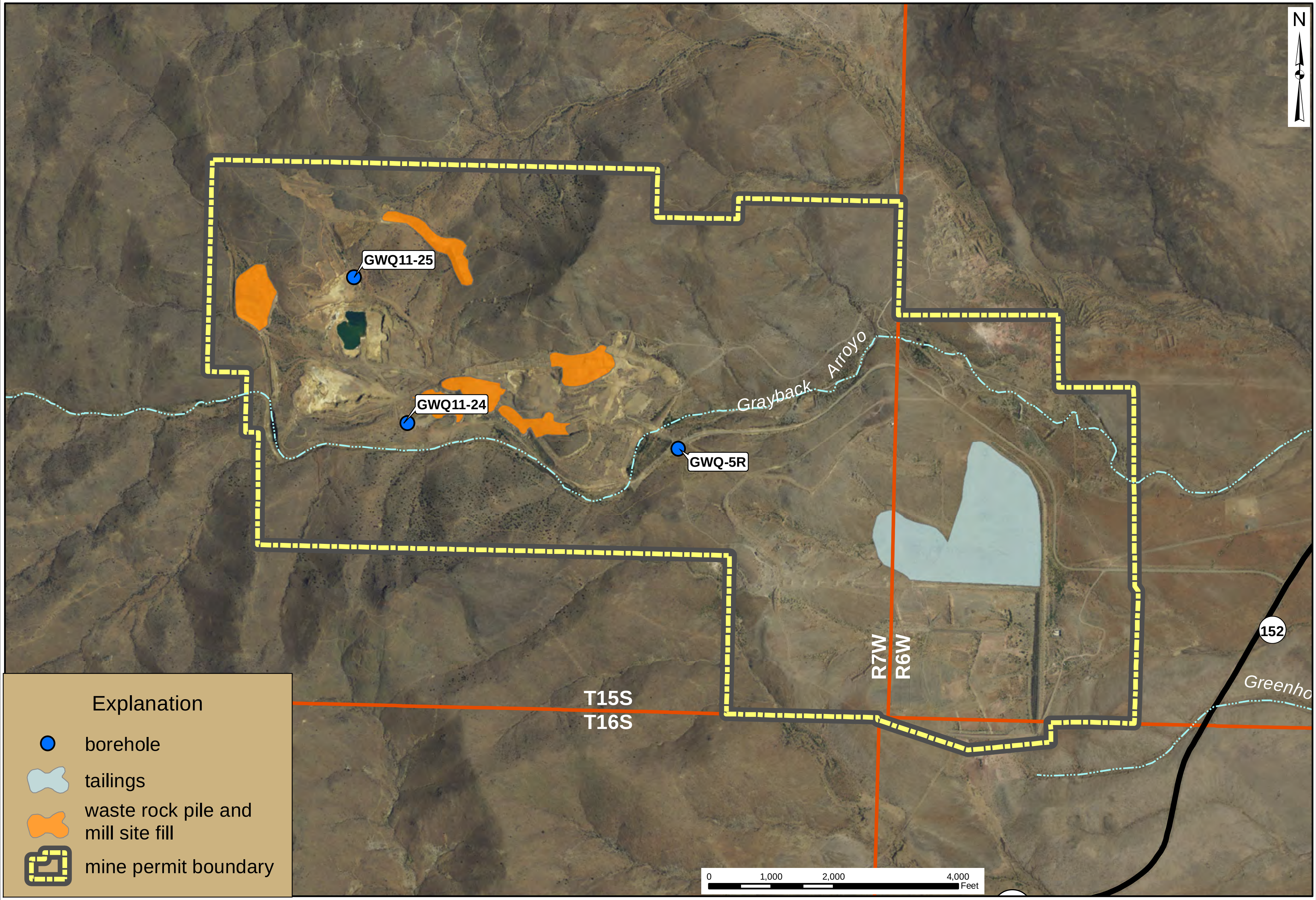
Houlsby, A., 1976, Routine interpretation of the Lugeon water-test: Quarterly Journal of Engineering Geology (UK), v. 9, pp. 303-313.

Lugeon, M., 1933, *Barrage et Géologie*: Dunod, Paris.

Quiñones-Rozo, C., 2010, Lugeon test interpretation, revisited: United States Society on Dams, 30th Annual Conference Proceedings, pp. 405-414.

ILLUSTRATIONS



Aerial Photograph: NAIP 2011

July 26, 2013

Figure 1. Aerial photograph showing locations of three boreholes and facilities associated with the former Copper Flat Mine operated by Quintana Minerals, Sierra County, New Mexico.

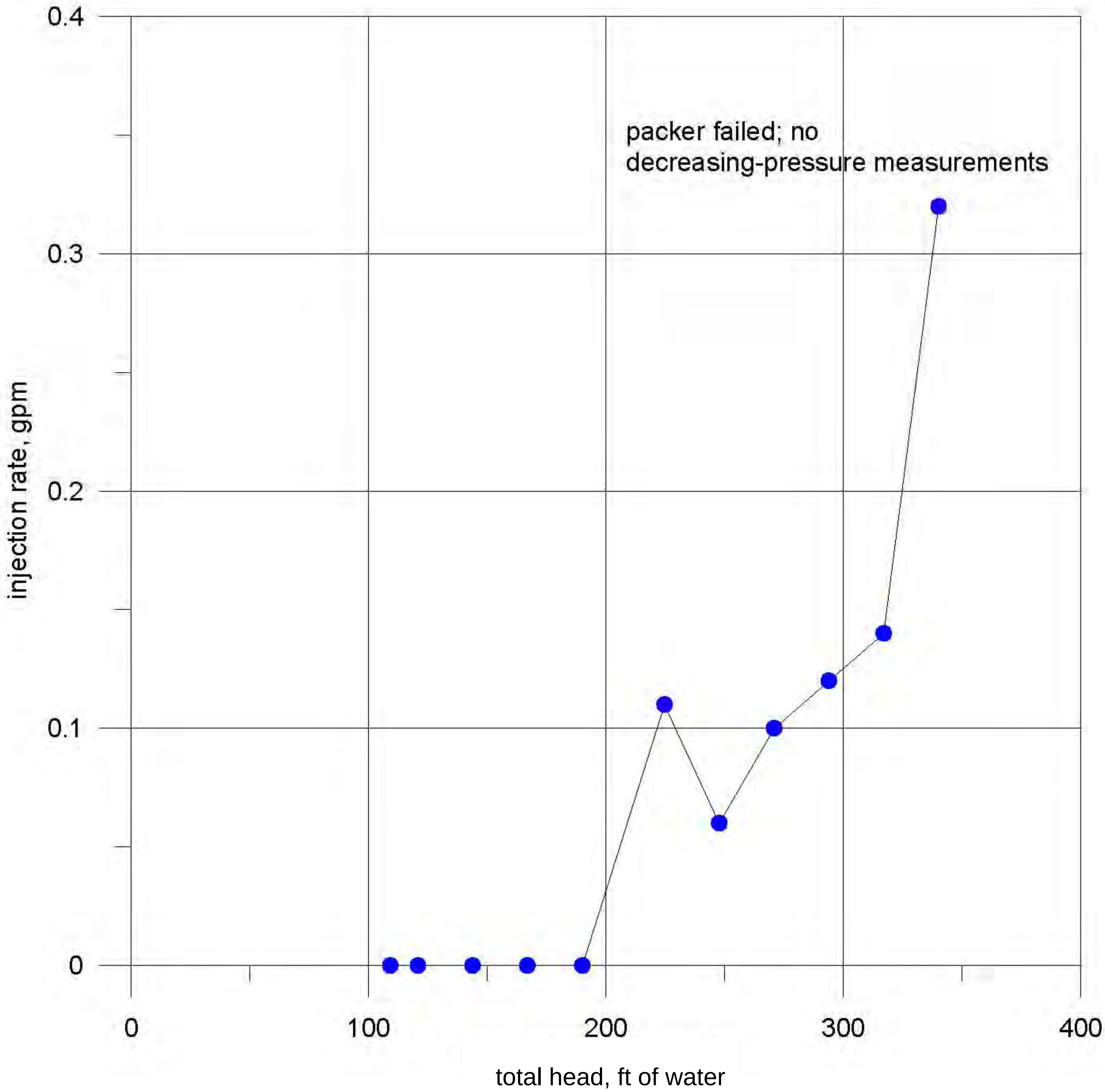


Figure 2. Pressure injection test, New Mexico Copper GWQ 5-R, Zone 1 (64-100 ft), Series 1, August 31, 2011.

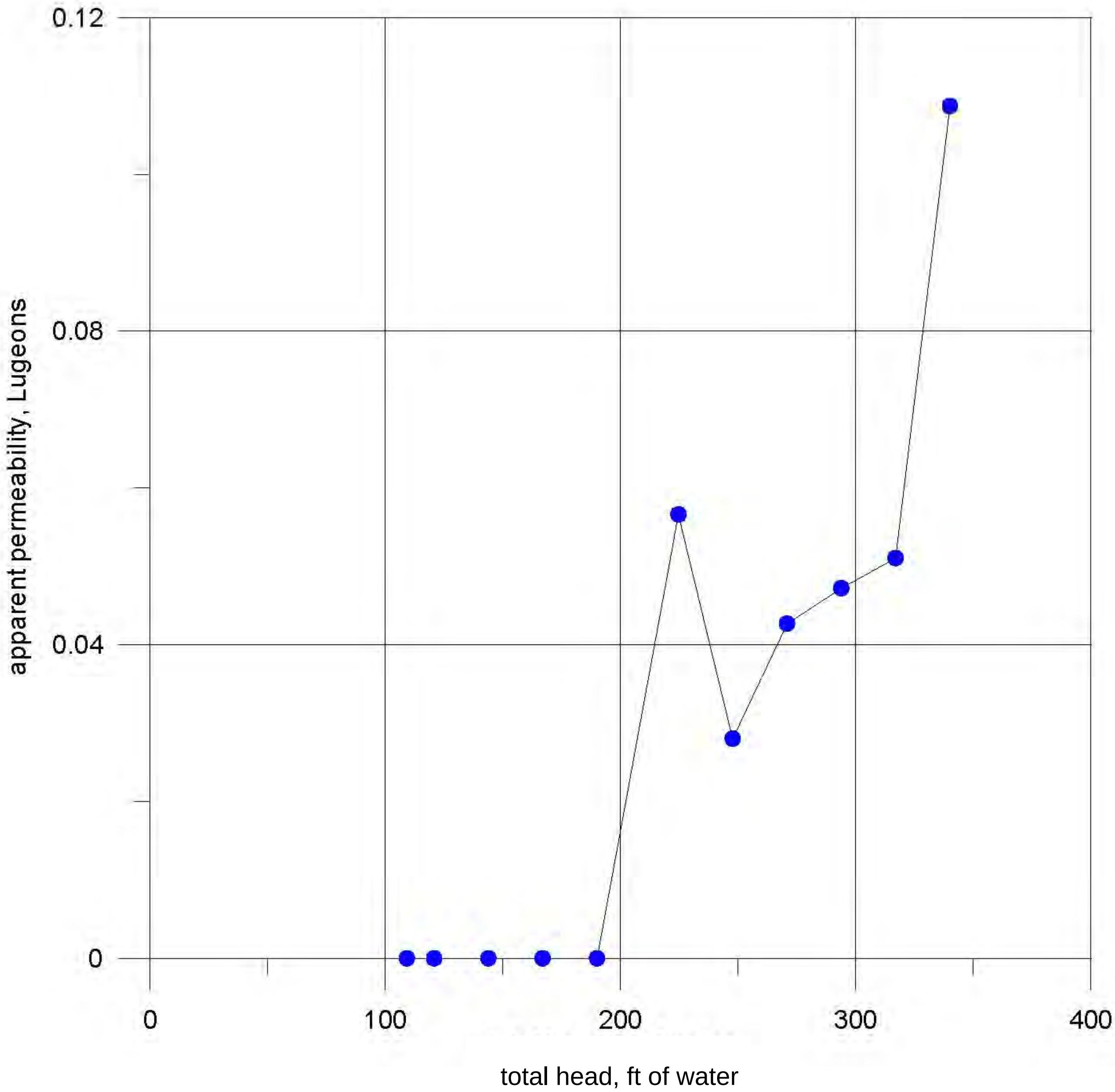


Figure 3. Apparent permeability from pressure injection test, New Mexico Copper GWQ 5-R, Zone 1 (64-100 ft), Series 1, August 31, 2011.

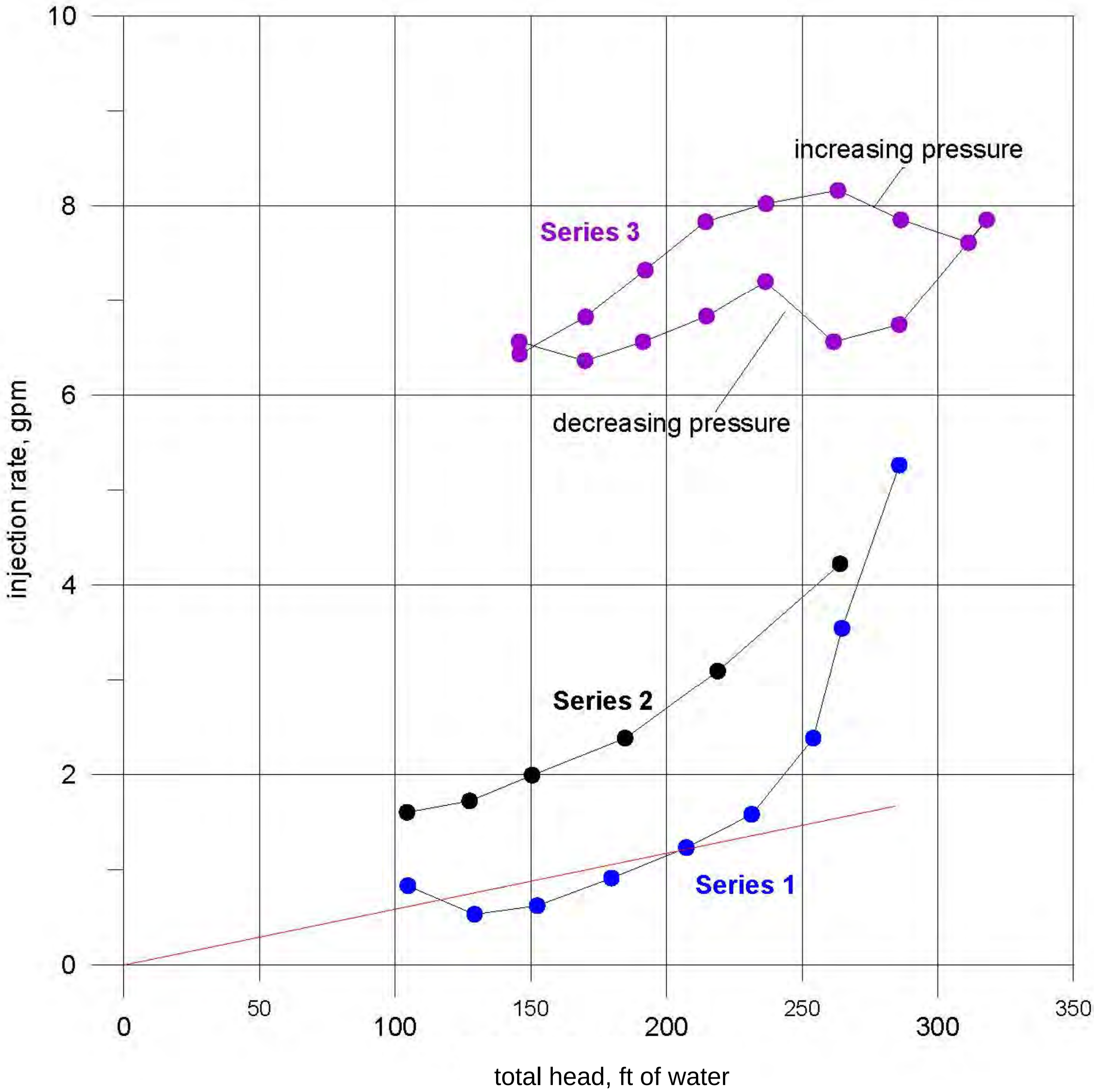


Figure 4. Pressure injection tests, New Mexico Copper GWQ 11-24, Zone 1 (100-147 ft), Series 1 and 2 (centrifugal pump), and Series 3 (positive displacement pump), July 27, 2011.

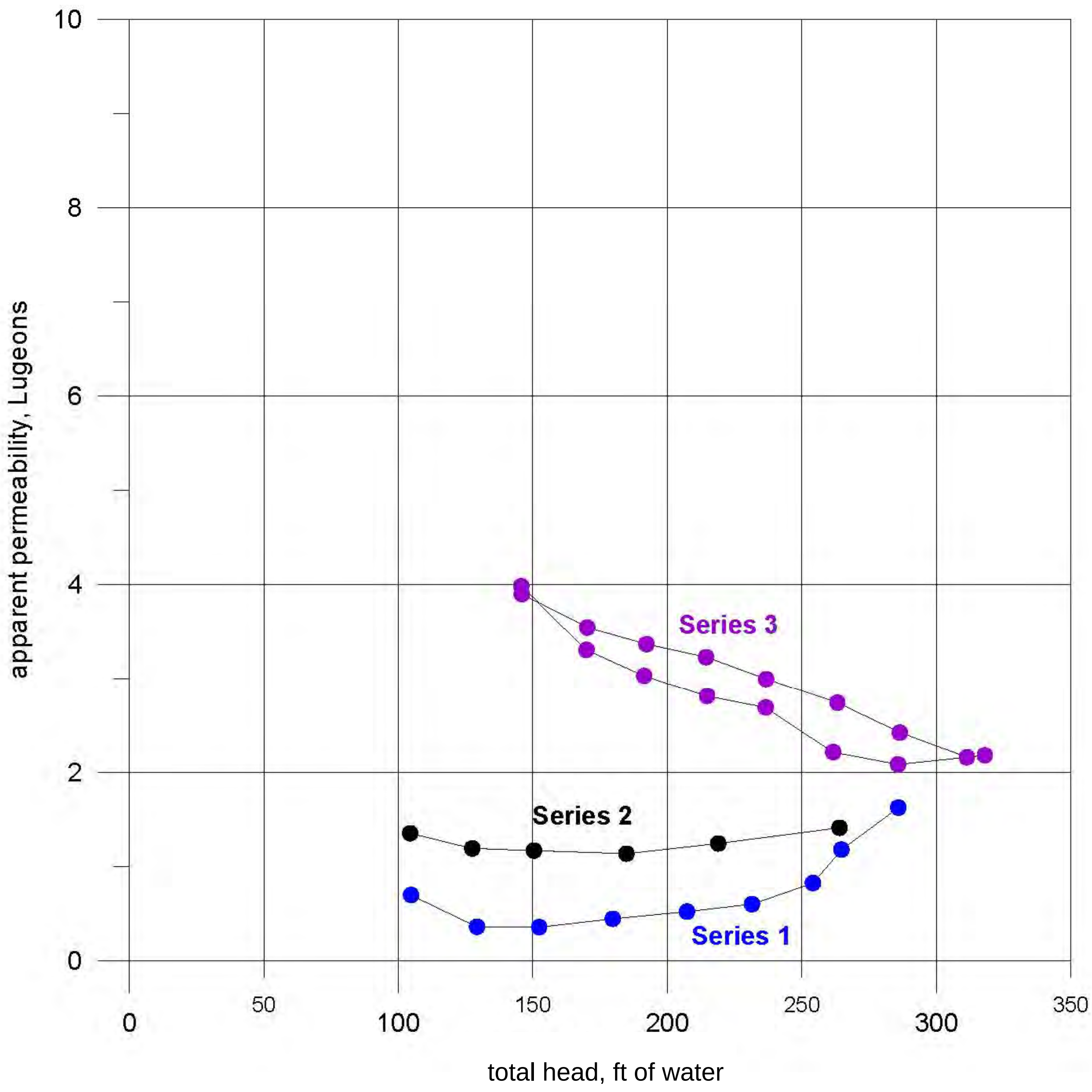


Figure 5. Apparent permeability from pressure injection tests, New Mexico Copper GWQ 11-24, Zone 1 (100-147 ft), Series 1 and 2 (centrifugal pump), and Series 3 (positive displacement pump), July 27, 2011.

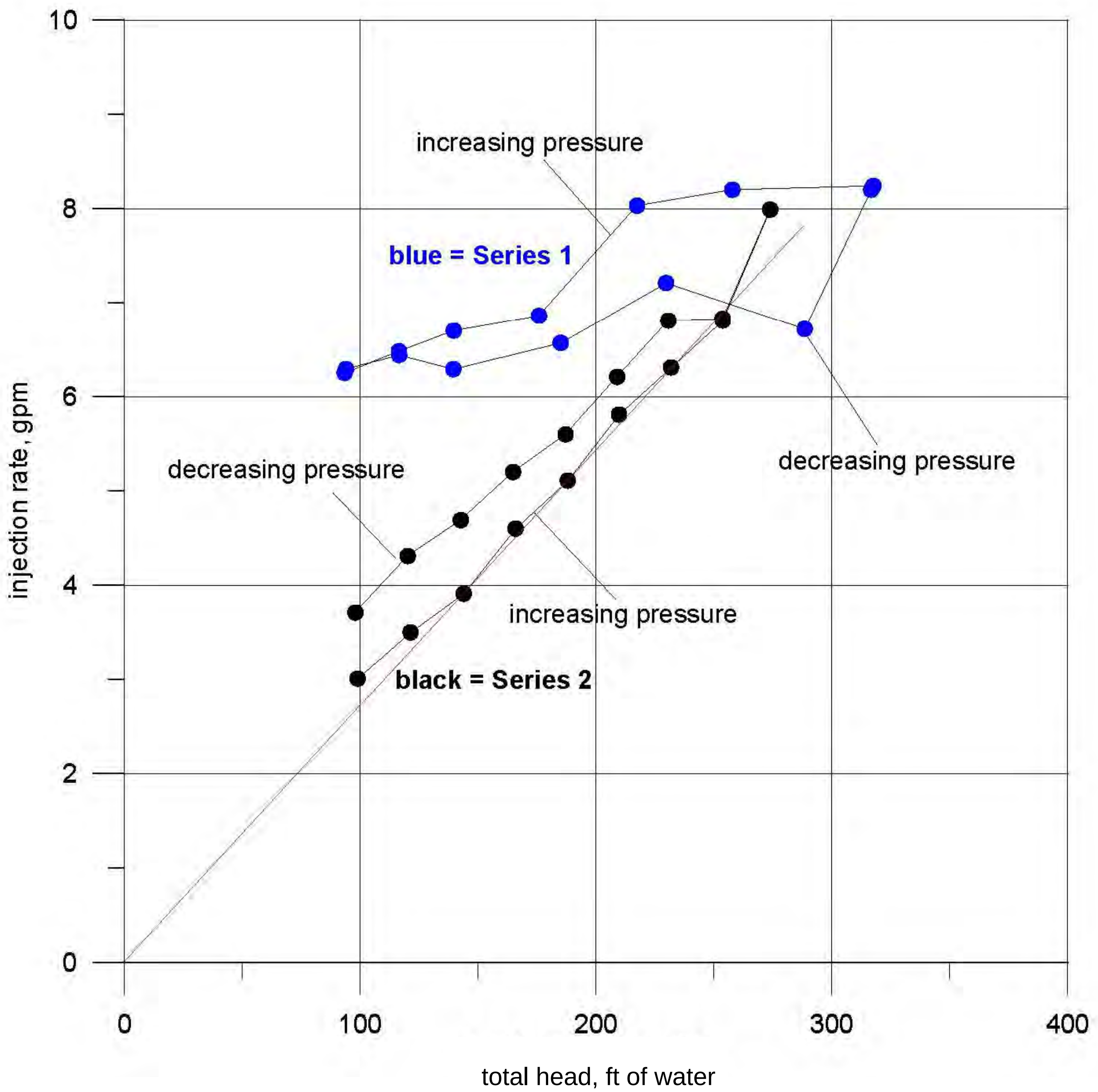


Figure 6. Pressure injection test, New Mexico Copper GWQ 11-24, Zone 2 (150-197 ft), Series 1 and 2, July 30, 2011.

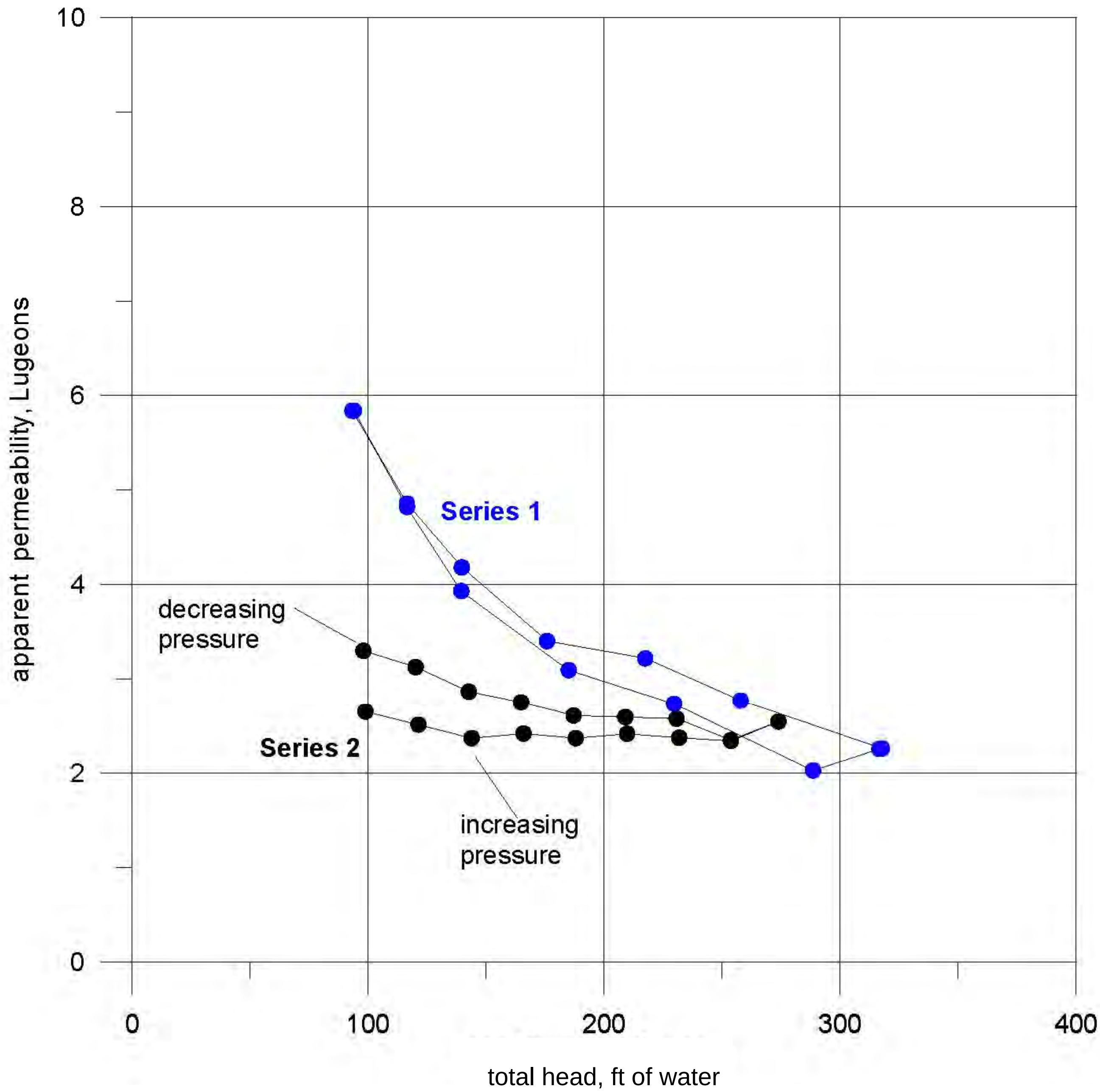


Figure 7. Apparent permeability from pressure injection test, New Mexico Copper GWQ 11-24, Zone 2 (150-197 ft), Series 1 and 2, July 30, 2011.

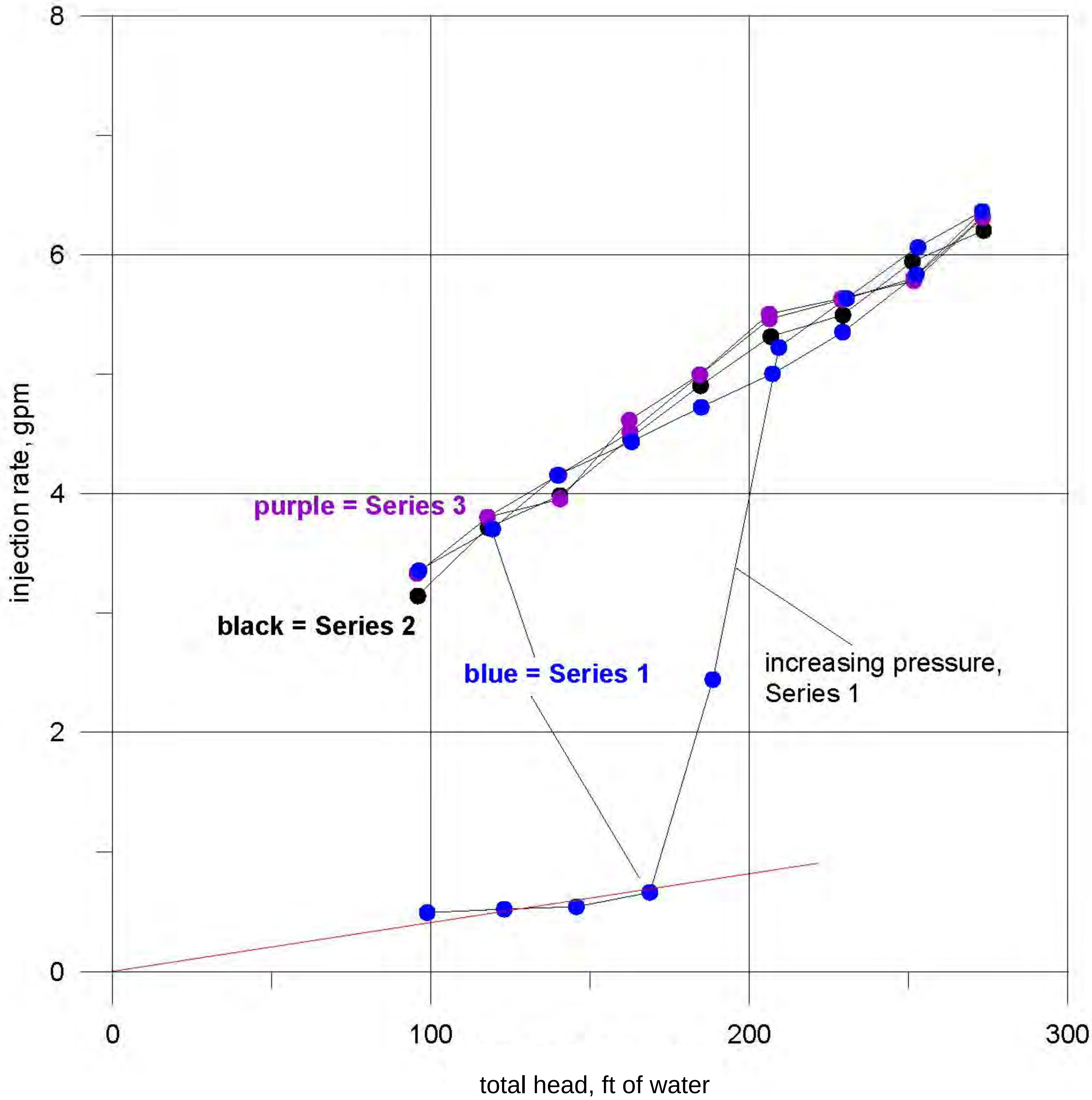


Figure 8. Pressure injection test, New Mexico Copper GWQ 11-24,
Zone 3 (204-251 ft), Series 1, 2, and 3, August 1, 2011.

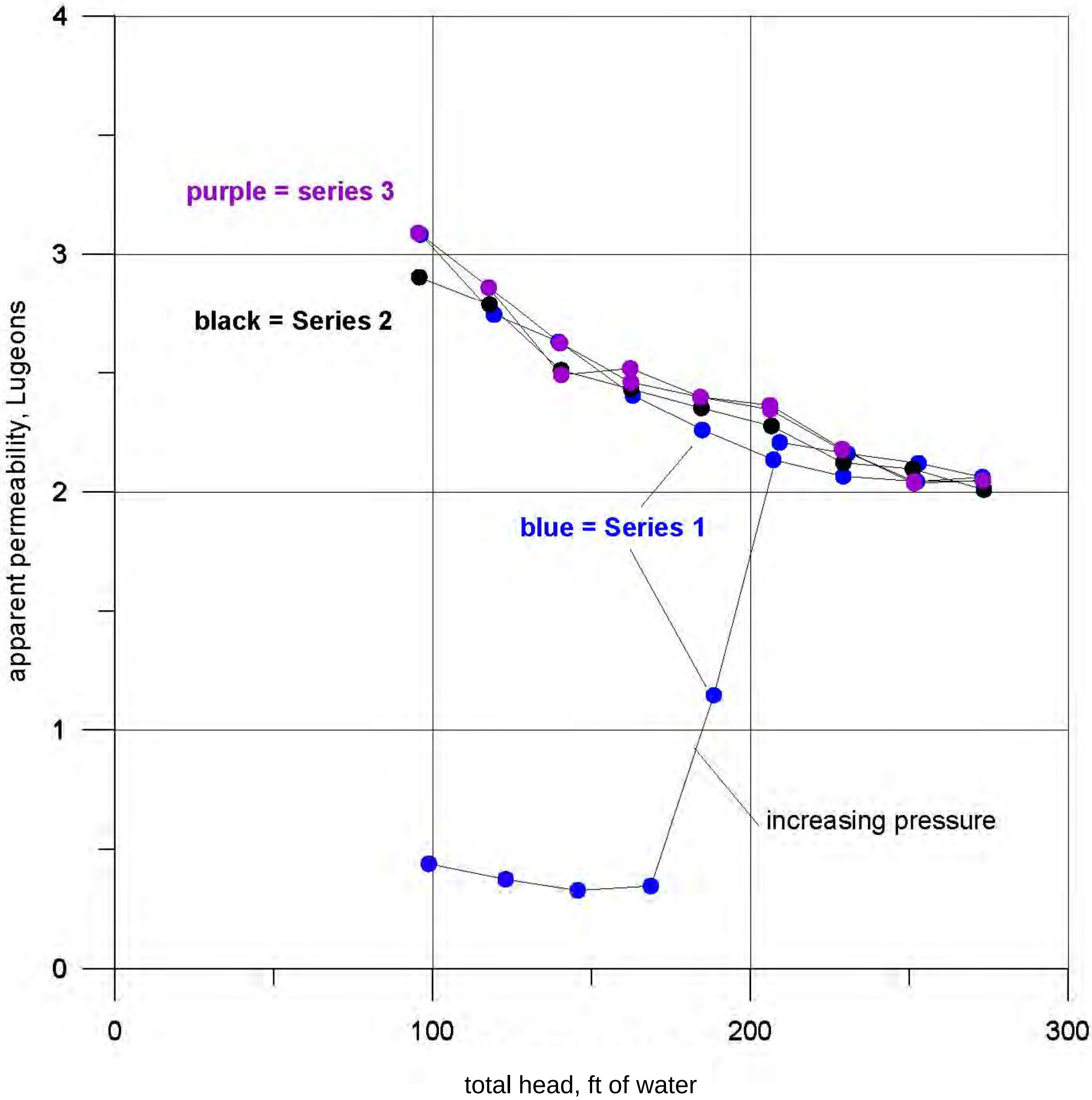


Figure 9. Apparent permeability from pressure injection test, New Mexico Copper GWQ 11-24, Zone 3 (204-251 ft), Series 1, 2, and 3, August 1, 2011.

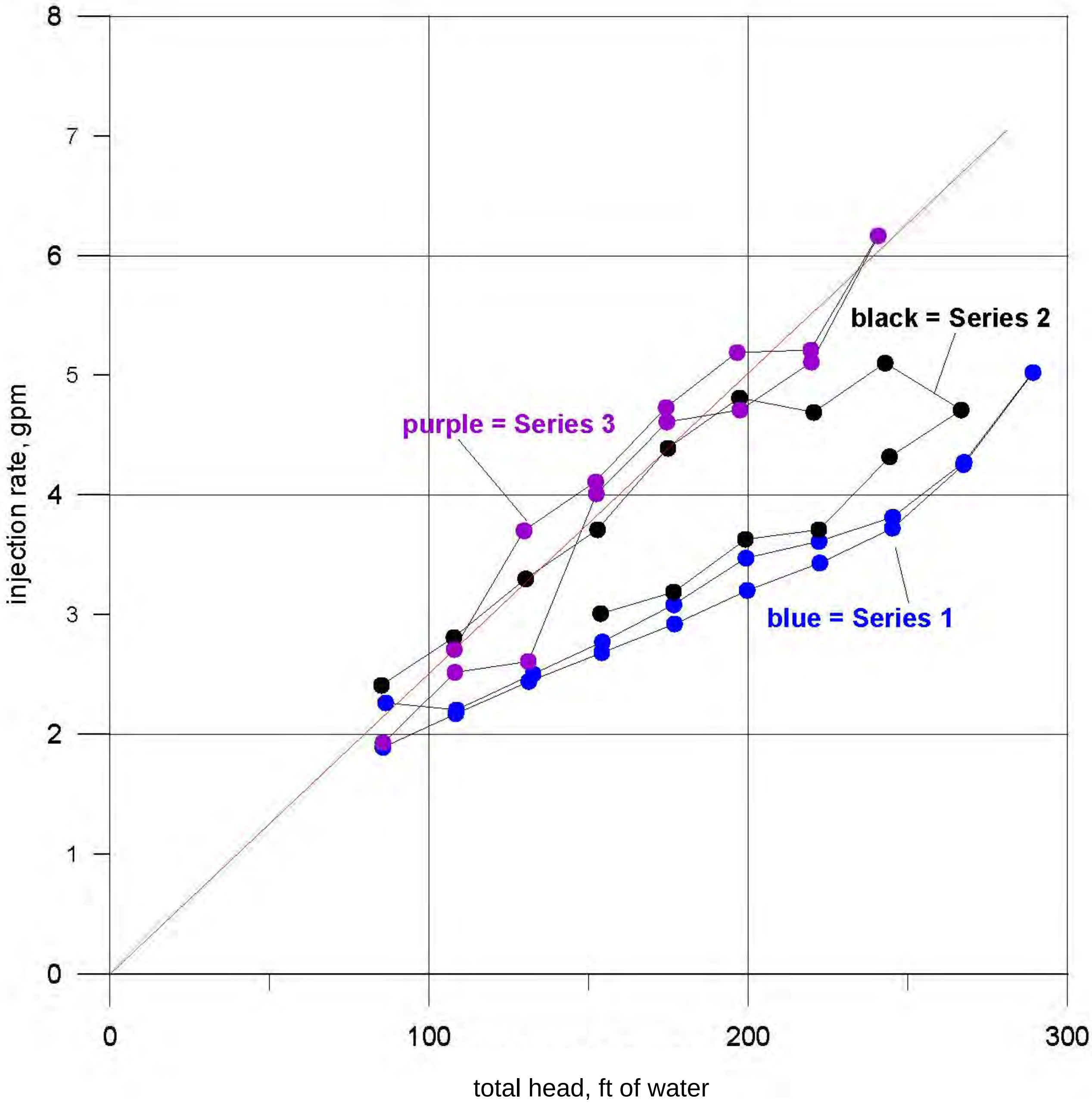


Figure 10. Pressure injection test, New Mexico Copper GWQ 11-25,
Zone 2 (150-197.7 ft), Series 1, 2, and 3, August 16, 2011.

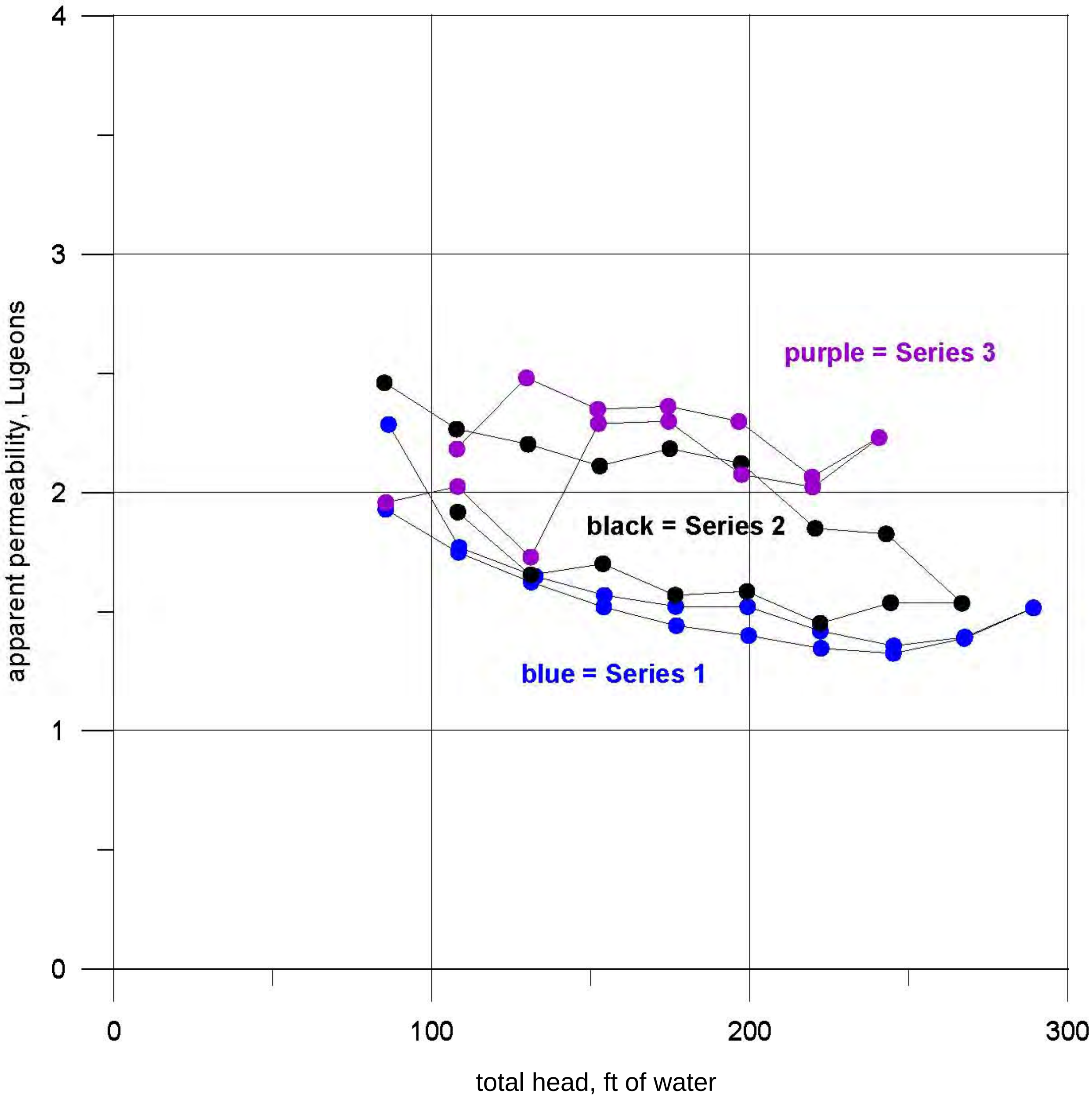


Figure 11. Apparent permeability from pressure injection test, New Mexico Copper GWQ 11-25, Zone 2 (150-197.7 ft), Series 1, 2, and 3, August 16, 2011.

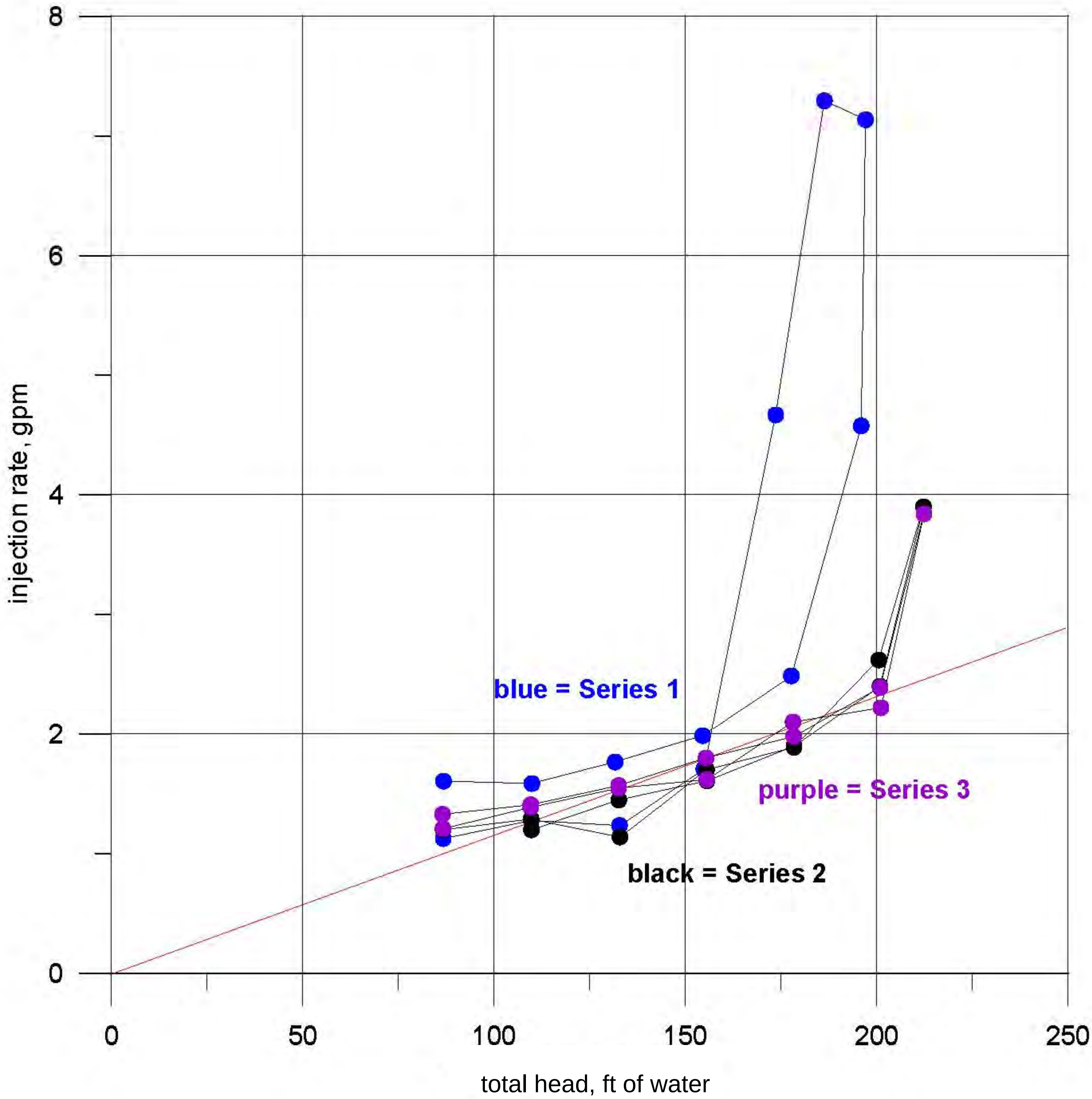


Figure 12. Pressure injection test, New Mexico Copper GWQ 11-25, Zone 3 (207-251 ft), Series 1, 2 and 3, August 24, 2011.

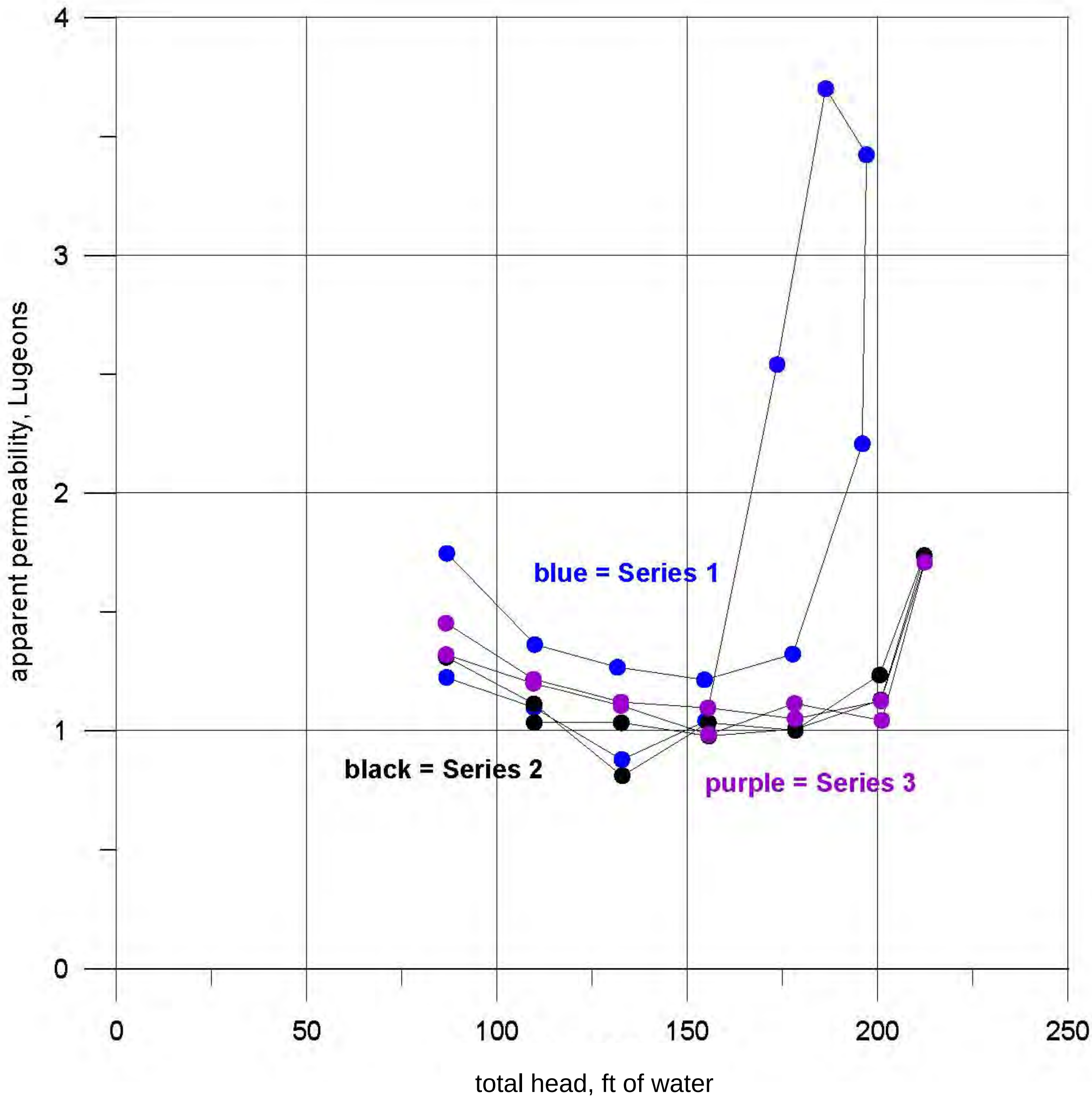


Figure 13. Apparent permeability from pressure injection test, New Mexico Copper GWQ 11-25, Zone 3 (207-251 ft), Series 1, 2, and 3, August 24, 2011.

APPENDIX

Appendix.

Basic data for pressure-injection tests

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	**8/31/2011**
Client	**New Mexico Copper Corp**
Project	**Copper Flat**
Well Name	**GWQ 5-R**
Hydrologist	**JJK**

later WLs indicate dry to 100 ft; use (64+100)/2

Starting Water Level (ft bgl)	**5.6 (not representative of Static)**
Elevation (ft GL)	
Injection Interval (ft bgl)	**64 to 100**
Bore/Casing Depth (ft bgl)	**100**

Packer Dia	**2 inch**
Bore/Casing Dia	**3-3/4 inch**
Injection Pipe Dia	**1 inch**
Pressure gauge height above GL	**4 ft**

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
11:25	0		6000		10	0	Packer at 200 psi
11:26	1	1	6000	0.00	10	0	
11:27	2	2	6000	0.00	10	0	
11:28	3	3	6000	0.00	10	0	
11:29	4	4	6000	0.00	10	0	
11:30	5	5	6000	0.00	10	0	
11:31	6	1	6000	0.00	20	0	
11:32	7	2	6000	0.00	20	0	
11:33	8	3	6000	0.00	20	0	
11:34	9	4	6000	0.00	20	0	
11:35	10	5	6000	0.00	20	0	
11:36	11	1	6000	0.00	30	0	
11:37	12	2	6000	0.00	30	0	
11:38	13	3	6000	0.00	30	0	
11:39	14	4	6000	0.00	30	0	
11:40	15	5	6000	0.00	30	0	
11:41	16	1	6000	0.00	40	0	
11:42	17	2	6000	0.00	40	0	
11:43	18	3	6000	0.00	40	0	
11:44	19	4	6000	0.00	40	0	
11:45	20	5	6000	0.00	40	0	
11:46	21	1	6000	0.00	50	0	
11:47	22	2	6000	0.00	50	0	
11:48	23	3	6000	0.00	50	0	
11:49	24	4	6000	0.00	50	0	
11:50	25	5	6000	0.00	50	0	
11:51	26	1	6000	0.00	60	0	
11:52	27	2	6000	0.00	60	0	
11:53	28	3	6000.3	0.30	60	0.3	
11:54	29	4	6000.3	0.00	60	0.3	
11:55	30	5	6000.5	0.20	60	0.5	
11:56	31	1	6000.7	0.2	60	0.7	
11:57	32	2	6000.9	0.2	60	0.9	
11:58	33	3	6001	0.1	60	1	
11:59	34	4	6001.1	0.1	60	1.1	
12:00	35	5	6001.1	0	60	1.1	
12:01	36	1	6001.2	0.1	70	1.2	
12:02	37	2	6001.2	0	70	1.2	
12:03	38	3	6001.2	0	70	1.2	
12:04	39	4	6001.3	0.1	70	1.3	
12:05	40	5	6001.3	0	70	1.3	
12:06	41	6	6001.5	0.2	70	1.5	
12:07	42	7	6001.5	0	70	1.5	
12:08	43	8	6001.5	0	70	1.5	
12:09	44	9	6001.7	0.2	70	1.7	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
12:10	45	10	6001.7	0	70	1.7	
12:11	46	1	6001.9	0.2	80	1.9	
12:12	47	2	6002	0.1	80	2	
12:13	48	3	6002.1	0.1	80	2.1	
12:14	49	4	6002.1	0	80	2.1	
12:15	50	5	6002.1	0	80	2.1	
12:16	51	6	6002.4	0.3	80	2.4	
12:17	52	7	6002.4	0	80	2.4	
12:18	53	8	6002.5	0.1	80	2.5	
12:19	54	9	6002.7	0.2	80	2.7	
12:20	55	10	6002.7	0	80	2.7	
12:21	56	1	6002.8	0.1	90	2.8	
12:22	57	2	6003	0.2	90	3	
12:23	58	3	6003	0	90	3	
12:24	59	4	6003.2	0.2	90	3.2	
12:25	60	5	6003.2	0	90	3.2	
12:26	61	6	6003.3	0.1	90	3.3	
12:27	62	7	6003.4	0.1	90	3.4	
12:28	63	8	6003.6	0.2	90	3.6	
12:29	64	9	6003.7	0.1	90	3.7	
12:30	65	10	6003.9	0.2	90	3.9	
12:31	66	1	6004	0.10	100	4	
12:32	67	2	6004.2	0.20	100	4.2	
12:33	68	3	6004.2	0.00	100	4.2	
12:34	69	4	6004.5	0.30	100	4.5	
12:35	70	5	6004.7	0.20	100	4.7	
12:36	71	1	6004.7	0	100	4.7	
12:37	72	2	6004.9	0.2	100	4.9	
12:38	73	3	6005.1	0.2	100	5.1	
12:39	74	4	6005.1	0	100	5.1	
12:40	75	5	6005.3	0.2	100	5.3	
12:41	76	1	6005.7	0.4	110	5.7	
12:42	77	2	6006	0.3	110	6	
12:43	78	3	6006.4	0.4	110	6.4	
12:44	79	4	6006.6	0.2	110	6.6	
12:45	80	5	6006.9	0.3	110	6.9	
12:46	81	6	6007.3	0.4	110	7.3	
12:47	82	7	6007.7	0.4	110	7.7	
12:48	83	8	6007.9	0.2	110	7.9	
12:49	84	9	6008.2	0.3	110	8.2	
12:50	85	10	6008.5	0.3	110	8.5	
12:51	86	1	6011.2	2.7	120	11.2	Fluid moving up hole
12:52	87	2	6013.8	2.6	122	13.8	
12:53	88	3	6016.2	2.4	115	16.2	Fluid at top of conductor
12:54	89	4	6021.2	5	113	21.2	
12:55	90	5	6026.3	5.1	110	26.3	
12:56	91	6	6032	5.7	110	32	
12:57	92	7	6037.6	5.6	110	37.6	
12:58	93	8	6043.5	5.9	110	43.5	
12:59	94	9	6049.2	5.7	110	49.2	Approximatly 5 + gallons flowing at surface
13:00	95	10	6055	5.8	110	55	Stop pump
13:01	96		6055	0		NA	Packer pressure has dropped to 160
13:02	97		6055	0		NA	
13:03	98		6055	0		NA	
13:04	99		6055	0		NA	
13:05	100		6055	0		NA	
13:06	101		6055	0		NA	Attempt to reinflate packer and stabilize

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
13:07	102		6055	0		NA	
13:08	103		6055	0		NA	
13:09	104		6055	0		NA	
13:10	105		6055	0		NA	Unable to stabilize packer psi
13:11	106		6055	0		NA	
13:12	107		6055	0		NA	
13:13	108		6055	0		NA	
13:14	109		6055	0		NA	
13:15	110		6055	0		NA	
13:16	111		6055	0		NA	
13:17	112		6055	0		NA	
13:18	113		6055	0		NA	
13:19	114		6055	0		NA	
13:20	115		6055	0		NA	Pull and replace packer
13:21	116		6055	0		NA	
13:22	117		6055	0		NA	
13:23	118		6055	0		NA	
13:24	119		6055	0		NA	
13:25	120		6055	0		NA	
13:26	121		6055	0		NA	
13:27	122		6055	0		NA	
13:28	123		6055	0		NA	
13:29	124		6055	0		NA	
13:30	125		6055	0		NA	
13:31	126		6055	0		NA	
13:32	127		6055	0		NA	
13:33	128		6055	0		NA	
13:34	129		6055	0		NA	
13:35	130		6055	0		NA	
13:36	131		6055	0		NA	
13:37	132		6055	0		NA	
13:38	133		6055	0		NA	
13:39	134		6055	0		NA	
13:40	135		6055	0		NA	
13:41	136		6055	0		NA	
13:42	137		6055	0		NA	
13:43	138		6055	0		NA	
13:44	139		6055	0		NA	
13:45	140		6055	0		NA	
13:46	141		6055	0		NA	
13:47	142		6055	0		NA	
13:48	143		6055	0		NA	
13:49	144		6055	0		NA	
13:50	145		6055	0		NA	
13:51	146		6055	0		NA	
13:52	147		6055	0		NA	
13:53	148		6055	0		NA	
13:54	149		6055	0		NA	
13:55	150		6055	0		NA	
13:56	151		6055	0		NA	
13:57	152		6055	0		NA	
13:58	153		6055	0		NA	
13:59	154		6055	0		NA	New packer installed and inflated to 200 psi
14:00	155	1	6057	2	100	55	Filling hose and 1 inch
14:01	156	2	6057.4	0.4	110		
14:02	157	3	6057.5	0.1	110		
14:03	158	4	6057.5	0	125		
14:04	159	5	6057.5	0	123		

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
14:05	160	6	6057.5	0	120		
14:06	161	7	6057.5	0	120		Pump shear pin fails
14:07	162	8	6057.5	0	0		Stop to repair pump
14:08	163		6057.5	0	0		
14:09	164		6057.5	0	0		
14:10	165		6057.5	0	0		
14:11	166		6057.5	0	0		
14:12	167		6057.5	0	0		
14:13	168		6057.5	0	0		
14:14	169		6057.5	0	0		
14:15	170		6057.5	0	0		
14:16	171		6057.5	0	0		
14:17	172		6057.5	0	0		
14:18	173		6057.5	0	0		
14:19	174		6057.5	0	0		
14:20	175		6057.5	0	0		
14:21	176		6057.5	0	0		
14:22	177		6057.5	0	0		
14:23	178		6057.5	0	0		
14:24	179		6057.5	0	0		
14:25	180		6057.5	0	0		
14:26	181		6057.5	0	0		
14:27	182		6057.5	0	0		
14:28	183		6057.5	0	0		
14:29	184		6057.5	0	0		
14:30	185		6057.5	0	0		
14:31	186		6057.5	0	0		
14:32	187		6057.5	0	0		
14:33	188		6057.5	0	0		
14:34	189		6057.5	0	0		
14:35	190		6057.5	0	0		
14:36	191		6057.5	0	0		
14:37	192		6057.5	0	0		
14:38	193		6057.5	0	0		
14:39	194		6057.5	0	0		
14:40	195		6057.5	0	0		
14:41	196		6057.5	0	0		
14:42	197		6057.5	0	0		
14:43	198		6057.5	0	0		
14:44	199		6057.5	0	0		
14:45	200		6057.5	0	0		
14:46	201		6057.5	0	0		
14:47	202		6057.5	0	0		
14:48	203		6057.5	0	0		
14:49	204		6057.5	0	0		
14:50	205		6057.5	0	0		
14:51	206		6057.5	0	0		
14:52	207		6057.5	0	0		
14:53	208		6057.5	0	0		
14:54	209		6057.5	0	0		
14:55	210		6057.5	0	0		
14:56	211		6057.5	0	0		
14:57	212		6060	2.5	0		Test pump to ground
14:58	213		6067.5	7.5	0		
14:59	214		6075	7.5	0		
15:00	215		6082.5	7.5	0		
15:01	216		6082.5	0	0		
15:02	217		6082.5	0	0		

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
15:03	218		6082.5	0	0		
15:04	219		6082.5	0	0		
15:05	220		6082.5	0	0		
15:06	221		6082.5	0	0		
15:07	222		6082.5	0	0		
15:08	223		6082.5	0	0		
15:09	224		6082.5	0	0		
15:10	225		6082.5	0	0		
15:11	226	1	6082.7	0.2	120	55.2	
15:12	227	2	6082.9	0.2	120	55.4	
15:13	228	3	6083	0.1	120	55.5	
15:14	229	4	6083	0	120	55.5	
15:15	230	5	6083.2	0.2	120	55.7	
15:16	231	6	6083.3	0.1	120	55.8	
15:17	232	7	6083.3	0	120	55.8	
15:18	233	8	6083.3	0	120	55.8	
15:19	234	9	6083.3	0	120	55.8	
15:20	235	10	6083.3	0	120	55.8	
15:21	236	1	6083.3	0	130	28.3	
15:22	237	2	6083.3	0	130	28.3	
15:23	238	3	6083.4	0.1	130	28.4	
15:24	239	4	6083.4	0	130	28.4	
15:25	240	5	6083.4	0	130	28.4	
15:26	241	6	6083.4	0	130	28.4	
15:27	242	7	6083.4	0	130	28.4	
15:28	243	8	6083.4	0	130	28.4	
15:29	244	9	6083.5	0.1	130	28.5	
15:30	245	10	6083.5	0	130	28.5	
15:31	246	1	6083.5	0	150	28.5	
15:32	247	2	6083.5	0	150	28.5	
15:33	248	3	6083.6	0.1	150	28.6	1 inch injection pipe pushing up
15:34	249	4	6083.7	0.1	150	28.7	
15:35	250	5	6083.7	0	150	28.7	Packer pressure moving up 240
15:36	251	6	6083.7	0	150	28.7	
15:37	252	7	6083.7	0	150	28.7	Packer pressure moving up 260
15:38	253	8	6083.7	0	150	28.7	
15:39	254	9	6083.9	0.2	150	28.9	Packer pressure moving up 290
15:40	255	10	6084	0.1	150	29	
15:41	256	1	6084	0	130	29	
15:42	257	2	6084	0	130	29	
15:43	258	3	6084.2	0.2	130	29.2	
15:44	259	4	6084.2	0	130	29.2	
15:45	260	5	6084.2	0	130	29.2	Packer pressure down to 260
15:46	261	6	6084.2	0	130	29.2	
15:47	262	7	6084.3	0.1	130	29.3	
15:48	263	1	6084.3	0	120	29.3	
15:49	264	2	6084.3	0	120	29.3	
15:50	265	3	6084.3	0	120	29.3	
15:51	266	4	6084.3	0	120	29.3	
15:52	267	5	6084.3	0	120	29.3	
15:53	268	6	6084.3	0	120	29.3	
15:54	269	7	6084.3	0	120	29.3	
15:55	270	8	6084.3	0	120	29.3	
15:56	271	9	6084.3	0	120	29.3	
15:57	272	10	6084.4	0.1	120	29.4	
15:58	273	1	6084.4	0	110	29.4	
15:59	274	2	6084.4	0	110	29.4	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
16:00	275	3	6084.4	0	110	29.4	
16:01	276	4	6084.5	0.1	110	29.5	
16:02	277	5	6084.5	0	110	29.5	
16:03	278	1	6084.5	0	100	29.5	
16:04	279	2	6084.5	0	100	29.5	
16:05	280	3	6084.5	0	100	29.5	
16:06	281	4	6084.5	0	100	29.5	
16:07	282	5	6084.5	0	100	29.5	
16:08	283	1	6084.5	0	90	29.5	
16:09	284	2	6084.5	0	90	29.5	
16:10	285	3	6084.5	0	90	29.5	
16:11	286	4	6084.5	0	90	29.5	
16:12	287	5	6084.5	0	90	29.5	
16:13	288	1	6084.5	0	80	29.5	
16:14	289	2	6084.5	0	80	29.5	
16:15	290	3	6084.5	0	80	29.5	
16:16	291	4	6084.5	0	80	29.5	
16:17	292	5	6084.5	0	80	29.5	
16:18	293	1	6084.5	0	70	29.5	
16:19	294	2	6084.5	0	70	29.5	
16:20	295	3	6084.5	0	70	29.5	
16:21	296	4	6084.5	0	70	29.5	
16:22	297	5	6084.5	0	70	29.5	
16:23	298	1	6084.5	0	60	29.5	
16:24	299	2	6084.5	0	60	29.5	
16:25	300	3	6084.5	0	60	29.5	
16:26	301	4	6084.5	0	60	29.5	
16:27	302	5	6084.5	0	60	29.5	
16:28	303	1	6084.5	0	50	29.5	
16:29	304	2	6084.5	0	50	29.5	
16:30	305	3	6084.5	0	50	29.5	
16:31	306	4	6084.5	0	50	29.5	
16:32	307	5	6084.5	0	50	29.5	
16:33	308	1	6084.5	0	40	29.5	
16:34	309	2	6084.5	0	40	29.5	
16:35	310	3	6084.5	0	40	29.5	
16:36	311	4	6084.5	0	40	29.5	
16:37	312	5	6084.5	0	40	29.5	
16:38	313	1	6084.5	0	30	29.5	
16:39	314	2	6084.5	0	30	29.5	
16:40	315	3	6084.5	0	30	29.5	
16:41	316	4	6084.5	0	30	29.5	
16:42	317	5	6084.5	0	30	29.5	
16:43	318	6	6084.5	0	20	29.5	
16:44	319	7	6084.5	0	20	29.5	
16:45	320	8	6084.5	0	20	29.5	
16:46	321	9	6084.5	0	20	29.5	
16:47	322	10	6084.5	0	20	29.5	

Repeated steps summarized								
psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
								No duplicat test performed

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	**7/21/2011**
Client	**New Mexico Copper Corp**
Project	**Copper Flat**
Well Name	**GWQ 11-24 Zone 1**
Hydrologist	**JJK**

Starting Water Level (ft bgl)	**54.61**	**Packer Dia**	**2 inch**
Elevation (ft GL)		**Bore/Casing Dia**	**3-3/4 inch**
Injection Interval (ft bgl)	**100 to 147**	**Injection Pipe Dia**	**1 inch**
Bore/Casing Depth (ft bgl)	**147**	**Pressure gauge height above GL**	**4 ft**

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
8:25	0		9		20	0	20 psi
8:26	1	1	9.8	0.80	20	0.8	
8:27	2	2	10.59	0.79	20	1.59	
8:28	3	3	11.4	0.81	20	2.4	
8:29	4	4	12.2	0.80	20	3.2	
8:30	5	5	13.1	0.90	20	4.1	
8:31	6	6	14	0.90	20	5	
8:32	7	7	14.8	0.80	20	5.8	
8:33	8	8	15.6	0.80	20	6.6	
8:34	9	9	16.5	0.90	20	7.5	
8:35	10	10	17.3	0.80	20	8.3	Average 0.83 gpm
8:36	11	1	17.8	0.5	30	8.8	30 psi
8:37	12	2	18.3	0.5	32	9.3	
8:38	13	3	18.9	0.6	30	9.9	
8:39	14	4	19.6	0.7	31	10.6	
8:40	15	5	20	0.4	30	11	
8:41	16	6	20.5	0.5	32	11.5	
8:42	17	7	21	0.5	31	12	
8:43	18	8	21.5	0.5	30	12.5	
8:44	19	9	22.1	0.6	30	13.1	
8:45	20	10	22.6	0.5	30	13.6	Average 0.53 gpm
8:46	21	1	23.22	0.62	40	14.22	Attempt 40 psi. Oscillating + - 5 psi
8:47	22	2	23.8	0.58	40	14.8	
8:48	23	3	24.4	0.6	40	15.4	
8:49	24	4	25	0.6	40	16	
8:50	25	5	25.6	0.6	40	16.6	
8:51	26	6	26.3	0.7	40	17.3	
8:52	27	7	26.9	0.6	40	17.9	
8:53	28	8	27.5	0.6	40	18.5	
8:54	29	9	28.1	0.6	42	19.1	
8:55	30	10	28.8	0.7	44	19.8	Average 0.62 gpm
8:56	31	1	29.7	0.9	50-55	20.7	Attempt 50 psi. Oscillating + - 5 psi
8:57	32	2	30.6	0.9	50-55	21.6	
8:58	33	3	31.5	0.9	50-55	22.5	
8:59	34	4	32.4	0.9	50-55	23.4	
9:00	35	5	33.3	0.9	50-55	24.3	
9:01	36	6	34.3	1	50-55	25.3	
9:02	37	7	35.2	0.9	50-55	26.2	
9:03	38	8	36.2	1	50-55	27.2	
9:04	39	9	37	0.8	50-55	28	
9:05	40	10	37.9	0.9	50-55	28.9	Average 0.91 gpm
9:06	41	1	39.1	1.2	60	30.1	Attempt 60 psi. Oscillating + - 8 psi
9:07	42	2	40.3	1.2	65	31.3	
9:08	43	3	41.5	1.2	65	32.5	
9:09	44	4	42.8	1.3	65	33.8	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
9:10	45	5	44	1.2	65	35	
9:11	46	6	45.3	1.3	65	36.3	
9:12	47	7	46.6	1.3	65	37.6	
9:13	48	8	47.8	1.2	65	38.8	
9:14	49	9	49	1.2	65	40	
9:15	50	10	50.2	1.2	65	41.2	Average 1.23 gpm
9:16	51	1	51.8	1.6	75	42.8	Attempt 70 psi Oscillating + - 10 to 12 psi
9:17	52	2	53.4	1.6	75	44.4	
9:18	53	3	55	1.6	75	46	
9:19	54	4	56.5	1.5	75	47.5	
9:20	55	5	58	1.5	75	49	
9:21	56	6	59.6	1.6	75	50.6	
9:22	57	7	61	1.4	75	52	
9:23	58	8	62.5	1.5	75	53.5	
9:24	59	9	64.1	1.6	75	55.1	
9:25	60	10	66	1.9	75	57	Average 1.58 gpm
9:26	61	1	68.4	2.4	85	59.4	Attempt 80 psi Oscillating + - 10 to 20 psi
9:27	62	2	70.7	2.3	85	61.7	
9:28	63	3	73	2.3	85	64	
9:29	64	4	75.5	2.5	85	66.5	
9:30	65	5	78	2.5	85	69	
9:31	66	6	80.3	2.3	85	71.3	
9:32	67	7	82.7	2.4	85	73.7	
9:33	68	8	85	2.3	85	76	
9:34	69	9	87.4	2.4	85	78.4	
9:35	70	10	89.8	2.4	85	80.8	Average 2.38 gpm
9:36	71	1	93.32	3.52	90	84.32	Attempt 90 psi Oscillating + - 20 to 30 psi
9:37	72	2	96.8	3.48	90	87.8	
9:38	73	3	100	3.2	90	91	
9:39	74	4	103.5	3.5	90	94.5	
9:40	75	5	107	3.5	90	98	
9:41	76	6	110.5	3.5	90	101.5	
9:42	77	7	114.2	3.7	90	105.2	
9:43	78	8	117.8	3.6	90	108.8	
9:44	79	9	121.4	3.6	90	112.4	
9:45	80	10	125.2	3.8	90	116.2	Average 3.54 gpm
9:46	81	1	130.4	5.2	100	121.4	Valve fully open readings on gauge 85 to 118
9:47	82	2	135.8	5.4	100	126.8	Test abandoned at 90 minutes due to excess
9:48	83	3	141	5.2	100	132	fluctuation in pressure gauge.
9:49	84	4	146.3	5.3	100	137.3	
9:50	85	5	151.5	5.2	100	142.5	
9:51	86	6	156.8	5.3	100	147.8	
9:52	87	7	162	5.2	100	153	
9:53	88	8	167.3	5.3	100	158.3	
9:54	89	9	172.5	5.2	100	163.5	
9:55	90	10	177.8	5.3	100	168.8	Average 5.26 gpm

Second attempt on 7-26-2011 with centrifugal pump

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
7:44	0		180				
7:45	1	1	181.6	3.8	20	1.6	
7:46	2	2	183.1	1.5	20	3.1	
7:47	3	3	184.7	1.6	20	4.7	
7:48	4	4	186.4	1.7	20	6.4	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
7:49	5	5	188	1.6	20	8	
7:50	6	6	189.7	1.7	20	9.7	
7:51	7	7	191.2	1.5	20	11.2	
7:52	8	8	192.8	1.6	20	12.8	
7:53	9	9	194.5	1.7	20	14.5	
7:54	10	10	196	1.5	20	16	Average 1.6 gpm
7:55	11	1	197.7	1.7	30	17.7	
7:56	12	2	199.5	1.8	30	19.5	
7:57	13	3	201.3	1.8	30	21.3	
7:58	14	4	203	1.7	30	23	
7:59	15	5	204.6	1.6	30	24.6	
8:00	16	6	206.4	1.8	30	26.4	
8:01	17	7	208	1.6	30	28	
8:02	18	8	209.7	1.7	30	29.7	
8:03	19	9	211.5	1.8	30	31.5	
8:04	20	10	213.2	1.7	30	33.2	Average 1.72 gpm
8:05	21	1	215.2	2	40	35.2	
8:06	22	2	217.3	2.1	40	37.3	
8:07	23	3	219.2	1.9	40	39.2	
8:08	24	4	221	1.8	40	41	
8:09	25	5	223	2	40	43	
8:10	26	6	225.1	2.1	40	45.1	
8:11	27	7	227.2	2.1	40	47.2	
8:12	28	8	229.3	2.1	40	49.3	
8:13	29	9	231.1	1.8	40	51.1	
8:14	30	10	233.1	2	40	53.1	Average 1.99 gpm
8:15	31	1	235.5	2.4	50 - 60	55.5	Gauge reading from 45 to 65 psi
8:16	32	2	237.9	2.4	50 - 60	57.9	
8:17	33	3	240	2.1	50 - 60	60	
8:18	34	4	242.4	2.4	50 - 60	62.4	
8:19	35	5	244.9	2.5	50 - 60	64.9	
8:20	36	6	247.2	2.3	50 - 60	67.2	
8:21	37	7	249.6	2.4	50 - 60	69.6	
8:22	38	8	252	2.4	50 - 60	72	
8:23	39	9	254.5	2.5	50 - 60	74.5	
8:24	40	10	256.9	2.4	50 - 60	76.9	Average 2.38 gpm
8:25	41	1	260	3.1	65 - 75	80	Gauge reading from 60 to 80 psi
8:26	42	2	263.1	3.1	65 - 75	83.1	
8:27	43	3	266.3	3.2	65 - 75	86.3	
8:28	44	4	269.3	3.1	65 - 75	89.3	
8:29	45	5	272.3	3	65 - 75	92.3	
8:30	46	6	275.4	3.1	65 - 75	95.4	
8:31	47	7	278.4	3	65 - 75	98.4	
8:32	48	8	281.5	3.1	65 - 75	101.5	
8:33	49	9	284.7	3.2	65 - 75	104.7	
8:34	50	10	287.8	3.1	65 - 75	107.8	Average 3.09 gpm
8:35	51	1	292	4.2	80 - 100	112	Gauge reading from 65 to 115
8:36	52	2	296.1	4.1	80 - 100	116.1	Test abandoned at 60 minutes due to excess
8:37	53	3	300	3.9	80 - 100	120	fluctuation in pressure gauge
8:38	54	4	304.2	4.2	80 - 100	124.2	
8:39	55	5	308.5	4.3	80 - 100	128.5	
8:40	56	6	312.9	4.4	80 - 100	132.9	
8:41	57	7	317.2	4.3	80 - 100	137.2	
8:42	58	8	321.5	4.3	80 - 100	141.5	
8:43	59	9	325.8	4.3	80 - 100	145.8	
8:44	60	10	330	4.2	80 - 100	150	Average 4.22 gpm

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
Third attempt on 7-27-2011 with screw pump							
Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
11:20	0	0	350		40	0	
11:21	1	1	356.2	6.2	40	6.2	
11:22	2	2	362.73	6.53	40	12.73	
11:23	3	3	369.3	6.57	40	19.3	
11:24	4	4	375.8	6.5	40	25.8	
11:25	5	5	382.3	6.5	40	32.3	
11:26	6	6	388.6	6.3	40	38.6	
11:27	7	7	395.1	6.5	40	45.1	
11:28	8	8	401.6	6.5	40	51.6	
11:29	9	9	408	6.4	40	58	
11:30	10	10	414.3	6.3	41	64.3	6.43 average gpm
11:31	11	1	421.1	6.8	50	71.1	Gauge oscillating + - 3 psi
11:32	12	2	427.9	6.8	50	77.9	
11:33	13	3	434.8	6.9	51	84.8	
11:34	14	4	441.7	6.9	51	91.7	
11:35	15	5	448.6	6.9	52	98.6	
11:36	16	6	455.4	6.8	50	105.4	
11:37	17	7	462.2	6.8	52	112.2	
11:38	18	8	469	6.8	51	119	
11:39	19	9	475.8	6.8	50	125.8	
11:40	20	10	482.5	6.7	52	132.5	6.82 average gpm
11:41	21	1	489.9	7.4	60	139.9	Gauge oscillating + - 3 psi
11:42	22	2	497.2	7.3	61	147.2	
11:43	23	3	504.4	7.2	61	154.4	
11:44	24	4	511.8	7.4	62	161.8	
11:45	25	5	519.2	7.4	62	169.2	
11:46	26	6	526.4	7.2	61	176.4	
11:47	27	7	533.7	7.3	60	183.7	
11:48	28	8	541	7.3	60	191	
11:49	29	9	548.3	7.3	60	198.3	
11:50	30	10	555.7	7.4	61	205.7	7.32 average gpm
11:51	31	1	563.6	7.9	70	213.6	Gauge oscillating + - 3 psi
11:52	32	2	571.4	7.8	71	221.4	
11:53	33	3	579.1	7.7	70	229.1	
11:54	34	4	587	7.9	70	237	
11:55	35	5	594.9	7.9	71	244.9	
11:56	36	6	602.9	8	72	252.9	
11:57	37	7	610.7	7.8	72	260.7	
11:58	38	8	618.5	7.8	70	268.5	
11:59	39	9	626.3	7.8	70	276.3	
12:00	40	10	634	7.7	72	284	7.83 average gpm
12:01	41	1	642	8	81	292	Gauge oscillating + - 3 psi
12:02	42	2	650.1	8.1	81	300.1	
12:03	43	3	658.2	8.1	80	308.2	
12:04	44	4	666	7.8	80	316	
12:05	45	5	674	8	80	324	
12:06	46	6	682.2	8.2	80	332.2	
12:07	47	7	690.3	8.1	81	340.3	
12:08	48	8	698.2	7.9	82	348.2	
12:09	49	9	706.1	7.9	80	356.1	
12:10	50	10	714.2	8.1	81	364.2	8.02 average gpm

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
12:11	51	1	722.4	8.2	90	372.4	Gauge oscillating + - 4 psi
12:12	52	2	730.5	8.1	92	380.5	
12:13	53	3	738.5	8	94	388.5	
12:14	54	4	746.8	8.3	95	396.8	
12:15	55	5	755	8.2	92	405	
12:16	56	6	763.1	8.1	92	413.1	
12:17	57	7	771.3	8.2	91	421.3	
12:18	58	8	779.3	8	92	429.3	
12:19	59	9	787.5	8.2	93	437.5	
12:20	60	10	795.8	8.3	91	445.8	8.16 average gpm
12:21	61	1	803.7	7.9	100	453.7	Gauge oscillating + - 5 psi
12:22	62	2	811.4	7.7	101	461.4	
12:23	63	3	819.2	7.8	102	469.2	
12:24	64	4	827	7.8	101	477	
12:25	65	5	834.9	7.9	103	484.9	
12:26	66	6	842.8	7.9	104	492.8	
12:27	67	7	850.9	8.1	102	500.9	
12:28	68	8	858.6	7.7	104	508.6	
12:29	69	9	866.5	7.9	102	516.5	
12:30	70	10	874.3	7.8	101	524.3	7.85 average gpm
12:31	71	1	881.9	7.6	110	531.9	Gauge oscillating + - 5 psi
12:32	72	2	889.3	7.4	112	539.3	
12:33	73	3	896.9	7.6	114	546.9	
12:34	74	4	904.7	7.8	112	554.7	
12:35	75	5	912.3	7.6	115	562.3	
12:36	76	6	919.9	7.6	112	569.9	
12:37	77	7	927.6	7.7	112	577.6	
12:38	78	8	935	7.4	112	585	
12:39	79	9	942.7	7.7	113	592.7	
12:40	80	10	950.4	7.7	114	600.4	7.61 average gpm
12:41	81	1	958.3	7.9	115	608.3	Gauge oscillating + - 5 psi
12:42	82	2	966	7.7	116	616	
12:43	83	3	973.9	7.9	115	623.9	
12:44	84	4	981.8	7.9	116	631.8	
12:45	85	5	989.6	7.8	117	639.6	
12:46	86	6	997.7	8.1	115	647.7	
12:47	87	7	1005.4	7.7	115	655.4	
12:48	88	8	1013.1	7.7	117	663.1	
12:49	89	9	1021	7.9	115	671	
12:50	90	10	1028.9	7.9	116	678.9	7.85 average gpm
12:51	91	1	1035.6	6.7	101	685.6	Gauge oscillating + - 5 psi
12:52	92	2	1042.4	6.8	100	692.4	
12:53	93	3	1049	6.6	102	699	
12:54	94	4	1055.8	6.8	101	705.8	
12:55	95	5	1062.6	6.8	100	712.6	
12:56	96	6	1069.4	6.8	102	719.4	
12:57	97	7	1076.2	6.8	100	726.2	
12:58	98	8	1083	6.8	101	733	
12:59	99	9	1089.7	6.7	102	739.7	
13:00	100	10	1096.3	6.6	100	746.3	6.74 average gpm
13:01	101	1	1102.9	6.6	90	752.9	Gauge oscillating + - 4 psi
13:02	102	2	1109.5	6.6	89	759.5	
13:03	103	3	1116	6.5	90	766	
13:04	104	4	1122.6	6.6	89	772.6	
13:05	105	5	1129	6.4	90	779	
13:06	106	6	1135.5	6.5	91	785.5	
13:07	107	7	1142	6.5	90	792	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
13:08	108	8	1148.6	6.6	92	798.6	
13:09	109	9	1155.2	6.6	91	805.2	
13:10	110	10	1161.9	6.7	91	811.9	6.56 average gpm
13:11	111	1	1169	7.1	80	819	Gauge oscillating + - 4 psi
13:12	112	2	1176.2	7.2	79	826.2	
13:13	113	3	1183.4	7.2	80	833.4	
13:14	114	4	1190.5	7.1	81	840.5	
13:15	115	5	1197.8	7.3	81	847.8	
13:16	116	6	1205	7.2	80	855	
13:17	117	7	1212.3	7.3	78	862.3	
13:18	118	8	1219.6	7.3	80	869.6	
13:19	119	9	1226.7	7.1	79	876.7	
13:20	120	10	1233.9	7.2	81	883.9	7.2 average gpm
13:21	121	1	1240.9	7	68	890.9	Gauge oscillating + - 3 psi
13:22	122	2	1247.8	6.9	69	897.8	
13:23	123	3	1254.6	6.8	70	904.6	
13:24	124	4	1261.3	6.7	71	911.3	
13:25	125	5	1268	6.7	70	918	
13:26	126	6	1274.9	6.9	71	924.9	
13:27	127	7	1281.9	7	70	931.9	
13:28	128	8	1288.7	6.8	70	938.7	
13:29	129	9	1295.5	6.8	71	945.5	
13:30	130	10	1302.2	6.7	72	952.2	6.86 average gpm
13:31	131	1	1308.9	6.7	60	958.9	Gauge oscillating + - 3 psi
13:32	132	2	1315.5	6.6	60	965.5	
13:33	133	3	1322	6.5	59	972	
13:34	134	4	1328.5	6.5	60	978.5	
13:35	135	5	1335.1	6.6	60	985.1	
13:36	136	6	1341.6	6.5	60	991.6	
13:37	137	7	1348	6.4	59	998	
13:38	138	8	1354.7	6.7	61	1004.7	
13:39	139	9	1361.2	6.5	60	1011.2	
13:40	140	10	1367.8	6.6	60	1017.8	6.56 average gpm
13:41	141	1	1374.2	6.4	50	1024.2	
13:42	142	2	1380.9	6.7	50	1030.9	
13:43	143	3	1387	6.1	50	1037	
13:44	144	4	1393.2	6.2	50	1043.2	
13:45	145	5	1399.6	6.4	51	1049.6	
13:46	146	6	1406	6.4	50	1056	
13:47	147	7	1412	6	50	1062	
13:48	148	8	1418.5	6.5	51	1068.5	
13:49	149	9	1424.9	6.4	52	1074.9	
13:50	150	10	1431.4	6.5	51	1081.4	6.36 average gpm
13:51	151	1	1438	6.6	40	1088	
13:52	152	2	1444.5	6.5	40	1094.5	
13:53	153	3	1451	6.5	40	1101	
13:54	154	4	1457.7	6.7	39	1107.7	
13:55	155	5	1464.2	6.5	40	1114.2	
13:56	156	6	1470.8	6.6	40	1120.8	
13:57	157	7	1477.3	6.5	41	1127.3	
13:58	158	8	1483.9	6.6	41	1133.9	
13:59	159	9	1490.4	6.5	40	1140.4	
14:00	160	10	1497	6.6	40	1147	6.56 average gpm

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	**7/30/2011**
Client	**New Mexico Copper Corp**
Project	**Copper Flat**
Well Name	**GWQ 11-24 Zone 2**
Hydrologist	**JJK**

Starting Water Level (ft bgl)	**53.5**	**Packer Dia**	**2 inch**
Elevation (ft GL)		**Bore/Casing Dia**	**3-3/4 inch**
Injection Interval (ft bgl)	**150 to 197**	**Injection Pipe Dia**	**1 inch**
Bore/Casing Depth (ft bgl)	**197**	**Pressure gauge height above GL**	**1 ft**

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
11:00	0		70				New meter
11:01	1	1	76.2	6.2	20	6.2	
11:02	2	2	82.3	6.1	20	12.3	
11:03	3	3	88.5	6.2	20	18.5	
11:04	4	4	94.7	6.2	20	24.7	
11:05	5	5	100.8	6.1	20	30.8	
11:06	6	6	107.2	6.4	20	37.2	
11:07	7	7	113.4	6.2	20	43.4	
11:08	8	8	119.6	6.2	20	49.6	
11:09	9	9	126	6.4	20	56	
11:10	10	10	132.5	6.5	20	62.5	6.25 gpm average for 20 psi
11:11	11	1	139	6.5	30	69	Up to approximately 30 psi
11:12	12	2	145.5	6.5	30	75.5	
11:13	13	3	152.1	6.6	30	82.1	
11:14	14	4	158.4	6.3	30	88.4	
11:15	15	5	164.9	6.5	30	94.9	
11:16	16	6	171.2	6.3	30	101.2	
11:17	17	7	177.7	6.5	30	107.7	
11:18	18	8	184	6.3	30	114	
11:19	19	9	190.5	6.5	32	120.5	
11:20	20	10	197.3	6.8	30	127.3	6.48 gpm average for 30 psi
11:21	21	1	204	6.70	40	134	Up to approximately 40 psi
11:22	22	2	210.6	6.60	40	140.6	
11:23	23	3	217.3	6.70	41	147.3	
11:24	24	4	224	6.70	40	154	
11:25	25	5	230.4	6.40	40	160.4	
11:26	26	6	237.1	6.70	41	167.1	
11:27	27	7	243.9	6.80	42	173.9	
11:28	28	8	250.6	6.70	41	180.6	
11:29	29	9	257.4	6.80	40	187.4	
11:30	30	10	264.3	6.90	40	194.3	6.70 gpm average for 40 psi
11:31	31	1	271.2	6.9	55	201.2	Up to approximately 55 psi
11:32	32	2	278.1	6.9	55	208.1	
11:33	33	3	285.0	6.9	55	215	
11:34	34	4	291.8	6.8	55	221.8	
11:35	35	5	298.5	6.7	56	228.5	
11:36	36	6	305.4	6.9	55	235.4	
11:37	37	7	312.4	7	56	242.4	
11:38	38	8	319.3	6.9	59	249.3	
11:39	39	9	326	6.7	59	256	
11:40	40	10	332.9	6.9	58	262.9	6.86 gpm average for 55 psi
11:41	41	1	340.4	7.5	70	270.4	Up to approximately 75 psi
11:42	42	2	348.5	8.1	75	278.5	
11:43	43	3	356.7	8.2	76	286.7	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
11:44	44	4	364.6	7.9	76	294.6	
11:45	45	5	372.8	8.2	76	302.8	
11:46	46	6	380.7	7.9	76	310.7	
11:47	47	7	388.9	8.2	76	318.9	
11:48	48	8	397	8.1	77	327	
11:49	49	9	405	8	77	335	
11:50	50	10	413.2	8.2	77	343.2	8.03 gpm average for 75 psi
11:51	51	1	421.5	8.3	90	351.5	Up to approximately 95 psi
11:52	52	2	429.8	8.3	90	359.8	
11:53	53	3	438	8.2	91	368	
11:54	54	4	446.1	8.1	93	376.1	
11:55	55	5	454.3	8.2	94	384.3	
11:56	56	6	462.6	8.3	95	392.6	
11:57	57	7	470.6	8	95	400.6	
11:58	58	8	478.8	8.2	96	408.8	
11:59	59	9	486.9	8.1	95	416.9	
12:00	60	10	495.2	8.3	94	425.2	8.2 gpm average for 95 psi
12:01	61	1	503.4	8.2	115	433.4	Up to approximately 120 psi
12:02	62	2	511.7	8.3	118	441.7	
12:03	63	3	520	8.3	120	450	
12:04	64	4	528.3	8.3	120	458.3	
12:05	65	5	536.7	8.4	120	466.7	
12:06	66	6	545	8.3	120	475	
12:07	67	7	553.2	8.2	120	483.2	
12:08	68	8	561.5	8.3	120	491.5	
12:09	69	9	569.5	8	120	499.5	
12:10	70	10	577.6	8.1	120	507.6	8.24 gpm average for 120 psi
12:11	71	1	585.8	8.2	120 to 123	515.8	Valve fully open.
12:12	72	2	594	8.2	120 to 123	524	
12:13	73	3	602.2	8.2	120 to 124	532.2	
12:14	74	4	610.4	8.2	120 to 122	540.4	
12:15	75	5	618.7	8.3	119 to 121	548.7	
12:16	76	6	626.8	8.1	119	556.8	
12:17	77	7	635	8.2	118	565	
12:18	78	8	643.2	8.2	118	573.2	
12:19	79	9	651.5	8.3	119	581.5	
12:20	80	10	659.6	8.1	120	589.6	8.2 gpm average for 120 psi
12:21	81	1	666.3	6.7	105	596.3	Down to approximately 100 psi
12:22	82	2	673.1	6.8	100 to 105	603.1	
12:23	83	3	679.8	6.7	100 to 105	609.8	
12:24	84	4	686.4	6.6	100 to 105	616.4	
12:25	85	5	693.2	6.8	100 to 105	623.2	
12:26	86	6	700	6.8	100 to 105	630	
12:27	87	7	706.7	6.7	100 to 105	636.7	
12:28	88	8	713.5	6.8	100 to 105	643.5	
12:29	89	9	720.1	6.6	100 to 105	650.1	
12:30	90	10	726.8	6.7	100 to 105	656.8	6.72 gpm average for 100 psi
12:31	91	1	734	7.2	80	664	Down to approximately 80 psi
12:32	92	2	741.2	7.2	80	671.2	
12:33	93	3	748.3	7.1	75 to 80	678.3	
12:34	94	4	755.6	7.3	75 to 80	685.6	
12:35	95	5	762.9	7.3	75 to 80	692.9	
12:36	96	6	770.1	7.2	75 to 80	700.1	
12:37	97	7	777.4	7.3	75 to 80	707.4	
12:38	98	8	784.6	7.2	75 to 80	714.6	
12:39	99	9	791.7	7.1	75 to 80	721.7	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
12:40	100	10	798.9	7.2	75 to 80	728.9	7.21 gpm average for 80 psi
12:41	101	1	805.5	6.6	60	735.5	Down to approximately 60 psi
12:42	102	2	812.1	6.6	55 to 60	742.1	
12:43	103	3	818.9	6.8	55 to 60	748.9	
12:44	104	4	825.3	6.4	55 to 60	755.3	
12:45	105	5	831.9	6.6	55 to 60	761.9	
12:46	106	6	838.4	6.5	55 to 60	768.4	
12:47	107	7	845	6.6	55 to 60	775	
12:48	108	8	851.5	6.5	55 to 60	781.5	
12:49	109	9	858.2	6.7	55 to 60	788.2	
12:50	110	10	864.6	6.4	55 to 60	794.6	6.57 gpm average for 60 psi
12:51	111	1	871	6.4	40	801	Down to approximately 40 psi
12:52	112	2	877.3	6.3	40	807.3	
12:53	113	3	883.6	6.3	40	813.6	
12:54	114	4	890	6.4	40	820	
12:55	115	5	896.3	6.3	40	826.3	
12:56	116	6	902.3	6	40	832.3	
12:57	117	7	908.5	6.2	40	838.5	
12:58	118	8	914.8	6.3	40	844.8	
12:59	119	9	921.1	6.3	40	851.1	
13:00	120	10	927.5	6.4	40	857.5	6.29 gpm average for 40 psi
13:01	121	1	933.92	6.42	30	863.92	Down to approximately 30 psi
13:02	122	2	940.4	6.48	30	870.4	
13:03	123	3	946.8	6.4	30	876.8	
13:04	124	4	953.2	6.4	31	883.2	
13:05	125	5	959.6	6.4	30	889.6	
13:06	126	6	966	6.4	30	896	
13:07	127	7	972.5	6.5	31	902.5	
13:08	128	8	979	6.5	30	909	
13:09	129	9	985.4	6.4	30	915.4	
13:10	130	10	991.9	6.5	30	921.9	6.44 gpm average for 30 psi
13:11	131	1	998.3	6.4	20	928.3	Down to approximately 20 psi
13:12	132	2	1004.6	6.3	20	934.6	
13:13	133	3	1010.9	6.3	20	940.9	
13:14	134	4	1017.3	6.4	21	947.3	
13:15	135	5	1023.5	6.2	22	953.5	
13:16	136	6	1029.8	6.3	20	959.8	
13:17	137	7	1036.1	6.3	20	966.1	
13:18	138	8	1042.3	6.2	20	972.3	
13:19	139	9	1048.5	6.2	20	978.5	
13:20	140	10	1054.8	6.3	20	984.8	6.29 gpm average for 20 psi

Repeated steps summarized

psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
3.00	20.0	6.82	90.0					Set pressure. Wait 1 minute
3.49	30.0	6.80	80.0					average over 2 minutes. Repeat
3.90	40.0	6.20	70.0					
4.59	50.0	5.59	60.0					
5.10	60.0	5.19	50.0					
5.80	70.0	4.68	40.0					
6.30	80.0	4.30	30.0					
6.80	90.0	3.70	20.0					
7.98	100.0							

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	**8/1/2011**
Client	**New Mexico Copper Corp**
Project	**Copper Flat**
Well Name	**GWQ 11-24 Zone 3**
Hydrologist	**JJK**

Starting Water Level (ft bgl)	**51.42**	**Packer Dia**	**2 inch**
Elevation (ft GL)		**Bore/Casing Dia**	**3-3/4 inch**
Injection Interval (ft bgl)	**204 to 251**	**Injection Pipe Dia**	**1 inch**
Bore/Casing Depth (ft bgl)	**251**	**Pressure gauge height above GL**	**1 ft**

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
11:50	0		2910		20	0	
11:51	1	1	2911	1.00	20	1	
11:52	2	2	2912.1	1.10	20	2.1	
11:53	3	3	2913	0.90	20	3	
11:54	4	4	2913.3	0.30	20	3.3	
11:55	5	5	2913.5	0.20	20	3.5	
11:56	6	6	2913.8	0.30	20	3.8	
11:57	7	7	2914.1	0.30	20	4.1	
11:58	8	8	2914.4	0.30	20	4.4	
11:59	9	9	2914.7	0.30	21	4.7	
12:00	10	10	2914.9	0.20	20	4.9	0.49 gpm average for 20 psi
12:01	11	1	2915.4	0.5	30	5.4	Up to approximately 30 psi
12:02	12	2	2915.9	0.5	31	5.9	
12:03	13	3	2916.4	0.5	30	6.4	
12:04	14	4	2917.1	0.7	31	7.1	
12:05	15	5	2917.6	0.5	31	7.6	
12:06	16	6	2918.1	0.5	31	8.1	
12:07	17	7	2918.7	0.6	31	8.7	
12:08	18	8	2919.2	0.5	30	9.2	
12:09	19	9	2919.6	0.4	31	9.6	
12:10	20	10	2920.1	0.5	30	10.1	0.52 gpm average for 30 psi
12:11	21	1	2920.8	0.7	38	10.8	Up to approximately 40 psi
12:12	22	2	2921.4	0.6	40	11.4	
12:13	23	3	2921.9	0.5	40	11.9	
12:14	24	4	2922.3	0.4	40	12.3	
12:15	25	5	2922.8	0.5	39	12.8	
12:16	26	6	2923.3	0.5	41	13.3	
12:17	27	7	2923.8	0.5	40	13.8	
12:18	28	8	2924.4	0.6	43	14.4	
12:19	29	9	2924.9	0.5	41	14.9	
12:20	30	10	2925.5	0.6	42	15.5	0.54 gpm average for 40 psi
12:21	31	1	2926.3	0.8	50	16.3	Up to approximately 50 psi
12:22	32	2	2927.2	0.9	51	17.2	
12:23	33	3	2928	0.8	52	18	
12:24	34	4	2928.6	0.6	50	18.6	
12:25	35	5	2929.2	0.6	50	19.2	
12:26	36	6	2929.8	0.6	50	19.8	
12:27	37	7	2930.4	0.6	50	20.4	
12:28	38	8	2931	0.6	50	21	
12:29	39	9	2931.5	0.5	51	21.5	
12:30	40	10	2932.1	0.6	50	22.1	0.66 gpm average for 50 psi
12:31	41	1	2932.6	0.5	59	22.6	
12:32	42	2	2933.4	0.8	60	23.4	
12:33	43	3	2934	0.6	60	24	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
12:34	44	4	2934.8	0.8	60 to 25	24.8	psi drops to 25
12:35	45	5	2935.5	0.7	25 to 60	25.5	adjust valves to maintain 60 psi
12:36	46	6	2940	4.5	60	30	
12:37	47	7	2943.5	3.5	50 to 60	33.5	adjust valves to maintain 60 psi
12:38	48	8	2947.2	3.7	50 to 60	37.2	adjust valves to maintain 60 psi
12:39	49	9	2952	4.8	60	42	
12:40	50	10	2956.5	4.5	59	46.5	2.44 gpm average for 60 psi
12:41	51	1	2961.5	5	70	51.5	
12:42	52	2	2968.8	7.3	71	58.8	
12:43	53	3	2971	2.2	72	61	
12:44	54	4	2973.9	2.9	70 to 60	63.9	psi drops to 60
12:45	55	5	2981.5	7.6	60 to 70	71.5	adjust valves to maintain 70 psi
12:46	56	6	2987	5.5	70	77	
12:47	57	7	2992.5	5.5	72	82.5	
12:48	58	8	2998	5.5	72	88	
12:49	59	9	3003.5	5.5	70	93.5	
12:50	60	10	3008.7	5.2	71	98.7	5.22 gpm average for 70 psi
12:51	61	1	3015	6.3	81	105	
12:52	62	2	3020.5	5.5	82	110.5	
12:53	63	3	3026	5.5	82	116	
12:54	64	4	3032	6	81	122	
12:55	65	5	3037.5	5.5	82	127.5	
12:56	66	6	3042.9	5.4	82	132.9	
12:57	67	7	3048.8	5.9	80	138.8	
12:58	68	8	3054	5.2	79	144	
12:59	69	9	3059.5	5.5	79	149.5	
13:00	70	10	3065	5.5	79	155	5.63 gpm average for 80 psi
13:01	71	1	3071	6	92	161	Gauge is oscillating + or - 3 psi
13:02	72	2	3077.5	6.5	90	167.5	
13:03	73	3	3083.6	6.1	92	173.6	
13:04	74	4	3090	6.4	92	180	
13:05	75	5	3095.9	5.9	92	185.9	
13:06	76	6	3102	6.1	90	192	
13:07	77	7	3108.7	6.7	90	198.7	
13:08	78	8	3113.8	5.1	90	203.8	
13:09	79	9	3119.9	6.1	90	209.9	
13:10	80	10	3125.6	5.7	91	215.6	6.06 gpm average for 90 psi
13:11	81	1	3132	6.4	100	222	Gauge is oscillating + or - 5 psi
13:12	82	2	3138.5	6.5	100	228.5	
13:13	83	3	3145	6.5	100	235	
13:14	84	4	3151.4	6.4	100	241.4	
13:15	85	5	3157.5	6.1	100	247.5	
13:16	86	6	3163.7	6.2	100	253.7	
13:17	87	7	3170.3	6.6	100	260.3	
13:18	88	8	3176.3	6	100	266.3	
13:19	89	9	3182.8	6.5	100	272.8	
13:20	90	10	3189.2	6.4	100	279.2	6.36 gpm average for 100 psi
13:21	91	1	3195	5.8	91	285	Gauge is oscillating + or - 3 psi
13:22	92	2	3201	6	90	291	
13:23	93	3	3206.6	5.6	90	296.6	
13:24	94	4	3212.5	5.9	91	302.5	
13:25	95	5	3218.5	6	89	308.5	
13:26	96	6	3224	5.5	90	314	
13:27	97	7	3229.8	5.8	91	319.8	
13:28	98	8	3235.5	5.7	91	325.5	
13:29	99	9	3241.4	5.9	91	331.4	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
13:30	100	10	3247.5	6.1	90	337.5	5.83 gpm average for 90 psi
13:31	101	1	3252.5	5	80	342.5	psi down to 80
13:32	102	2	3257.8	5.3	80	347.8	
13:33	103	3	3263	5.2	80	353	
13:34	104	4	3268.5	5.5	81	358.5	
13:35	105	5	3273.8	5.3	80	363.8	
13:36	106	6	3279.4	5.6	80	369.4	
13:37	107	7	3284.5	5.1	79	374.5	
13:38	108	8	3290	5.5	79	380	
13:39	109	9	3295.1	5.1	80	385.1	
13:40	110	10	3301	5.9	79	391	5.35 gpm average for 80 psi
13:41	111	1	3305.5	4.5	70	395.5	psi down to 70
13:42	112	2	3310.9	5.4	70	400.9	
13:43	113	3	3315.7	4.8	71	405.7	
13:44	114	4	3321	5.3	70	411	
13:45	115	5	3325.7	4.7	69	415.7	
13:46	116	6	3331	5.3	69	421	
13:47	117	7	3335.7	4.7	70	425.7	
13:48	118	8	3340.9	5.2	70	430.9	
13:49	119	9	3345.7	4.8	70	435.7	
13:50	120	10	3351	5.3	70	441	5.0 gpm average for 70 psi
13:51	121	1	3355.5	4.5	60	445.5	psi down to 60
13:52	122	2	3360.2	4.7	58	450.2	
13:53	123	3	3364.9	4.7	60	454.9	
13:54	124	4	3369.7	4.8	60	459.7	
13:55	125	5	3374.4	4.7	60	464.4	
13:56	126	6	3379.2	4.8	60	469.2	
13:57	127	7	3383.9	4.7	61	473.9	
13:58	128	8	3389	5.1	60	479	
13:59	129	9	3393.5	4.5	60	483.5	
14:00	130	10	3398.2	4.7	60	488.2	4.72 gpm average for 60 psi
14:01	131	1	3402.6	4.4	51 to 52	492.6	psi to 50
14:02	132	2	3407.5	4.9	52 to 50	497.5	
14:03	133	3	missed		52 to 50		
14:04	134	4	3416	4.25	50	506	
14:05	135	5	3420.7	4.7	50	510.7	
14:06	136	6	3425	4.3	50	515	
14:07	137	7	3429.4	4.4	48 to 50	519.4	
14:08	138	8	3433.7	4.3	51	523.7	
14:09	139	9	3438.2	4.5	50	528.2	
14:10	140	10	3442.5	4.3	50	532.5	4.43 gpm average for 50 psi
14:11	141	1	3447	4.5	40	537	psi to 40
14:12	142	2	3451.1	4.1	40	541.1	
14:13	143	3	3454.8	3.7	40	544.8	
14:14	144	4	3459	4.2	40	549	
14:15	145	5	3463	4	40	553	
14:16	146	6	3467.1	4.1	40	557.1	
14:17	147	7	3471.3	4.2	41	561.3	
14:18	148	8	3475.4	4.1	39	565.4	
14:19	149	9	3479.7	4.3	38	569.7	
14:20	150	10	3484	4.3	40	574	4.15 gpm average for 40 psi
14:21	151	1	3487.4	3.4	34	577.4	psi to 30
14:22	152	2	3491.2	3.8	30	581.2	
14:23	153	3	3494.8	3.6	30	584.8	
14:24	154	4	3498.7	3.9	29	588.7	
14:25	155	5	3502.3	3.6	30	592.3	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
14:26	156	6	3506	3.7	30	596	
14:27	157	7	3509.8	3.8	29	599.8	
14:28	158	8	3513.3	3.5	31	603.3	
14:29	159	9	3517	3.7	31	607	
14:30	160	10	3521	4	32	611	3.7 gpm average for 30 psi
14:31	161	1	3524.2	3.2	20	614.2	psi to 20
14:32	162	2	3527.6	3.4	20	617.6	
14:33	163	3	3531.1	3.5	21	621.1	
14:34	164	4	3534.3	3.2	21	624.3	
14:35	165	5	3538	3.7	20	628	
14:36	166	6	3541.4	3.4	20	631.4	
14:37	167	7	3544.6	3.2	20	634.6	
14:38	168	8	3548	3.4	20	638	
14:39	169	9	3551.4	3.4	20	641.4	
14:40	170	10	3554.5	3.1	21	644.5	3.35 gpm average for 20 psi

Repeated steps summarized

psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
3.14	20.0	3.14	20.0	3.80	30.0	5.78	90.0	Set pressure. Wait 1 minute
3.71	30.0	3.71	30.0	3.95	40.0	5.63	80.0	average over 2 minutes. Repeat
3.98	40.0	3.98	40.0	4.61	50.0	5.50	70.0	
4.46	50.0	4.46	50.0	4.99	60.0	4.99	60.0	
4.90	60.0	4.90	60.0	5.46	70.0	4.51	50.0	
5.31	70.0	5.31	70.0	5.62	80.0	4.15	40.0	
5.49	80.0	5.49	80.0	5.80	90.0	3.80	30.0	
5.94	90.0	5.94	90.0	6.31	100.0	3.33	20.0	
6.20	100.0	6.20	100.0					

same data as "increase" series

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	**8/13/2011**
Client	**New Mexico Copper Corp**
Project	**Copper Flat**
Well Name	**GWQ 11-25 Zone 1**
Hydrologist	**JJK**

Starting Water Level (ft bgl)	**29.0 (not representative of Static)**
Elevation (ft GL)	
Injection Interval (ft bgl)	**100 to 147.7**
Bore/Casing Depth (ft bgl)	**147.7**

Packer Dia	**2 inch**
Bore/Casing Dia	**3-3/4 inch**
Injection Pipe Dia	**1 inch**
Pressure gauge height above GL	**3 ft**

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
15:00	0		4400		10	0	
15:01	1	1	4400	0.00	10	0	
15:02	2	2	4400	0.00	10	0	
15:03	3	3	4400	0.00	10	0	
15:04	4	4	4400	0.00	10	0	
15:05	5	5	4400	0.00	10	0	
15:06	6	6	4400	0.00	10	0	
15:07	7	7	4400	0.00	10	0	
15:08	8	8	4400	0.00	10	0	
15:09	9	9	4400	0.00	10	0	
15:10	10	10	4400	0.00	10	0	
15:11	11	1	4400	0.00	20	0	
15:12	12	2	4400	0.00	20	0	
15:13	13	3	4400	0.00	20	0	
15:14	14	4	4400	0.00	20	0	
15:15	15	5	4400	0.00	20	0	
15:16	16	6	4400	0.00	20	0	
15:17	17	7	4400	0.00	20	0	
15:18	18			0.00		0	Break out meter to verify operation of same
15:19	19			0.00		0	
15:20	20			0.00		0	Operating to spec
15:21	21	1	4410	0.00	30	0	
15:22	22	2	4410	0.00	30	0	
15:23	23	3	4410	0.00	30	0	
15:24	24	4	4410	0.00	30	0	
15:25	25	5	4410	0.00	30	0	
15:26	26	1	4410	0.00	40	0	
15:27	27	2	4410	0.00	40	0	
15:28	28	3	4410	0.00	40	0	
15:29	29	4	4410	0.00	40	0	
15:30	30	5	4410	0.00	40	0	
15:31	31	1	4410	0	50	0	
15:32	32	2	4410	0	50	0	
15:33	33	3	4410	0	50	0	
15:34	34	4	4410	0	50	0	
15:35	35	5	4410	0	50	0	
15:36	36	1	4410	0	60	0	
15:37	37	2	4410	0	60	0	
15:38	38	3	4410	0	60	0	
15:39	39	4	4410	0	60	0	
15:40	40	5	4410	0	60	0	
15:41	41	1	4410	0	70	0	
15:42	42	2	4410	0	70	0	
15:43	43	3	4410	0	70	0	
15:44	44	4	4410	0	70	0	
15:45	45	5	4410	0	70	0	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
15:46	46	1	4410	0	80	0	
15:47	47	2	4410	0	80	0	
15:48	48	3	4410	0	80	0	
15:49	49	4	4410	0	80	0	
15:50	50	5	4410	0	80	0	
15:51	51	1	4410	0	90	0	
15:52	52	2	4410	0	90	0	
15:53	53	3	4410	0	90	0	
15:54	54	4	4410	0	90	0	
15:55	55	5	4410	0	90	0	
15:56	56	1	4410	0	100	0	
15:57	57	2	4410	0	100	0	
15:58	58	3	4410	0	100	0	
15:59	59	4	4410	0	100	0	
16:00	60	5	4410	0	100	0	
16:01	61	1	4410	0	110	0	
16:02	62	2	4410	0	110	0	
16:03	63	3	4410	0	110	0	
16:04	64	4	4410	0	110	0	
16:05	65	5	4410	0	110	0	
16:06	66	6	4410	0.00	110	0	
16:07	67	7	4410	0.00	110	0	
16:08	68	8	4410	0.00	110	0	
16:09	69	9	4410	0.00	110	0	
16:10	70	10	4410	0.00	110	0	
16:11	71	1	4410	0	120	0	
16:12	72	2	4410	0	120	0	
16:13	73	3	4410	0	120	0	
16:14	74	4	4410	0	120	0	
16:15	75	5	4410	0	120	0	
16:16	76	6	4410	0	120	0	
16:17	77	7	4410	0	120	0	
16:18	78	8	4410	0	120	0	
16:19	79	9	4410	0	120	0	
16:20	80	10	4410	0	120	0	
16:21	81	1	4410	0	130	0	
16:22	82	2	4410	0	130	0	
16:23	83	3	4410	0	130	0	
16:24	84	4	4410	0	130	0	
16:25	85	5	4410	0	130	0	
16:26	86	6	4410	0	130	0	
16:27	87	7	4410	0	130	0	
16:28	88	8	4410	0	130	0	
16:29	89	9	4410	0	130	0	
16:30	90	10	4410	0	130	0	
16:31	91	1	4410	0	140	0	
16:32	92	2	4410	0	140	0	
16:33	93	3	4410	0	140	0	
16:34	94	4	4410	0	140	0	
16:35	95	5	4410	0	140	0	
16:36	96	6	4410	0	140	0	
16:37	97	7	4410	0	140	0	
16:38	98	8	4410	0	140	0	
16:39	99	9	4410	0	140	0	
16:40	100	10	4410	0	140	0	Lightning on site forces suspension of test
Resume test on 8-14-2011							
6:00	101	1	4420	0	0	0	Slow repeat of previous ramp up
6:01	102	2	4420	0	40	0	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
6:02	103	3	4420	0	40	0	
6:03	104	4	4420	0	40	0	
6:04	105	5	4420	0	40	0	
6:05	106	1	4420	0	50	0	
6:06	107	2	4420	0	50	0	
6:07	108	3	4420	0	50	0	
6:08	109	4	4420	0	50	0	
6:09	110	5	4420	0	50	0	
6:10	111	1	4420	0	60	0	
6:11	112	2	4420	0	60	0	
6:12	113	3	4420	0	60	0	
6:13	114	4	4420	0	60	0	
6:14	115	5	4420	0	60	0	
6:15	116	1	4420	0	70	0	
6:16	117	2	4420	0	70	0	
6:17	118	3	4420	0	70	0	
6:18	119	4	4420	0	70	0	
6:19	120	5	4420	0	70	0	
6:20	121	1	4420	0	80	0	
6:21	122	2	4420	0	80	0	
6:22	123	3	4420	0	80	0	
6:23	124	4	4420	0	80	0	
6:24	125	5	4420	0	80	0	
6:25	126	1	4420	0	90	0	
6:26	127	2	4420	0	90	0	
6:27	128	3	4420	0	90	0	
6:28	129	4	4420	0	90	0	
6:29	130	5	4420	0	90	0	
6:30	131	1	4420	0	100	0	
6:31	132	2	4420	0	100	0	
6:32	133	3	4420	0	100	0	
6:33	134	4	4420	0	100	0	
6:34	135	5	4420	0	100	0	
6:35	136	1	4420	0	110	0	
6:36	137	2	4420	0	110	0	
6:37	138	3	4420	0	110	0	
6:38	139	4	4420	0	110	0	
6:39	140	5	4420	0	110	0	
6:40	141	1	4420	0	120	0	
6:41	142	2	4420	0	120	0	
6:42	143	3	4420	0	120	0	
6:43	144	4	4420	0	120	0	
6:44	145	5	4420	0	120	0	
6:45	146	1	4420	0	130	0	
6:46	147	2	4420	0	130	0	
6:47	148	3	4420	0	130	0	
6:48	149	4	4420	0	130	0	
6:49	150	5	4420	0	130	0	
6:50	151	1	4420	0	140	0	
6:51	152	2	4420	0	140	0	
6:52	153	3	4420	0	140	0	
6:53	154	4	4420	0	140	0	
6:54	155	5	4420	0	140	0	
6:55	156	1	4420	0	150	0	
6:56	157	2	4420	0	150	0	
6:57	158	3	4420	0	146	0	First injection
6:58	159	4	4422.9	2.9	150	2.9	All 150 psi readings are approximate.
6:59	160	5	4425.9	3	150	5.9	Gauge oscillating from 140 to 158

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
7:00	161	6	4428.7	2.8	150	8.7	
7:01	162	7	4431.5	2.8	150	11.5	
7:02	163	8	4434.5	3	150	14.5	
7:03	164	9	4437.4	2.9	150	17.4	
7:04	165	10	4440.3	2.9	150	20.3	
7:05	166	11	4443.1	2.8	150	23.1	
7:06	167	12	4444	0.9	150	24	
7:07	168	13	4447.2	3.2	150	27.2	
7:08	169	14	4450.1	2.9	150	30.1	
7:09	170	15	4452.8	2.7	150	32.8	2.73 average for 150 psi
7:10	171	0	4457.1	4.3	130	37.1	Attempt to stabilize at 140 psi. abandon
7:11	172	1	4459.3	2.2	130	39.3	All 130 psi readings are approximate.
7:12	173	2	4461.2	1.9	130	41.2	Gauge oscillating from 125 to 137
7:13	174	3	4464.1	2.9	130	44.1	
7:14	175	4	4466.3	2.2	130	46.3	
7:15	176	5	4468.1	1.8	130	48.1	
7:16	177	6	4470.9	2.8	130	50.9	
7:17	178	7	4473.2	2.3	130	53.2	
7:18	179	8	4475.2	2	130	55.2	
7:19	180	9	4477.1	1.9	130	57.1	
7:20	181	10	4478.9	1.8	130	58.9	2.18 average for 130 psi
7:21	182	1	4480.9	2	100	60.9	
7:22	183	2	4482.7	1.8	100	62.7	
7:23	184	3	4484.6	1.9	100	64.6	
7:24	185	4	4486.4	1.8	100	66.4	
7:25	186	5	4488.2	1.8	100	68.2	
7:26	187	6	4490.1	1.9	100	70.1	
7:27	188	7	4491.9	1.8	100	71.9	
7:28	189	8	4493.9	2	100	73.9	
7:29	190	9	4495.7	1.8	100	75.7	
7:30	191	10	4497.6	1.9	100	77.6	1.87 average for 100 psi
7:31	192	1	4499.5	1.9	90	79.5	
7:32	193	2	4500.7	1.2	90	80.7	
7:33	194	3	4502.7	2	90	82.7	
7:34	195	4	4504.7	2	90	84.7	
7:35	196	5	4506.5	1.8	90	86.5	
7:36	197	6	4508.2	1.7	90	88.2	
7:37	198	7	4510	1.8	90	90	
7:38	199	8	4511.6	1.6	90	91.6	
7:39	200	9	4513.5	1.9	90	93.5	
7:40	201	10	4515.2	1.7	90	95.2	1.76 average for 90 psi
7:41	202	1	4516.6	1.4	80	96.6	
7:42	203	2	4518.2	1.6	80	98.2	
7:43	204	3	4519.9	1.7	80	99.9	
7:44	205	4	4521.3	1.4	80	101.3	
7:45	206	5	4523	1.7	80	103	
7:46	207	6	4524.7	1.7	80	104.7	
7:47	208	7	4526.4	1.7	80	106.4	
7:48	209	8	4528.2	1.8	80	108.2	
7:49	210	9	4530.1	1.9	80	110.1	
7:50	211	10	4531.9	1.8	80	111.9	1.67 average for 80 psi
7:51	212	1	4533.5	1.6	70	113.5	
7:52	213	2	4535.2	1.7	70	115.2	
7:53	214	3	4536.7	1.5	70	116.7	
7:54	215	4	4538.5	1.8	70	118.5	
7:55	216	5	4540.2	1.7	70	120.2	
7:56	217	6	4541.1	0.9	70	121.1	
7:57	218	7	4542.4	1.3	70	122.4	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
7:58	219	8	4544.3	1.9	70	124.3	
7:59	220	9	4545.9	1.6	70	125.9	
8:00	221	10	4547.5	1.6	70	127.5	1.56 average for 70 psi
8:01	222	1	4548.9	1.4	60	128.9	
8:02	223	2	4550.5	1.6	60	130.5	
8:03	224	3	4552.1	1.6	60	132.1	
8:04	225	4	4553.8	1.7	60	133.8	
8:05	226	5	4555.3	1.5	60	135.3	
8:06	227	6	4556.9	1.6	60	136.9	
8:07	228	7	4558.5	1.6	60	138.5	
8:08	229	8	4560	1.5	60	140	
8:09	230	9	4561.6	1.6	60	141.6	
8:10	231	10	4563.3	1.7	60	143.3	1.58 average for 60 psi
8:11	232	1	4564.7	1.4	50	144.7	
8:12	233	2	4566	1.3	50	146	
8:13	234	3	4567.3	1.3	50	147.3	
8:14	235	4	4568.6	1.3	50	148.6	
8:15	236	5	4570	1.4	50	150	
8:16	237	6	4571.4	1.4	50	151.4	
8:17	238	7	4572.8	1.4	50	152.8	
8:18	239	8	4574.2	1.4	50	154.2	
8:19	240	9	4575.3	1.1	50	155.3	
8:20	241	10	4576.5	1.2	50	156.5	1.32 average for 50 psi
8:21	242	1	4577.6	1.1	40	157.6	
8:22	243	2	4578.9	1.3	40	158.9	
8:23	244	3	4580.2	1.3	40	160.2	
8:24	245	4	4581.5	1.3	40	161.5	
8:25	246	5	4582.8	1.3	40	162.8	
8:26	247	6	4584.1	1.3	40	164.1	
8:27	248	7	4585.4	1.3	40	165.4	
8:28	249	8	4586.5	1.1	40	166.5	
8:29	250	9	4587.6	1.1	40	167.6	
8:30	251	10	4588.9	1.3	40	168.9	1.24 average for 40 psi
8:31	252	1	4590	1.1	30	170	
8:32	253	2	4591.2	1.2	30	171.2	
8:33	254	3	4592.3	1.1	30	172.3	
8:34	255	4	4593.2	0.9	30	173.2	
8:35	256	5	4594.6	1.4	30	174.6	
8:36	257	6	4595.7	1.1	30	175.7	
8:37	258	7	4596.8	1.1	30	176.8	
8:38	259	8	4597.9	1.1	30	177.9	
8:39	260	9	4599	1.1	30	179	
8:40	261	10	4600.1	1.1	30	180.1	1.12 average for 30 psi
8:41	262	1	4601.2	1.1	20	181.2	
8:42	263	2	4602.1	0.9	20	182.1	
8:43	264	3	4603.3	1.2	20	183.3	
8:44	265	4	4604.4	1.1	20	184.4	
8:45	266	5	4605.4	1	20	185.4	
8:46	267	6	4606.3	0.9	20	186.3	
8:47	268	7	4607.4	1.1	20	187.4	
8:48	269	8	4608.4	1	20	188.4	
8:49	270	9	4609.4	1	20	189.4	
8:50	271	10	4610.5	1.1	20	190.5	1.04 average for 20 psi
8:51	272	1	4611.4	0.9	10	191.4	
8:52	273	2	4612.4	1	10	192.4	
8:53	274	3	4613.3	0.9	10	193.3	
8:54	275	4	4614.2	0.9	10	194.2	
8:55	276	5	4615.1	0.9	10	195.1	

Time 24 hr.	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks	
8:56	277	6	4616	0.9	10	196		
8:57	278	7	4617	1	10	197		
8:58	279	8	4617.9	0.9	10	197.9		
8:59	280	9	4618.7	0.8	10	198.7		
9:00	281	10	4619.6	0.9	10	199.6	0.91 average for 10 psi	
Repeated steps summarized								
psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
0.98	10	2.31	130	1.02	10	2.45	130	Set pressure. Wait 1 minute
1.12	20	2.24	100	1.18	20	2.23	100	average over 2 minutes. Repeat
1.15	30	2.05	90	1.18	30	2.1	90	
1.26	40	1.8	80	1.29	40	1.82	80	
1.55	50	1.81	70	1.56	50	1.8	70	
1.78	60	1.78	60	1.8	60	1.83	60	
1.81	70	1.56	50	1.83	70	1.54	50	
1.81	80	1.31	40	1.82	80	1.33	40	
2.02	90	1.21	30	2.01	90	1.2	30	
2.20	100	1.13	20	2.19	100	1.14	20	
2.21	130	1	10	2.23	130	1.02	10	
2.98	150			3.12	150			
0.00	1	4	6084.5	0	60	1664.5		
0.00	2	5	6084.5	0	60	1664.5		
0.69	303	1	6084.5	0	50	1664.5		
0.69	304	2	6084.5	0	50	1664.5		
0.69	305	3	6084.5	0	50	1664.5		
0.69	306	4	6084.5	0	50	1664.5		
0.69	307	5	6084.5	0	50	1664.5		
0.69	308	1	6084.5	0	40	1664.5		
0.69	309	2	6084.5	0	40	1664.5		
0.69	310	3	6084.5	0	40	1664.5		
0.69	311	4	6084.5	0	40	1664.5		
0.69	312	5	6084.5	0	40	1664.5		
0.69	313	1	6084.5	0	30	1664.5		
0.69	314	2	6084.5	0	30	1664.5		
0.69	315	3	6084.5	0	30	1664.5		
0.70	316	4	6084.5	0	30	1664.5		
0.70	317	5	6084.5	0	30	1664.5		
0.70	318	6	6084.5	0	20	1664.5		
0.70	319	7	6084.5	0	20	1664.5		
0.70	320	8	6084.5	0	20	1664.5		
0.70	321	9	6084.5	0	20	1664.5		
0.70	322	10	6084.5	0	20	1664.5		
Repeated steps summarized								
psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
								No duplicat test performed

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	8/16/2011
Client	New Mexico Copper Corp
Project	Copper Flat
Well Name	GWQ 11-25 Zone 2
Hydrologist	JJK

Starting Water Level (ft bgl)	60.2	Packer Dia	2 inch
Elevation (ft GL)		Bore/Casing Dia	3-3/4 inch
Injection Interval (ft bgl)	150 to 197.7	Injection Pipe Dia	1 inch
Bore/Casing Depth (ft bgl)	197.7	Pressure gauge height above GL	3 ft

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
7:25	0		4700		10	0	
7:26	1	1	4704.5	4.50	12	4.5	
7:27	2	2	4707	2.50	10	7	
7:28	3	3	4709	2.00	10	9	
7:29	4	4	4711	2.00	12	11	
7:30	5	5	4712.9	1.90	10	12.9	
7:31	6	6	4714.9	2.00	10	14.9	
7:32	7	7	4717	2.10	11	17	
7:33	8	8	4718.8	1.80	10	18.8	
7:34	9	9	4720.7	1.90	10	20.7	
7:35	10	10	4722.6	1.90	10	22.6	2.26 gpm average for 10 psi
7:36	11	1	4724.8	2.2	20	24.8	
7:37	12	2	4727.1	2.3	20	27.1	
7:38	13	3	4729.2	2.1	21	29.2	
7:39	14	4	4731.4	2.2	20	31.4	
7:40	15	5	4733.6	2.2	19	33.6	
7:41	16	6	4735.8	2.2	20	35.8	
7:42	17	7	4738	2.2	20	38	
7:43	18	8	4740.2	2.2	21	40.2	
7:44	19	9	4742.4	2.2	20	42.4	
7:45	20	10	4744.6	2.2	20	44.6	2.20 gpm average for 20 psi
7:46	21	1	4747.1	2.5	30	47.1	
7:47	22	2	4749.6	2.5	31	49.6	
7:48	23	3	4752.3	2.7	31	52.3	
7:49	24	4	4754.8	2.5	32	54.8	
7:50	25	5	4757.2	2.4	31	57.2	
7:51	26	6	4759.7	2.5	30	59.7	
7:52	27	7	4762.3	2.6	30	62.3	
7:53	28	8	4764.7	2.4	31	64.7	
7:54	29	9	4767.2	2.5	30	67.2	
7:55	30	10	4769.6	2.4	30	69.6	2.50 gpm average for 30 psi
7:56	31	1	4772.4	2.8	38	72.4	
7:57	32	2	4775.3	2.9	40	75.3	
7:58	33	3	4778.2	2.9	41	78.2	
7:59	34	4	4781	2.8	40	81	
8:00	35	5	4783.8	2.8	40	83.8	
8:01	36	6	4786.4	2.6	40	86.4	
8:02	37	7	4789.1	2.7	40	89.1	
8:03	38	8	4791.9	2.8	41	91.9	
8:04	39	9	4794.2	2.3	40	94.2	
8:05	40	10	4797.3	3.1	41	97.3	2.77 gpm average for 40 psi
8:06	41	1	4800.5	3.2	50	100.5	Oscilating = or - 3 to 4 psi
8:07	42	2	4803.6	3.1	50	103.6	
8:08	43	3	4806.6	3	50	106.6	
8:09	44	4	4809.7	3.1	50	109.7	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
8:10	45	5	4812.8	3.1	50	112.8	
8:11	46	6	4815.8	3	50	115.8	
8:12	47	7	4818.9	3.1	50	118.9	
8:13	48	8	4822	3.1	50	122	
8:14	49	9	4825	3	50	125	
8:15	50	10	4828.1	3.1	50	128.1	3.08 gpm average for 50 psi
8:16	51	1	4831.6	3.5	60	131.6	Oscilating = or - 3 to 4 psi
8:17	52	2	4834.9	3.3	60	134.9	
8:18	53	3	4838	3.1	60	138	
8:19	54	4	4841.8	3.8	60	141.8	
8:20	55	5	4844.9	3.1	60	144.9	
8:21	56	6	4848.3	3.4	60	148.3	
8:22	57	7	4851.9	3.6	60	151.9	
8:23	58	8	4855.5	3.6	60	155.5	
8:24	59	9	4859.1	3.6	60	159.1	
8:25	60	10	4862.8	3.7	60	162.8	3.47 gpm average for 60 psi
8:26	61	1	4866.4	3.6	70	166.4	Oscilating = or - 3 to 4 psi
8:27	62	2	4870.2	3.8	70	170.2	
8:28	63	3	4874	3.8	70	174	
8:29	64	4	4877.5	3.5	70	177.5	
8:30	65	5	4881	3.5	70	181	
8:31	66	6	4884.6	3.6	70	184.6	
8:32	67	7	4888.1	3.5	70	188.1	
8:33	68	8	4891.7	3.6	70	191.7	
8:34	69	9	4895.5	3.8	70	195.5	
8:35	70	10	4898.9	3.4	70	198.9	3.61 gpm average for 70 psi
8:36	71	1	4903	4.1	80	203	Oscilating = or - 3 to 4 psi
8:37	72	2	4906.8	3.8	80	206.8	
8:38	73	3	4910.4	3.6	80	210.4	
8:39	74	4	4914.2	3.8	81	214.2	
8:40	75	5	4918	3.8	80	218	
8:41	76	6	4921.9	3.9	80	221.9	
8:42	77	7	4925.6	3.7	80	225.6	
8:43	78	8	4929.3	3.7	80	229.3	
8:44	79	9	4933.1	3.8	80	233.1	
8:45	80	10	4937	3.9	80	237	3.81 gpm average for 80 psi
8:46	81	1	4941.1	4.1	90	241.1	Oscilating = or - 5 psi
8:47	82	2	4945.4	4.3	90	245.4	
8:48	83	3	4949.6	4.2	90	249.6	
8:49	84	4	4954	4.4	91	254	
8:50	85	5	4958.1	4.1	90	258.1	
8:51	86	6	4962.3	4.2	90	262.3	
8:52	87	7	4966.6	4.3	90	266.6	
8:53	88	8	4971.2	4.6	90	271.2	
8:54	89	9	4975.3	4.1	90	275.3	
8:55	90	10	4979.7	4.4	90	279.7	4.27 gpm average for 90 psi
8:56	91	1	4984.8	5.1	100	284.8	Oscilating = or - 6 psi
8:57	92	2	4989.9	5.1	100	289.9	
8:58	93	3	4995	5.1	100	295	
8:59	94	4	5000	5	100	300	
9:00	95	5	5005.1	5.1	100	305.1	
9:01	96	6	5010	4.9	100	310	
9:02	97	7	5015.1	5.1	100	315.1	
9:03	98	8	5020	4.9	100	320	
9:04	99	9	5025	5	100	325	
9:05	100	10	5029.9	4.9	100	329.9	5.02 gpm average for 100 psi
9:06	101	1	5034	4.1	90	334	Oscilating = or - 5 psi

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
9:07	102	2	5038	4	90	338	
9:08	103	3	5042.1	4.1	90	342.1	
9:09	104	4	5046.5	4.4	90	346.5	
9:10	105	5	5050.7	4.2	90	350.7	
9:11	106	6	5055	4.3	90	355	
9:12	107	7	5059.2	4.2	90	359.2	
9:13	108	8	5063.4	4.2	90	363.4	
9:14	109	9	5067.7	4.3	90	367.7	
9:15	110	10	5072.4	4.7	90	372.4	4.25 gpm average for 90 psi
9:16	111	1	5076.2	3.8	80	376.2	Oscilating = or - 5 psi
9:17	112	2	5079.9	3.7	80	379.9	
9:18	113	3	5083.5	3.6	80	383.5	
9:19	114	4	5087.1	3.6	80	387.1	
9:20	115	5	5090.5	3.4	80	390.5	
9:21	116	6	5094.3	3.8	80	394.3	
9:22	117	7	5098	3.7	80	398	
9:23	118	8	5101.8	3.8	80	401.8	
9:24	119	9	5105.6	3.8	80	405.6	
9:25	120	10	5109.6	4	80	409.6	3.72 gpm average for 80 psi
9:26	121	1	5113	3.4	70	413	Oscilating = or - 3 to 4 psi
9:27	122	2	5116.2	3.2	70	416.2	
9:28	123	3	5119.8	3.6	70	419.8	
9:29	124	4	5123	3.2	70	423	
9:30	125	5	5126.5	3.5	70	426.5	
9:31	126	6	5130.2	3.7	70	430.2	
9:32	127	7	5133.7	3.5	70	433.7	
9:33	128	8	5137.2	3.5	70	437.2	
9:34	129	9	5140.4	3.2	70	440.4	
9:35	130	10	5143.9	3.5	70	443.9	3.43 gpm average for 70 psi
9:36	131	1	5147	3.1	60	447	Oscilating = or - 3 to 4 psi
9:37	132	2	5150.1	3.1	60	450.1	
9:38	133	3	5153.5	3.4	60	453.5	
9:39	134	4	5156.5	3	60	456.5	
9:40	135	5	5159.7	3.2	60	459.7	
9:41	136	6	5163	3.3	60	463	
9:42	137	7	5166.2	3.2	60	466.2	
9:43	138	8	5169.4	3.2	60	469.4	
9:44	139	9	5172.7	3.3	60	472.7	
9:45	140	10	5175.9	3.2	60	475.9	3.20 gpm average for 60 psi
9:46	141	1	5178.7	2.8	50	478.7	Oscilating = or - 3 to 4 psi
9:47	142	2	5181.6	2.9	50	481.6	
9:48	143	3	5184.7	3.1	50	484.7	
9:49	144	4	5187.5	2.8	50	487.5	
9:50	145	5	5190.3	2.8	50	490.3	
9:51	146	6	5193.3	3	50	493.3	
9:52	147	7	5196.1	2.8	50	496.1	
9:53	148	8	5199	2.9	50	499	
9:54	149	9	5202.1	3.1	50	502.1	
9:55	150	10	5205.1	3	50	505.1	2.92 gpm average for 50 psi
9:56	151	1	5207.8	2.7	40	507.8	
9:57	152	2	5210.1	2.3	40	510.1	
9:58	153	3	5212.8	2.7	40	512.8	
9:59	154	4	5215.6	2.8	40	515.6	
10:00	155	5	5218.1	2.5	40	518.1	
10:01	156	6	5221	2.9	40	521	
10:02	157	7	5223.8	2.8	40	523.8	
10:03	158	8	5226.4	2.6	40	526.4	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
10:04	159	9	5229	2.6	40	529	
10:05	160	10	5231.9	2.9	40	531.9	2.68 gpm average for 40 psi
10:06	161	1	5234.2	2.3	30	534.2	
10:07	162	2	5236.5	2.3	30	536.5	
10:08	163	3	5238.9	2.4	30	538.9	
10:09	164	4	5241.4	2.5	30	541.4	
10:10	165	5	5244	2.6	30	544	
10:11	166	6	5246.3	2.3	30	546.3	
10:12	167	7	5248.7	2.4	30	548.7	
10:13	168	8	5251.2	2.5	30	551.2	
10:14	169	9	5253.7	2.5	30	553.7	
10:15	170	10	5256.3	2.6	30	556.3	2.44 gpm average for 30 psi
10:16	171	1	5258.2	1.9	20	558.2	
10:17	172	2	5260.2	2	20	560.2	
10:18	173	3	5262.6	2.4	20	562.6	
10:19	174	4	5264.8	2.2	20	564.8	
10:20	175	5	5267	2.2	20	567	
10:21	176	6	5269.1	2.1	20	569.1	
10:22	177	7	5271.3	2.2	20	571.3	
10:23	178	8	5273.6	2.3	20	573.6	
10:24	179	9	5275.9	2.3	20	575.9	
10:25	180	10	5278	2.1	20	578	2.17 gpm average for 20 psi
10:26	181	1	5279.7	1.7	10	579.7	
10:27	182	2	5281.6	1.9	10	581.6	
10:28	183	3	5283.5	1.9	10	583.5	
10:29	184	4	5285.4	1.9	10	585.4	
10:30	185	5	5287.2	1.8	10	587.2	
10:31	186	6	5289.1	1.9	10	589.1	
10:32	187	7	5291	1.9	10	591	
10:33	188	8	5293	2	10	593	
10:34	189	9	5295	2	10	595	
10:35	190	10	5296.9	1.9	10	596.9	1.89 gpm average for 10 psi

Repeated steps summarized

psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	Injection rate, gals	Injection pressure, psi	
NA	10.0	(*)	90.0	2.70	20.0	(*)	90.0	Set pressure. Wait 1 minute
2.38	20.0	5.09	80.0	3.69	30.0	(*)	80.0	average over 2 minutes. Repeat
2.49	30.0	4.68	70.0	4.10	40.0	5.10	70.0	
3.00	40.0	4.80	60.0	4.72	50.0	4.70	60.0	
3.18	50.0	4.38	50.0	5.18	60.0	4.60	50.0	
3.62	60.0	3.70	40.0	5.20	70.0	4.00	40.0	
3.70	70.0	3.29	30.0	6.16	80.0	2.60	30.0	
4.31	80.0	2.80	20.0	(*)	90.0	2.51	20.0	
4.70	90.0	2.40	10.0	(*)	100.0	1.92	10.0	
(*)	100.0							

(*) unable to maintain pressure

JOHN SHOMAKER & ASSOCIATES, INC.
WATER-RESOURCE AND ENVIRONMENTAL CONSULTANTS
2611 BROADBENT PARKWAY NE
ALBUQUERQUE, NEW MEXICO 87107
(505) 345-3407, FAX (505) 345-9920
WWW.SHOMAKER.COM

Date	8/24/2011
Client	New Mexico Copper Corp
Project	Copper Flat
Well Name	GWQ 11-25, Zone 3
Hydrologist	JJK

Starting Water Level (ft bgl)	60.00	Packer Dia	2 inch
Elevation (ft GL)		Bore/Casing Dia	3-3/4 inch
Injection Interval (ft bgl)	207 to 251	Injection Pipe Dia	1 inch
Bore/Casing Depth (ft bgl)	251	Pressure gauge height above GL	4 ft

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
8:10	0		5463		11	0	
8:11	1	1	5465	2.00	10	2	
8:12	2	2	5465.7	0.70	11	2.7	
8:13	3	3	5468.3	2.60	11	5.3	
8:14	4	4	5470	1.70	10	7	
8:15	5	5	5471.4	1.40	10	8.4	
8:16	6	6	5472.8	1.40	10	9.8	
8:17	7	7	5474.4	1.60	10	11.4	
8:18	8	8	5475.9	1.50	10	12.9	
8:19	9	9	5477.4	1.50	10	14.4	
8:20	10	10	5479	1.60	10	16	1.6 gpm average for 10 psi
8:21	11	1	5480.5	1.5	20	17.5	
8:22	12	2	5482.2	1.7	20	19.2	
8:23	13	3	5483.5	1.3	20	20.5	
8:24	14	4	5485.2	1.7	20	22.2	
8:25	15	5	5486.7	1.5	21	23.7	
8:26	16	6	5488.4	1.7	20	25.4	
8:27	17	7	5490	1.6	20	27	
8:28	18	8	5491.6	0	20	28.6	
8:29	19	9	5493.1	1.5	20	30.1	
8:30	20	10	5494.8	1.7	21	31.8	1.58 gpm average for 20 psi
8:31	21	1	5496.5	1.7	30	33.5	
8:32	22	2	5498.1	1.6	29	35.1	
8:33	23	3	5499.9	1.8	30	36.9	
8:34	24	4	5501.5	1.6	30	38.5	
8:35	25	5	5503.1	1.6	30	40.1	
8:36	26	6	5505	1.9	30	42	
8:37	27	7	5506.6	1.6	30	43.6	
8:38	28	8	5508.6	2	30	45.6	
8:39	29	9	5510.4	1.8	29	47.4	
8:40	30	10	5512.4	2	29	49.4	1.76 gpm average for 30 psi
8:41	31	1	5514.3	1.9	40	51.3	
8:42	32	2	5516.2	1.9	40	53.2	
8:43	33	3	5518.3	2.1	40	55.3	
8:44	34	4	5520.4	2.1	40	57.4	
8:45	35	5	5522.3	1.9	40	59.3	
8:46	36	6	5524.3	2	40	61.3	
8:47	37	7	5526.3	2	40	63.3	
8:48	38	8	5528.2	1.9	39	65.2	
8:49	39	9	5530.2	2	39	67.2	
8:50	40	10	5532.2	2	39	69.2	1.98 gpm average for 40 psi
8:51	41	1	5534.4	2.2	50	71.4	All 50 psi readings are approximate
8:52	42	2	5536.6	2.2	50	73.6	pressure gauge is oscillating + - 3 to 4 psi
8:53	43	3	5539.1	2.5	50	76.1	
8:54	44	4	5541.6	2.5	50	78.6	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
8:55	45	5	5544.1	2.5	50	81.1	
8:56	46	6	5546.6	2.5	50	83.6	
8:57	47	7	5549.2	2.6	50	86.2	
8:58	48	8	5551.7	2.5	50	88.7	
8:59	49	9	5554.3	2.6	50	91.3	
9:00	50	10	5557	2.7	50	94	2.48 gpm average for 50 psi
9:01	51	1	0	-5557	60	-5463	All 60 psi readings are approximate
9:02	52	2	5565.1	5565.1	60	102.1	pressure gauge is oscillating + - 3 to 4 psi
9:03	53	3	5569.7	4.6	60	106.7	
9:04	54	4	5573.9	4.2	60	110.9	
9:05	55	5	5578.5	4.6	60	115.5	
9:06	56	6	5583.4	4.9	60	120.4	
9:07	57	7	5587.4	4	58	124.4	
9:08	58	8	5592.2	4.8	58	129.2	
9:09	59	9	5597.4	5.2	60	134.4	
9:10	60	10	5602.7	5.3	60	139.7	4.57 gpm average for 60 psi
9:11	61	1	5609	6.3	65	146	Valve fully open. Water moving past packer
9:12	62	2	5616.1	7.1	65	153.1	
9:13	63	3	5623.1	7	65	160.1	
9:14	64	4	5630.3	7.2	65	167.3	
9:15	65	5	5637.6	7.3	65	174.6	
9:16	66	6	5645.1	7.5	63	182.1	Water at surface
9:17	67	7	5652.3	7.2	62	189.3	
9:18	68	8	5659.8	7.5	62	196.8	
9:19	69	9	5666.9	7.1	60	203.9	
9:20	70	10	5674	7.1	60	211	7.13 gpm average for 65 psi
9:21	71	1	5681.4	7.4	60	218.4	
9:22	72	2	5688.6	7.2	60	225.6	
9:23	73	3	5696	7.4	59	233	
9:24	74	4	5703.2	7.2	59	240.2	
9:25	75	5	5710.6	7.4	58	247.6	
9:26	76	6	5717.8	7.2	58	254.8	
9:27	77	7	5725	7.2	58	262	
9:28	78	8	5732.3	7.3	58	269.3	
9:29	79	9	5739.5	7.2	59	276.5	
9:30	80	10	5746.9	7.4	59	283.9	7.29 gpm average for 60 psi
9:31	81	1	5752.3	5.4	50	289.3	Water now moving down casing
9:32	82	2	5757	4.7	50	294	
9:33	83	3	5761.3	4.3	50	298.3	
9:34	84	4	5766	4.7	50	303	
9:35	85	5	5770.5	4.5	50	307.5	
9:36	86	6	5775	4.5	50	312	
9:37	87	7	5779.7	4.7	50	316.7	
9:38	88	8	5784.3	4.6	50	321.3	
9:39	89	9	5788.8	4.5	50	325.8	
9:40	90	10	5793.5	4.7	50	330.5	4.66 average for 50 psi
9:41	91	1	5796.5	3	40	333.5	
9:42	92	2	5798	1.5	40	335	
9:43	93	3	5799.9	1.9	40	336.9	
9:44	94	4	5801.2	1.3	39	338.2	
9:45	95	5	5802.8	1.6	40	339.8	
9:46	96	6	5804.4	1.6	39	341.4	
9:47	97	7	5806	1.6	40	343	
9:48	98	8	5807.5	1.5	40	344.5	
9:49	99	9	5809.2	1.7	40	346.2	
9:50	100	10	5810.5	1.3	39	347.5	1.7 average for 40 psi
9:51	101	1	5812.1	1.6	30	0	

Time 24 hr	Elapsed minutes	Injection period	Water meter reading, gals	Injection rate, gals	Injection pressure, psi	total water injected, gals	Remarks
9:52	102	2	5813.4	1.3	30	1.3	
9:53	103	3	5814.8	1.4	30	2.7	
9:54	104	4	5816.3	1.5	30	4.2	
9:55	105	5	5817.6	1.3	30	5.5	
9:56	106	6	5818.9	1.3	30	6.8	
9:57	107	7	5820.3	1.4	30	8.2	
9:58	108	8	5821.8	1.5	30	9.7	
9:59	109	9	5823	1.2	30	10.9	
10:00	110	10	5824.4	1.4	30	12.3	1.39 average for 30 psi
10:01	111	1	5825.7	1.3	20	13.6	
10:02	112	2	5827	1.3	20	14.9	
10:03	113	3	5828.3	1.3	20	16.2	
10:04	114	4	5829.5	1.2	20	17.4	
10:05	115	5	5830.8	1.3	20	18.7	
10:06	116	6	5832.1	1.3	20	20	
10:07	117	7	5833.3	1.2	20	21.2	
10:08	118	8	5834.6	1.3	20	22.5	
10:09	119	9	5835.9	1.3	20	23.8	
10:10	120	10	5837.1	1.2	20	25	1.27 average for 20 psi
10:11	121	1	5838.2	1.1	10	26.1	
10:12	122	2	5839.3	1.1	10	27.2	
10:13	123	3	5840.3	1	10	28.2	
10:14	124	4	5841.8	1.5	10	29.7	
10:15	125	5	5842.7	0.9	10	30.6	
10:16	126	6	5843.8	1.1	10	31.7	
10:17	127	7	5845	1.2	10	32.9	
10:18	128	8	5846.1	1.1	10	34	
10:19	129	9	5847.2	1.1	10	35.1	
10:20	130	10	5848.3	1.1	10	36.2	1.12 average for 10 psi

Repeated steps summarized

psi increased		psi decreased		psi increased		psi decreased		Notes
Injection rate, gals	**Injection pressure, psi**	**Injection rate, gals**	**Injection pressure, psi**	**Injection rate, gals**	**Injection pressure, psi**	**Injection rate, gals**	**Injection pressure, psi**	
NA	10.0	NA	65.0	1.21	10.0	NA	65.0	Set pressure. Wait 1 minute
1.20	20.0	2.62	60.0	1.39	20.0	2.39	60.0	average over 2 minutes. Repeat
1.45	30.0	1.89	50.0	1.55	30.0	1.98	50.0	
1.61	40.0	1.70	40.0	1.62	40.0	1.80	40.0	
1.90	50.0	1.14	30.0	2.10	50.0	1.57	30.0	
2.40	60.0	1.29	20.0	2.22	60.0	1.41	20.0	
3.90	66.0	1.20	10.0	3.84	66.0	1.33	10.0	

Appendix D.

MODFLOW Code Documentation

DOCUMENTATION FOR MODFLOW CODE VERSION

The following report first presents general details and documentation for the MODFLOW version titled maj10_12mar10. Documentation for LAK2 is presented as an Appendix.

DOCUMENTATION FOR MODFLOW CODE VERSION

page

DOCUMENTATION FOR MODFLOW CODE VERSION

INTRODUCTION

This report documents a version of the US Geological Survey modular ground-water flow model, or MODFLOW (McDonald and Harbaugh, 1988). Major non-standard features include:

- Modifications to module BCF2 and other modules involving the treatment of perched aquifers, dry cells and cell rewetting. These modifications preserve continuity of the governing equations of flow and also preserve mass balance accounting.
- Module RIV2 (adapted from Miller, 1988). The original program has been revised to improve the surface water mass balance accounting, to improve I/O options and to accommodate the sub-module DIV1.
- RIV2 sub-module DIV1. This module simulates the diversion of surface water and the optional re-injection of diverted water into the groundwater system.
- Module LAK2. This module is used to simulate lakes, well bores and other open water bodies connected to groundwater systems.
- Module OUT1 manages output control.
- Module ZON1 computes and outputs zone-by-zone budgets

Minor features include:

- Additional options for the formatting of input arrays (from Zheng, 1989, Appendix B)
- The Drain Package, DRN1, has been modified to also perform the functions of the WEL module, in addition to the DRN function. In addition, a second copy of the DRN module has been implemented in the code. These modifications are useful in simulating complex, multi-component and highly variable pumping regimes.
- The Well Package, WEL1, has been modified to optionally transfer pumping to the next layer down when a pumping cell goes dry.
- The Output Control (OC1) sub-module of the Basic Package, BAS has been modified to include the output of hydrographs and to allow the output of volumetric budget terms to a separate file
- Addition of a repeating seasonal input option to the Evapotranspiration (EVT1) and Recharge (RCH1) modules.

GENERAL DOCUMENTATION

Modules

MODFLOW packages are invoked using the IUNIT array (McDonald and Harbaugh, 1988, ch. 4). This particular version contains the following selection of modules:

IUNIT#	PACKAGE	TYPE	
1	BCF2	G	Block-Centered Flow Package BCF2 (McDonald et al., 1991) modified
2	WEL	B	Well Package modified
3	DRN	B	Drain Package modified
4	RIV	B	River Package
5	EVT	B	Evapotranspiration Package, modified
6	RIV2	S	River Package 2 (adapted from Miller, 1988)
7	GHB	B	General Head Boundary Package
8	RCH	B	Recharge Package, modified
9	SIP	M	Strongly Implicit Procedure solver Package
10	PCG	M	Preconditioned Conjugate Gradient solver Package (Hill, 1990)
11	SOR1	M	Slice-successive OverRelaxation solver Package
12	OC	O	Output Control Option, modified
13	LAK2	S	Lake Package
14	DRN	B	Drain Package modified (second entry)
15	NCF1	G	Node-Centered Flow Package (Jones, 1997)
16	SOL1	M	ITPACK2C matrix solvers (Kincaid et al., 1992)
17	CHD1	B	Time-variant Constant HeaD Package (Leake and Prudic, 1988, Appendix C)
18	OUT1	O	Output Control Package
19	HFB	G	Horizontal Flow Barrier Package (Hsieh and Freckleton, 1992)
20	ZON1	O	Zone Budget Package
21	(unused)		
2	LKMT	O	Package creates interface files to MT3D, modified
23	LKMP1	O	Package creates interface files to MODPATH
24	(unused)		

Types
G: Groundwater flow domain / Aquifer properties
B: Boundary conditions to Groundwater domain
S: Surface water flow / Boundary conditions to Groundwater domain
O: Output control
M: Matrix inversion/ solution

Name file

MODFLOW has been modified to run from a single input file (the Name file) containing a list of input and output file names and unit numbers. The file is equivalent to the ".NAM" file of MODFLOW96 and later, though with different format. In addition to providing instructions to the program, the Name file serves to define the simulation and is a useful file for record keeping. File names needed include

the BAS input file (unit 1),
the main output file (unit 2),
all input file units specified in the IUNIT array,
all output units specified in individual input files (including modules OC1, OUT1, ZON1, LAK2, etc.)

When MODFLOW.EXE is run, the program first reads the console for the name of the Name file. The Name file consists of one line for each file to be used during the simulation, in the following format:

Input Records

RECORD1 : read once for each file to be opened during simulation.

variable:	**KUNIT**	**FNAME**	**UNFC**
format:	I5	A20	A1

Explanation of Variables

KUNIT : Unit number of file to be opened.
FNAME : Name of file to be opened.
UNFC : Format flag.
If UNFC = 'U' or 'u', the file is opened as unformatted.
Otherwise the file is opened as formatted.

Array Readers

Input instructions throughout MODFLOW refer to the input formats U2DREL , U1DREL , and U2DINT. These "formats" are utility package array reading subroutines. Options for the format of input arrays have been added to the original MODFLOW routines, following Zheng (1989). One option not in Zheng (1989) has also been added.

Options for the format of input arrays are characterized here by the value of an input variable, LOCAT (see below). The options available with 1988 MODFLOW are

LOCAT<0
LOCAT>0

The options added by (Zheng, 1989) are

LOCAT = 100
LOCAT = 101
LOCAT = 102
LOCAT = 103

one more option has been added:

LOCAT<-100

The file opening aspects of the (Zheng, 1989) subroutines have not been utilized.

Input Records

When called to read a data array from an input file, the array readers first read an array control record. The data array may then be read in various formats from the same file or from a different file, depending on specifications in the array control record

For the real array readers (U2DREL, U1DREL)
Array control record

variable:	**LOCAT**	**CNSTNT**	**FMTIN**	**IPRN**
format:	I10	F10.0	5A4	I10

For the integer array readers (U2DINT)
Array control record

variable:	**LOCAT**	**ICONST**	**FMTIN**	**IPRN**
format:	I10	F10.0	5A4	I10

The data array may or may not follow the input control record, depending on the value of LOCAT.

Explanation of Variables

LOCAT : Data location and format style.

if LOCAT<-100, the array is read from unit (-LOCAT-100) using format FMTIN. The array input unit is then rewound, so that the same array may be used later.

if -100<LOCAT<0, the array is read unformatted from unit -LOCAT.

if LOCAT=0, the array is set to the constant CNSTNT/ICONST.

if LOCAT>0, but LOCAT does not take the values 100, 101, 102 or 103, the array is read from unit LOCAT using format FMTIN.

if LOCAT=100, the array is read from the current unit (the file from which the array control record was read) using format FMTIN.

if LOCAT=101, the array is read from the current unit using a block format (Zheng, 1989).

if LOCAT=102, the array is read from the current unit using a zone format (Zheng, 1989).

if LOCAT=103, the array is read from the current unit using a list-directed or free format (Zheng, 1989).

CNSTNT/ICONST : constant.
if LOCAT=0, each element of the array is set to CNSTNT/ICONST.
if LOCAT≠0, each element of the array is multiplied by CNSTNT/ICONST.

FMTIN : Input format, enclosed in parenthesis.

IPRN : Printout flag and format.
If IPRN<0, the array is not printed.
Otherwise, the array is printed in the main output file, using a format determined by the value of IPRN:

IPRN	U1/2DREL	U2DINT
0	10G11.4	10I11
1	11G10.3	60I1
2	9G13.6	40I2
3	15F7.1	30I3
4	15F7.2	25I4
5	15F7.3	20I5
6	15F7.4	
7	20F5.0	
8	20F5.1	
9	20F5.2	
10	20F5.3	
11	20F5.4	
12	10G11.4	

OUTPUT CONTROL MODULES

The modifications and new modules described below perform output control functions and are not directly related to the numerical computations of water levels and flows. They are, however valuable for viewing, evaluating and presenting model results.

Modifications to module BAS1/OC1

The Basic Package has been modified from its original version (McDonald and Harbaugh, 1988). The Output Control Option has been modified to output hydrographs and to output volumetric budget information to a separate file. The modified option is referred to here as OC2. OC2 will not correctly read unmodified OC1 input files. OC2 capabilities are identical to those of OC1, with the following exceptions:

(1) OC2 allows the specification of a number of cells/nodes as observed head locations: For each time step the user may specify a list of cells/nodes whose hydraulic head will be printed to the file number JHEDUN.

(2) OC2 allows output of the volumetric budget to file number IBUD, as well as to the main output file.

To work correctly with the modified model, input files created for OC1 must be modified. To convert an older file, insert input record 1, with a value of zero, at the beginning of the file:

sample OC1 input file

```
4    4    81   82
0    1    1    0
0    0    1    0
```

modified input file

```
0
4    4    81   82
0    1    1    0
0    0    1    0
```

Input Records

Record 1 is read by module OC1AL and *is read once for a simulation*.

record 1: Maximum number of individual head values (observed heads) to be printed to unit JHEDUN in any one time step.
variable: MXHEADS
format: I10

Record 2 is read by module BAS1RP and *is read once for a simulation*.

record 2: Print formats for head and drawdown, unit numbers for head, drawdown, observed heads and volumetric budget.

variable:	IHEDFM	IDDNFM	IHEDUN	IDDNUN	JHEDUN	IBUD
format:	I10	I10	I10	I10	I10	I10

Records 3, 4 and 5 are read by module BAS1OC and *are read once for each time step*.

record 3: Flag for layer-by-layer head and drawdown output requests, flags for head/drawdown, volumetric budget and cell-by-cell or node-by-node flow components, number of observed heads for this time step.

variable:	INCODE	IHDDFL	IBUDFL	ICBCFL	NHEADS
format:	I10	I10	I10	I10	I10

record 4: Layer, row and column of observed heads. Read NHEADS times when NHEADS is greater than zero.

variable:	LAYER	ROW	COLUMN
format:	I10	I10	I10

record 5: Layer-by-layer output specifications for head and drawdown. Read zero, one or NLAY times, depending on the value of INCODE.

variable:	HDPR	DDPR	HDSV	DDSV
format:	I10	I10	I10	I10

Explanation of Variables

Record 1

MXHEADS : Maximum number of individual head values, or observed heads, to be written to unit JHEDUN in any one time step.

Record 2

IHEDFM : Format code for printing heads.
IDDNFM : Format code for printing drawdowns.

Format codes have the same meaning for head and drawdown. A positive entry indicates wrap format, a negative entry strip format. The absolute value of IDDNFM specifies the printout format as follows:

0 - 10G11.4	7 - 20F5.0
1 - 11G10.3	8 - 20F5.1
2 - 9G13.6	9 - 20F5.2
3 - 15F7.1	10 - 20F5.3
4 - 15F7.2	11 - 20F5.4
5 - 15F7.3	12 - 10G11.4
6 - 15F7.4	

IHEDUN : Unit number to which heads are written, if they are saved.
IDDNUN : Unit number to which drawdowns are written, if they are saved.
JHEDUN : Unit number to which observed head values are to be written.
IBUD : Unit number to which volumetric budget is to be written when flag IBUDFL is set. A value of zero indicates the budget is written to the main output file.

Record 3

INCODE : Head/drawdown output code. Determines the number of times record 5 is read. If INCODE is:

< 0 : layer-by-layer specifications from last time step are used. Record 5 is not read.
= 0 : all layers are treated the same way. Record 5 is read once.
> 0 : Input record 5 is read for each layer.

IHDDFL : Head/drawdown output flag. If IHDDFL is nonzero, heads and drawdowns will be printed or saved according to the flags for each layer specified in input record 5.
IBUDFL : Budget print flag. If IBUDFL is nonzero, overall volumetric budget is printed. Exception: The budget is always printed at the end of a stress period.
ICBCFL : node-by-node flow-term flag. If ICBCFL is nonzero, node-by-node flow terms are printed or saved according to flags set in the individual packages.
NHEADS : Number of individual head values to be written to unit JHEDUN for current time step. If NHEADS<0, the list of individual heads from the previous time step is reused.

Record 4

LAYER, ROW, COLUMN : Layer, row, and column of individual head to be written to unit JHEDUN. (Read NHEADS times, when NHEADS>0).

Record 5

HDPR : Flag for head printing. Head is printed if HDPR is nonzero.
DDPR : Flag for drawdown printing. Drawdown is printed if DDPR is nonzero.
HDSV : Flag for head saving to disk. Head is saved if HDSV is nonzero.
DDSV : Flag for drawdown saving to disk. Drawdown is saved if DDSV is nonzero.

Changes to BAS1 Code

Changes to the BAS1 code are listed below by BAS1 module subroutine.

OC1AL

OC1AL is a new subroutine added to allocate array space for hydrograph output using the Output Control package.

BAS1RP

Subroutine BAS1RP has been modified to reserve values of IBOUND and to accommodate hydrograph and budget output. The parameters JHEDUN and IBUD, unit numbers for hydrograph and budget output, have been added. Special IBOUND values (currently 30000 and 99) are reserved in bold text following comment **C5a**. The call statement to subroutine SBAS1I is indicated in bold text following comment **C8**.

BAS1ST

BAS1ST has been modified to include the stress period length (variable PERLEN) as a subroutine argument. This makes this variable available for use by other subroutines.

SBAS1I

Subroutine SBAS1I has been modified to read unit numbers for hydrograph output (JHEDUN) and budget output (IBUD). The parameters JHEDUN and IBUD have been added. The unit numbers are read in the bold text following comment **C2**.

BAS1OC

Subroutine BAS1OC has been modified to read output hydrograph data. The parameters MXHEDS and NHEADS and the array XHEDMT have been added. Hydrograph cell locations are read from the output control input file in the bold text following comments **C3** and **C3a**.

BAS1OT

Subroutine BAS1OT has been modified to accommodate hydrograph and budget output. The parameters JHEDUN, IBUD, MXHEDS and NHEADS and the array XHEDMT have been added. The call statement to subroutine SBAS1H has been modified in the bold text following comment **C3**. A call statement to subroutine SBAS1B has been added in the bold text following comment **C4**.

SBAS1H

Subroutine SBAS1H has been modified to output hydrograph data. The parameters JHEDUN, MXHEDS and NHEADS and the array XHEDMT have been added. Hydrograph data are output in the bold text following comment **C0**.

SBAS1B

SBAS1B is a new subroutine added to print the volumetric budget to a separate output file.

DOCUMENTATION FOR OUT1

OUT1 is an output control package for MODFLOW that generates a user-specified set of output. OUT1 is activated in IUNIT(18) of the BAS input file in MODFLOW version **maj6x5**. Output is specified in a format similar to MODAFT. OUT1 performs the functions of MODAFT and STARTHED.

Input Records

Record 1 is read by module OUT1AL and *is read once for a simulation*.

variable: KOUTOP MXOTRC
format: I10 I10

Record 2 is read by module OUT1OT and is read:

once for each time step when KOUTOP=0.
once for each stress period when KOUTOP>0.
variable: ITMP
format: I10

Records 3 and 4 are read by module OUT1OT a combined total of ITMP times when ITMP>0.

record 3 Read up to ITMP times when ITMP>0. Not read when ITMP≤0.
variable: KCOM KSUB KNDX KFRM KFIL
format: I10 I10 I10 I10 I10

record 4 Read KNDX times when KSUB=4. Not read otherwise.
variable: KLAY KROW KCOL
format: I10 I10 I10

Explanation of Variables

1. KOUTOP : Output control option.
   If KOUTOP=0, output control specifications are read for each time step.
   Output is generated for each time step.
   If KOUTOP=1, output control specifications are read for each stress period.
   Output is generated for each time step.
   If KOUTOP=2, output control specifications are read for each stress period.
   Output is generated for the last time step of each stress period.

   MOTRC: Maximum number of output control records. Must be greater than or equal to the largest value of ITMP (Record 2) within a simulation.

2. ITMP: Number of output control records.
   If ITMP <0, output control specifications from the previous time step or stress period are re-used.
   If ITMP>0, ITMP output control records (combined total of records 3 and 4) are read.
   If ITMP=0, no output is generated for the current time step or stress period.

3. KCOM: Component of output desired:

If KCOM =0, **hydraulic head** is output.
=1, "**storage**" flow is output.
=2, "**constant head**" flow is output.
=3, "**flow right face**" is output.
=4, "**flow front face**" is output.
=5, "**flow lower face**" is output.
=6, "**wells**" (WEL1) flow is output.
=7, "**drains**" flow (DRN1, copy 1, IUNIT 3) is output.
=8, "**recharge**" (RCH1) flow is output.
=9, "**ET**" (EVT1) flow is output.
=10, "**river leakage**" (RIV1 flow) is output.
=11, "**head dependent bounds**" (GHB) flow is output.
=12, "**river 2 leakage**" (RIV2 flow to groundwater) is output.
=13, "**lake seepage**" (LAK2 flow to groundwater) is output.
=14, "**drains**" flow (DRN1, copy 2, IUNIT 14) is output.
=15, "**river 2 downstream flow**" (RIV2 surface flow) is output.
=16, **hydraulic head** is output (same as KCOM=0).
=17, (inactive, reserved for NCF1 "diagonal flow")
=18, "**river 2 reinjection**" (DIV1 injection of diverted surface flow) is output
=19, (inactive, reserved for "drawdown")

KSUB: Subset of output desired:

If KSUB=0, the entire array is output
=1, a layer of the array is output
=2, a row of the array is output
=3, a column of the array is output
=4, a selection of points from the array is output

KNDX: Index number for KSUB:

If KSUB=0, KNDX is not used.
If KSUB=1, KNDX is the layer number output
If KSUB=2, KNDX is the row number output
If KSUB=3, KNDX is the column number output
If KSUB=4, KNDX is the number of points to be output (read in Record 4)

KFRM: format of output. KFRM is discussed below.

KFIL: Unit number for output file. Output described by KCOM, KSUB, KNDX and KFRM is output to unit KFIL.

4. KLAY KROW KCOL

The layer, row, column indices of specific points to be output.
Read KNDX times when KSUB=4.

Explanation of KFRM

KFRM is the format of output. Its meaning is dependent on the value of KSUB.

If KSUB=0 (entire array output):

If KFRM=0, the array is output as a list of records in the form of *layer, row, column, value*

=1, the array is output in UBUDSV format (3 dimensional unformatted output, used in MODFLOW for unformatted cell-by-cell flow output).

=2, the array is output in ULASAV format (layer by layer unformatted output, used in MODFLOW for unformatted head output). Use this format to generate starting head files.

=3, the array is output as a list of records in the form of *row, column, period, step, time, value*

If KSUB=1 (one layer output):

If KFRM=0, the layer is output as a list of records in the form of *layer, row, column, value*

=1, the layer is output as a list of records in the form of *row, column, value*

=2, the layer is output in ULASAV format (layer by layer unformatted MODFLOW output).

=3, the layer is output as a list of records in the form of *row, column, period, step, time, value*

>11, the layer is output in wrap/strip format (ULAPRW and ULAPRS, used by mudflow to print heads). The format number used is determined by computing KFRM1=KFRM-24: If KFRM1<0, strip format (ULAPRS) is used, with format number –KFRM1. Otherwise, wrap format (ULAPRW) is used, with format number KFRM1:

KFRM1	U1/2DREL	U2DINT
0	10G11.4	10I11
1	11G10.3	60I1
2	9G13.6	40I2
3	15F7.1	30I3
4	15F7.2	25I4
5	15F7.3	20I5
6	15F7.4	
7	20F5.0	
8	20F5.1	
9	20F5.2	
10	20F5.3	
11	20F5.4	
12	10G11.4	

If KSUB=2 (one row output):

If KFRM=0, the row is output as a list of records in the form of *layer, row, column, value*

=1, the row is output as a list of records in the form of *layer, column, value*

=2, the row is output as a list of records in the form of *layer, column, period, step, value*

=3, the row is output as a list of records in the form of *layer, column, period, step, time, value*

=4, the row is output as a list of records in the form of *layer, column, time, value*

If KSUB=3 (one column output):

If KFRM=0, the column is output as a list of records in the form of *layer, row, column, value*

=1, the column is output as a list of records in the form of *layer, row, value*

=2, the column is output as a list of records in the form of *layer, row, time, value*

=3, the column is output as a list of records in the form of *layer, row, period, step, value*

=4, the column is output as a list of records in the form of *layer, row, period, step, time, value*

If KSUB=4 (list of points output):

If KFRM=0, output is generated in hydrograph format: Each line of the output file contains stress period and time step numbers and a value for each point. The header of the file contains the layer, row and column location of each point.

=1, output is generated in list format: Each line of the output file contains information in the form of *period, step, layer, row, column, value*

DOCUMENTATION FOR ZON1

ZON1 is an output control package for MODFLOW that generates zone budgets. ZON1 is activated in IUNIT(20) of the BAS input file in MODFLOW version **maj6x5**. ZON1 uses the memory allocated by OUT1 (IUNIT(18)), and will not run if OUT1 is not also activated.

Input Records

Record 1 is read by module ZON1AL and *is read once for a simulation*.

variable:	NZONES	KZONOP	KZONOT
format:	I10	I10	I10

Record 2 is read by module ZON1OT and *is read once for each layer*.

variable:	IZON (NCOL,NROW)
format:	(U2DINT)

Record 3 is read by module ZON1OT and *is read* *once for each stress period if KZONOP>0*,
once for each time step if KZONOP=0

variable:	ITMP
format:	(I10)

Record 4 is read by module ZON1OT when ITMP > 0

variable:	ICODES (NZONES)
format:	(50I2)

Explanation of Variables

1. NZONES: The number of zones in the model grid. Set NZONES equal to the highest number in the zone array, IZON.

   KZONOP: Options for zone budget output
   - If KZONOP=0 Record 3 is read each time step. Output is generated each time step.
   - =1 Record 3 is read each stress period. Output is generated each time step.
   - =2 Record 3 is read each stress period. Output is generated on the last time step of each stress period.

   KZONOT: Unit number for zone budget output.

2. IZON: Zone designation for each cell. One array is read for each layer

3. ITMP: Flag for reading output specifications (Record 4)
   - If ITMP>0 Record 4 is read. Output is generated based on flags set in Record 4.
   - =0 Record 4 is not read. No output is generated.
   - <0 Record 4 is not read. Output is generated based on the previous reading of Record 4.

4. ICODES: Output flag for each zone. If ICODES(K) is not zero, output is generated for zone K.

MODIFICATIONS TO LKMT

The LKMT package has been added to enable use of MT3D (Zheng, 1996). The LKMT package saves MODFLOW output in the format used for MT3D input.

Modifications

(a) the LKMT package has been made into a subroutine; (b) the LKMT package is distributed as an included block in the main MODFLOW program; (c) subroutine LKMT contains the code from the included block; (d) subroutines LAK2MT and RIV2MT have been added to the LKMT package to allow MT3D interfaces for the LAK2 and RIV2 packages.

DOCUMENTATION FOR LKMP1

The LKMP1 package has been added to facilitate the use of MODPATH (Pollock, 1994), a particle tracking program. The LKMP1 package saves MODFLOW output in the format used for MODPATH input. LKMP1 generates a MODPATH input file, the Composite Budget File (*.cbf),

LKMP1 is activated by setting IUNIT(23) in the .BAS file to a non-zero unit number, then listing a file (*.cbf) with the same unit number in the master input file (".NAM" file). The CBF file will be saved to the unit number (IUNIT[23]) and filename specified.

PERCHED WATER, DRY CELLS, AND REWETTING

This group of modifications to MODFLOW was inspired by conditions encountered along the Carlin Trend of Northern Nevada. A highly-transmissive carbonate rock aquifer (the carbonate aquifer) has been dewatered for mining. The carbonate aquifer is represented using multiple model layers, with some cells becoming dry during the course of dewatering. These cells are rewet during the simulation of post-mining water level recovery.

The Carlin Formation overlies the carbonate aquifer in parts of the model area. It is composed of Tertiary-aged alluvial deposits with much lower permeability than the carbonate aquifer. Over the course of dewatering the carbonate water level has dropped below the bottom of the Carlin Formation and created a perched Carlin water table overlying a zone of desaturated carbonate rock.

Water drains through the dewatered but highly transmissive carbonate rock. Components of recharge to the carbonate aquifer that pass through the dewatered part of the aquifer include:

a) Recharge from the Carlin formation. Water drains from the Carlin Formation downward, through the dewatered carbonate rock, to the carbonate water table below.

b) Recharge from stream networks. Stream channels including Brush Creek, Rodeo Creek, Boulder Creek, and Bell Creek directly recharge the carbonate in outcrop areas.

c) Areal recharge. Direct infiltration of precipitation occurs over carbonate outcrops.

In order to properly represent the above conditions, the following modifications were made to the MODFLOW code.

Vertical Leakage Transfer

The BCF2 package (McDonald et al., 1991) has been modified to (optionally) transmit vertical leakage from above a dry cell to a lower, active layer. Thus the Carlin formation in Layer 1, initially leaking water to the carbonate aquifer in Layer 2, will leak water to the carbonate in Layer 3 after Layer 2 is dry.

Without modifications, MODFLOW already simulates perched aquifer units: Under non-perched conditions, vertical flow between two layers is calculated based on the difference in head between the two layers. As water level in the lower layer drops below the bottom of the upper layer, MODFLOW switches to calculating a flow based on water head in the upper layer only, assuming gravity drainage through the unsaturated zone to the water table below in the lower layer.

A problem arises as the Layer 2 carbonate aquifer cells become dry. Without modification, MODFLOW stops simulating drainage from the perched Carlin Formation to the carbonate water table below. This discontinuity in the equations used to calculate flow produced unrealistic results in the simulated carbonate aquifer water balance and in the simulated Carlin Formation water level trends and water balance.

With the modification, water continues draining at the same rate it was before the Layer 2 carbonate aquifer cells became dry. This restores continuity to the equations used to simulate groundwater flow.

The transfer of vertical leakage is appropriate to apply to the situation along the Carlin Trend, where a lower permeability unit is perched above a higher permeability unit. In some cases, the use of the unmodified algorithm, in which drainage stops as Layer 2 becomes dry, would be more appropriate. In other cases, the use of an unsaturated flow algorithm to represent Layer 2 may be most appropriate.

Vertical Transfer of Recharge and River Leakage

The RCH1 package (McDonald and Harbaugh, 1988) was already equipped with an option (NRCHOP=3) to add areal recharge to the uppermost active layer; therefore, no modifications were necessary to simulate recharge to a lower layer when the uppermost carbonate layers are dry.

The RIV2 package was similarly equipped with a feature that adds stream infiltration to the uppermost active layer. Thus rivers initially recharging the carbonate aquifer in Layer 1 will recharge the Layer 2 carbonate when Layer 1 is dry (and Layer 3 when Layer 2 is dry).

Vertical Transfer of Pumping

Historical pumping rates are modeled as specified flows using the module WEL1. Without modifications, MODFLOW removes pumping from the model when a pumping cell becomes dry. The WEL1 package has been modified to (optionally) shift pumping to the next layer down when a pumping cell becomes dry. This option preserves specified pumping rates.

The approach can be appropriate for representing dewatering wells that are completed in multiple layers, or wells that are assumed to be replaced when pumping levels become too low, and it eliminates the need to re-partition pumping between layers and re-specify WEL package input every time a cell becomes dry.

Transfer of Residual Storage

In a model time step in which a cell becomes dry, MODFLOW normally ignores the water stored in the cell at the beginning of the time step. This volume of water is lost to the model mass balance accounting. In the carbonate aquifer, however, this volume of water would percolate to the water table below. The BCF2 package has been modified to (optionally) transfer the residual storage volume from a dry cell to a lower, active cell, thus preserving the mass-balance accounting of aquifer storage.

Cell Rewetting

A simplified rewetting method allows dry cells to be rewet with a zero rewetting threshold, resulting in smoother rewetting and better continuity of groundwater flow equations. Dry cells are rewet when head in an underlying or adjacent cell is above the bottom of a dry cell. Cells may be rewet with a zero saturated thickness and cells can remain wet with a small saturated thickness.

MODIFICATIONS TO MODULE BCF2

The BCF2 package (McDonald et al., 1991) has been modified from its original version for the purpose of simulating conditions of drawdown and recovery of a high-permeability formation underlying a low-permeability formation. The modifications allow the simulation of a perched leaky aquifer by allowing the vertical flow of water through inactive high-permeability cells to a water table in the underlying active cells.

Modifications

The modifications to BCF2 provide an option for vertical transfer of flow, including:

The transfer of vertical flow from an active cell, goes through the underlying inactive cells to the uppermost active cell below. The transfer of vertical flow allows the simulation of a perched water table.

The transfer of storage flow from of a cell, in the time step in which it goes dry, to the uppermost active cell below. The vertical transfer of storage improves computation of cumulative mass balance.

The input parameter IWETIT, previously not used for rewetting simulations with vertical transfer, now is a cutoff iteration for rewetting. When IWETIT is greater than zero, cells are not rewet after iteration IWETIT.

The vertical transfer option may be used with or without rewetting. Vertical transfer simulations use a simplified rewetting algorithm appropriate to high-permeability material: A dry cell is rewet at the beginning of any iteration in which the cell below has a head higher than the bottom of the dry cell. The initial head of the rewet cell is set equal to the cell bottom.

Input Records

Input records for the modified BCF2 are unchanged from the original BCF2. Explanations of input parameters are unchanged except for the following:

IWDFLG rewetting/flux transfer flag.
if IWDFLG=0, cell rewetting and transfer of BCF2 flux components are not enabled.
if IWDFLG>0, BCF2 cell rewetting is enabled.
if IWDFLG<0, vertical transfer of BCF2 flux components is enabled.
if IWDFLG=-2, cell rewetting and vertical transfer of BCF2 flux components are enabled.

WETDRY rewetting array.
When IWDFLG=0 or -1, WETDRY is not read.
When IWDFLG>0 WETDRY is the rewetting array as originally used in BCF2.
When IWDFLG<-1 WETDRY is a rewetting flag: A cell may be rewet if WETDRY for the cell is not equal to zero.

Changes to BCF2 Code

BCF2AL

Subroutine BCF2AL has been modified to reflect vertical transfer of flow. The vertical transfer option is identified in bold text following comment **C2a**. The condition for allocation of array WETDRY is changed in the bold text following comment **C7a**.

BCF2RP

Changes to subroutine BCF2RP accommodating the vertical transfer option are indicated in bold text following comment **C2H**.

SBCF2N

Changes to subroutine SBCF2N accommodating the vertical transfer option are indicated in bold text following comments **C4B1** and **C4B4**.

BCF2AD

Subroutine BCF2AD has been modified to initialize HOLD for inactive cells during simulations using vertical transfer. The parameters KPER and KSTP have been added. New code is indicated in bold text following comment **C1**. Modified code is indicated in bold text following comment **C1a**.

BCF2FM

Transfer of Flux Components

BCF2 has been modified to transfer storage from dry cells to lower layers. Storage is transferred in subroutine BCF2FM in the bold text following comments **C4a**, **C4b** and **C5d**. BCF2 has also been modified to transfer vertical leakage from above to a lower layer from cells that desaturate. Vertical leakage is transferred in subroutine BCF2FM in the bold text following comments **C6** and **C6a**.

Secondary Modifications

Transfer of storage and vertical leakage is invoked in subroutine BCF2FM by an IBOUND value of 99, set in SBCF2H. Cells with an IBOUND value of 99 are deactivated in subroutine BCF2FM in the bold text following comment **C8d**.

SBCF2H

Rewetting

In transient simulations, vertical transfer of flux components from dry cells maintains the head in dry cells at the layer bottom. Dry cells may be rewet with a zero saturated thickness by ending transfer of flux components and restoring vertical conductance values. No wetting threshold is required, allowing cells to remain wet with a small saturated thickness. Dry cells are rewet when head in the layer below is above the bottom of the dry cell. The rewetting criteria are therefore equivalent to the bottom wetting option in BCF2 (WETDRY<0) with a rewetting interval of 1 (IWETIT=1) and a zero wetting threshold (WETFCT=0 and WETDRY=0). Cells are rewet in the bold text following comment **C2c**.

Secondary Modifications

Transfer of storage and vertical leakage is invoked in subroutine BCF2FM by an IBOUND value of 99. SBCF2H sets the IBOUND value of dry cells to 99 when the flux transfer option is invoked. Head in dry cells is set at the layer bottom elevation to allow computation of storage in dry cells. Dry cells entering SBCF2H are assigned IBOUND values of 99 in the bold text following comment **C2b**. As in the unmodified BCF2, horizontal and vertical conductance terms are set to zero. Unlike unmodified BCF2, vertical conductance from above is not set to zero (bold text following comment **C2d**), enabling the transfer of vertical leakage to lower layers. IBOUND values and heads are assigned to cells that become dry in the bold text following comment **C6c**.

BCF1BD

Subroutine BCF1BD has been modified to recognize the vertical transfer of storage from dry cells to lower layers. Flag IWDFLG and array CVWD have been added to the subroutine parameters. Modifications are contained in bold text in the subroutine header and in bold text following comments **C6** and **C6aa** and in the call statement to subroutine SBCF1F

SBCF1F

Subroutine SBCF1F has been modified to recognize the transfer of vertical flow through dry cells during computation of constant head flows. Flag IWDFLG and array CVWD have been added to the subroutine parameters. Modifications are contained in bold text following comments **C6E1** and **C6F1**.

Verification of Changes Made to BCF2

The modifications to BCF2 were verified using the example problems described in the BCF2 Package documentation (McDonald, Harbaugh, Orr, and Ackerman, 1991). Following is a brief description of the example problems and a comparison of the model results using both BCF2 and modified BCF2:

Problem 1 A steady-state problem, referred to as Problem 1 in the BCF2 Package documentation, was run. First the original problem was duplicated employing the modified BCF2 Package, with IWDFLG>0. The problem was then run with the flux transfer/rewetting option (IWDFLG=-2). Results closely matched the published Problem 1 results, computing the same number and location of active cells and a maximum head difference between simulations of .02 feet.

Problem 2a A steady-state problem, referred to as Problem 2a in the BCF2 Package documentation, was run. First the original problem was run, with IWDFLG>0. Results were confirmed to be identical to the published BCF2 results.

In a second simulation the problem was modified by the specification of absolute values of .0001 for WETDRY and WETFCT. The small wetting values approximate the zero wetting values of the flux transfer/rewetting option (IWDFLG=-2). Results were close to the published 2A results, with 2 more active cells in Layer 2, 3 more active cells in Layer 5 and head differences of up to .1 feet.

In a third simulation the problem was run with the flux-transfer/rewetting option (IWDFLG=-2). Results were identical to those of the second simulation.

Problem 2d A transient problem, 2d, was run. First the original problem was run, with IWDFLG>0. Results were confirmed to be identical to the published BCF2 results.

Second the problem was modified by the specification of absolute values of .0001 for WETDRY and WETFCT. The small wetting values approximate the zero wetting values of the flux transfer/rewetting option (IWDFLG=-2). The results of changing WETDRY and WETFCT for problem 2d resembled the results of changing WETDRY and WETFCT for problem 2a, with several more active nodes and head differences of up to .1 feet.

Third the problem was run with the flux-transfer/rewetting option (IWDFLG=-2). Results were identical to those of the second simulation.

Fourth, the problem was modified to test the transfer of vertical leakage. The recharge package was turned off and replaced with an initially wet Layer 1. The flux transfer option without rewetting (IWDFLG=-1) was enabled. Layer 1 was specified as active, with an initial head of 70 feet and a bottom of 65 feet. The last row and the last column of Layer 1 were de-activated to avoid vertical transfer of flow directly into constant head cells. Layers 2-9 were specified as inactive, unable to be rewet. Layers 10-14 were specified as active, with an initial head of 25 feet. Layer 1 is thus separated from the rest of the grid by inactive layers. The problem was run for 50 1-day time steps. As a perched aquifer, Layer 1 should drain according to the equation

$$Sy \frac{\partial h}{\partial t} = Vc(h-b) \, ,$$

where,

h is hydraulic head
Sy=0.2 is specific yield
Vc=0.05/dy is vertical conductance
b=65 ft is layer bottom,

with a solution of $h = 65\,ft + (5\,ft)e^{-t/4dy}$

A comparison of numerical and analytical solutions is shown on the figure below:

.

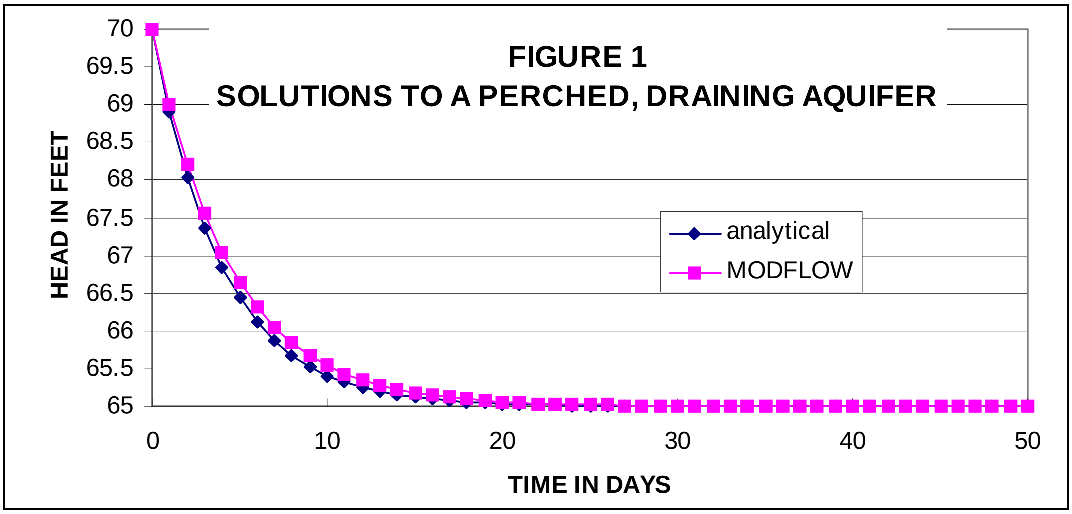


Figure 1 shows that the isolated layer drains as expected, with a reasonable match of the analytical solution. Furthermore, a 1-point implicit finite difference spreadsheet solution exactly matched the MODFLOW solution. Inspection of the mass balance table in the simulation output also shows that the water from Layer 1 enters aquifer storage or exits through constant heads in the active Layers 10-14.

Fifth, the problem was modified to test the transfer of storage. The bottom of Layer 1 is re-specified at 69.1 feet. The simulation is run for a 1 day time step, during which Layer 1 goes dry. Inspection of the mass balance table in the simulation output shows that the correct volume of storage flows from Layer 1:

$$(39 \text{ rows}) \times (39 \text{ columns}) \times (125 \text{ ft})^2 \times (0.9 \text{ ft}) \times (0.2) = 4.2778 \times 10^6 \text{ft}^3$$

The Layer 1 storage entering the model exits the model as storage or constant head flow in the active Layers 10-14.

MODIFICATIONS TO BOUNDARY CONDITION MODULES

The following sections describe mostly minor modifications that are used to specify boundary conditions to a groundwater flow domain, including modules RCH1, EVT1, WEL1 and DRN1.

Modifications to Module WEL1

The original WEL package (McDonald and Harbaugh, 1988) has been modified to shift pumping down to the uppermost active layer when the assigned cell for a well is dry. This vertical flux transfer serves to maintain the total specified pumping flow for a simulated well that is completed in several layers. Prior to modification, MODFLOW removes pumping from the simulation when a cell goes dry; vertical flux transfer therefore eliminates the need to re-partition pumping between layers and re-specify WEL package input every time a cell goes dry. Vertical flux transfer is accomplished by means of an extra variable in the WELL array that serves as a flag indicating whether vertical transfer is to be used for a given well. Modifications to WEL1AL, WEL1RP, WEL1FM and WEL1BD are indicated in bold text.

Modifications

In subroutine WEL1AL the dimensioning of array WELL is 5* MXWEL instead of 4* MXWEL. Modified code is indicated by bold text in the line following comment **C4**. The new dimension of WELL is also indicated by bold text in the DIMENSION statements of WEL1RP, WEL1FM and WEL1BD.

In subroutine WEL1RP the READ statement in the fifth line following comment **C5** has been modified to also read a vertical transfer flag. Modified code is indicated by bold text.

In subroutine WEL1FM, vertical transfer is performed in the bold text following comment **C2aa**.

In subroutine WEL1BD, vertical transfer is performed in the bold text following comment **C5aa**.

Input Records

Record 1 is read by module WEL1AL and *is read once for a simulation*.

record 1	variable:	MXWEL	IWELCB			
	format:	I10	I10			

Records 2 and 3 are read by module WEL1RP and *are read once for each stress period*.

record 2	variable:	ITMP				
	format:	I10				
record 3	Read ITMP times when ITMP>0. Not read when ITMP≤0.					
	variable:	LAYER	ROW	COLUMN	RATE	IVTF
	format:	I10	I10	I10	F10.0	I10

Explanation of Variables

1. MXWEL : Maximum number of wells in any stress period.
   IWELCB : Flag and unit number for node-by-node WEL output.
   If IWELB>0, well flows are saved unformatted on unit number IWELCB whenever the flag ICBCFL from the OC Package is nonzero.
   If IWELCB<0, well flows are printed to the main output file. In the future they will be printed to unit number -IWELCB.
   If IWELCB=0, well flows are not printed or saved.
2. ITMP : If ITMP≥0, ITMP is the number of wells used in the current stress period.
   If ITMP<0, the well list from the previous stress period is reused.
3. LAYER : Layer of well cell/node.
   ROW : Row of well cell/node.
   COLUMN : Column of well cell/node.
   RATE : Pumping rate of well.
   IVTF : Vertical transfer flag for well.
   If IVTF is not equal to zero, vertical transfer is performed.
   If IVTF is equal to zero, vertical transfer is not used.

Modifications to Module DRN1

The Drain Package has been modified from its original version (McDonald and Harbaugh, 1988). The function of the Well Package has been incorporated into the Drain Package. The modification allows a convenient representation of pumping wells, in which a well may pump a specified rate or a head-dependent rate. Vertical flow transfer may be used with the Well package function of DRN.

Modifications

In subroutine DRN1AL a vertical transfer is read following comment **C2**. The dimension of array DRAI is 6* MXDRN instead of 5* MXDRN. Modified code is indicated by bold text in the line following comment **C4**. The new dimension of DRAI is also indicated by bold text in the DIMENSION statements of DRN1RP, DRN1FM and DRN1BD.

In subroutine DRN1RP the READ statement in the fifth line following comment **C7** has been modified to also read a pumping rate. Modified code is indicated by bold text.

In subroutine DRN1FM the function of the Well Package is performed in the bold text following comment **C3b**. Vertical transfer for the Well package function is performed in the bold text following comment **C3a**.

In subroutine DRN1BD the function of the Well Package is performed in the bold text following comment **C5c** and indicated by bold text in the lines following comments **C5a** and **C9**. Vertical transfer for the Well package function is performed in the bold text following comment **C5b**.

Input Records

Record 1 is read by module DRN1AL and *is read once for a simulation*.

record 1	variable:	MXDRN	IDRNCB	ID1VT		
	format:	I10	I10	I10		

Records 2 and 3 are read by module DRN1RP and *are read once for each stress period*.

record 2	variable:	ITMP					
	format:	I10					
record 3	Read ITMP times when ITMP>0. Not read when ITMP≤0.						
	variable:	LAYER	ROW	COLUMN	HEAD	COND	RATE
	format:	I10	I10	I10	(3F10.0)		

Explanation of Variables

1. MXDRN : Maximum number of drains in any stress period.
   IDRNCB : flag and unit number for node-by-node DRN output.
   If IDRNCB>0, drain flows are saved unformatted on unit number IDRNCB whenever the flag ICBCFL from the OC Package is nonzero.
   If IDRNCB<0, drain flows are printed to the main output file. In the future they will be printed to unit number -IDRNCB.
   If IDRNCB=0, drain flows are not printed or saved.
   ID1VT : Vertical transfer flag. If ID1VT is not zero, vertical transfer is used for the well function part of DRN : Pumping (RATE in record 3) is placed in the uppermost active layer.
2. ITMP : If ITMP≥0, ITMP is the number of drains used in the current stress period.
   If ITMP<0, the drain list from the previous stress period is reused.
3. LAYER : Layer of drain cell/node.
   ROW : Row of drain cell/node.
   COLUMN : Column of drain cell/node.
   HEAD : Elevation of drain.
   COND : Conductance of drain.
   RATE : Pumping rate of well

Modifications to Module RCH1

The areal Recharge Package, version 1, RCH1 (McDonald and Harbaugh, 1988), has been modified to include a seasonal input option. When the seasonal option is invoked, the RCH1 input file is rewound and recharge data from the first stress period are used. The seasonal option may be seen in subroutine RCH1RP in the bold text following comment **C2**. Following are revised input instructions. The seasonal input option is described in Record 2 (INRECH).

Input Records

Record 1 is read by module RCH1AL and *is read once for a simulation.*

record 1.

variable:	NRCHOP	IRCHCB
format:	I10	I10

Records 2-4 are read by module RCH1RP and *are read once for each stress period.*

record 2.

variable:	INRECH	INIRCH
format:	I10	I10

record 3. Read if INRECH is greater than or equal to 0.
variable: RECH(NCOL,NROW)
format: U2DREL

record 4. Read if NRCHOP=2 and INIRCH is greater than or equal to 0.
variable: IRCH(NCOL,NROW)
format: U2DINT

Explanation of Variables

<u>record 1</u>

NRCHOP : RCH option.
If NRCHOP=1, recharge is specified for the top layer.
If NRCHOP=2, the user specifies the recharge layer at each horizontal location using array IRCH.
If NRCHOP=3, recharge is applied to the top-most active layer. If the top-most active layer at a given horizontal location is a constant head cell/node, recharge is not applied to that location.

IRCHCB : flag and unit number for node-by-node RCH output.
When IRCHCB>0, node-by-node terms are recorded on unit IRCHCB.

<u>record 2</u>

INRECH : recharge rate (RECH) read flag.
If INRECH is greater than or equal to 0, RECH is read.
If INRECH=-1, RECH from the previous stress period is used.
If INRECH<-1, the input file is rewound and RCH input for the first stress period is read.

INIRCH : Layer indicator (IRCH) read flag.
If NRCHOP=2 and INIRCH is greater than or equal to 0, IRCH is read. Otherwise (if NRCHOP=2), IRCH from the previous stress period is used.

<u>record 3</u>

RECH : recharge rate (L/t).

<u>record 4</u>

IRCH : Layer indicator array. Used if NRCHOP=2. At each horizontal location, IRCH indicates the layer to which recharge is applied.

Modifications to Module EVT1

The Evapotranspiration Package, version 1, EVT1 (McDonald and Harbaugh, 1988), has been modified to include a seasonal input option. When the seasonal option is invoked, the EVT1 input file is rewound and recharge data from the first stress period are used. The seasonal option may be seen in subroutine EVT1RP in the bold text following comment **C2**. Following are revised input instructions. The seasonal input option is described in Record 2 (INSURF).

Input Records

Record 1 is read by module EVT1AL and *is read once for a simulation.*

record 1.

variable: NEVTOP IEVTCB
format: I10 I10

Records 2-6 are read by module EVT1RP and *are read once for each stress period.*

record 2.

variable: INSURF INEVTR INEXDP INIEVT
format: I10 I10 I10 I10

record 3. Read if INSURF greater than or equal to 0.
variable: SURF(NCOL,NROW)
format: U2DREL

record 4. Read if INEVTR greater than or equal to 0.
variable: EVTR(NCOL,NROW)
format: U2DREL

record 5. Read if INEXDP greater than or equal to 0.
variable: EXDP(NCOL,NROW)
format: U2DREL

record 6. Read if NEVTOP=2 and INIEVT greater than or equal to 0.
variable: IEVT(NCOL,NROW)
format: U2DINT

Explanation of Variables:

record 1.

NEVTOP : ET option.
1 - ET is calculated for the top layer.
2 - the user specifies the ET layer at each horizontal location using array IEVT.

IEVTCB : flag and unit number for node-by-node EVT output.
When IEVTCB>0, node-by-node terms are recorded on unit IEVTCB.

record 2.

INSURF : ET surface (SURF) read flag.

If INSURF greater than or equal to 0, SURF is read.

If INSURF=-1, SURF from the previous stress period is used.

If INSURF<-1, the input file is rewound and EVT input for the first stress period is read and used.

INEVTR : Maximum ET rate (EVTR) read flag. If INEVTR is greater than or equal to 0, EVTR is read.

Otherwise, EVTR from the previous stress period is used.

INEXDP : Extinction depth (EXDP) read flag. If INEXDP is greater than or equal to 0, EXDP is read.

Otherwise, EXDP from the previous stress period is used.

INIEVT : Layer indicator (IEVT) read flag. If NEVTOP=2 and INIEVT greater than or equal to 0, IEVT is read. Otherwise (if NEVTOP=2), IEVT from the previous stress period is used.

record 3: SURF : ET surface elevation.

record 4: EVTR : Maximum ET rate.

record 5: EXDP : Extinction depth.

record 6: IEVT : Layer indicator array. Used if NEVTOP=2.

At each horizontal location, IEVT indicates the layer from which ET is taken.

DOCUMENTATION FOR RIV2

The River Package, version 2 (RIV2), developed by the USGS (Miller, 1988) is a FORTRAN package for the U.S. Geological Survey Modular Groundwater Flow Model, MODFLOW (McDonald and Harbaugh, 1988). RIV2 has been modified to allow unformatted output of streamflow, to include a seasonal input option, to allow input of new river reach data while repeating river node data and to allow input of new river node data while repeating river reach data. In addition, river recharge is now placed in the uppermost active layer. The capability to simulate diversion of river flow and optional transfer and re-injection of diverted flow to a new location has also been added. This diversion capability was added through a set of subroutines that all include the characters “DIV1” in their names. Input data for the diversion capability is in a file that is separate from the RIV2 input file.

RIV2 Narrative (from Miller, 1988)

The main features of RIV2 are:

1. The river system is divided into reaches and simulated river discharge is routed from one reach to another in a specified sequence. Within a reach, river discharge is routed from one node to the next.
2. Inflow (river discharge) entering the upstream end of a reach can be specified.
3. More than one river can be represented at one node and rivers can cross, as when representing a siphon.
4. The quantity of leakage to or from the aquifer at a given node is proportional to the hydraulic-head difference between that specified for the river and that calculated for the aquifer. Also, the quantity of leakage to the aquifer at any node can be limited by the user and, within this limit, the maximum leakage to the aquifer is the discharge available in the river. This feature allows for the simulation of intermittent rivers and drains that have no discharge routed to their upstream reaches.
5. An accounting of river discharge is maintained.

Neither stage-discharge relations nor storage in the river or river banks is simulated.

The modeling concepts necessary for the operation of RIV2 differ little from those for RIV1. The differences are largely due to features adapted from the modeling code of Posson et al. (1980) and Hearne (1982). The RIV2 code represents a number of nodes that simulate leakage from or to an overlying river. Certain features of a river that would be essential in a surface-water model, such as storage in the channel or banks, are not represented because RIV2, like RIV1, is considered to be a boundary condition in a ground-water model, not a surface-water model.

The rate of leakage at each node is directly proportional to the difference between the hydraulic head in the aquifer and the stage of the river, but is limited to the lesser of either a user-specified maximum or the intermittent and ephemeral rivers. Leakage from the aquifer to the river is not limited in RIV2.

The user needs to supply the hydraulic-connection coefficient, the limiting maximum rate of leakage to the aquifer, and the river stage for each node. It is possible for the user to re-specify the river characteristics (stage, hydraulic-connection coefficient, and limiting maximum rate of leakage to the aquifer and river stage) for each stress period. They hydraulic-connection coefficient, CRIV, may be defined as the conductance of the reach of the riverbed with units of length squared per unit time:

$$CRIV = K' A'/b$$

where K' = vertical hydraulic conductivity of the riverbed material
A' = area of the river channel; and
b = thickness of the riverbed material

The river discharge for a node is equal to the river discharge into the node minus the leakage to the aquifer or plus the leakage from the aquifer. The river stage, the wetted perimeter of the river channel, and the conductance of the riverbed material in a river vary with the discharge of the river. The constant values used in RIV2 limit its accuracy, but the error probably is not as great as it would be if the aquifer were allowed to gain more water from the river than the river contained.

The river-discharge-routing procedure in RIV2 uses a higher order structure that is not used in RIV1. A river, as represented in the framework of the model, consists of one or more reaches, and each reach consists of one or more nodes. (This definition of the term "reach" is distinctly different from that of RIV1.) A node may be part of more than one river reach. The river discharge at the upstream end of a reach consists of the river discharge from upstream reaches plus any user-specified tributary inflow. The river discharge from the downstream end of a reach may be routed to any downstream reach. The structure allows representation of tributaries.

RIV2, like RIV1, separates the leakage term into explicit and implicit parts. The explicit part of the leakage term is added to the variable RHS. (RHS is the right side of a finite-difference equation and is an accumulation of the terms that are independent of hydraulic head at the current time step. Terms in RHS are defined by various model packages.) The term added to RHS may have either of two forms. If the hydraulic head computed for the aquifer during the previous iteration was greater that the hydraulic head required to produce the limiting value of leakage to the aquifer, then the following FORTRAN assignment is made:

$$RHS = CRIV * HRIV$$

where, HRIV is the river stage, and other terms are as previously defined. If the hydraulic head computed for the aquifer during the previous iteration was less than or equal to the hydraulic head required to produce the limiting value of leakage to the aquifer, then the assignment is:

$$RHS = RHS - CRIV * (HRIV - HMIN)$$

where, HMIN is the hydraulic head required to produce the limiting value of leakage to the aquifer, and other terms are as previously defined.

The implicit part of the leakage term is added to the variable HCOF. (HCOF) is the coefficient of hydraulic head for the node (J, I, K) in the finite-difference equation.) The implicit term may, like the explicit term, have either of two forms. If the hydraulic head computed for the aquifer during the previous iteration was greater than the hydraulic head required to produce the limiting value of leakage to the aquifer, then the following FORTRAN assignment is made:

$$HCOF = HCOF - CRIV$$

where, all terms are as previously defined. The implicit term is zero when the hydraulic head computed for the aquifer during the previous iteration was less than or equal to the hydraulic head necessary to produce the limiting value of leakage to the aquifer. In this instance, the leakage term included in the solution algorithm is explicit.

Modifications

The following are modifications to the original RIV2 Package:

The River Package, version 2, RIV2, has been modified to allow unformatted output of streamflow. Streamflow for each river node is saved when the flag IDQ (record 1) is set.

RIV2 has been modified to include a seasonal input option. The RIV2 input file is rewound, and river data from the first stress period re-read, when the flag ITMP (record 3) is less than -1.

RIV2 has been modified to allow input of new river reach data while repeating river node data. River reach data will be read, and river node data repeated, when the flag IREAC (record 3) is set.

RIV2 has been modified to allow river leakage to be placed in the uppermost active model layer. The flux transfer option is invoked by the flag IR2VT in record 1 below.

DIV1**,** which is a subpackage to RIV2, has been developed to expand the capabilities of the River Package. DIV1 permits a portion of existing river flow to be diverted and routed to another location in the model. Streamflow is subtracted from a user specified river node. All or part of the flow is added directly to the RHS vector of a user specified model cell.

Input Records

Records 1 and 2 are read by module RIV2AL and are *read once for a simulation*:

<u>record 1</u>

Data:	MXRIVR	IRIVCB	IDQ	IDIV	IR2VT
Format:	I10	I10	I10	I10	I10

<u>record 2</u>

Data:	MXREAC
Format:	I10

Records 3, 4, 5 and 6 are read by module RIV2RP and are *read each stress period*.

<u>record 3</u>

Data:	ITMP	IREAC
Format:	I10	I10

<u>record 4</u>

Data:	NR
Format:	I10

<u>record 5</u> read NR times.

Data:	NREA	NNRE	RQIN	NADD
Format:	I10	I10	F1O.0	I10

(record 5 consists of one record for each river reach active during the current stress period. The reaches need to be specified in downstream order.)

<u>record 6</u> read ITMP times, when ITMP>0.

Data:	Layer	Row	Column	STAGE	COND	QMAX
Format:	I10	I10	I10	F10.0	F10.0	F10.0

(record 6 consists of one record for each river node active during the current stress period. The nodes need to be specified in downstream order, consistent with the specification of the river reaches.)

Explanation of Variables

<u>record 1</u>
MXRIVR is the maximum number of river nodes active at one time.
IRIVCB is a flag and a unit number.
If IRIVCB > 0, then node-by-node flow terms will be recorded on unit IRIVCB whenever ICBCFL (see Output Control) is set.
If IRIVCB = 0, then node-by-node flow terms will be neither printed nor recorded.
If IRIVCB < 0, then river leakage for each reach will be printed whenever ICBCFL is set.

IDQ is a flag indicating whether downstream flows are to be saved.
If IDQ ≠ 0, then streamflow for each river node will be recorded on unit IRIVCB whenever ICBCFL (see Output Control) is set.
If IDQ = 0, then streamflow will not be recorded.

IDIV is a flag and a unit number activating the DIV1 subpackage for river diversions.
If IDIV > 0 then DIVI is unit number from which DIV1 input is read (see input instructions below).

IR2VT is a flag for vertical transfer of river leakage.
If IR2VT=0, vertical transfer is not used: River leakage is placed in the specified layer, if active.
If IR2VT≠ 0, vertical transfer is used: River leakage is placed in the uppermost active layer.

<u>record 2</u> MXREAC is the maximum number of river reaches active at one time.

<u>record 3</u>
ITMP is a flag and a counter.
If ITMP <-1, the input file is rewound. River node data and river reach data from the first stress period are used.
If ITMP =-1, then river node data from last stress period will be re-used.
If ITMP ≥ 0, ITMP is the number of river nodes active during the current stress period.
IREAC is a flag for reading river reach data when ITMP=-1.
If IREAC = 0 and ITMP=-1, river reach data and river node data from the previous stress period are re-used. Records 4, 5 and 6 are not read.
If IREAC ≠ 0 and ITMP=-1, river reach data is read, but river node data from the previous stress period are re-used. Records 4 and 5 are read, and record 6 is not read.

<u>record 4</u> NR if NR<0, river reach data from the previous stress period are re-used.
if NR>0, NR is the number of river reaches active in the current stress period.

<u>record 5</u> **river reach data**
NREA is the river-reach number.
NNRE is the number of river nodes in the reach.
RQIN is the river discharge added at the upstream end of the reach.
NADD is the number of the downstream reach (zero, if none).

<u>record 6</u> **river node data**
LAYER is the layer number of the river node.
ROW is the row number of the river node.
COLUMN is the column number of the river node.
STAGE is the hydraulic head in the river.
COND is the riverbed hydraulic conductance.
QMAX is the maximum allowable leakage to the aquifer.

DOCUMENTATION FOR DIV1

DIV1 enables water to be diverted from a river channel and permits the optional transfer of the diverted water to another location within the model. This feature allows the simulation of processes such as the extraction of river water for application to agricultural lands, direct recharge of a reservoir or unspecified municipal/industrial use. Multiple diversions may be made, each being extracted from a single river node and re-injected into a single model cell. Each diversion is specified using the following variables:

NODE = RIV2 node from which water is to be diverted. $NODE \in (1, MXRIVR)$

Qd = maximum rate of water to be diverted. The actual flow diverted by DIV1 is the minimum of Qd and available river flow.

Qa = That portion of Qd assumed to be accounted for elsewhere, not to be re-injected by DIV1. Qa may represent water put into the model by other MODFLOW packages or water removed from the simulation. The amount of water diverted over Qa is re-injected.

ILAY, IROW, ICOL = The layer, row and column indices of the cell into which diverted water is re-injected.

For each RIV2 node (node number) to be diverted from, subroutine DIV1RP sets a flag in MXRIVR(7,NODE) to indicate the diversion. As subroutine RIV2FM is looping through river nodes it checks the flag for diversions. When diversions are found, RIV2FM calls subroutine DIV1FM to perform the diversion.

The amount of water diverted is computed as the minimum of Qd and available river flow:

$$Qdiverted = \min(Qd, Q(NODE))$$

where, Q(NODE) is the streamflow at the river node.

The amount of water re-injected is the difference between the amount diverted and Qa:

$$Qreinjected = \max(0, Qdiverted - Qa)$$

Input Records

Records 1 is read by module DIV1AL and is read *once for a simulation*:

record 1

Data:	MXDIV	IDIVOT
Format:	I10	I10

Records 2, and 3 are read by module RIV2RP and are read *each stress period*

record 2

Data:	ITMP
Format:	I10

record 3

Read ITMP times when ITMP ≥ 0

Data:	NODE	ILAY	IROW	ICOL	QD	QA
Format:	I10	I10	I10	I10	F10.0	F10.0

Explanation of Variables

record 1
MXDIV is the maximum number of river diversions occurring during the simulation.
IDIVOT is a flag and a unit number.

If IDIVOT > 0, then node-by-node flow terms will be recorded on unit IDIVOT whenever ICBCFL (see Output Control) is set.

If IDIVOT = 0, then node-by-node flow terms will be neither printed nor recorded.

record 2
ITMP is a flag and a counter.

If ITMP <0, information from the previous stress period is repeated. River reach data from the first stress period is used.

If ITMP ≥ 0, ITMP is the number of river nodes active during the current stress period.

record 3
NODE is the river node number as defined in RIV2 (from 1 to MXRIVR) from which water is to be diverted.
ILAY is the layer number of the location for the re-injection of diverted water
IROW is the row number of the location for the re-injection of diverted water
ICOL is the column number of the location for the re-injection of diverted water
QD is the volume of water diverted from the river
QA is the volume of water re-injected into the modeled system

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APPENDIX: DOCUMENTATION FOR MODULE LAK2

DOCUMENTATION OF LAK2: A COMPUTER PROGRAM TO SIMULATE THE PRESENCE OF LAKES AND OTHER OPEN WATER BODIES WITHIN A GROUNDWATER FLOW SYSTEM USING THE MODFLOW GROUNDWATER FLOW MODEL

ABSTRACT

LAK2 is a module for the U.S. Geological Survey Modular Groundwater Flow Model (MODFLOW) that simulates the interconnection between a groundwater system and an adjacent open water body such as a lake, an open pit or a well bore.

The module has been in use since 1998. Although other modules have subsequently been published (lake package, USGS OFR 00-4167 and Multi-Node Well Package, USGS OFR 02-293) that perform some of the same functions, these only provide stable and accurate solutions for a limited range of problems, and break down under strongly transient or nonlinear conditions, when aquifer water level and "lake" water level are each sensitive to the other.

The main difference between LAK2 and other modules is the method used to solve two parallel but interdependent (coupled) sets of equations governing (1) groundwater levels and flows and (2) "lake" water levels and flows. Other modules solve partially decoupled forms of the equations with good results for a limited range of problems, but with slow convergence, instability and mass balance errors for other applications. LAK2 solves the fully coupled system of equations and provides efficient, stable, convergent solutions without mass balance errors.

LAK2 was first reviewed and accepted for use in the state of Nevada for simulation of post-mining water level recovery in an open pit (BLM, 2000). LAK2 has since been applied to pit-filling simulations for sites in Nevada, New Mexico, Canada, Chile, and Tanzania. Other applications have involved modeling borehole hydraulics and wells intersecting multiple model cells. Further applications potentially include the representation of natural lakes, caverns or other open spaces linked to a groundwater system.

This report presents LAK2 documentation and selected applications including:

- Module documentation: Presentation of algorithm, input instructions and simple test case.
- Archimedes pit: Demonstration of the representation of lake (pit) geometry and water balance, projection of future water level and water balance.
- Ortiz pit: Calibration of a groundwater flow model to historical pit water levels, post-audit of water level projections.
- Belen municipal well: Representation of a well pumping from multiple layers, correcting the erratic numerical solution previously obtained.
- Fan Sediments aquifer test: Simulation of borehole water levels for analysis of aquifer test results and projection of future pumping water levels.

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DOCUMENTATION OF LAK2: A COMPUTER PROGRAM TO SIMULATE THE PRESENCE OF LAKES AND OTHER OPEN WATER BODIES WITHIN A GROUNDWATER FLOW SYSTEM USING THE MODFLOW GROUNDWATER FLOW MODEL

INTRODUCTION

This report describes a module that has been used since 1998 to solve the fully coupled system of equations describing groundwater flow and lake/water body mass balance. The module applies to both larger-scale water bodies such as open pits and smaller-scale bodies such as well bores.

Previous Work

Software for modeling of lakes in conjunction with surrounding groundwater systems, using the U.S. Geological Survey Modular Groundwater Flow Model (MODFLOW), dates back to at least 1993 (Cheng and Anderson, 1993). Other lake modules developed for MODFLOW include those by HSI Geotrans (Council, 1999) and most recently by USGS (Merritt and Konikow, 2000). Another module was developed to represent well bores intersecting multiple model cells (Halford and Hanson, 2002).

All of these modules utilize an algorithm that treats the mass balance equation governing lake stage as if it were decoupled from the equations governing the groundwater system. They have been successfully used to represent natural lakes with little change, or slow change, in water level and they work acceptably well for a range of applications where lake stage does not strongly influence groundwater heads and where simulation time steps are sufficiently small so that the lake stage does not change too much in a single time step.

The decoupling of equations is done as follows: MODFLOW iteratively solves the system of equations governing groundwater head. The equation governing lake stage is then solved, after the iterative process has finished. Because groundwater head and lake stage are mutually dependent variables, errors result in both groundwater and lake solutions.

The decoupled solution algorithms break down for strongly transient problems, such as recovery of water level in an open pit after mining has ceased, or for highly sensitive problems where lake stage strongly influences groundwater levels. Mass balance errors become large and stability or convergence limits require impractically short time step lengths with long model run times.

The module described here solves the fully coupled system of equations describing groundwater flow and lake mass balance. The equations governing lake stage are solved at each iterative step of the groundwater flow solution process, thus simultaneously solving for lake stage and groundwater head. The algorithm produces stable, efficient and convergent solutions without mass balance error.

Structure of Report

This report includes the following chapters:

1. Module documentation: Presentation of algorithm, input instructions and simple test case.
2. Application: Archimedes pit. Representation of lake (pit) geometry and water balance, projection of future water level and water balance.
3. Application: Ortiz pit. Calibration of a groundwater flow model to historical pit water levels, post-audit of water level projections.
4. Application: Belen municipal well. Representation of a well pumping from multiple layers, correcting the erratic numerical solution previously obtained.
5. Application: Fan Sediments aquifer test. Simulation of borehole water levels for analysis of aquifer test results and projection of future pumping water levels.

1.0 DOCUMENTATION

1.1 LAKE WATER BALANCE

Groundwater flow systems can be influenced by stationary surface water features (lakes) including natural lakes, constructed reservoirs, retired mine pits and wetlands. Lakes can function as hydraulic sinks with groundwater inflow, as hydraulic sources of groundwater recharge or as flow-through lakes with both groundwater inflow and groundwater outflow. A lake may serve to connect distinct parts of a groundwater flow system.

Lake water balance components are illustrated on Figure 1.1 and can include:

- direct precipitation and runoff from surface catchment
- evaporation of water from lake surface
- groundwater inflow
- inflow from surface streams
- groundwater outflow
- surface water outflow

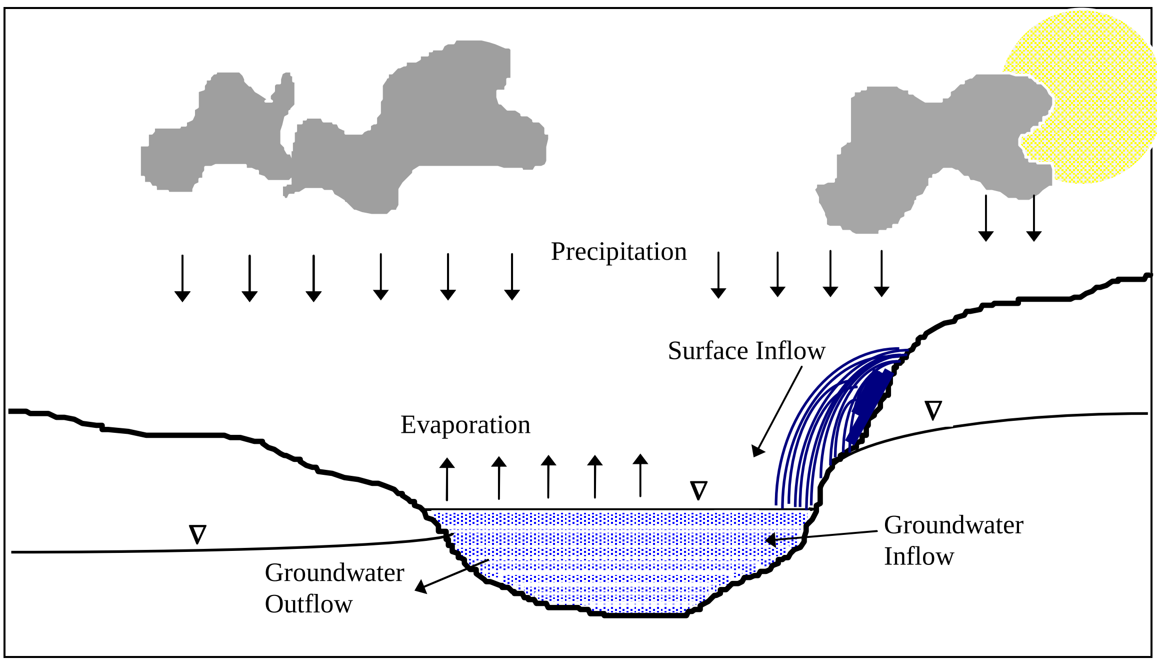

Figure 1.1 Components of lake water balance.

The governing equation for lake stage used by LAK2 is

$$\frac{\partial H_{LAKE}}{\partial t} = \frac{1}{A_{LAKE}}\{Q_{str\,in} - Q_{str\,out} + P - E + Q_{gw} - W\} \qquad (1)$$

where:

H_{LAKE} is the lake water surface elevation (L).
A_{LAKE} is the water surface area of the lake at stage HLAKE (L^2).
Q_{strin} is the rate of streamflow into the lake (L^3/t).
Q_{strout} is the rate of streamflow out of the lake (L^3/t).
P is the rate of precipitation inflow to the lake (L^3/t).
E is the rate of evaporation from the lake (L^3/t).
Q_{gw} is the net rate of groundwater flow to the lake (L^3/t).
W is the rate of pumping or other diversion out of or into the lake (L^3/t).

1.1.1 Geometric Representation of Lake

A lake is defined by a list of cells (lake cells) in the groundwater flow domain that are connected to the lake. A conceptual view is shown on Figure 1.2, indicating lake cells (groundwater cells connected to the lake) and inactive cells (not part of the groundwater domain).

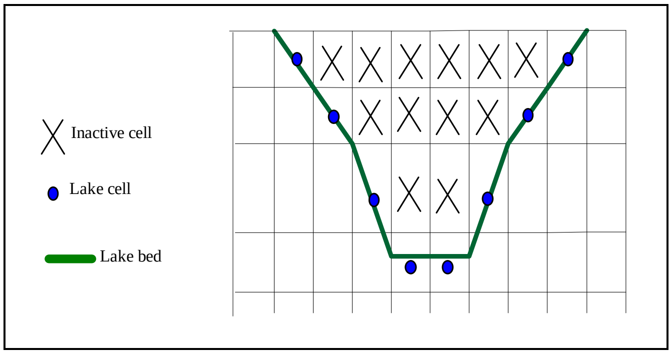

Figure 1.2. Cross-sectional view of a lake in a MODFLOW grid.

Each lake cell is specified with a lakebed minimum elevation, lakebed maximum elevation and maximum water surface area.

Water surface area of the lake is computed by summing the contribution of each cell to the total water surface. The contribution for a cell is equal to zero when lake water level is at or below the lakebed minimum elevation, increasing linearly with lake water level to the maximum water surface area when lake water level is at or above the lakebed maximum elevation.

The bottom of a lake is the lowest lakebed minimum elevation among the lake nodes. Two options exist for representation of the lake bottom:

1. A flat bottom lake is defined when the lakebed minimum elevation is equal to lakebed maximum elevation for the lowermost cell(s) of the lake.
2. A non-flat bottom lake is defined when the lakebed minimum elevation is lower than the lakebed maximum elevation for the lowermost cell(s) of the lake.

The two types of lake bottom have different implications for Equation (1) above when water level is near the lake bottom elevation. For a non-flat bottom, the water surface area A_{LAKE} approaches zero as water level approaches bottom elevation. For a flat bottom, the water surface area A_{LAKE} approaches a nonzero constant as water level approaches bottom elevation. For both types, A_{LAKE} is zero when the lake is dry (water level equal to bottom elevation) and Equation (1) is undefined. Lake bottom type is considered in the computation of the components of Equation (1) and in the handling and rewetting of dry lakes.

1.1.2 Stream Connections

LAK2 is configured to recognize surface water inflows and outflows simulated using the streamflow routing package RIV2 (Miller, 1988, Jones, 2010). RIV2 has been developed to provide the streamflow routing function in an efficient and simple way without surface water mass balance errors. Other streamflow routing modules for Modflow could readily be utilized by LAK2 with minor code changes.

A list of RIV2 reaches may be specified to flow into a LAK2 lake. The simulated streamflow at the bottom node of each inflowing reach is added to Q_{strin} in Equation (1).

A single RIV2 reach may be specified to flow out of a lake at a specified spill elevation. Spill from the lake, Q_{strout} in Equation (1), is computed by setting water level equal to spill elevation and then computing the resulting water surplus. The simulated inflow at the top node of the outflowing reach is set equal to spill from the lake.

Note: Other lake modules including (Merritt and Konikow, 2000) have used a Manning equation to estimate a spill rating curve and thus compute spill as a function of water level above spill elevation. To date, the models to which LAK2 has been applied have not been concerned with the small margin of water level above spill elevation. A Manning equation-based spill computation could be readily implemented into LAK2 with minor code changes.

1.1.3 Precipitation

Total precipitation inflow to a lake consists of direct precipitation on the water surface as well as runoff from the surface catchment above the lake water level. A runoff coefficient for each lake cell is specified to define the portion of precipitation that runs off to the lake from areas above the lake water level.

Total precipitation inflow to the lake is computed as precipitation multiplied by water surface area, plus precipitation multiplied by runoff coefficient multiplied by catchment area above the lake water level, or

$$P=p[\ \alpha\ A_{MAX} + (1-\ \alpha)\ A_{LAKE}] \qquad (2)$$

where

p is precipitation rate over the lake (L/t).
α is runoff coefficient for the lake cell.
A_{MAX} is the maximum water surface area of the lake cell (L^2).
A_{LAKE} is the actual water surface area of the lake cell (L^2).

Note that the right-hand side of equation (2) represents a summation over the individual lake cells defining a lake, each cell having its own α, A_{MAX} and contribution to A_{LAKE}.

1.1.4 Evaporation

Lake evaporation is computed as

$$E = eA_{LAKE} \qquad (3)$$

where

e is evaporation rate over the lake (L/t).

<u>Evaporation/Evapotranspiration from ephemeral, flat-bottom lakes</u>

If groundwater level is close to a flat lake bottom, groundwater evapotranspiration (ET) may occur when the lake is dry. LAK2 recognizes this condition and adds boundary conditions to each lake cell on a dry lake bottom equivalent to those added by the EVT1 module (McDonald and Harbaugh, 1988). An extinction depth is specified for each flat bottom lake to define the reduction of ET with depth. ET is zero if the lake is not dry. ET rate is equal to e when groundwater head is at the lakebed elevation, decreasing linearly to zero when groundwater head drops to extinction depth below the lake bottom. Simulated ET is included as part of the “groundwater inflow” and “evaporation” components of the lake water balance.

Other considerations arise in the computation of evaporation over a discrete time step in which a flat bottom lake is dry or becomes dry. Evaporation in this case is reduced from the maximum rate by limiting evaporation to lake inflow, reflecting the evaporation of all available water in only part of the time step. If, in addition, groundwater levels are close to the lake bottom, maximum ET rate is specified such that the sum of lake evaporation and maximum ET rate is equal to the evaporation rate e, reflecting evaporation for one part of the time step and ET for the other part.

1.1.5 Groundwater Flow

Groundwater flow into and out of the lake is computed based on the difference between lake water level and groundwater head at each lake cell, multiplied by lake cell conductance. The conductance of each lake cell is specified as described in Numerical Implementation below.

Conductance for each lake cell is adjusted based on water levels. Conductance is equal to the specified (maximum) conductance when either lake water level or groundwater level is above the lakebed maximum elevation. Conductance is equal to zero when water level is below the lakebed minimum elevation. Conductance decreases linearly for water levels between the lakebed maximum and lakebed minimum elevations.

Groundwater flow to or from lake cell n is computed as

$$Q_n = -C_n(\max[H_{LAKE}, BOTLK_n] - \max[H_n, BOTLK_n])$$

where

Q_n is the groundwater flux into the lake at lake cell n (L3/t).
C_n is the conductance of lake cell n (L2/t).
H_n is the groundwater head in lake cell n (L).
$BOTLK_n$ is the lakebed minimum elevation in lake cell n (L): If HLAKE > $BOTLK_n$, the lake is wet at lake cell n. If HLAKE < $BOTLK_n$, the lake is dry at lake cell n.

Total groundwater inflow and outflow to the lake are equal to the respective sum of inflows and outflows from each lake cell. Net rate of groundwater flow to the lake is computed as $Q_{gw} = \sum_n Q_n$.

1.2 NUMERICAL IMPLEMENTATION

1.2.1 Discrete Equation

The discrete equation for lake stage used by LAK2 for a MODFLOW time step may be written as

$$\frac{\Delta S}{\Delta t} = P - E + Q_{gw} + Q_{strin} - Q_{strout} \quad (1)$$

where

$\Delta S = \int_{t0}^{t0+\Delta t} A_{LAKE} \frac{\partial H_{LAKE}}{\partial t} dt$ is the change in lake storage during the time step
t_0 is the beginning of the time step
Δt is the length of the time step

1.2.2 Change in Lake Storage

Change in lake storage is computed as

$$\Delta S = \sum_{n=1}^{N} \left[\int_{h1_n}^{h2_n} A_n \, dh \right]$$

where

$Hnew_{LAKE}$ is lake stage at the end of the time step
$Hold_{LAKE}$ is lake stage at the beginning of the time step

$h1_n = \max[Hold_{LAKE}, BOTLK_n]$

$h2_n = \max[Hnew_{LAKE}, BOTLK_n$

The above equation can be written in the form

(2)
$$\Delta S = D_0 + D_1 Hnew_{LAKE} + D_2\ Hold_{LAKE}$$
where

$$D_0 = \sum_{\{n \in [1,N] \mid Hnew_{LAKE} < BOTLK_n\}} A_n BOTLK_n - \sum_{\{n \in [1,N] \mid Hold_{LAKE} < BOTLK_n\}} A_n BOTLK_n$$

$$D_1 = \sum_{\{n \in [1,N] \mid Hnew_{LAKE} > BOTLK_n\}} A_n$$

$$D_2 = -\sum_{\{n \in [1,N] \mid Hold_{LAKE} > BOTLK_n\}} A_n$$

1.2.3 Precipitation

As above, lake precipitation is computed as

(3)
$$P = p\alpha A_{MAX} + p(1-\alpha)A_{LAKE}$$

1.2.4 Evaporation

As above, lake evaporation is computed as

(4)
$$E = eA_{LAKE}$$

1.2.5 Groundwater Flow

Groundwater flow to a lake is defined to be the sum of groundwater flow to each lake node:

(i)
$$Q_{gw} = \sum_{n=1}^{N} Q_n$$
where

Q_n is the groundwater flux to lake node n (L^3/t).

(ii)
$$Q_n = -C_n(\max[H_{LAKE}, BOTLK_n] - \max[H_n, BOTLK_n])$$
where

H_n is the groundwater head in lake node n

C_n is the lake bed conductance at lake node n (L^2/t).

Equation (ii) may be written in the form

(iv)
$$Q_n = R_n + \gamma_n H_{LAKE} + \beta_n H_n$$
where

βn	=Cn	if	Hn>BOTLKn		
	=0	if	Hn<BOTLKn		
γn	= -Cn	if	HLAKE>BOTLKn		
	=0	if	HLAKE<BOTLKn		
Rn	=CnBOTLKn	if	Hn<BOTLKn	and	HLAKE>BOTLKn
	= -CnBOTLKn	if	Hn>BOTLKn	and	HLAKE<BOTLKn
	=0	if	Hn,HLAKE<BOTLKn	or	

$H_n, H_{LAKE} > BOTLK_n$

Combining equations (i) and (iv) yields an equation of the form

$$Q_{gw} = \alpha + \beta_0 \mathrm{H}_{\mathrm{LAKE}} + \sum_{n=1}^{N} \beta_n \mathrm{H}_n \qquad (5)$$

where

$$\beta_0 = \sum_{n=1}^{N} \gamma_n$$

$$\alpha = \sum_{n=1}^{N} R_n$$

1.2.6 Lakebed Conductance

Lakebed conductance is specified by the LAK2 user. Conductance may be computed externally to the simulation as

C_n = (lakebed area)x(hydraulic conductivity)/(bed thickness).

Three models of lakebed conductance are shown on Figures 1.3a, b and c.

Lakebed area: If the lakebed is horizontal, then lakebed area is equal to lake cell surface area. Lakebed area may also be computed as lake cell surface area divided by the cosine of the average angle of lakebed inclination.

Hydraulic conductivity: Effective hydraulic conductivity for the zone crossed by the bold line in Figures 1.3a, b or c may be specified to compute conductance. If the lakebed is horizontal, a vertical hydraulic conductivity should be used. If the lakebed is vertical, a horizontal hydraulic conductivity should be used.

Bed thickness: Bed thickness for each of the three conductance models is indicated by the bold line in Figures 1.3a, b and c.

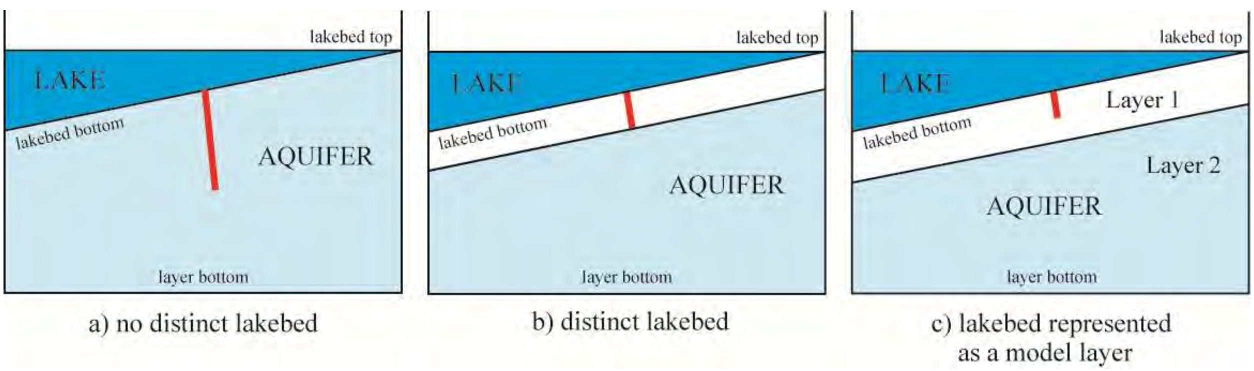

Figure 1.3. Models of lakebed conductance.

LAK2 adjusts conductance for each node to reflect partial saturation:

Let X= max (H_n,H_{LAKE}). Let $TOPLK_n$ = lakebed max elevation in lake cell n

1. If $X \geq TOPLK_n$, C_n is set to the user-specified conductance.
2. If $BOTLK_n < X < TOPLK_n$, C_n is set equal to the user-specified conductance times the factor

$$\left[\frac{X - BOTLK_n}{TOPLK_n - BOTLK_n}\right]$$

3. If $X \leq BOTLK_n$, C_n is set equal to zero

1.2.7 Interpolation of HLAKE

The lake stage used for computing Qgw in equations (3), (4) and (5) is defined by

(6) $$H_{LAKE} = \theta Hnew_{LAKE} + (1-\theta)Hold_{LAKE} ,$$

where

θ is a specified explicit/implicit parameter, with $0 \le \theta \le 1$.

$\theta=0$ is the explicit formulation of lake stage,
$\theta=1$ is the implicit formulation of lake stage and
$0<\theta<1$ is an intermediate formulation of lake stage.

In the explicit formulation, lake stage at the beginning of a time step is used to compute flow between the lake and the aquifer. Lake stage is updated at the end of each time step. The explicit formulation converges most easily, but is unstable for large time steps.

In the implicit formulation, lake stage at the end of a time step is used to compute flow between the lake and the aquifer. Lake stage is updated at the end of each iteration of the groundwater flow equation.

In an intermediate formulation, an intermediate stage is used to compute flow between the lake and the aquifer. Lake stage is updated at the end of each iteration of the groundwater flow equation.

The implicit formulation is used for all of the applications presented here, matching the implicit formulation of groundwater flow equations used by the Modflow module BCF.

1.2.8 Numerical Equation

The LAK2 code substitutes equations (2), (3), (4), (5) and (6) into equation (1) to get an equation for lake stage in the following form:

$$\alpha_0 Hnew_{LAKE} + \sum_{n=1}^{N} \beta_n H_n = RHS_{LAKE} \quad (7)$$

where

$$\alpha_0 = \frac{D_1}{\Delta t} + \theta\beta_0$$

$$RHS_{LAKE} = \frac{D_0}{\Delta t} + \frac{D_2}{\Delta t} Hold_{LAKE} + P - E + Q_{strin} - Q_{strout} + \alpha + (1-\theta)\beta_0 Hold_{LAKE}$$

equation (7) may be solved as

$$Hnew_{LAKE} = \frac{1}{\alpha_0}\{RHS_{LAKE} - \sum_{n=1}^{N} \beta_n H_n\}.$$

Because the equations for lake stage are nonlinear, equation (7) is formulated iteratively. Equation (7) is formulated and solved until computed lake stage in successive iterations changes by less than a specified tolerance, or until the specified maximum number of iterations are performed.

After completing iteration of equation (7), LAK2 modifies the groundwater flow equation for each lake node to reflect flow between aquifer and lake. Inserting equation (6) into equation (iv) above yields a modified form of equation (iv):

$$Q_n = R'_n + \gamma'_n Hnew_{LAKE} + \beta_n H_n \quad \text{(iv')}$$

where

$\gamma'_n = \gamma_n \theta$
$R'_n = R_n + \gamma_n (1-\theta) Hold_{LAKE}$

LAK2 modifies the MODFLOW equation for each lake node according to equation (iv') by adding boundary conditions to the HCOF and RHS arrays of the MODFLOW equation:

β_n is added to the HCOF entry for lake node n.
The term $R'_n + \gamma'_n Hnew_{LAKE}$ is added to the RHS array entry for lake node n.

On the subsequent iteration of the main MODFLOW equation, the iterative formulation and solution of lake stage is repeated and the MODFLOW equation is again modified.

1.3 Input Instructions

Input consists of parameters for the entire simulation, parameters for each lake, parameters for each lake and stress period and parameters for each lake node.

Parameters for the entire simulation include the following:

1. Total number of lake cells.
2. Number of lakes.
3. Unit number for main lake output file.
4. Unit number for cell by cell output.
5. Unit number for lakebed zone budget output.
6. Explicit/implicit parameter THETA.
7. Head change convergence criteria used in lake stage computation.
8. Maximum number of iterations allowed in lake stage computation.
9. Flow change convergence criteria, used when lake stage is at spill elevation.
10. Total number of river reaches flowing into lakes

Parameters for each lake include the following:

1. Number of lake cells
2. Initial water stage
3. Listing of inflowing river reaches, if any
4. Identification of outflowing river reach, if any
5. Spill elevation (lakes with outflowing river reaches only)
6. ET extinction depth (flat bottomed lakes only).

Parameters for each lake and stress period include the following:

1. Precipitation (L),
2. Evaporation (L) and
3. Pumping to/from the lake(L^3/t)

The following are input for each lake cell:

1. Lakebed maximum elevation (L),
2. Lakebed minimum elevation (L),
3. Water surface area (L^2),
4. Conductance (L^2/t)
5. Runoff coefficient ()
6. Zone number, for groundwater zone budgets. Groundwater flow to and from lake nodes may be broken down by zones. This allows, for example, computation of pit lake chemical balances based on groundwater flow from different rock types. Each lake node is assigned a zone number. Flow totals into and out of each zone are computed.

1.3.1 Input Records

For Each Simulation:
Record 1.

variable:	MXLKND	NLAKES	ILKC1	ILKC2	ILKC3	THETA	TOL	MXITER	TOL2	MXRIVIN
format:	I10	I10	I10	I10	I10	F10.0	F10.0	I10	F10.0	I10

For Each Lake:
Record 2. Read NLAKES times.

variable:	NODES	STAGE0	NRVIN	KRVOT	XSPIL	EXDP
format:	I10	F10.0	I10	I10	F10.0	F10.0

Record 3: Read when NRVIN > 0.

variable:	IRI(NRVIN)
format:	*

For Each Lake Node:
Record 4. Read MXLKND times.

variable:	ILAY	IROW	ICOL	COND	BOT	TOP	XAREA	IBZON	RUNCOF
format:	I10	I10	I10	F10.0	F10.0	F10.0	F10.0	I10	

For Each Stress Period:
Record 5.

variable:	ITMP
format:	I10

Record 6. Read NLAKES times.

variable:	XEVAP	XPREC	Q
format:	F10.0	F10.0	F10.0

1.3.2 Explanation of Variables

Record 1. Read once for a simulation/

MXLKND: total number of lake nodes.
NLAKES: number of lakes.
ILKC1: unit number for main lake output file.
ILKC2: flag and unit number for cell by cell output.
ILKC3: flag and unit number for lakebed zone budget output.
THETA: explicit/implicit parameter.
TOL: head change convergence criteria used in lake stage computation.
MXITER: maximum number of iterations allowed in lake stage computation.
TOL2: flow change convergence criteria, used when lake stage equals spill elevation.
MXRIVIN: total number of river reaches flowing into lakes

Record 2. Read NLAKES times.

NODES: number of nodes representing lake.
STAGE0: initial lake stage.
NRVIN: number of RIV2 reaches flowing into lake.
KRVOT: reach number of RIV2 reach flowing out of lake.
XSPIL: spill elevation for lake (L).
EXDP: extinction depth for playa surface.

Record 3. Read when NRVIN > 0.

IRI(NRVIN): reach numbers of RIV2 reaches flowing into lake.

Record 4. Read MXLKND times.

ILAY: layer of lake node.
IROW: row of lake node.
ICOL: column of lake node.
COND: maximum conductance of lake node (L2/t)
BOT: lowest lake bed elevation within lake node.
TOP: highest lake bed elevation within lake node.
XAREA: maximum area of horizontal water surface for node.
IBZON: zone number of lake node, used in computation of lakebed zone budget.
RUNCOF: runoff coefficient for lake node, defined to be the fraction of precipitation falling draining directly to lake ().

Record 5. Read once for each stress period.

ITMP: flag for reading evaporation rate, precipitation rate, and spill elevatiion.
If ITMP>0, record 7 is read.
If ITMP<0, values from the previous stress period are used.

Record 6. Read NLAKES times when ITMP>0.

EVAP: lake evaporation rate for stress period (L/t)
PRECIP: lake precipitation rate for stress period (L/t)
Q: pumping/withdrawal rate from lake (L3/t). A negative value signifies addition of water to the lake.

1.4 CODE VERIFICATION

1.4.1 Example 0: Large-diameter well recovery

The LAK2 stage computation is tested using a pair of MODFLOW simulations. Water level recovery in a large diameter well is simulated in two different ways, with and without LAK2. Results are then compared to confirm the basic functioning of the code.

1.4.2 Example 0a: Without LAK2

A sample grid is constructed with 100 rows, 100 columns and 2 layers. Each column and row has a width of 1000 units. A confined layer type (type 0) is specified. Initial head is specified as 0, except for a group of four layer 1 cells in the center of the grid (Fig. 1.4). The initial head at these cells is specified as -100. Storage coefficient is specified as 1 at the four cells and .001 everywhere else, Transmissivity for each layer is specified everywhere as .001 square units per second. Vertical conductance is specified as 10-9 /second. A 100 year recovery is simulated. By symmetry, head in each of the group of four cells is the same.

1.4.3 Example 0b: With LAK2

The model grid and aquifer parameters from the large diameter well recovery are retained. The four cells are specified as inactive cells. A lake is specified using twelve LAK2 cells as shown in Figure 1.4. An implicit lake stage computation is selected. Initial lake stage is specified as -100. Lake evaporation and precipitation are specified as 0. The four lake cells in the center are placed in layer 2 and are considered to lie underneath a horizontal lake bed. The eight cells on the perimeter are placed in layer 1 and are considered to lie next to a vertical lake bed.

Area of each of the four lake cells in the center is specified as row width times column width, or 10^6 square units. Area of the eight remaining lake cells is specified as zero.

Conductance of each of the four lake cells in the center is specified as vertical conductance times cell area, or 10^{-3} square units per second. Conductance of the eight lake cells on the perimeter is specified as transmissivity times row width divided by column width, also 10^{-3} square units per second. Lakebed minimum and maximum for each lake cell are specified at a level below initial stage, leading to constant conductance for each lake cell throughout the simulation.

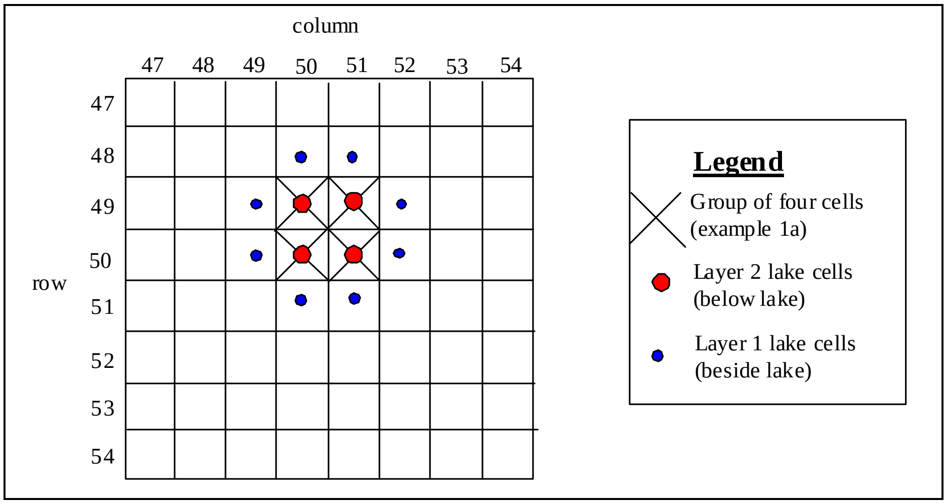

Figure 1.4. Layout of examples 0a and 0b.

1.4.4 Comparison of Results

The results of example 0a and example 0b are expected to be identical because

1. The specified area of the lake cells in example 0b matches the specified area of the group of four cells in example 0a. The storage coefficient of the group of four cells is specified as 1. The storage capacity of the lake is therefore identical to that of the group of four cells.
2. The specified conductances of the lake nodes match the specified horizontal and vertical conductances of Example 0a. In addition the lake node conductances are constant because lakebed elevations are specified below lake stage. Water is therefore transmitted to the lake at the same rate as to the group of four cells.
3. Heads in the group of four cells in example 0a are symmetric. The group of four cells is therefore represented by a single head, analogous to lake stage.
4. An implicit lake stage computation is used in example 0b. Example 0a, like most MODFLOW simulations, uses an implicit computation.

Head in the group of four cells of example 0a and stage in the lake of example 0b, both shown on Figure 1.5, are identical. Further inspection confirms that budget terms for the two simulations are also identical.

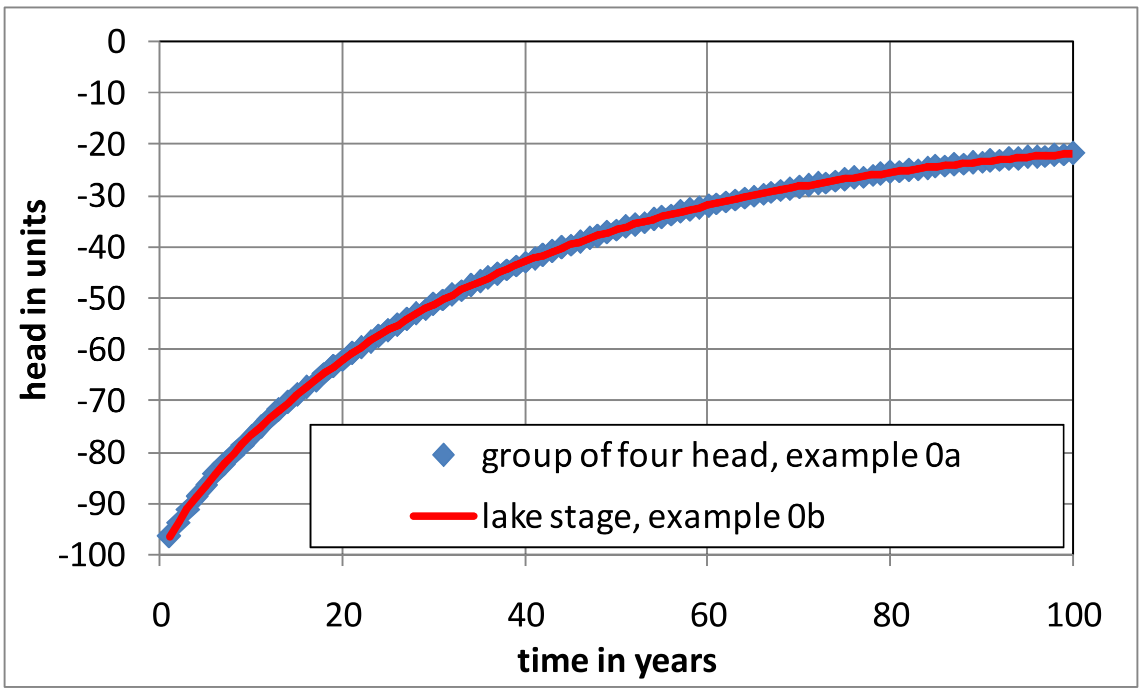

Figure 1.5. Comparison of water levels in examples 1a and 1b.

2.0 APPLICATION: ARCHIMEDES PIT

LAK2 was used to project the post-mining recovery of water level in the Archimedes pit near Eureka, Nevada. The pit bottom topography and pit surface catchment area are shown on Figure 2.1.

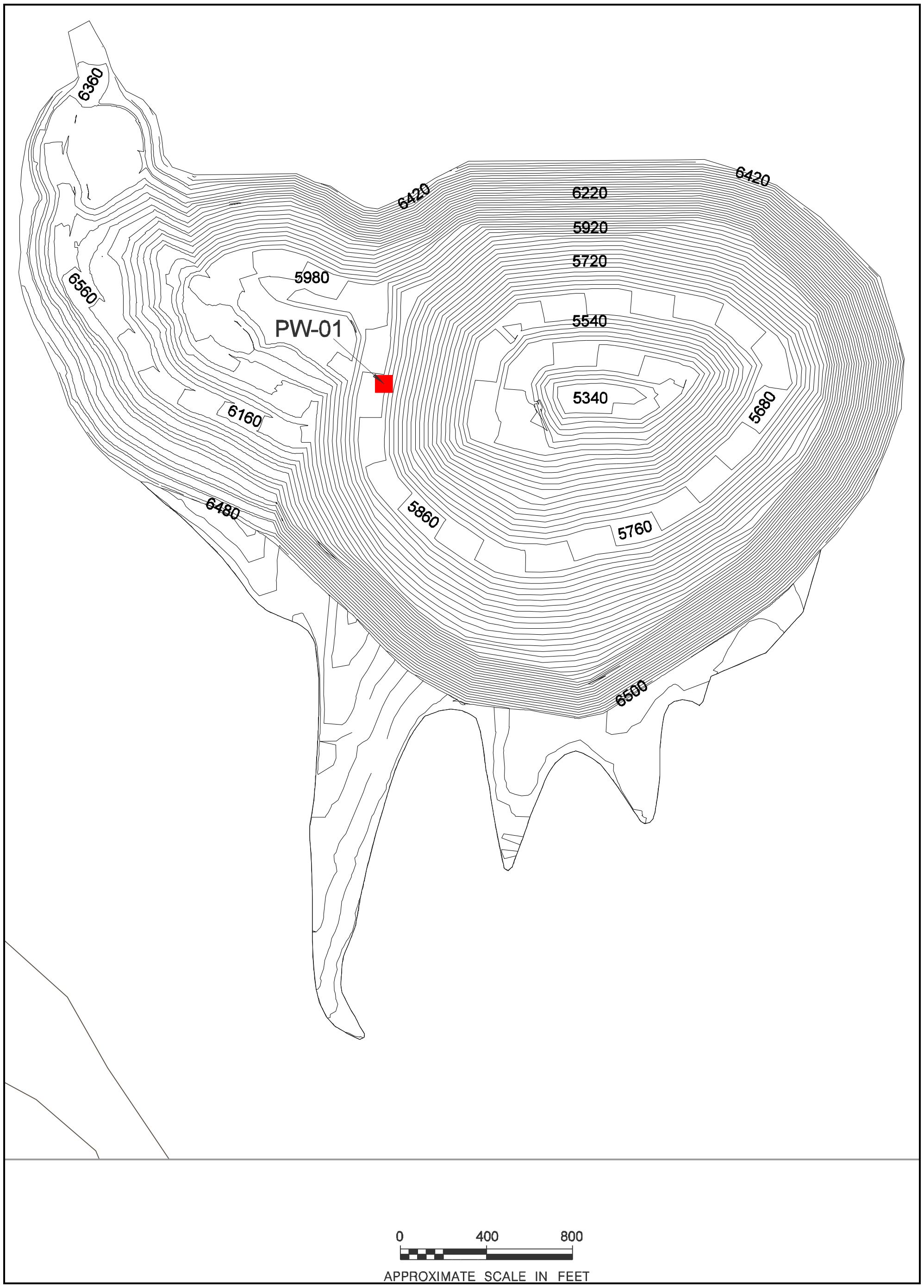

Figure 2.1. Ultimate pit contours.

The pit geometry was represented using LAK2 as described in Section 1 above, as a list of model cell locations. For each cell location, the following geometric parameters are spedified:

- Lowest pit bottom elevation within cell
- Highest pit bottom elevation within cell
- Maximum water surface area of each cell

The contribution of each cell to total open water surface area increases linearly from zero at the lowest pit bottom elevation, to the maximum area at the highest pit bottom elevation. Total water surface is computed as the sum of the area contributed by each cell.

The lowest and highest pit bottom elevations were initially assigned based on the contour map. Maximum open water surface was initially assigned to be the plan area of the MODFLOW finite difference grid cell.

The geometric parameters were then calibrated. The simulated lake bed elevations were adjusted to best reflect the actual increase of area with elevation for the portion of pit bottom within each cell. The measured and modeled pit stage-area-volume relationship is shown on Figure 2.2.

In addition to the pit geometry, the following inputs were required to simulate pit filling:

- Annual precipitation was estimated at 11.72 inches, based on records from the Eureka weather station (Western Regional Climate Center, 2004).
- A runoff coefficient of 0.15 was assumed for the pit catchment of about 210 acres.
- Annual lake evaporation was estimated at 45 inches (NOAA, 2004).

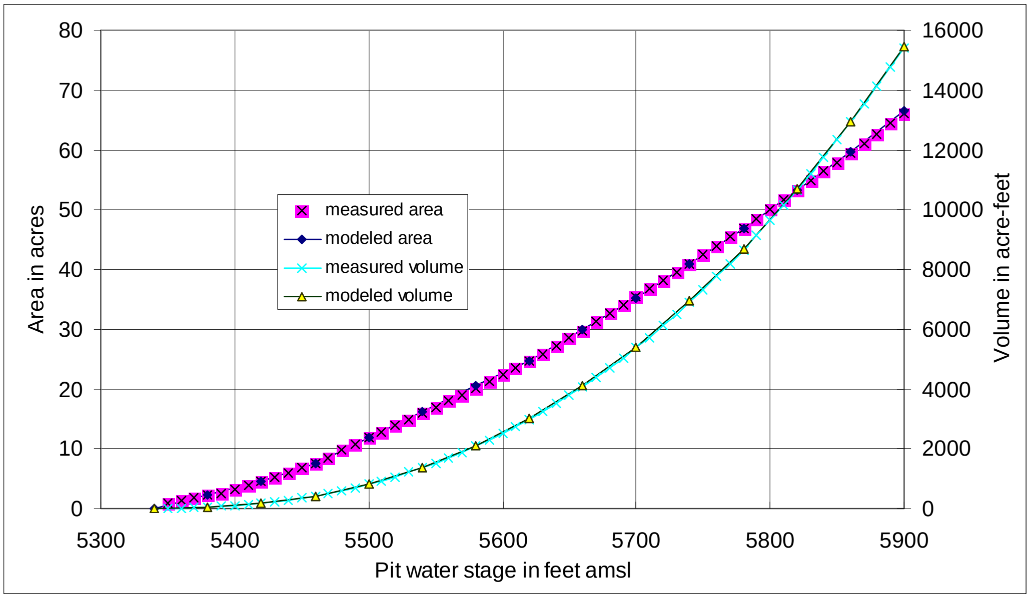

Figure 2.2. Measured and modeled pit stage-area-volume.

2.1 Changes to Original Groundwater Flow Model

Changes were also made to the specifications of aquifer geometry in MODFLOW module BCF, to reflect the presence of the pit: The layer top elevation, at which water level the layer becomes confined, was set equal to the mean of the low and high pit bottom elevations for each LAK2 cell.

2.2 Pit Filling

Recovery of water level after the end of active dewatering was simulated as described above. The projected pit water level is presented on Figure 2.3. The final equilibrium pit elevation is predicted to be 5861 feet amsl. The pit is projected to fill to 95% of recovery (elevation 5835 feet amsl) about 39 years after the end of active dewatering.

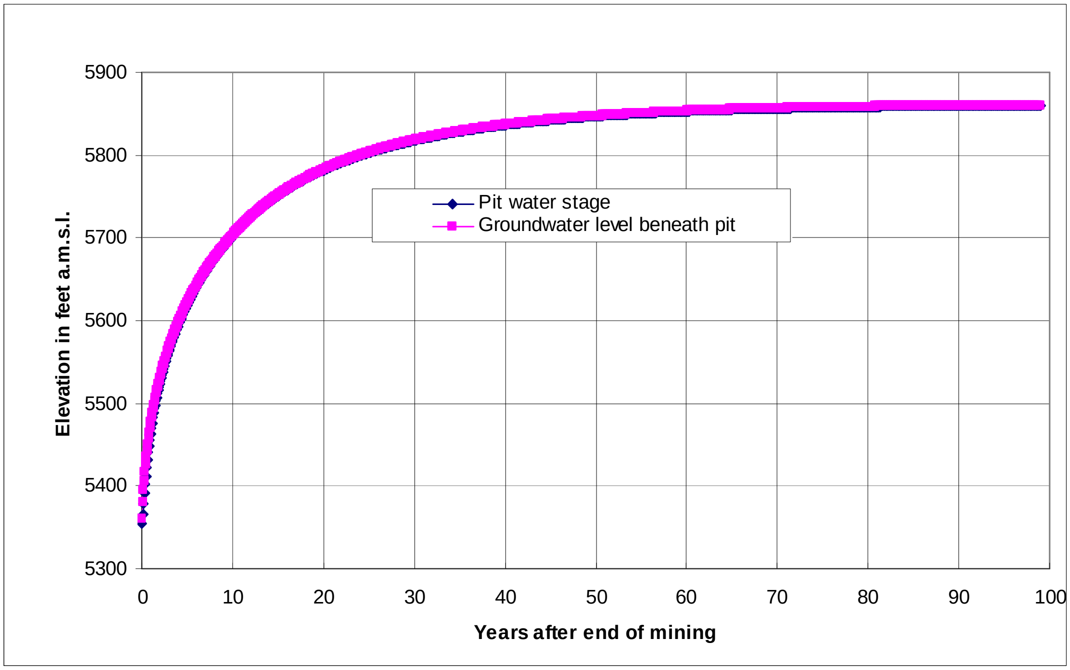

Figure 2.3. Projected pit water stage.

The projected pit water surface area and volume are presented on Figure 2.4. The final pit water surface area is predicted to be 60 acres. The final pit water volume is predicted to be 13,000 acre-feet.

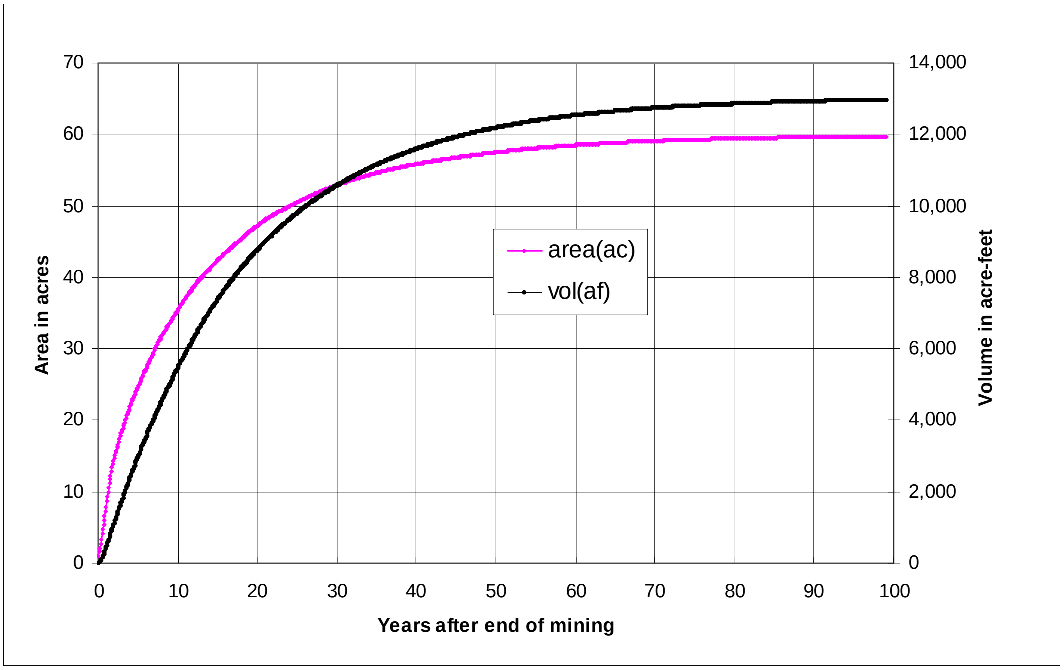

Figure 2.4. Projected pit water surface area and volume.

The projected pit water budget components are presented on Figure 2.5. The final average annual pit evaporation is predicted to be about 140 gpm. Groundwater outflow is predicted to be zero.

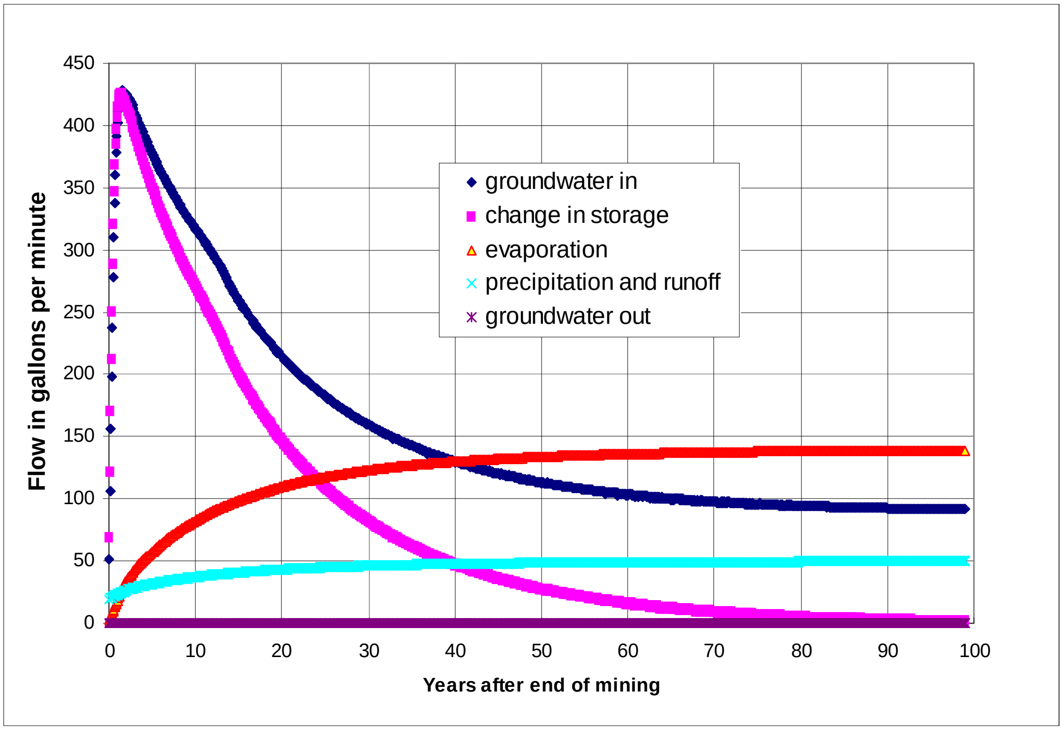

Figure 2.5. Projected pit water budget.

A map of the geochemical types exposed in the pit was provided. The units include:

- Oxide limestone (OgO)
- Oxide intrusive (KgO)
- Sulfide limestone (OgS)
- Sulfide intrusive (KgS)
- Alluvium (Qtal)
- Volcanic Tuff

The map of geochemical types was used to estimate the portions of pit inflow attributable to each unit, for use in projections of pit water chemistry. Groundwater inflow from each geochemical type is shown on Figure 2.6. Inflow from direct precipitation and from runoff over each geochemical type is shown on Figure 2.7.

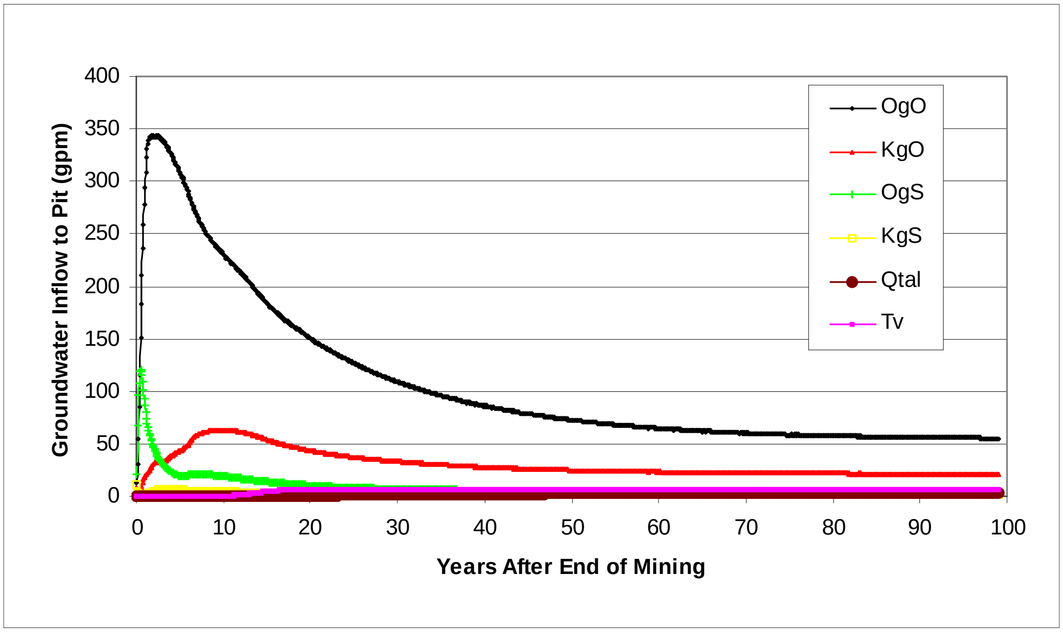

Figure 2.6. Groundwater inflow to pit by geochemical type.

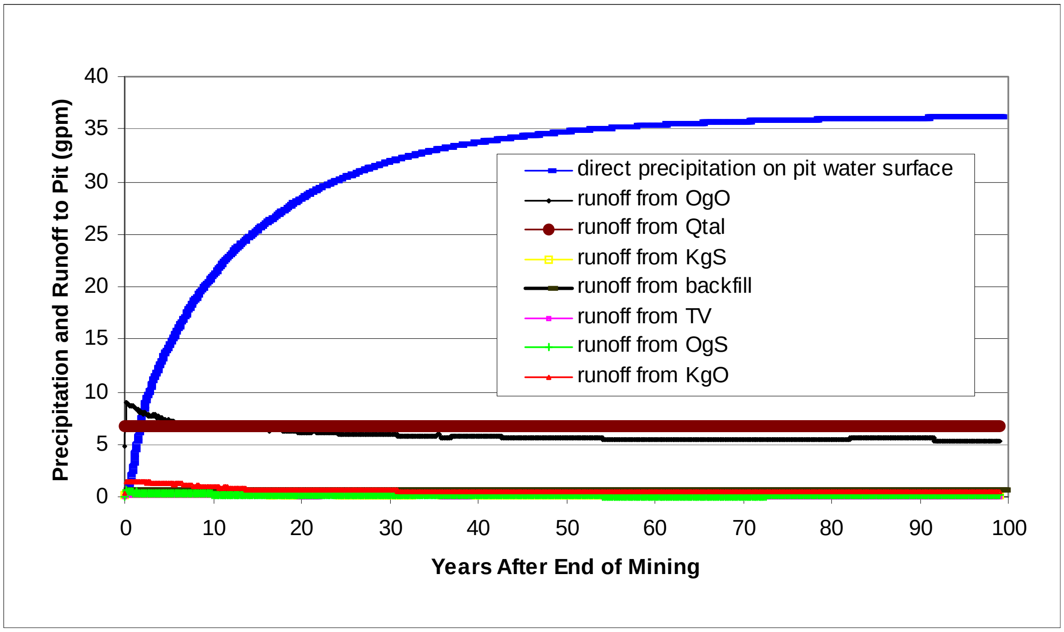

Figure 2.7. Precipitation and runoff to pit by geochemical type.

3.0 APPLICATION: ORTIZ PIT

LAK2 was used to calibrate a groundwater flow model to the measured history of mine dewatering and post-mining water level recovery in the Ortiz pit, near Cerrillos, New Mexico. Measured and simulated groundwater levels during mine dewatering, and measured and simulated post-mining pit water levels, are shown on Figure 3.1.

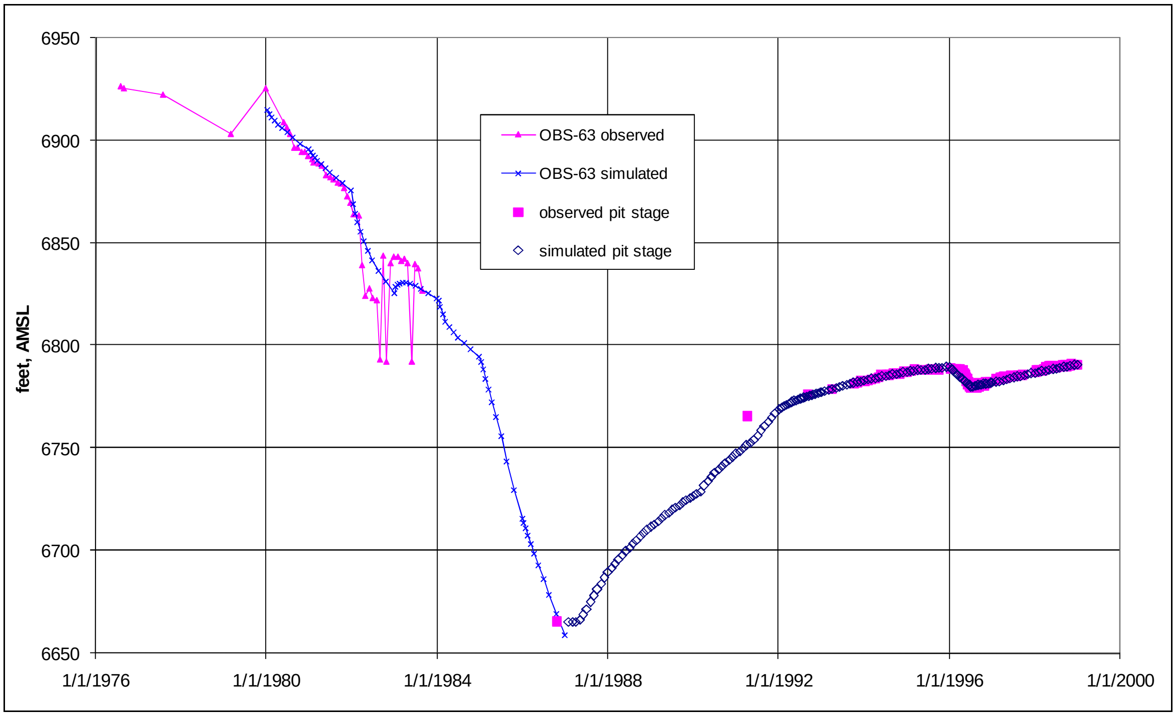

Figure 3.1. Measured and simulated historical water levels (JSAI, 1999).

The model was then used to project long-term water levels and the effect of diverting runoff from the up-gradient watershed into the pit, in order to submerge the acid seeps on the pit wall, which were adversely impacting pit water quality. Runoff from the watershed was estimated using the SCS curve number method. A series of projections of water level was developed, including, “normal”, “wet” and “dry” scenarios

4.0 APPLICATION: BELEN MUNICIPAL WELL

This section describes a problem that occurred with an application of the Middle Rio Grande Administrative (MRGA) model (Barroll, 2001), used to administer water rights in the Middle Rio Grande basin of New Mexico. The problem and its cause are analyzed and a solution is presented that utilizes LAK2 to more accurately represent pumping from a well.

4.1 The Problem

The Middle Rio Grande Administrative model (Barroll, 2001) has been employed in an attempt to evaluate the depletion effects of an additional 325 afy of groundwater pumping from the Belen municipal wells.

The results of the exercise are shown on Figure 4.1 which presents the simulated depletion, computed as the sum of the differences in total streamflow gain, streamflow loss and evapotranspiration between the base case model simulation and a simulation including the additional 325 afy of groundwater pumping. Also shown on Figure 4.1 is the portion of the additional pumping supplied by groundwater storage, rather than by depletion.

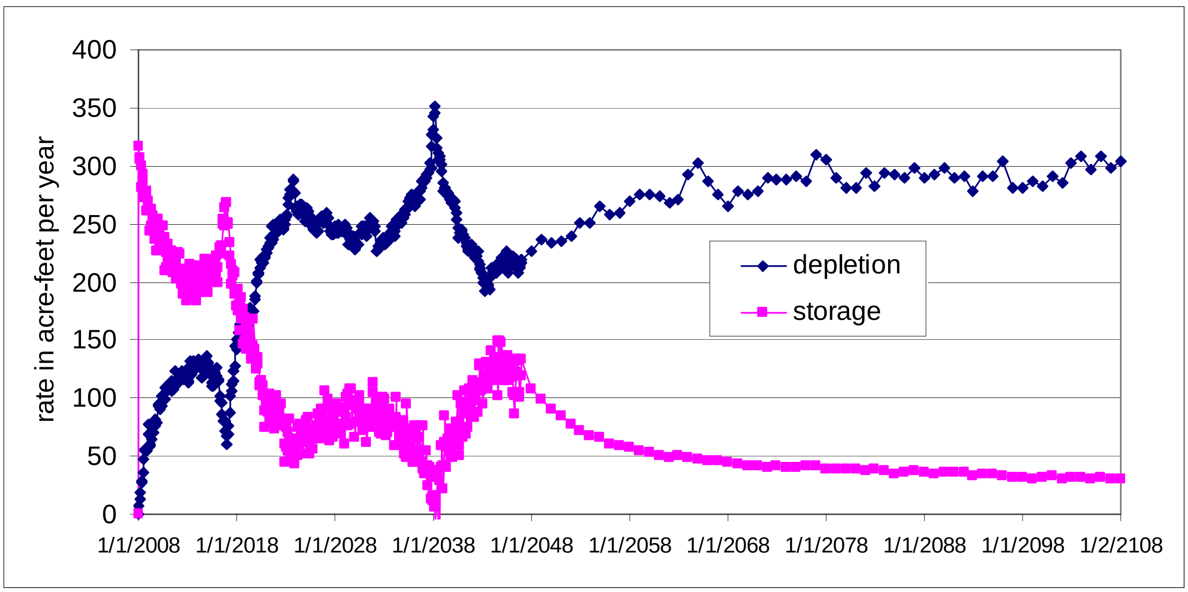

Figure 4.1. Model simulated depletion resulting from 325 afy additional pumping from belen municipal wells.

As can be seen in Figure 4.1, the results are suspicious. Instead of a steady increase in depletion from zero to 325 afy, with a corresponding decrease in the storage component from 325 afy to zero, the graph includes periods of increasing and decreasing depletion, with minima and maxima in between.

4.2 The Cause

The unexpected features of the graph shown on Figure 4.2 are the result of a dry cell in layer 2, row 100, column 37 of the model grid (corresponding to City of Belen Well 1). The cell becomes dry in both the base case simulation, in April 2038, and in the simulation with 325 afy additional pumping, in January 2017.

Simulated water levels for the cell that becomes dry, and for the cells immediately above and below, are presented for the base case ("without") and for the simulation with additional pumping ("with") in Figure 4.2.

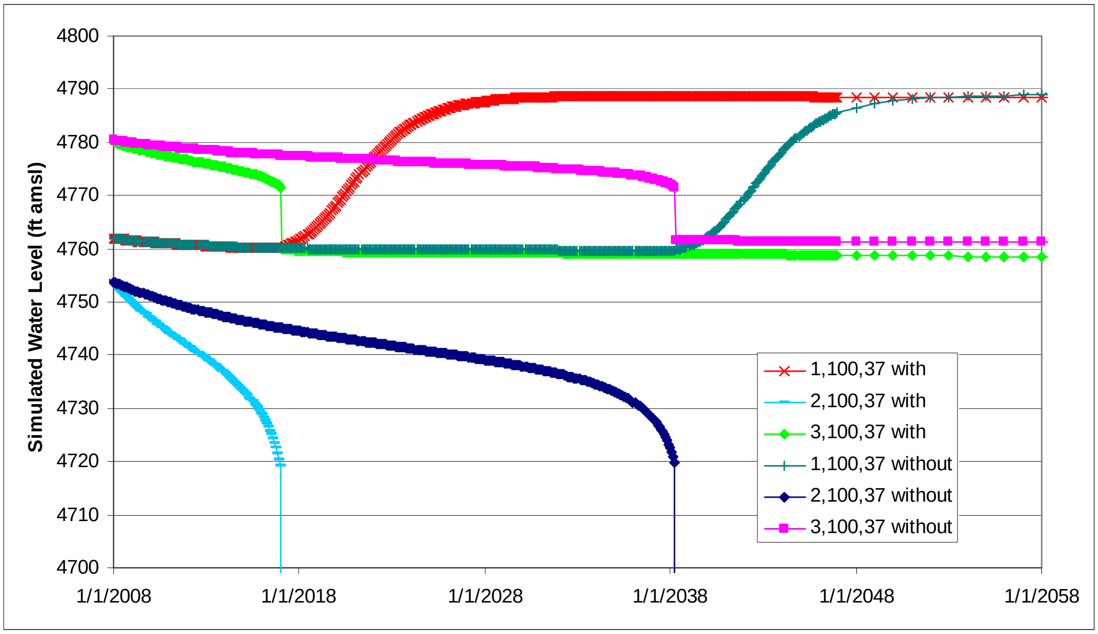

Figure 4.2. Simulated water levels in model cells in row 100, column 37.

In order to preserve simulated pumping rates, the convention adopted with the MRGA model is to shift pumping down a layer whenever a cell becomes dry (Barroll, 2001). Consequently a sharp drop in the layer 3 water level is shown on Figure 2 at the point when layer 2 becomes dry. In addition, the removal of the connection to layer 2 causes water level in layer 1 to begin to rise at the same time.

The correlation between the simulated depletion curve on Figure 4.1 and the simulated water levels on Figure 4.2 is shown graphically on Figure 4.3. Essentially, the dry cell causes discontinuities in the equations used to describe the groundwater flow system. The discontinuities occur at different times in the two simulations, impacting the depletion calculation (the difference between the two simulations) at both times.

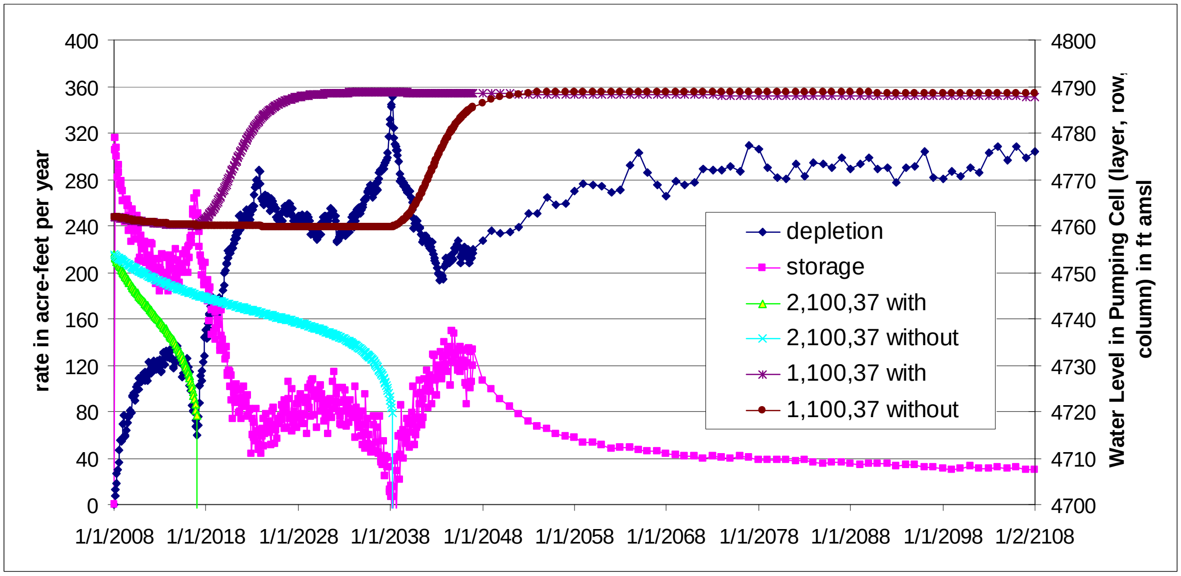

Figure 4.3. Simulated depletion and water levels.

4.3 A Solution

The problem can be addressed by restoring continuity to the equations describing the groundwater flow system. One way to do this is to represent the pumping in both layers 2 and 3. A difficulty with this approach is that results can be sensitive to the division of pumping between the layers. Proper division of pumping should be proportional to the conductivity of each layer, to the saturated screened interval and, if pumping water level is above the bottom of the screened interval, the difference between groundwater level in each cell and water level in the well bore.

The two model simulations were repeated representing the pumping in both layer 2 and layer 3. In order to properly partition the pumping, the well bore was explicitly represented in the model using LAK2 as a generic tool to represent open spaces, including well bores, connecting multiple model cells. Flows between model cells and the well are computed based on conductance terms, groundwater level in the cell, water level in the open space and elevation of the interface between the cell and the open space. The mass balance equation for the well considers the geometry of the space (a function of bore radius) and source/sink terms (pumping rate).

Results are presented in Figure 4.4.

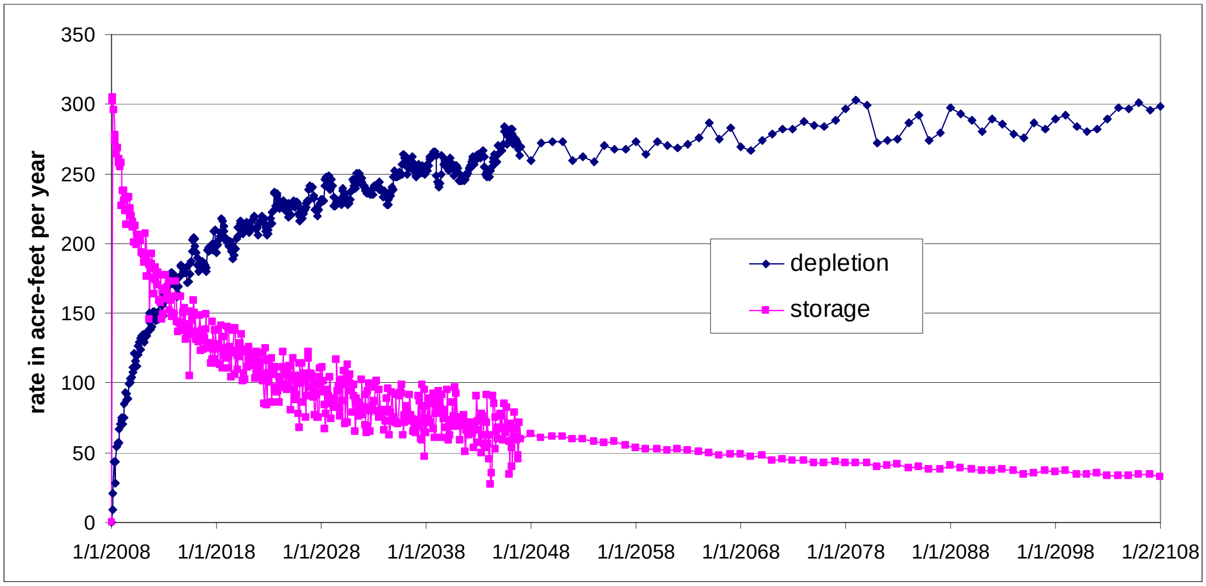

Figure 4.4. Model simulated depletion resulting from 325 afy additional pumping from Belen municipal wells, with pumping from two layers.

The oscillations remaining in the simulated depletion curve are a result of the small mass balance errors in the underlying groundwater flow simulation. These can be reduced through tighter convergence criteria, more iterations and longer run times.

5.0 APPLICATION: FAN SEDIMENTS AQUIFER TEST

LAK2 was used to simulate in-bore water levels in the analysis of aquifer test results. A numerical model was prepared to characterize the “Fan Sediments” colluvial aquifer .

A 21-day aquifer test was conducted. Three production bores, FSWW004-PB, FSWW013-PB, and FSWW020-PB, were pumped simultaneously at an average rate of about 35 liters per second each. Drawdown and recovery were measured in a total of 24 bores including:

- three pumping bores
- an observation bore located near each pumping bore, completed at a similar depth
- an observation bore located near each pumping bore, completed at a shallow depth
- a shallow observation bore located about 1 km from each pumping bore, in the area of the infiltration of pumped water
- regional observation bores, with deeper completions

A numerical model was developed to analyze the aquifer test in detail, considering saturated units above and below the production zone and responses measured in shallow, intermediate, and deep piezometers.

An observation bore is located near each pumping bore, within the same model cell, completed at a similar depth as the pumping bore. The drawdown at each model cell with a pumping bore was calibrated to match drawdown at the nearby observation bore.

In addition, water level in the pumping bore was represented directly using LAK2, in order to characterize the bore efficiency component of drawdown and to characterize the potential range of in-bore head losses that may be encountered in future production bores. The conductivity of each bore skin (the resistance to flow between aquifer and bore hole) was calibrated to match the measured pumping bore drawdown.

The water levels in observation bores FSWW012-MB and FSWW022-MB were also represented with the LAK2 module. Response in both bores to aquifer test pumping was found to be impacted by borehole problems, the first with an apparently blocked annulus and the second with apparent borehole leakage from a deeper formation. The LAK2 results help to confirm the explanation of borehole processes as the cause of each bore’s anomalous response.

Measured and simulated drawdown in pumping bore FSWW004-PB and in nearby monitoring bore FSWW003-MB are shown in Figures 5.1 and 5.2.

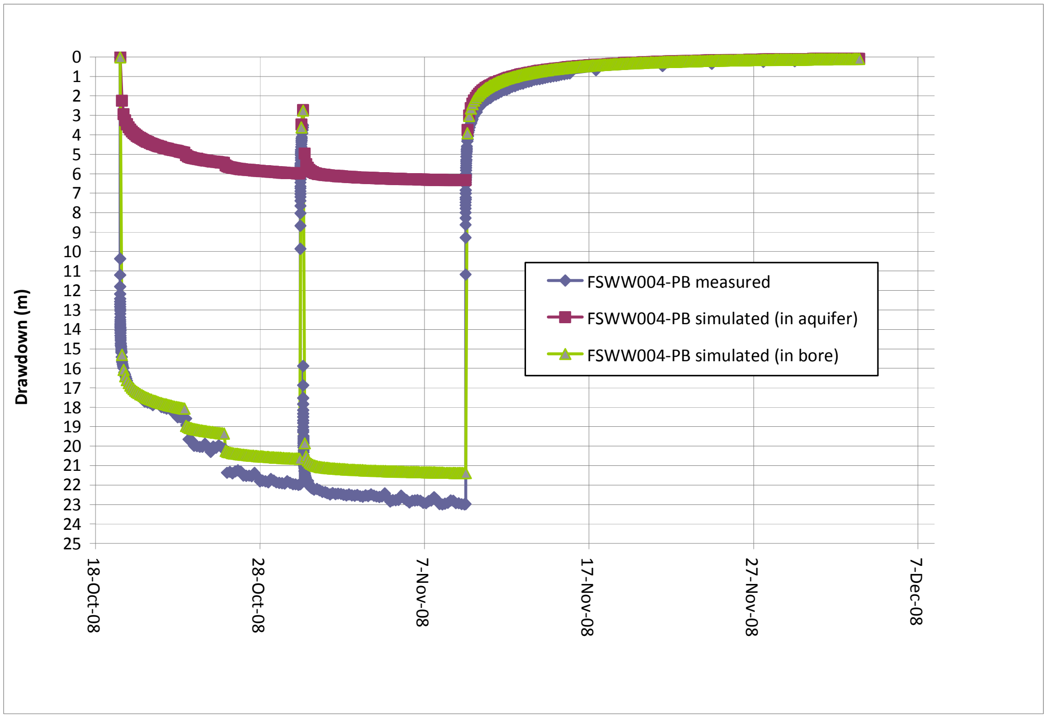

Figure 5.1. Measured and simulated aquifer test drawdown, FSWW004-PB.

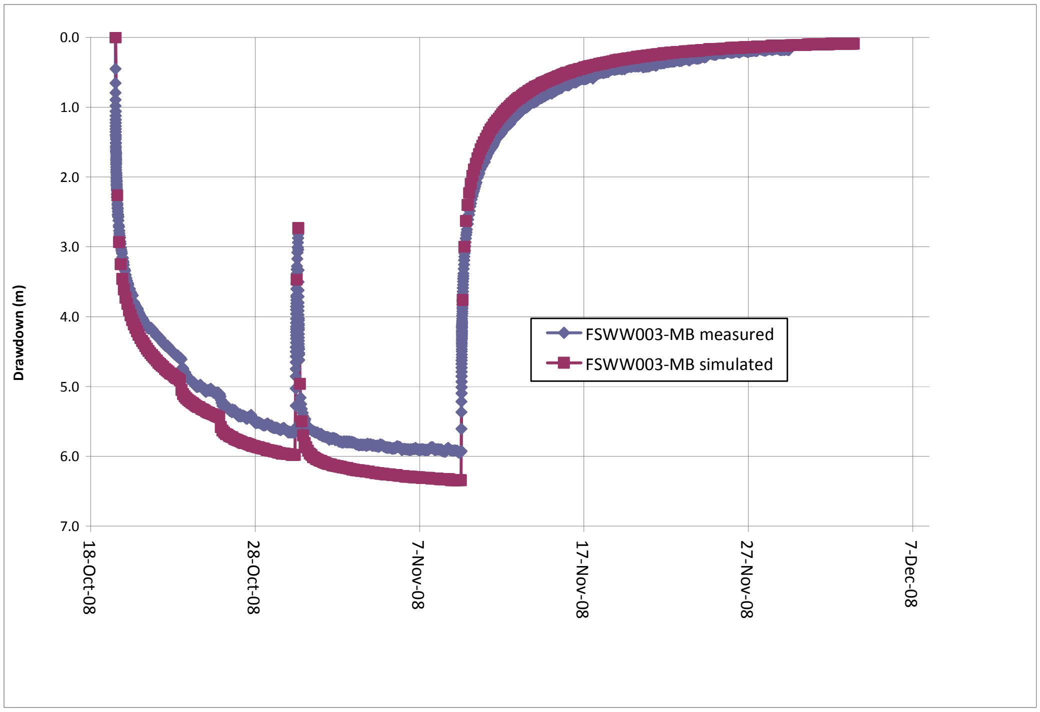

Figure 5.2. Measured and simulated aquifer test drawdown, FSWW003-MB.

Measured and simulated drawdown in pumping bore FSWW013-PB and in nearby monitoring bore FSWW010-MB are shown in Figures 5.3 and 5.4.

Measured and simulated drawdown in shallow observation bore FSWW022-MB is shown in Figure 5.5. The rapid and sharp response is characteristic of borehole leakage rather than water table drawdown. The apparent vertical connection observed in FSWW022-PB is likely a local borehole phenomenon. This was verified using LAK2 to simulate a bore in hydraulic communication with both Layers 1 and 2, resulting in a reasonably close reproduction of measured water levels.

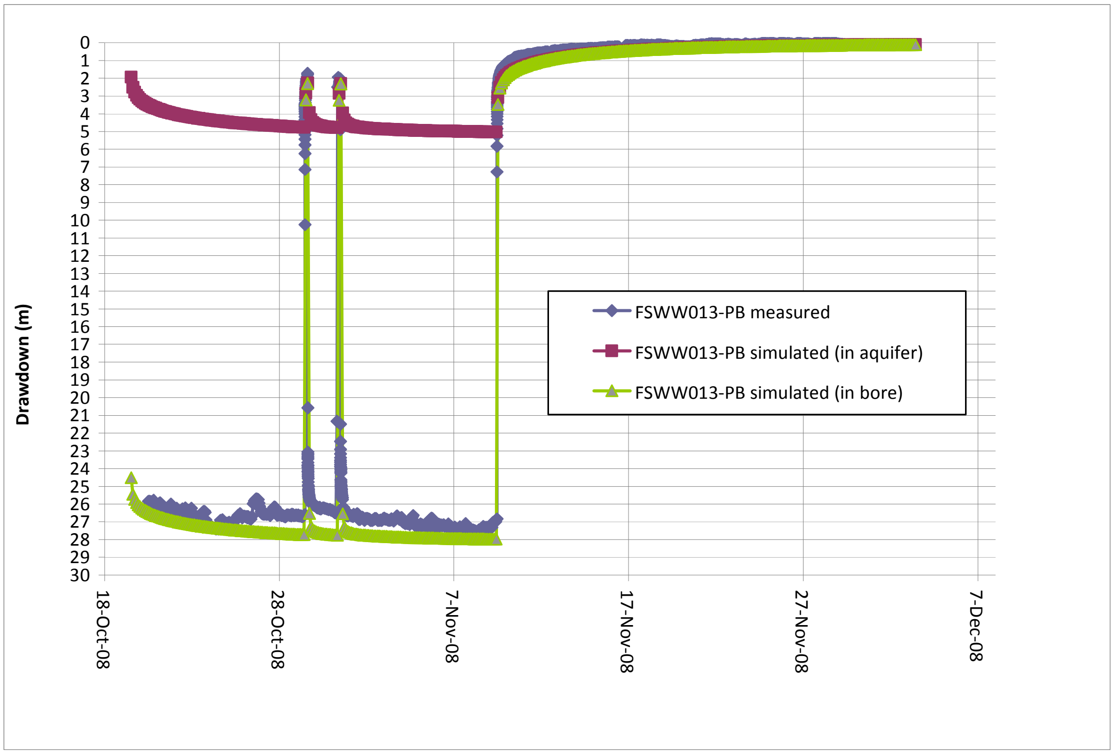

Figure 5.3. Measured and simulated aquifer test drawdown, FSWW013-PB.

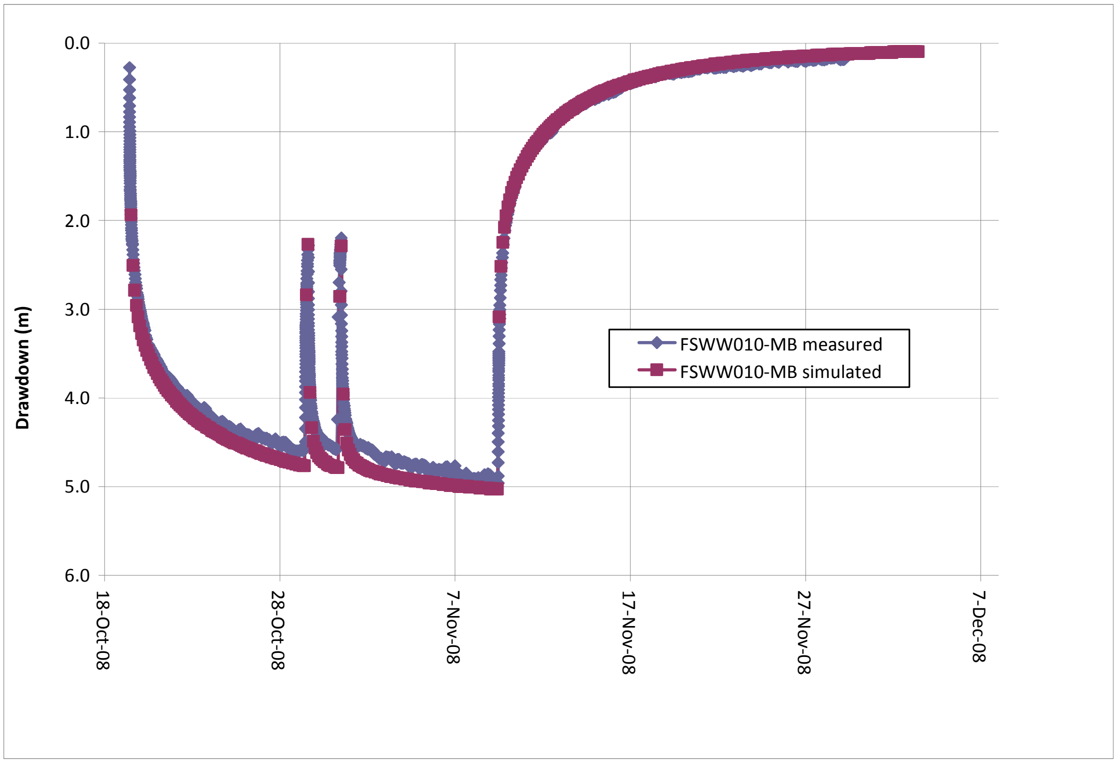

Figure 5.4. Measured and simulated aquifer test drawdown, FSWW010-MB.

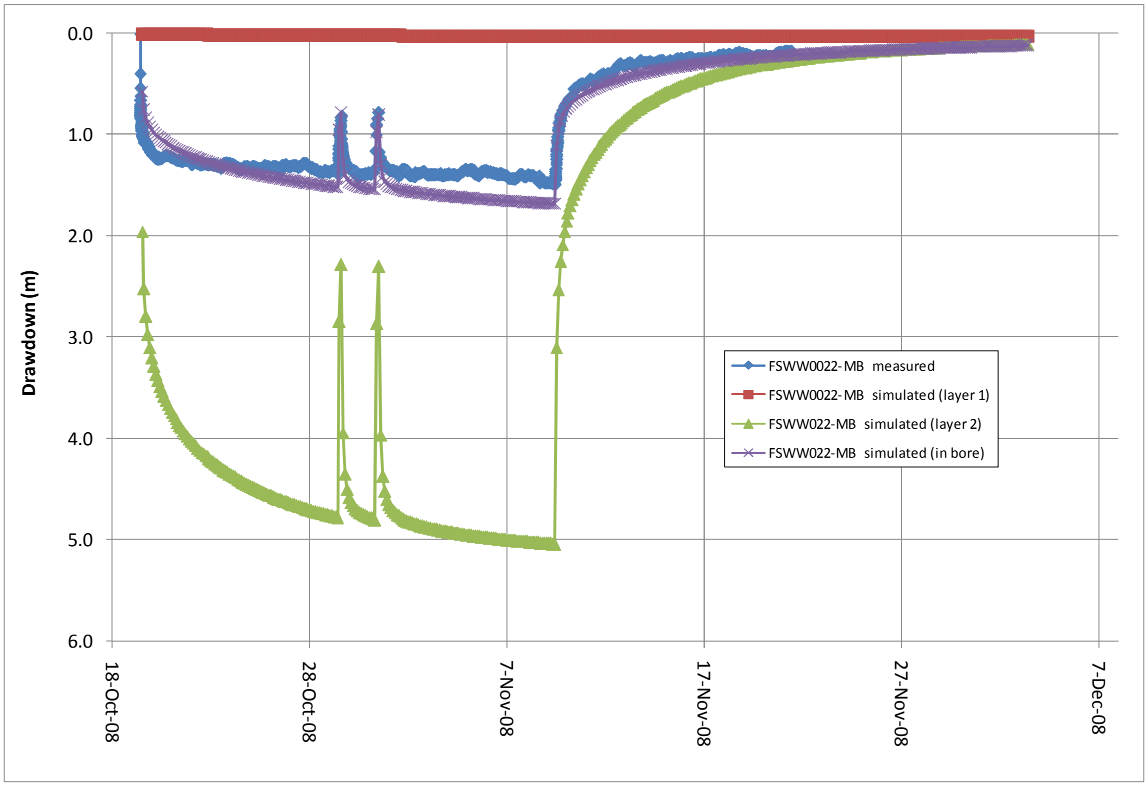

Figure 5.5. Measured and simulated aquifer test drawdown, FSWW022-MB.

Measured and simulated drawdown in pumping bore FSWW020-PB and in nearby monitoring bore FSWW018-MB are shown in Figures 5.6 and 5.7.

Farther away, water level in FSWW012-MB did not respond to pumping, as would be expected from the aquifer parameters indicated by the other observation bore responses. It was concluded, based on drilling results , that FSWW012-MB is isolated from the neighboring aquifer due to difficulties encountered during well construction and development. The lack of response at FSWW012-MB was simulated using the LAK2 module to represent an inefficient bore. Measured and simulated aquifer test drawdown at FSWW012-MB is shown on Figure 5.8.

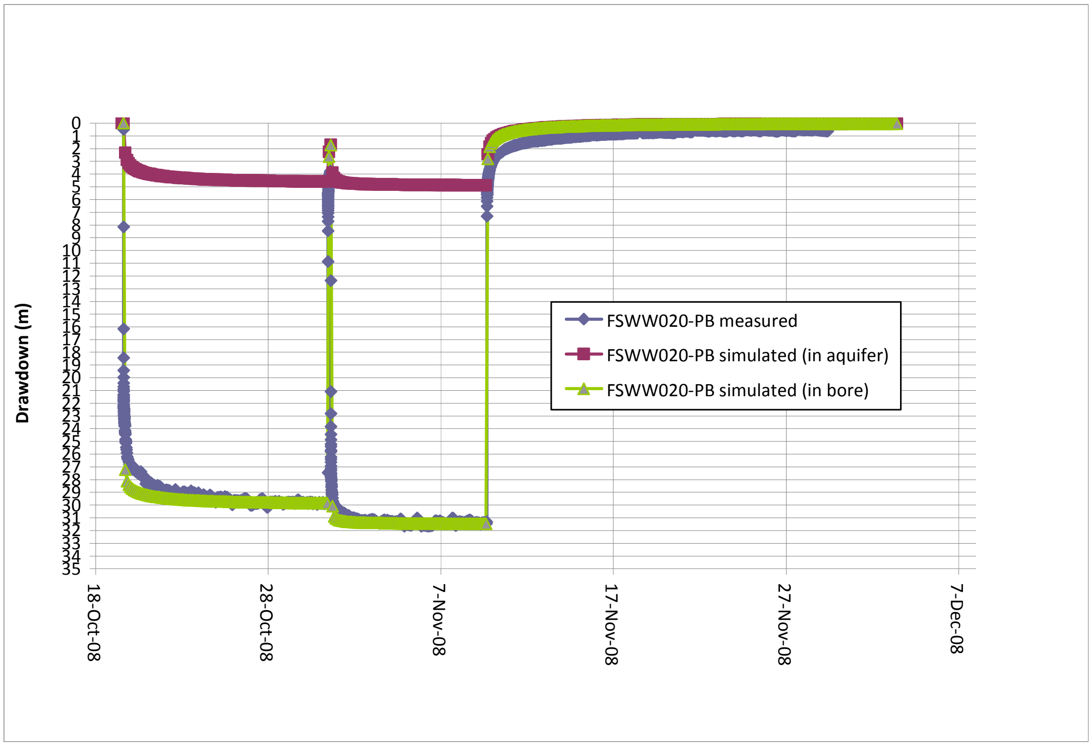

Figure 5.6. Measured and simulated aquifer test drawdown, FSWW020-PB.

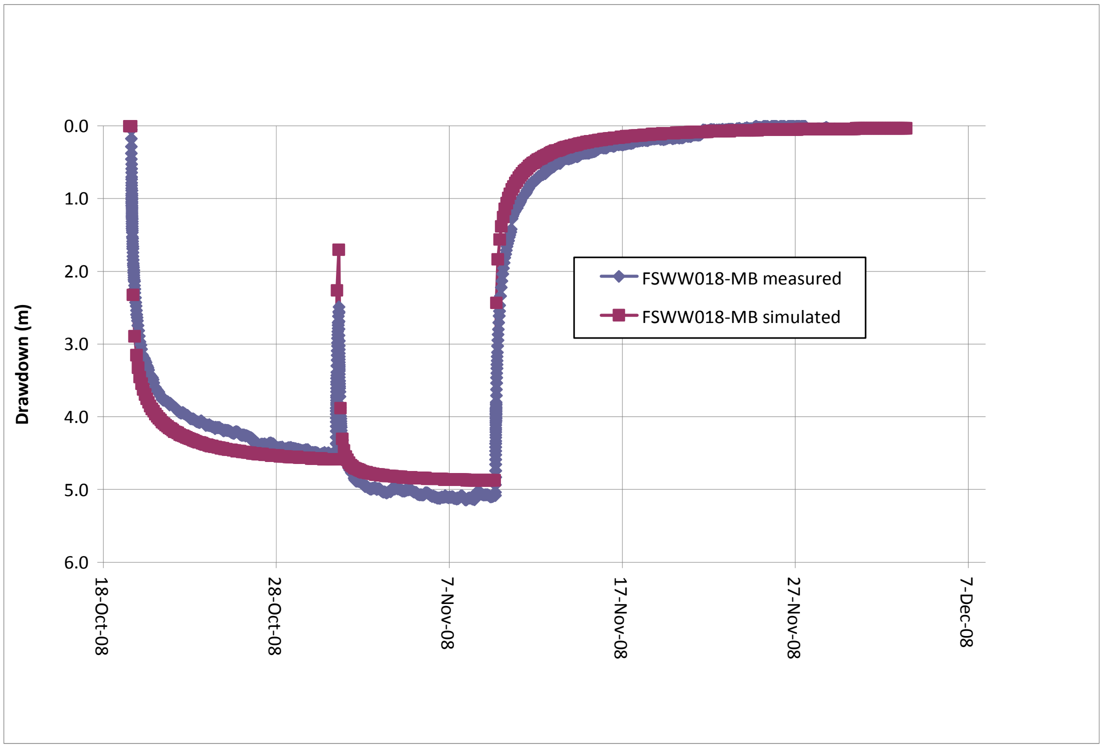

Figure 5.7. Measured and simulated aquifer test drawdown, FSWW018-MB.

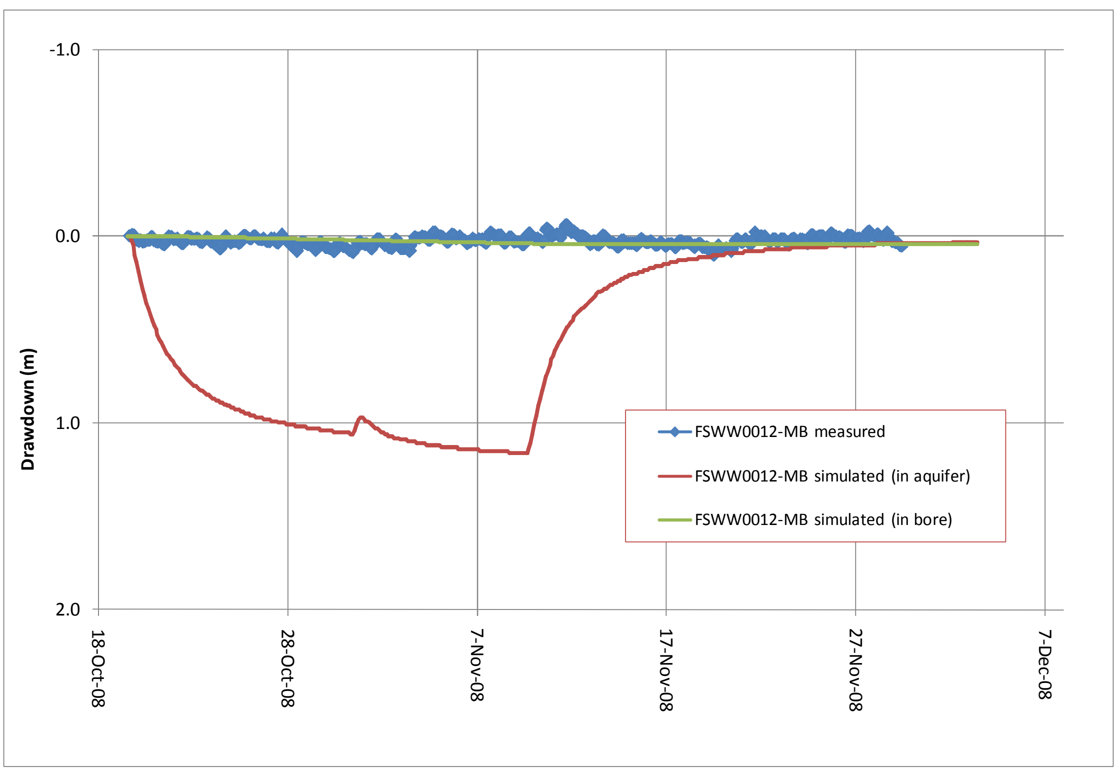

Figure 5.8. Measured and simulated aquifer test drawdown, FSWW012-MB.

6.0 REFERENCES

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