University of Nevada, Reno

Development of a Groundwater Flow Model for Hungry Valley, Washoe County, Nevada

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Hydrogeology

by

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THE GRADUATE SCHOOL

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Abstract

The Reno-Sparks Indian Colony (RSIC) has reservation land located on 1,960 acres in Hungry Valley, Washoe County, Nevada; located approximately 10 miles north of Reno. Future growth of the community is dependent on sustainable groundwater development. Previous hydrogeologic assessments and pumping tests have consistently concluded that the aquifers are of limited extent. The aquifers are characterized by low transmissivities with storativity values indicating the aquifers to be confined. Groundwater pumping began in 1991 and a decline in static water levels began to occur. With an alternate pumping strategy implemented in 2004 and additional production wells implemented in 2005 static water levels have improved and most appear to have stabilized with measurements taken through March 2010. There are currently four production wells: Well Nos. 4, 5, 7 and 8. The objective of this groundwater flow model is to develop optimization strategies to maintain the static water levels as high as possible, minimize the cost of groundwater pumping, and keep arsenic levels below drinking water standards (through blending of pumped groundwater), while meeting the supply needs of the RSIC. The modeling protocol according to Anderson and Woessner (2002) was generally followed to develop the model; and the construction of the model was accomplished through the GMS User Interface for MODFLOW. Optimization was performed using a trial and error approach. The model results indicate that a pumping scenario of 70% for Well Nos. 7 and 8 and 30% for Well Nos. 4 and 5 appears to balance drawdowns in the two aquifers. Additionally, it appears that the pumping average from 2000 through 2009 (excluding 2005) of 193 m^3/day (57 acre-feet per year) can be supported by the current well field. Future water demand, estimated to be 243 m^3/day (72 acre-feet per year), can also supported by the current well field with additional decreases in static water levels. This decrease in static water levels is modeled to be greatest at Well Nos. 4 and 5 at 3.7 meters and can be minimized by utilizing Well No. 3 as a production well and/or considering an additional production well.

Acknowledgments

I would like to acknowledge my thesis committee. Dr. Scott Tyler for suggesting a Master’s Program in Hydrogeology; his time and encouragement along the way. Dr. Greg Pohll for his course on modeling that started me on this path. Dr. Mark Walker for his thoughtful questions at the start of this project. And, Doug Gardipe for his time, providing data, and assistance during many trips to Hungry Valley and many more follow-up phone calls and emails. Lastly, a thank you to the Reno-Sparks Indian Colony for their support of this thesis effort.

I would also like to acknowledge my family. My wife, Kathy, for her patience and constant encouragement; my son, Josh, for helping with field work; and lastly, my father, Stan, for his gift of the love of education.

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Section 1 – Introduction

1.1 Problem Statement

The focus of the thesis effort is the development of a groundwater flow model for Hungry Valley. This groundwater flow model will allow the Reno-Sparks Indian Colony (RSIC) to consider strategies for additional well field development and/or optimization of the current groundwater pumping. This is the first known effort to develop a groundwater flow model for Hungry Valley.

Nevada-Sierra Planners in their 1999 report (Gebhardt et al, 1999) recommended that a numerical groundwater flow model be constructed for Hungry Valley. The model was proposed "to refine estimates of recharge, develop a defensible groundwater budget for the valley, predict future drawdowns in the aquifer, and assist RSIC and HVUD [Hungry Valley Utility District] in groundwater development strategies" (Gebhardt et al, 1999). Additionally, the RSIC identified in the introduction to their Wellhead Protection Program that groundwater is a vital natural resource for the Hungry Valley Community (RSIC, Wellhead Protection Program, 2006). Previous research has indicated that this sole source of drinking water is both a finite supply of groundwater and set in a relatively localized geologic setting. Therefore, future growth of the community is dependent on sustainable groundwater development.

1.2 Objectives

The objectives of the groundwater flow model are to develop optimization strategies to maintain the static water levels as high as possible while meeting the supply needs of the RSIC, insuring arsenic levels remain below drinking water standards (through blending of pumped groundwater), and minimize the cost of groundwater pumping.

1.3 Background

The project background includes the history of the Reno Sparks Indian Colony (RSIC) and the location map of the project site. Additionally, the unit convention utilized in this document will be metric (with the U.S. customary units indicated in parentheses).

1.3.1 Reno Sparks Indian Colony (RSIC)

The Reno-Sparks Indian Colony became a federally recognized Tribe on January 15, 1936. According to the RSIC website, the tribal membership consists of over 900 members from three Great Basin Tribes – the Paiute, the Shoshone, and the Washoe. The reservation lands consist of the 0.1 square kilometers (28 acres) residential Colony located in downtown Reno and the 7.9 square kilometers (1,960 acres) Hungry Valley reservation located nineteen miles north of downtown Reno (Reno-Sparks Indian Colony Website, www.rsic.org, 2010). The Hungry Valley land was purchased in 1982.

The Hungry Valley community relies solely on local groundwater to supply approximately 150 residential homes. The community has been in the valley since 1989, and currently requires a daily rate of pumping of approximately 273 m^3/day (72,000 gallons per day) to meet peak summer demand (Shanafield et al, 2005). The community also comprises various facilities, including the Hungry Valley Community Center, the Hungry Valley Recreation Center, the Head Start Center, and a Day Care Center; the Hungry Valley Utility Department operates and maintains the Public Water System (PWS) (RSIC, Wellhead Protection Program, 2006).

Figure 1. Hungry Valley Community, Looking Approximately East

1.3.2 Location Map

Hungry Valley is located in the northwest portion of the State if Nevada. It is in the Warm Springs Valley Hydrographic Area, Hydrographic Area No. 84; which is part of the Truckee River Basin, Hydrographic Basin No. 6. The Warm Springs Valley Hydrographic Area is 639.7 square kilometers (247 square miles or 158,080 acres) in size, located in Washoe County, and is a designated groundwater basin (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Website, 2010).

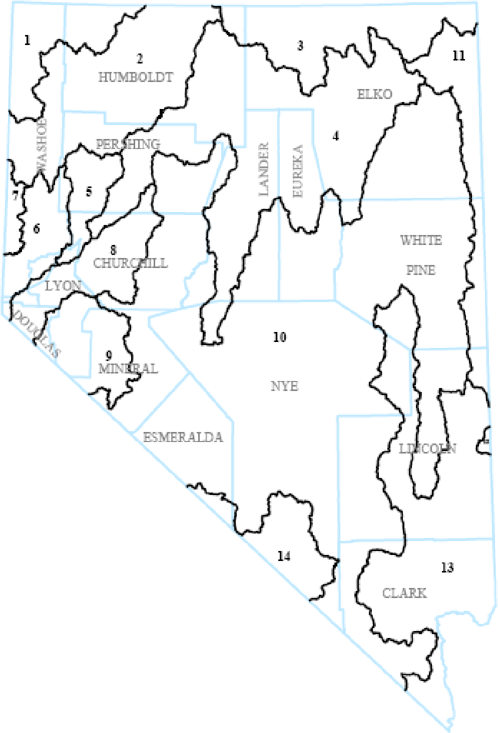


Figure 2. Hydrographic Regions of Nevada; Hungry Valley is Located in the Truckee River Basin, Hydrographic Basin No. 6 (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Designated Groundwater Basins, 2010)

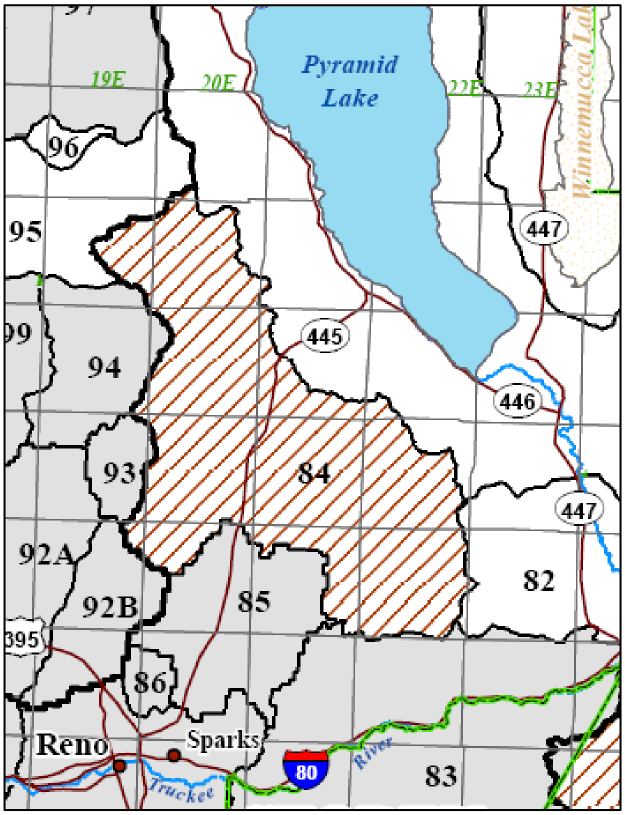


Figure 3. Designated Groundwater Basins of Nevada (Administered Groundwater Basin); Hungry Valley is located in the Warm Springs Valley Hydrographic Area, Hydrographic Area No. 84 (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Designated Groundwater Basins, 2010)

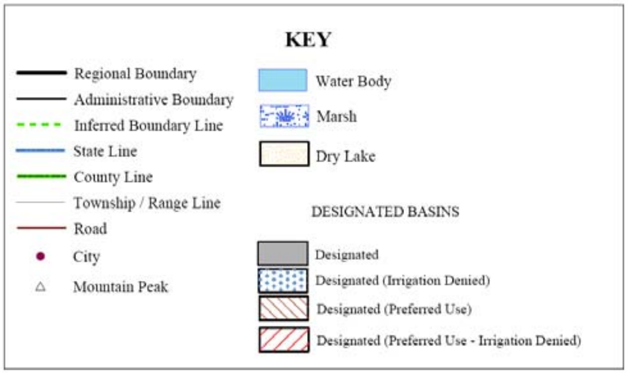


Figure 4. Legend for Designated Groundwater Basins of Nevada (Administered Groundwater Basin) (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Designated Groundwater Basins, 2010)

The State of Nevada describes a basin as a geographic area drained by a single major stream or an area consisting of a drainage system comprised of streams and lakes. Additionally, a designated groundwater basin is defined as a basin “where permitted ground water rights approach or exceed the estimated average annual recharge and the water resources are being depleted or require additional administration" (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Website, 2010). There are currently two orders issued by the State Engineer pertaining to the Warm Springs Valley Hydrographic Area. The first Order, No. 607 dated 1/18/1977, designated areas of the Warm Springs Valley Hydrographic Area, which includes Hungry Valley. These designated areas included T.21N, R.20E, Section 4, 9, and a portion of 16, all of which are located on the Hungry Valley Reservation (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Order 607, 1977). The second Order, No. 1205 dated 3/25/2010, estimated the perennial yield of the Warm Springs Valley Hydrographic Area as 3,700,446 m^3 (3,000 acre-feet) annually. The perennial yield is defined as the amount of usable water of a ground water reservoir that can be withdrawn and consumed economically each year for an indefinite period of time (Nevada State Water Plan, 1999). This second order also notes that the committed groundwater resource, in the form of permits and certificates of record, exceeds 8,017,632 m^3 (6,500 acre-feet) annually (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Order 1205, 2010). These permits and certificates of record are for committed groundwater resources throughout Hungry and Warm Springs Valleys.

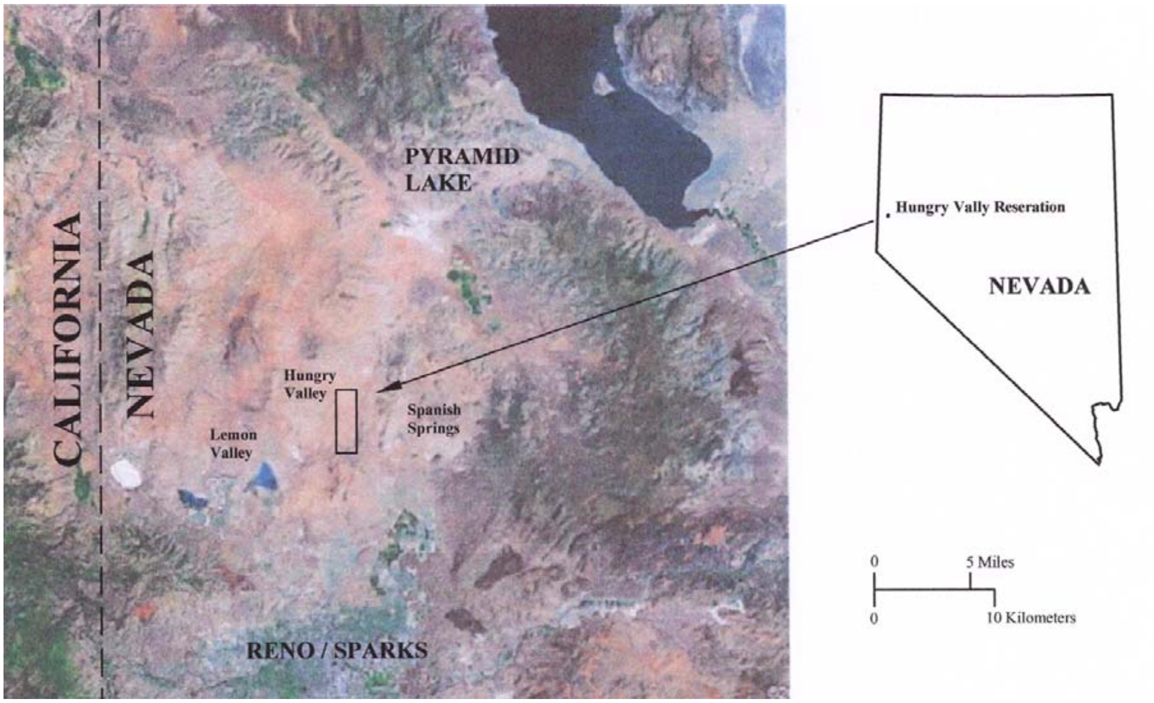


Figure 5. The Location of the Hungry Valley Community (maps.google.com); Location of Hungry Valley Reservation from U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, 2005 (U.S. Department of the Interior, 2005).

Section 2 – Previous Work

There have been several previous efforts to investigate the hydrogeology of Hungry Valley. These previous hydrogeologic assessments and aquifer (pump) tests have consistently concluded that the aquifers are of limited extent. The aquifers are characterized by low transmissivities with storativity values indicating the aquifers to be confined. In the following sections, the important previous work is summarized. This important work includes a conceptual hydrogeologic model, geology of the area, well and test hole overview, water quality, aquifer (pump) tests and observed static water levels, that have been utilized in the develop of the groundwater flow model for this thesis effort.

2.1 RSIC Hydrogeological Investigation and Wellhead Protection Program

Two important investigations into the hydrogeology of Hungry Valley are the Reno-Sparks Indian Colony, Phase I Hydrogeological Investigation of the Groundwater Supply at Hungry Valley, Nevada-Sierra Planners (Gebhardt et al, 1999) and the Hydrogeological Assessment of the Hungry Valley Groundwater Basin, Prepared for Reno-Sparks Indian Colony (Harrigan and Ball, 1996). These hydrogeological investigations include presentation of a conceptual hydrogeologic model, aquifer (pump) tests results and estimates of transmissivity, reported drawdowns and associated pumping rates, geology of the area, a well and test hole overview, and water quality data.

Additionally, there are two documents that address the wellhead protection for the wells of the Hungry Valley community. The first document is the Preliminary Well Head Protection Area (WHPA) Analysis for the Reno Sparks Indian Colony, Hungry Valley, Nevada (Tyler, Preliminary Well Head Protection Area (WHPA) Analysis, 2002). This was followed by the Reno-Sparks Indian Colony, Wellhead Protection Program, Prepared by the Hungry Valley Utility Department (RSIC, Wellhead Protection Program, 2006). These documents address wellhead water protection areas and potential contaminant sources.

2.2 UNR Graduate Program of Hydrologic Sciences

The Wellhead Protection Program, prepared by the Hungry Valley Utility Department, recognized the value of the aquifer and groundwater information provided through participation in the University of Nevada at Reno’s (UNR) Graduate Program of Hydrologic Sciences. The program’s director, Dr. Scott Tyler, has overseen annual fieldwork performed by graduate students beginning in 2000. Successive classes have conducted aquifer (pump) testing and analysis at the water production wells that include groundwater quality and trends in changing static levels (RSIC, Wellhead Protection Program, 2006).

2.3 Oil-Dri Corporation of Nevada, Reno Clay Plant Project

The Oli-Dri Corporation of Nevada, the world's largest manufacturer of cat litter, proposed to construct and operate an open-pit clay mine and ore processing facility for the development of a montmorillonite deposit with 270 metric tons of proven reserves (USGS, The Mineral Industry of Nevada, 2000). The project would have included construction of two open-pits, construction of haul and access roads, temporary stockpiling of overburden and growth medium, partial backfilling of open-pits, and construction and operation of an ore processing facility. The project would have been on land North and West of, and adjacent to, the RSIC. In support of the project, the document Final Environmental Impact Statement, Oil-Dri Corporation of Nevada, Reno Clay Plant Project EIS (BLM, 2001) was prepared. The environmental impact review included a look at the affected environment (including geology, water resources, etc.) and a discussion of the consequences of the proposed action and possible alternatives. However, the project was eventually abandoned.

2.4 Geology and Hydrogeologic Maps

Several geology and hydrogeological maps have been prepared for, or reference, Hungry Valley. A listing is provided below.

> 2010 – Preliminary Geological Map of the Griffith Canyon Quadrangle, Washoe County, Nevada, Nevada Bureau of Mines and Geology, Mackay School of Earth

Sciences and Engineering, College of Science, University of Nevada, Reno (Garside et al, 2010)

2005 – U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, (U.S. Department of the Interior, 2005)

1969 – Geology and Mineral Deposits of Washoe and Storey Counties, Nevada, Bulletin 70, Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada, Reno (Bonham, 1969)

1969 – Geologic Map of Washoe and Storey Counties, Nevada, Scale 1:250,000 (Bonham, Geologic Map, 1969)

1966 – Generalized Hydrogeologic Map of the Warm Springs – Lemmon Valley Area, Washoe County, Nevada and Lassen County, California; State of Nevada, Department of Conservation and Natural Resources; and United States Department of the Interior, Geological Survey; Base Map from Army Map Service 1:250,000 Series: Reno, 1960, and Lovelock, 1959 (Rush and Glancy, 1966)

Section 3 – Description of the Study Site

3.1 Physiography

Hungry Valley is a northeasterly reaching valley about 12.9 kilometers (8 miles) long and 3.2 to 4.8 kilometers (2 to 3 miles) wide. The valley is bounded on the east and separated from Spanish Springs Valley by Hungry Ridge. The valley is bounded on the west and separated from Antelope Valley by Hungry Mountain and Warm Springs Mountain. Both Warm Springs Valley and Spanish Springs Valley sit topographically lower than Hungry Valley; continuing north of Warm Springs Valley is Pyramid Lake.

Ephemeral surface drainage primarily flows northward down the valley axis and groundwater flows generally northward through Hungry Valley with eventual discharge at Little Hungry Spring and underflow to Warm Springs Valley (Shanafield et al, 2005). However, a concealed fault trending southeasterly could imply inhibited groundwater movement from Hungry Valley to Warm Springs Valley (Harrigan and Ball, 1996). There are three known springs to the north of Hungry Valley: Little Hungry Spring, Hungry Spring, and Butler Spring.

Hungry Valley is an area of hilly terrain, sparsely vegetated hills of sagebrush, and dry valleys in varying shades of tan and beige (BLM, 2001). Valley floor elevations range approximately from 1,600 m (5,250 feet) in the south to 1,400 m (4,590 feet) to the north.

To the east is Hungry Ridge with peaks of 1,835 m (6,020 feet); and to the west is Hungry Mountain with peaks of 1,816 m (5,960 feet).

Figure 6 provides the topography of Hungry Valley and the surrounding valleys.

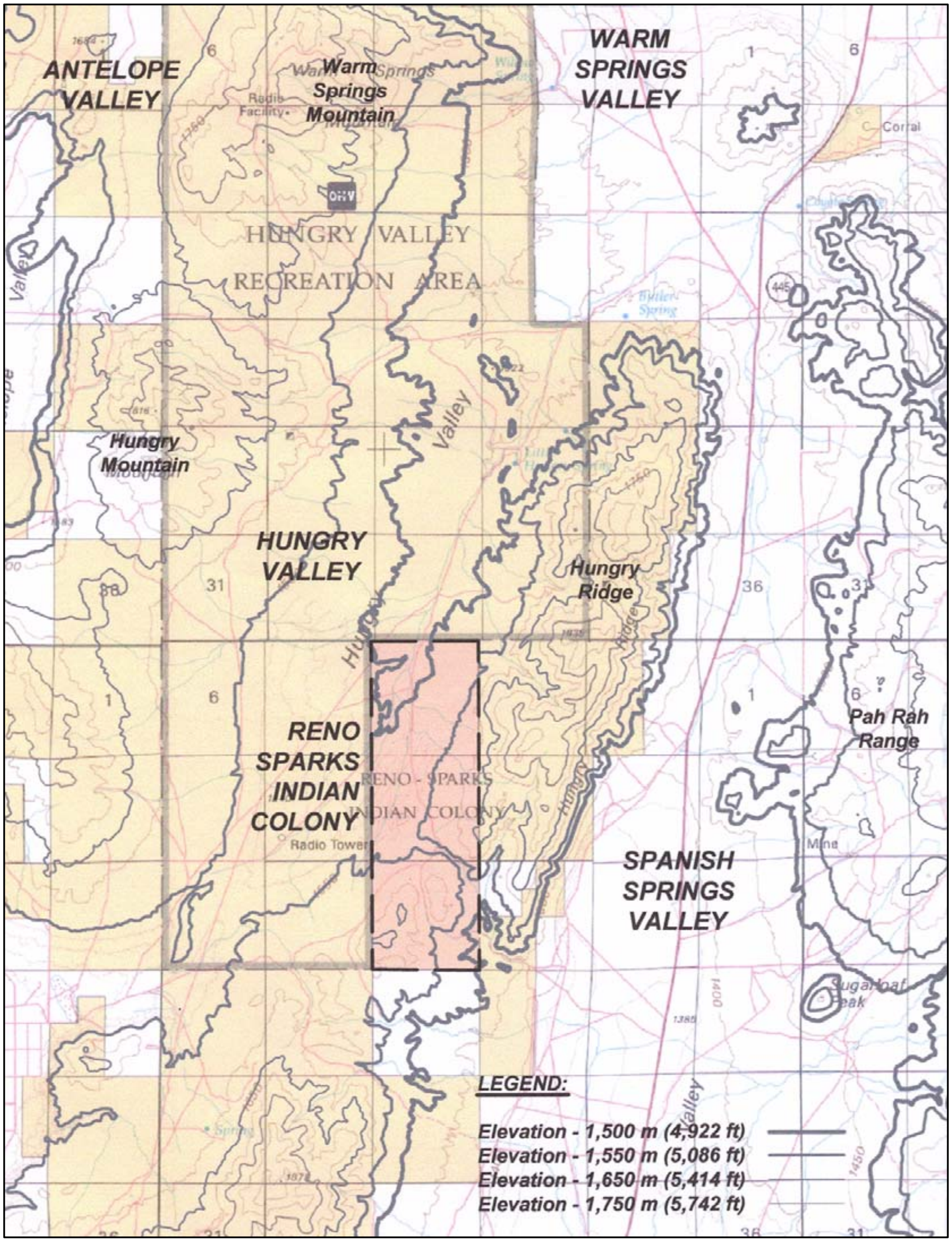


Figure 6. Physiography of Hungry Valley and Surroundings (Adapted from U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, 2005); Legend and Labels Added

3.2 Climate

Climate in Hungry Valley is considered as semiarid with annual average total precipitation less than 19.1 cm (7.5 inches); characterized by large variations in temperature, moderate wind, short hot summers, and moderately cold winters (BLM, 2001).

General meteorological conditions in Hungry Valley are represented by data collected by Western Regional Climate Center (WRCC) at Reno, Sparks, and Stead, Nevada.

Table 1. Mean Monthly Precipitation (centimeters (inches))

From Final Environmental Impact Statement: Oil-Dri Corporation of Nevada, Reno Clay Plant Project, Table 3-2 (BLM, 2001)

(centimeters (inches))

WEATHER STATION; ELEVATION (meters (feet)); and PERIOD OF RECORD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Reno WSFO Airport, Nevada; 1341 (4,400); 1937 – 2000	2.92 (1.15)	2.54 (1.00)	1.98 (0.78)	1.04 (0.41)	1.57 (0.62)	1.12 (0.44)	0.69 (0.27)	0.58 (0.23)	0.89 (0.35)	1.07 (0.42)	1.85 (0.73)	2.51 (0.99)	18.75 (7.38)
Sparks, Nevada; 1329 (4,360); 1988 – 2000	3.76 (1.48)	2.72 (1.07)	2.49 (0.98)	0.76 (0.30)	2.08 (0.82)	1.42 (0.56)	0.56 (0.22)	0.79 (0.31)	1.42 (0.56)	1.12 (0.44)	1.96 (0.77)	2.16 (0.85)	21.21 (8.35)
Stead, Nevada; 1561 (5,120); 1985 – 2000	4.98 (1.96)	5.69 (2.24)	4.47 (1.76)	1.22 (0.48)	1.85 (0.73)	1.91 (0.75)	1.04 (0.41)	0.74 (0.29)	1.88 (0.74)	1.27 (0.50)	2.41 (0.95)	3.86 (1.52)	31.34 (12.34)

Nevada-Sierra Planners estimated the higher elevations of Hungry Mountain, approximately 1,830 m (6,000 feet), receive 38 to 51 cm (15 to 20 inches) of annual precipitation; whereas the remaining valley about 25 to 38 (10 to 15 inches) annually (Gebhardt et al, 1999). These estimates are similar to those of the Geology and Mineral Deposits of Washoe and Storey Counties, Nevada that noted the annual precipitation varies from less than 13 cm (5 inches) at elevations of 1,160 m (3,800 feet) to 30 to 38 cm (12 to 15 inches) at 1,525 to 1,675 m (5,000 to 5,500 feet) (Bonham, 1969). The evidence of ephemeral channels following periods of heavy precipitation have been noted in the valley. Additionally, the RSIC has on-site weather monitoring equipment. Data provided is listed in Table 2.

Table 2. Weather Data from RSIC Air Station (2008)
(Approximate Elevation of Air Station Location is 1,500 meters)

PARAMETER		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Temperature (Average °C (°F))		0.5 (32.9)	3.3 (38.0)	6.0 (42.8)	9.2 (48.6)	13.6 (56.5)	18.4 (65.1)	22.0 (71.6)	20.9 (69.6)	15.8 (60.4)	10.4 (50.8)	4.6 (40.3)	0.4 (32.7)	
Extreme Temperatures (Days per Month)	Below 0 °C (32°F)	27	24	22	16	5	0	0	0	3	15	24	28	164
	Above 32 °C (90°F)	0	0	0	0	1	7	20	18	5	0	0	0	51
Precipitation (centimeters (inches))		2.8 (1.1)	2.5 (1.0)	1.8 (0.7)	1.0 (0.4)	1.8 (0.7)	1.3 (0.5)	0.8 (0.3)	0.8 (0.3)	1.0 (0.4)	1.0 (0.4)	2.3 (0.9)	2.5 (1.0)	19.6 (7.7)
Wind Speed (average m/s (mph))		1.9 (4.3)	2.1 (4.6)	n/d	n/d	n/d	3.3 (7.4)	2.7 (6.0)	2.7 (6.1)	1.9 (4.2)	2.0 (4.4)	1.4 (3.1)	1.9 (4.3)	

Note: ‘n/d’ indicates ‘no data’

Section 4 – Methods

4.1 Modeling Protocol

The modeling protocol according to Anderson and Woessner (2002) will be generally followed to develop the model; excluding the post audit. Figure 7 presents the modeling protocol graphically.

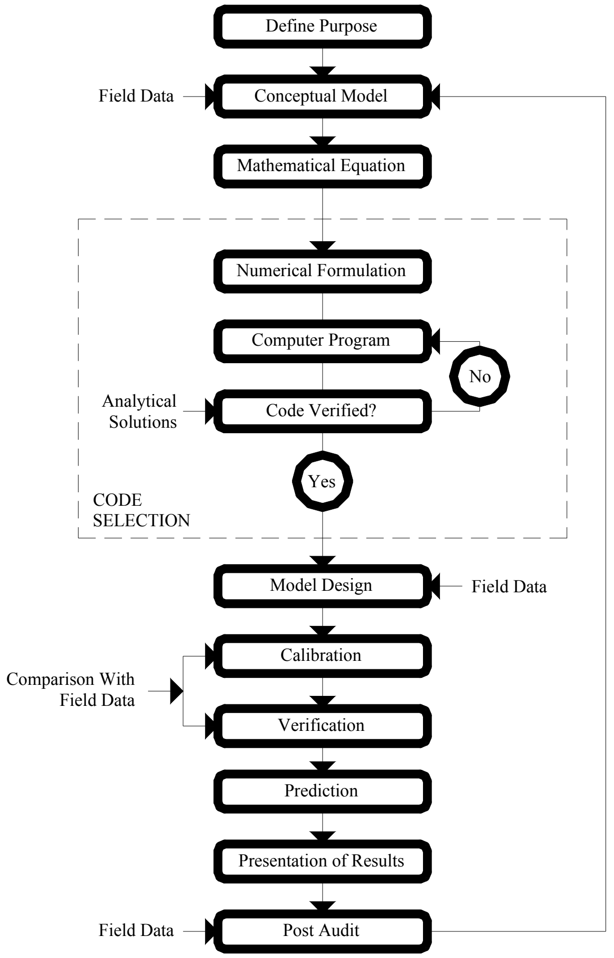


Figure 7. Modeling Protocol (Anderson and Woessner, 2002)

The steps in the modeling protocol are discussed below:

- **Define Purpose** – The purpose of this thesis effort was defined in the problem statement (see Section 1.1).
- **Conceptual Model** – The conceptual model is discussed in Section 4.3; and was developed from previous work and from lithologic logs from the Well Driller's Reports.
- **Mathematical Model and Code Selection** – In this thesis effort the code selected is MODFLOW; and the model was constructed through the GMS User Interface for MODFLOW.
- **Model Design** – This step included selecting the coverage and boundary conditions, identifying sources and sinks, setting model layers and types and the model grid, and preliminary selection of values for aquifer parameters. In addition, the transient simulation required selection of time steps and identifying hydrologic stresses.
- **Calibration** – The model was calibrated with observed static water levels and flows; by a trial-and-error approach. Calibration was assessed by the difference between observed and modeled values where there was a single data point and for multiple data points the Root Mean Squared Error (RMSE) and Relative Error (RE) was utilized.
- **Verification** – Verification was not performed for this thesis effort as the MODFLOW code and solutions have been verified in previous studies.
- **Prediction** – The model was utilized to compare optimization strategies and to predict the effect of future water demand.

- **Post Audit** – A post audit is recommended to verify the modeling effort.

4.2 MODFLOW

A computer code is needed to solve the set of algebraic equations generated by approximating the partial differential equations that form the mathematical model (Anderson and Woessner, 2002). For this thesis effort the GMS Interface for MODFLOW was selected because the code is widely used and readily available. The following discussion is derived from MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model – The Ground-Water Flow Process, Chapter 16 of Book 6. Modeling Techniques, Section A. Ground Water (Harbaugh, 2005):

> In MODFLOW, a block-centered finite difference approach is used to solve the partial-differential equation that describes the three-dimensional movement of ground water of constant density through porous earth material. This can be described as:
>
> > (Rate of mass inflow) – (Rate of mass outflow) + (Rate of mass production/consumption) = (rate of mass accumulation)
> >
> > Or as a formula:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

where

- K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of the hydraulic conductivity
- h is the potentiometric head
- W is a volumetric flux per unit volume representing sources and/or sinks of water, with $W < 0.0$ for flow out of the ground-water system, and $W > 0.0$ for flow into the system
- S_s is the specific storage of the porous material
- t is time

This equation describes ground-water flow under confined non-equilibrium conditions in a heterogeneous and anisotropic medium, provided the principal axes of hydraulic conductivity are aligned with the coordinate directions. This equation, together with specification of boundary conditions, constitutes a mathematical representation of a ground-water flow system.

The equation becomes the steady-state flow equation when the storage term is zero. The resulting equation specifies that the sum of all inflows (where outflow is a negative inflow) from adjacent cells and external stresses must be zero for each cell in the model. A steady-state problem requires only a single solution of simultaneous equations, rather than multiple solutions for multiple time steps (as required for a transient simulation). A transient simulation also requires an initial head to calculate the time derivative for the first time step.

4.3 Conceptual Hydrogeologic Model

The modeling effort began with a conceptual hydrogeologic model of the flow system. Nevada-Sierra Planners, Phase I Hydrogeological Investigation of the Groundwater

Supply at Hungry Valley (Gebhardt et al, 1999), indicates that the groundwater sources of Hungry Valley are both bedrock and basin-fill aquifers; and describe the basin-fill aquifers:

> The basin-fill aquifer consists of low-permeability alluvial sediments consisting of clays and silts with limited sand lenses. These sand lenses are probably laterally discontinuous over large areas but most likely intersect faulted bedrock along mountain front areas, as indicated by artesian conditions found at several of the test and production wells at the time of construction.

Nevada-Sierra Planners also proposed the following Conceptual Hydrogeologic Model (Gebhardt et al, 1999):

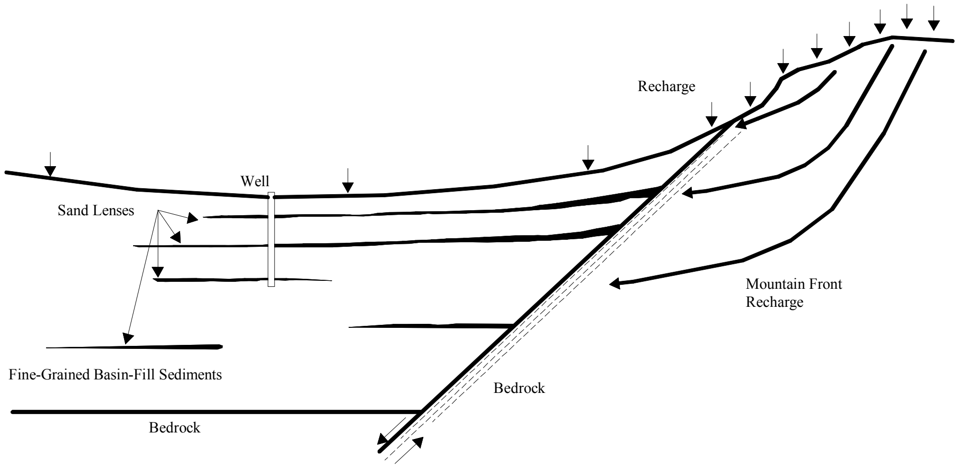


Figure 8. Conceptual Hydrogeologic Model

Another conceptual hydrogeologic model is presented below. This conceptual hydrogeologic model increases the level of detail as it is adapted from the Preliminary

Geological Map of the Griffith Canyon Quadrangle, Washoe County, Nevada, Section B (Garside et al, 2010):

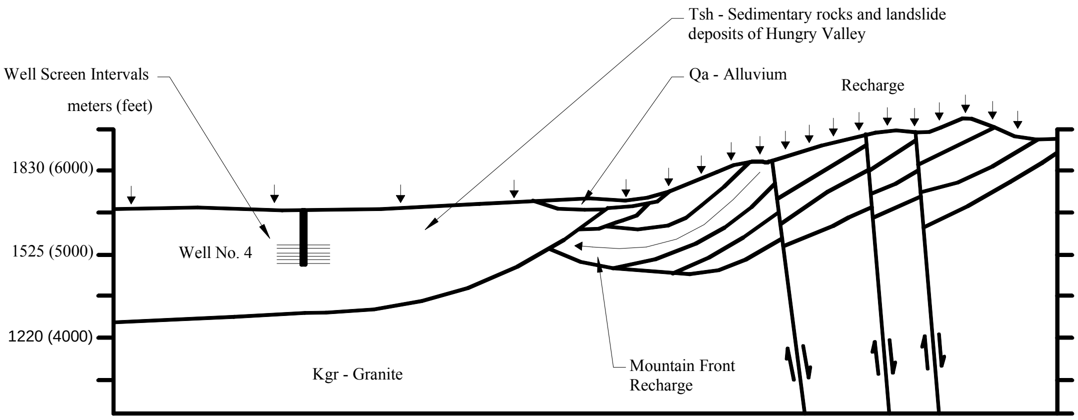


Figure 9. New Conceptual Hydrogeologic Model

This conceptual hydrogeologic model gives a spatial orientation of Hungry Valley and Well No. 4 (although Well No. 4 does not fall on Section B of the Geological Map of the Griffith Canyon Quadrangle, it has been shown on the figure generally where it would intersect the Section B line, with the Section B line North of Well No. 4 location). Also shown are the three intervals in which Well No. 4 is screened.

This conceptual hydrogeologic model indicates increased recharge at the higher elevations of Hungry Ridge with mountain front recharge; as also indicated on the Nevada-Sierra Planners conceptual hydrogeologic model. This mountain front recharge likely is channeled into the deep aquifers along range front faults and moves down fault lines and enters the basin-fill sediments laterally. However, this conceptual model shows different orientation of fault lines than the previous model. Additionally, as can be inferred from the well lithologic logs (located in the Appendix) the aquifer is more likely layers of clay/sand and clay/gravel, as very few sand lenses are indicated from the lithologic logs.

Section 5 – Geology of Hungry Valley

5.1 Geology

The southern two-thirds of Washoe County have topography typical of the Basin and Range physiographic province which is elongated mountain ranges separated by alluviated basins; igneous, metamorphic, and sedimentary rocks crop out in the area (Bonham, 1969). The rocks of Hungry Valley are primarily sedimentary with a thin layer of alluvium, as shown in Figures 10, 11 and 12.

Figure 10 shows a portion of the Preliminary Geological Map of the Griffith Canyon Quadrangle, Washoe County, Nevada:

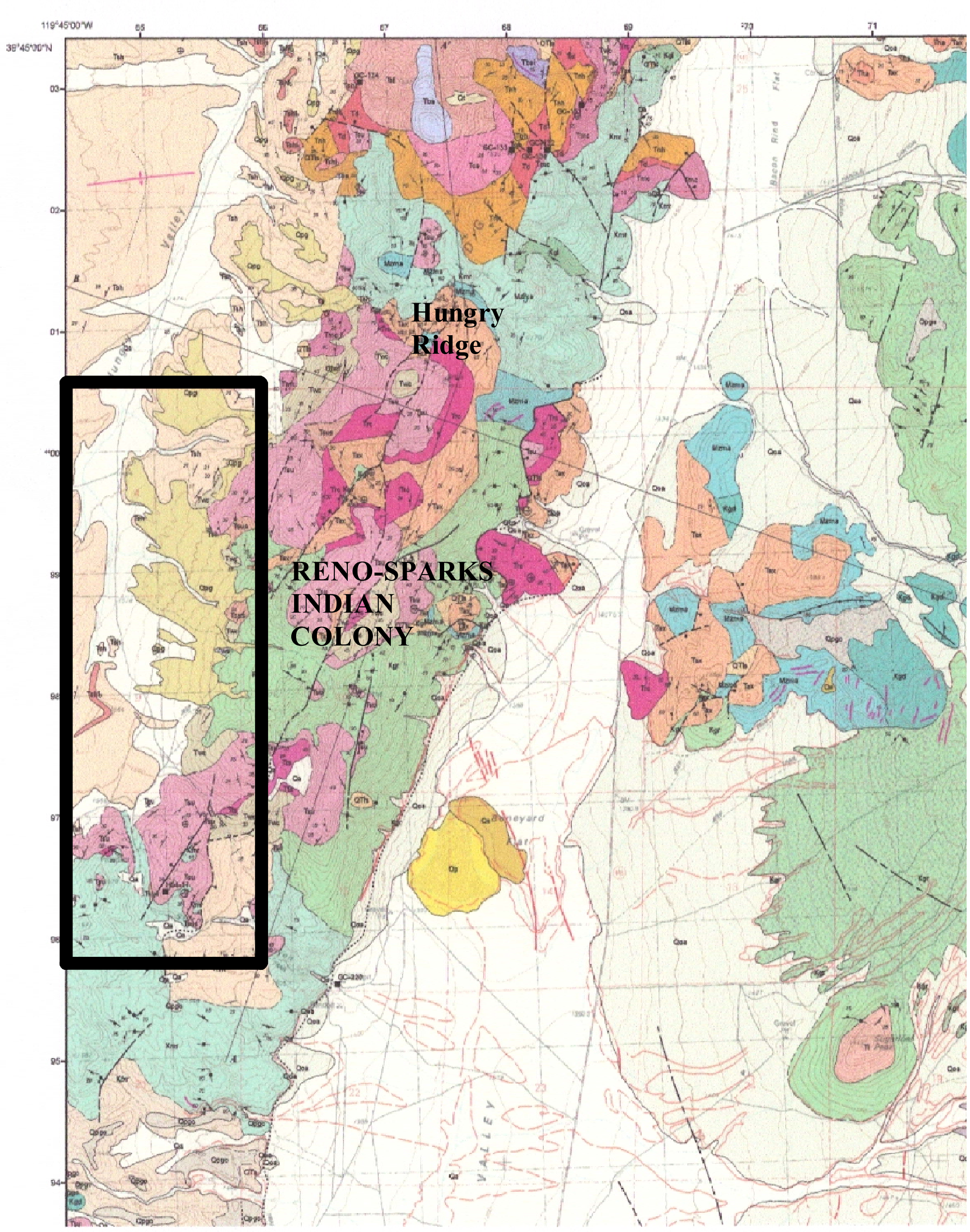


Figure 10. Geological Map of Hungry Valley (Garside et al, 2010); the Approximate Location of the Reno-Sparks Indian Colony is Shown

The top left corner of this preliminary geological map contains the southeast portion of Hungry Valley and the south portion of Hungry Ridge. This area is shown enlarged below:

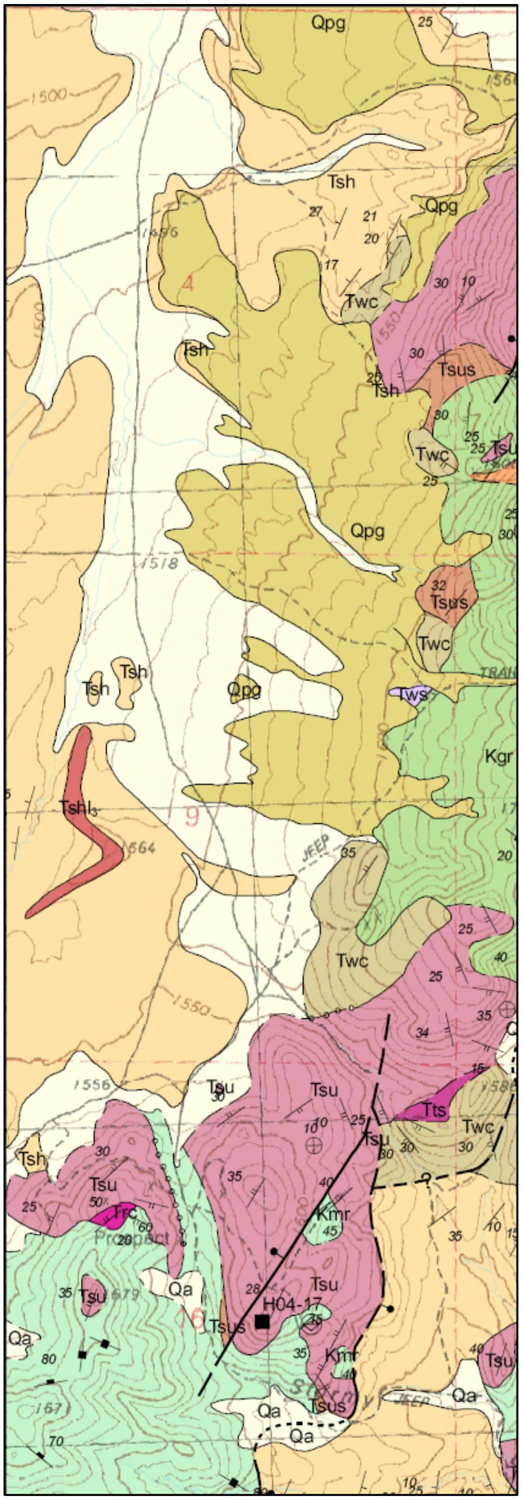
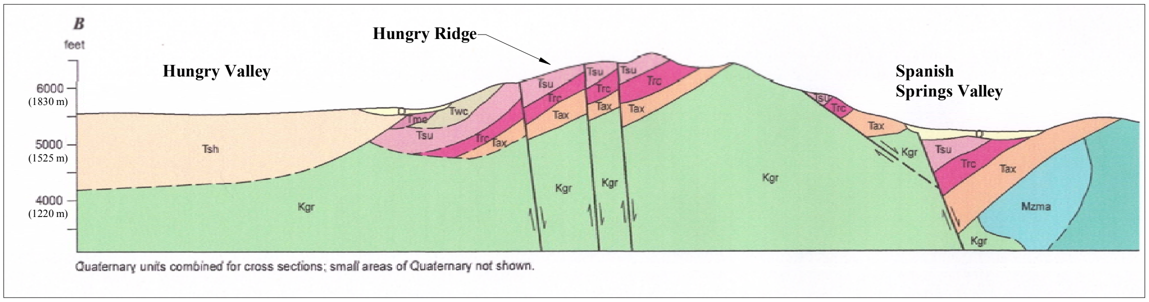


Figure 11. Enlarged Geological Map of Hungry Valley (Garside et al, 2010)

From Figure 11 it is noted that the surface deposits of Hungry Valley are primarily T_{sh} (Tertiary Unit, Pliocene, Sedimentary Rocks and Landslide Deposits of Hungry Valley) with occurrences of Q_a (Quaternary Deposit, Holocene, Alluvium) and some areas of Q_{pg} (Quaternary Deposit, Pleistocene, Pediment Deposits).

The units of the higher elevation of Hungry Ridge are shown in Figure 12. This figure is Section B of the <u>Preliminary Geological Map of the Griffith Canyon Quadrangle, Washoe County, Nevada</u>:



Quaternary units combined for cross sections; small areas of Quaternary not shown.

Figure 12. Preliminary Cross-Sectional Geological Map of Hungry Valley (Garside et al, 2010) (looking approximately northeast)

From Figure 12 it is noted that the cross-sectional geology of Hungry Valley is primarily T_{sh} (Tertiary Unit, Pliocene, Sedimentary Rocks and Landslide Deposits of Hungry Valley) in the valley and K_{gr} (Cretaceous Unit, Granite) below the valley deposits and under Hungry Ridge; with T_{wc}, T_{mc}, T_{su}, T_{rc}, and T_{ax} Tuff Deposits (Tertiary Units, Oligocene) forming the upper slopes of Hungry Ridge. Additionally, a thin deposit of Quaternary Deposits is shown at the base of Hungry Ridge. The Tertiary rocks are predominantly of volcanic origin and the volcanic piles contain intercalated lenses of sedimentary rocks (Bonham, 1969). In the figure below, the occurrence of Tuff can be seen where Little Hungry Spring emerges from part of Hungry Ridge (see Figure 15 for location of Little Hungry Spring).

Figure 13. Little Hungry Spring

Hungry Mountain and Warm Springs Mountain consist of Mesozoic granitic rocks ranging from diorite to quartz monzonite. Hungry Ridge has a core of Mesozoic granitic rocks overlain by welded ash-flow tuff and hornblende andesite breccias (Bonham, 1969). In Figure 14, a close-up photo of tuff from Little Hungry Spring, small black flecks of black crystals can be seen. These may be hornblende as referenced by Bonham (1969).

Figure 14. Close-Up Photo of Tuff from Little Hungry Spring

5.2 Faulting

Several areas of faulting in Hungry Valley are called out in the literature and potentially impact the movement of groundwater. For example, Geology and Mineral Deposits of Washoe and Storey Counties, Nevada (Bonham, 1969), addresses faulting on the east and west sides of Hungry Valley:

> Hungry Ridge on the east side of Hungry Valley is a westward-tilted fault block bounded by a major north-northeast trending fault on the east. This fault is apparently normal, and has a minimum dip-slip displacement of 457 m (1,500 feet).
>
> A continuous fault or fault zone could not be traced on the west side of Hungry Valley bounding Warm Springs Mountain and Hungry Mountain. A major normal fault must be concealed beneath the Pliocene rocks in Hungry Valley, however, because the welded ash

> flows on the east side of the valley dip to the west beneath the Pliocene rocks and have been eroded from Hungry Mountain and Warm Springs Mountain. A minimum dip-slip displacement of at least 366 m (1,200) feet on this concealed fault is required to account for this situation; the total displacement might be considerably larger.

5.3 Transition from Hungry Valley to Warm Springs Valley

In Section 3, a concealed fault at the transition between Hungry Valley and Warm Springs Valley was introduced. This faulting possibly inhibits underflow of groundwater from Hungry Valley to Warm Springs Valley, and is described by Harrigan and Ball in Hydrogeological Assessment of the Hungry Valley Groundwater Basin (Harrigan and Ball, 1996):

> At the junction between Hungry Valley and Warm Springs Valley, consolidated rocks are again in evidence on the east with the main surface drainage confined to a narrow canyon into Warm Springs Valley. The western portion of the junction, between consolidated rock exposures, features a concealed fault trending southeasterly mapped as sedimentary deposits on the south and quaternary alluvium on the north. These features could imply an inhibited ground water movement from Hungry Valley to Warm Springs Valley.

Additionally, the salinity, isotopic composition and pH of Little Hungry Spring have been reported as being similar to groundwater in Hungry Valley and its presence may be the result of this concealed fault (Shanafield et al, 2005).

5.4 Transition from Hungry Valley to Lemon Valley

The transition from Lemmon Valley to Hungry Valley is noted by a topographical high. A consolidated rock formation trending southeasterly featuring a small hill east of the southern portion of the Reno-Sparks Indian Colony, though covered with unknown depth of sedimentary material and quaternary alluvium, imposes a surface demarcation between Lemmon Valley and Hungry Valley (Harrigan and Ball, 1996).

Section 6 - Hydrogeology and the Flow System of Hungry Valley

6.1 Summary of Well Information

This section presents information about the wells located in Hungry Valley. The following tables present a summary of information from the Well Driller's Reports for the production and test wells of Hungry Valley; and include coordinates and elevations. The Well Driller's Reports are located in the Appendix for reference. The figure below indicates the locations of the wells and springs of Hungry Valley.

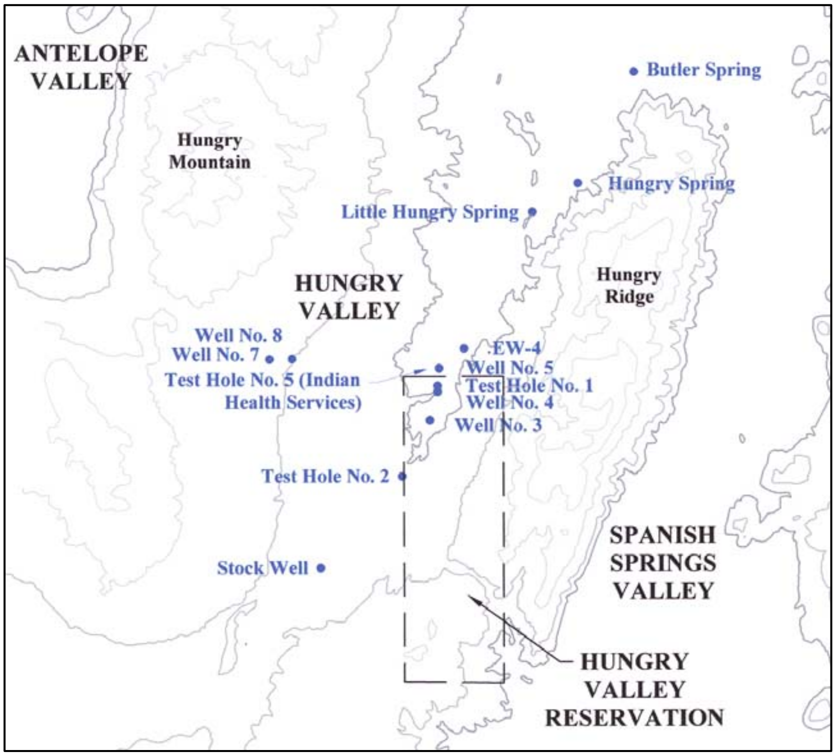


Figure 15. Location of Wells and Springs of Hungry Valley (Adapted from U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, 2005)

Table 3. Summary of Well Data from Well Driller's Reports (see Appendix for copies of Reports)

WELL NO.	COMPLETION DATE	TOTAL DEPTH DRILLED / CASED (meters (feet))	WELL DIAMETER / CASING DIAMETER (centimeters (inches))	SCREEN INTERVALS (meters (feet))	TOTAL SCREENED LENGTH (meters (feet))
Test Hole No. 1	10/9/1985	305 / 305 (1000 / 1000)	20 / 10 (8 / 4)	174 – 177 198 – 200 (570 – 580) (650 – 655)	5 (15)
Test Hole No. 2	9/17/1987	216 / 158 (710 / 520)	25 / 10 (9-7/8 / 4)	63 – 66 90 – 93 155 – 158 (206 – 216) (295 – 305) (510 – 520)	9 (30)
Well No. 3	10/1/1988	134 / 134 (440 / 440)	41 / 27 (16 / 10-3/4)	99 – 102 105 – 111 114 – 131 (325 – 335) (345 – 365) (375 – 430)	26 (85)
Well No. 4	4/28/1989	204 / 201 (670 / 660)	41 / 27 (0 to 128 m) and 17 (128 to 201 m) (16 / 10-3/4 (0 to 420 feet) and 6-5/8 (420 to 660 feet))	130 – 142 160 – 172 184 – 200 (425 – 465) (525 – 565) (605 – 655)	40 (130)
Well No. 5	6/22/1993	212 / 207 (695 / 680)	36 / 27 (0 to 140 m) and 17 (140 to 207 m) (14 / 10-3/4 (0 to 460 feet) and 6-5/8 (460 to 680 feet))	140 – 152 171 – 183 195 – 207 (460 – 500) (560 – 600) (640 – 680)	37 (120)
Test Hole No. 5 (Indian Health Services)	10/15/1993	256 / NA (840 / NA)	16 / 17 (0 to 4 m) (6-1/8 / 6-5/8 (0 to 12 feet))	Not Applicable (well was abandoned)	Not Applicable (well was abandoned)

Table 3. Summary of Well Data from Well Driller's Reports (see Appendix for copies of Reports) (continued)

WELL NO.	COMPLETION DATE	TOTAL DEPTH DRILLED / CASED (meters (feet))	WELL DIAMETER / CASING DIAMETER (centimeters (inches))	SCREEN INTERVALS (meters (feet))	TOTAL SCREENED LENGTH (meters (feet))
Well No. 7 (WW-1)	9/24/2001	168 / 164 (550 / 537)	31 (0 to 5 m) and 25 (5 to 168 m) / 22 (0 to 3 m) and 17 (3 to 164 m) (12-1/4 (0 to 17 feet) and 9-7/8 (17 to 550 feet) / 8-5/8 (0 to 9 feet) and 6-5/8 (9 to 537 feet))	75 – 81 87 – 94 118 – 148 (247 – 267) (287 – 307) (387 – 487)	43 (140)
Well No. 8 (WW-3)	10/10/2001	152 / 98 (500 / 320)	31 (0 to 5 m) and 25 (5 to 152 m) / 22 (0 to 3 m) and 17 (3 to 98 m) (12-1/4 (0 to 17 feet) and 9-7/8 (17 to 500 feet) / 8-5/8 (0 to 9 feet) and 6-5/8 (9 to 320 feet))	67 – 91 (220 – 300)	24 (80)
EW-4	10/25/2001	294 / 195 (965 / 640)	31 (0 to 5 m) and 25 (5 to 233 m) / 22 (0 to 3 m) and 17 (3 to 195 m) (12-1/4 (0 to 17 feet) and 9-7/8 (17 to 765 feet) / 8-5/8 (0 to 9 feet) and 6-5/8 (9 to 640 feet))	104 – 116 122 – 128 152 – 177 183 – 189 (340 – 380) (400 – 420) (500 – 580) (600 – 620)	49 (160)

Table 4. Summary of Well Coordinates and Elevations					
WELL NO.	**EASTING**	**NORTHING**	**METHOD**	**ELEVATION TO TOP OF CASING (meters (feet))**	**CASING HEIGHT ABOVE GROUND ELEVATION (meters (feet))**
Test Hole No. 1	264636	4400499	NAD 83	1488.9 (4885)	0.6 (1.9)
Test Hole No. 2	264014	4399137	NAD 83	1508.8 (4950)	0.3 (1.0)
Well No. 3	264493	4400032	NAD 83	1495.6 (4907)	1.0 (3.3)
Well No. 4	264635	4400487	NAD 83	1488.9 (4885)	0.4 (1.4)
Well No. 5	264638	4400587	NAD 83	1487.7 (4881)	1.0 (3.3)
Test Hole No. 5 (Indian Health Services)	264657	4400869	NAD 83	Unknown	0.0 (0.0)
Well No. 7 (WW-1)	261924	4401095	NAD 83	1556.9 (5108)	0.0 (0.0)
Well No. 8 (WW-3)	262291	4401091	NAD 83	1550.8 (5088)	0.0 (0.0)
EW-4	265085	4401174	NAD 83	1487.1 (4879)	0.0 (0.0)
Stock Well	262640	4397704	NAD 83	1540.8 (5055)	0.5 (1.8)

The following figures, Figure 16 through 27, present photographs of the production and test wells of Hungry Valley.

Figure 16. Test Hole No. 1 (adjacent to Well No. 4)

Figure 17. Well No. 3 (w/RSIC Air Station in the Background)

Figure 18. Well No. 4

Figure 19. Well No. 5

Figure 20. Well No. 7 (Enclosure)

Figure 21. Well No. 7

Figure 22. Well No. 8 (Enclosure)

Figure 23. Well No. 8

Figure 24. Test Hole No. 5 (Indian Health Service)

Figure 25. Stock Well (w/Hungry Valley Community in the Background)

Figure 26. Stock Well Marker

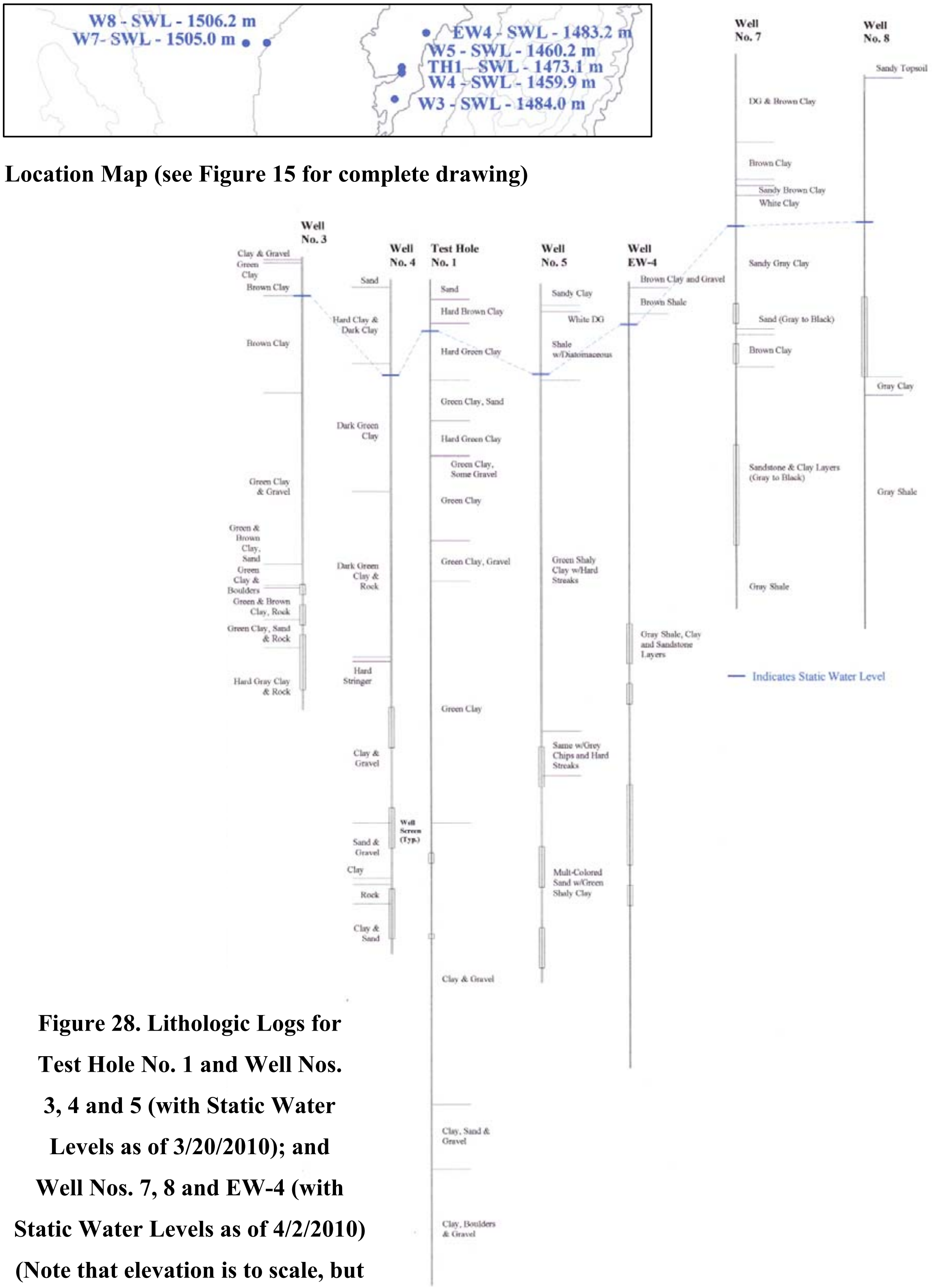
Figure 27. Hungry Valley Utility Department, Water Treatment Plant

Three of the original six wells drilled (Test Hole Nos. 1, 2 and 5; and Well Nos. 3, 4 and 5) were planned as production wells. The production wells were identified as Well Nos. 3, 4 and 5; yielding about 218 m^3/day (40 gpm), 818 m^3/day (150 gpm), and 818 m^3/day (150 gpm), respectively (Harrigan and Ball, 1996). Currently Well No. 3 is not used as a production well. It was noted that Test Hole No. 5 was abandoned. Due to static water levels declining, Well Nos. 7 and 8 were completed in 2001.

Test Hole No. 1 showed only a slight decline during the 2002 aquifer (pump) test (and subsequent tests) conducted by the UNR Graduate Program of Hydrologic Sciences for Wells Nos. 4 and 5. This possibly indicates that Test Hole No. 1 is poorly connected to the aquifer from which Well Nos. 4 and 5 are drawing water from. Test Hole No. 1 has limited screened intervals (~ 5 m total) and is not screened in the top interval of Well Nos. 4 and 5, but is screened in the second and third intervals. This suggests that the majority of water production in Well Nos. 4 and 5 is from the uppermost screened interval (Tyler, Summary of RSIC Hungry Valley Pump Testing, 2002). Additionally, it has been reported that Test Hole No. 1 has different water chemistry as compared to Well Nos. 4 and 5 (Shanafield et al, 2005).

As can be seen from the figure below, Well No. 3 has three screened intervals. These screened intervals sit topographically higher than the screened intervals of Test Hole No. 1 and Well Nos. 3 and 4.

It can also be seen from the figure below that Well EW-3 sits nearly at the same topographical elevation of Well No. 5. It has four screened intervals, two that are above the first screened intervals for Well Nos. 4 and 5, but at a similar elevation as those for Well No. 3. The second two screened intervals of Well EW-4 sit just below the first screened interval of Well No. 5, but at a similar elevation to the first screened interval of Test Hole No. 1. These screened intervals may support the similar static water levels of Test Hole No. 1, Well No. 3 and Well EW-3. Note also that Well EW-4 was artesian when drilled.



Location Map (see Figure 15 for complete drawing)

Figure 28. Lithologic Logs for Test Hole No. 1 and Well Nos. 3, 4 and 5 (with Static Water Levels as of 3/20/2010); and Well Nos. 7, 8 and EW-4 (with Static Water Levels as of 4/2/2010) (Note that elevation is to scale, but horizontal distance is not)

The following static water levels, as listed in Table 5, were taken from well logs (initial static water levels), UNR Graduate Program of Hydrologic Sciences and the RSIC records.

Table 5. Summary of Well Static Water Levels (SWLs) (Depth to Groundwater) From Well Driller's Reports, Previous UNR Class Field Work and RSIC (Note that some dates are estimated)

(meters (feet))

WELL NO. DATE	TEST HOLE NO. 1	TEST HOLE NO. 2	WELL NO. 3	WELL NO. 4	WELL NO. 5	WELL NO.7 (WW-1)	WELL NO. 8 (WW-3)	EW-4
10/28/1985	0.00 (0.00)							
9/30/1987		15.79 (51.80)						
10/10/1988			8.23 (27.00)					
5/15/1989				0.00 (0.00)				
6/22/1993					7.70 (25.25)			
9/1/1993			8.23 (27.00)					
6/24/1996	9.30 (30.50)	10.67 (35.00)	10.52 (34.50)	16.76 (55.00)	16.55 (54.00)			
3/1/1999	11.40 (37.40)	10.21 (33.50)	10.00 (32.80)	19.57 (64.20)	19.14 (62.80)			

**Table 5. Summary of Well Static Water Levels (SWLs) (Depth to Groundwater)
From Well Driller's Reports, Previous UNR Class Field Work and RSIC
(Note that some dates are estimated) (continued)**

(meters (feet))

WELL NO. / DATE	TEST HOLE NO. 1	TEST HOLE NO. 2	WELL NO. 3	WELL NO. 4	WELL NO. 5	WELL NO.7 (WW-1)	WELL NO. 8 (WW-3)	EW-4
1/31/2000	14.63 (48.00)	10.21 (33.50)	12.19 (40.00)	24.84 (81.50)	24.99 (82.00)			
3/15/2000	14.05 (46.10)	10.21 (33.50)	12.28 (40.30)	23.93 (78.50)	23.71 (77.80)			
4/16/2001	19.84 (65.10)			31.73 (104.10)	33.83 (111.00)			
10/17/2001						49.23 (161.50)		
11/5/2001							42.06 (138.00)	
11/21/2001								0.00 (0.00)
3/22/2002	20.39 (66.91)	10.20 (33.46)	15.91 (52.20)	31.82 (104.40)	31.71 (104.04)			2.70 (8.86)
2/8/2003		10.24 (33.60)				49.53 (162.50)	42.44 (139.25)	3.40 (11.15)
3/10/2003	18.64 (61.17)		16.90 (55.45)		36.58 (120.00)			
3/15/2003				36.76 (120.60)				

Table 5. Summary of Well Static Water Levels (SWLs) (Depth to Groundwater) From Well Driller's Reports, Previous UNR Class Field Work and RSIC (Note that some dates are estimated) (continued)

(meters (feet))

WELL NO. / DATE	TEST HOLE NO. 1	TEST HOLE NO. 2	WELL NO. 3	WELL NO. 4	WELL NO. 5	WELL NO.7 (WW-1)	WELL NO. 8 (WW-3)	EW-4
3/8/2004	20.51 (67.30)	10.31 (33.82)	16.74 (54.92)	39.39 (129.23)	39.40 (129.25)	49.57 (162.63)	42.14 (138.25)	4.27 (14.00)
3/10/2005				34.44 (113.00)	34.44 (113.00)			
4/23/2007	16.43 (53.92)	9.16 (30.05)	12.46 (40.89)	30.63 (100.50)	28.14 (92.33)			4.35 (14.26)
3/18/2008	15.85 (52.00)	9.98 (32.75)	12.44 (40.83)	29.26 (96.00)	28.13 (92.30)	51.00 (167.33)	44.22 (145.09)	
3/16/2009	15.83 (51.92)	9.94 (32.60)	12.07 (39.60)	28.88 (94.75)	27.28 (89.50)		45.32 (148.70)	3.85 (12.62)
3/20/2010	15.83 (51.93)	9.86 (32.34)	11.66 (38.26)	29.09 (95.45)	27.54 (90.35)			
4/2/2010						51.88 (170.20)	44.59 (146.30)	3.96 (13.00)

Note: Stock Well Static Water Level, Taken 3/16/2009, 17.2 m (56.3 ft.)

In 2003, the RSIC adopted a revised pumping strategy as recommended by the UNR Graduate Program of Hydrologic Sciences (S. Tyler Letter to RSIC, 2002). The previous pumping strategy was alternately pumping Well Nos. 4 and 5 at a maximum rate of 818 m^3/day (150 gpm) for 12 hours each day. The revised pumping strategy was implemented by operating Well Nos. 4 and 5 simultaneously each day for a maximum of 8 hours at a rate of 409 m^3/day (75 gpm); this pumping strategy allowed the RSIC to meet peak summer demand. This revised pumping strategy was implemented to address the drawdown in static water levels occurring at Well Nos. 4 and 5 (Shanafield et al, 2005). Additionally, Well Nos. 7 and 8 were developed on the west side of Hungry Valley and appear to have begun production in April of 2005.

As can be seen from the figures that follow, the implementation of the revised pumping strategy and the addition of the two new production wells (Well Nos. 7 and 8) in 2005, the static water levels for Well Nos. 4 and 5 have began a considerable recovery in static water levels. Static water levels appear to have stabilized. Note that pumping rate and recovery period play a large role in the measured static water levels; and need to be considered when viewing the following figures.

The following figures, Figures 29 through 36, graphically depict the static water levels for Test Hole Nos. 1 and 2; Well Nos. 3, 4, 5, 7 and 8; and EW-4. The graphs have been formatted to show the static water level in meters above mean sea level (AMSL).

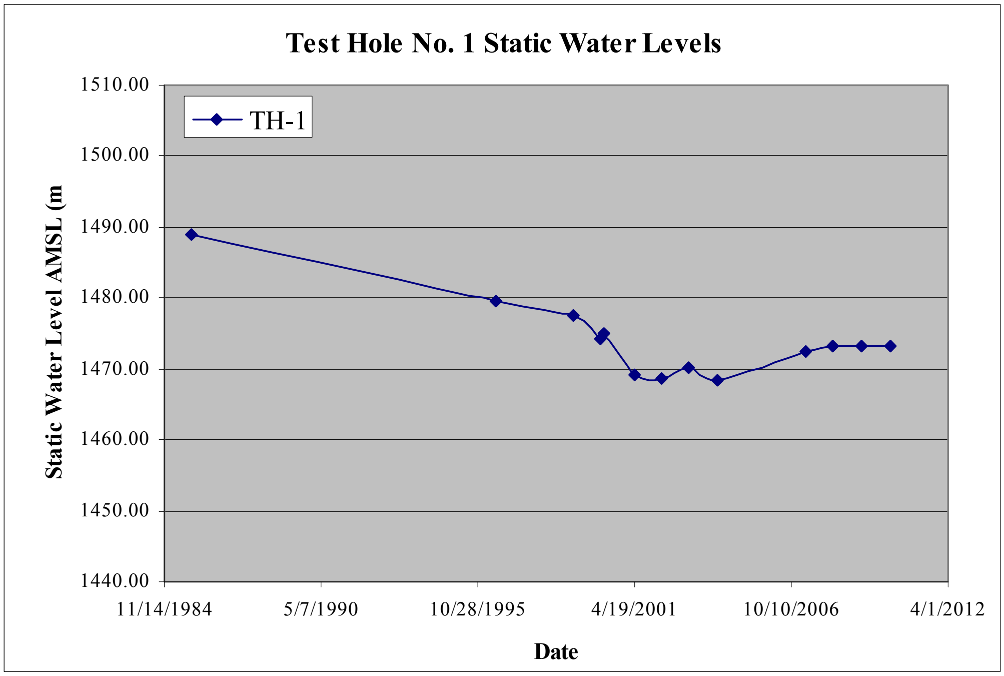


Figure 29. Test Hole No. 1 Static Water Levels

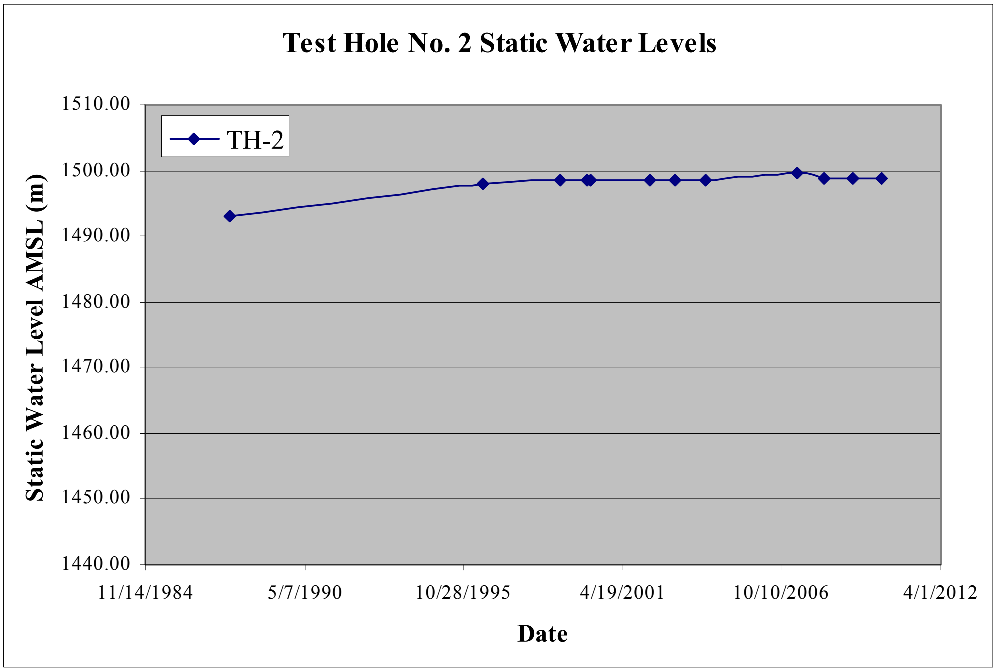


Figure 30. Test Hole No. 2 Static Water Levels

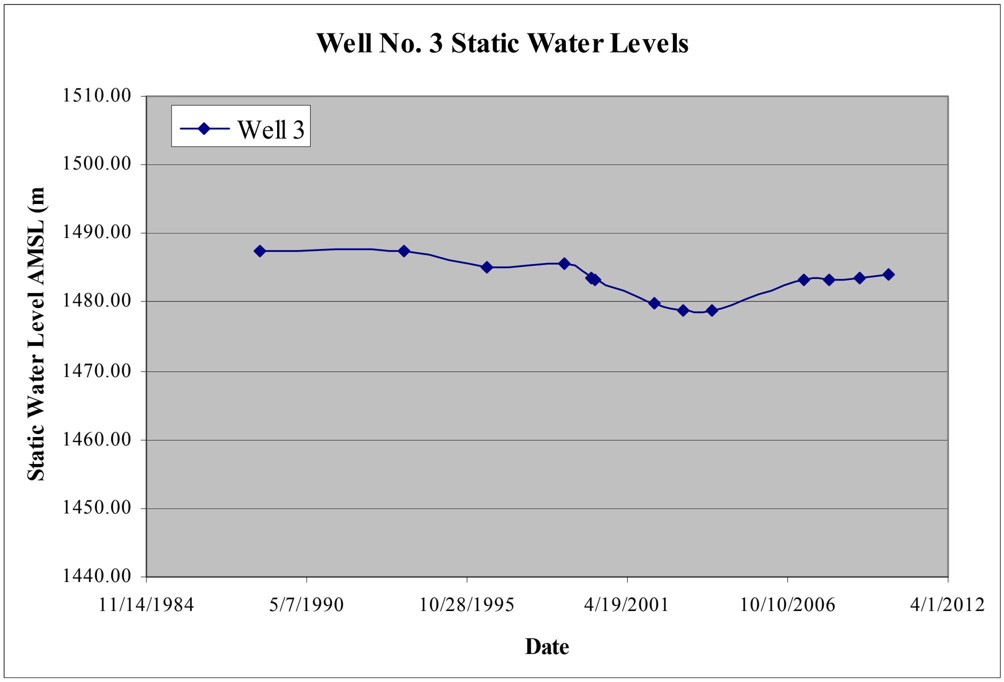


Figure 31. Well No. 3 Static Water Levels

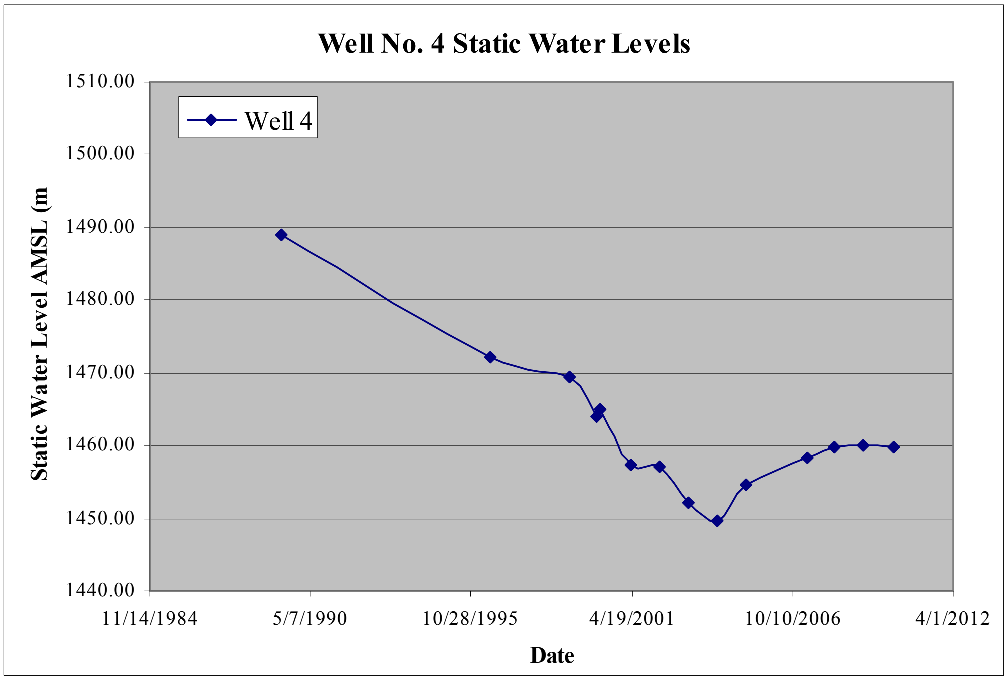


Figure 32. Well No. 4 Static Water Levels

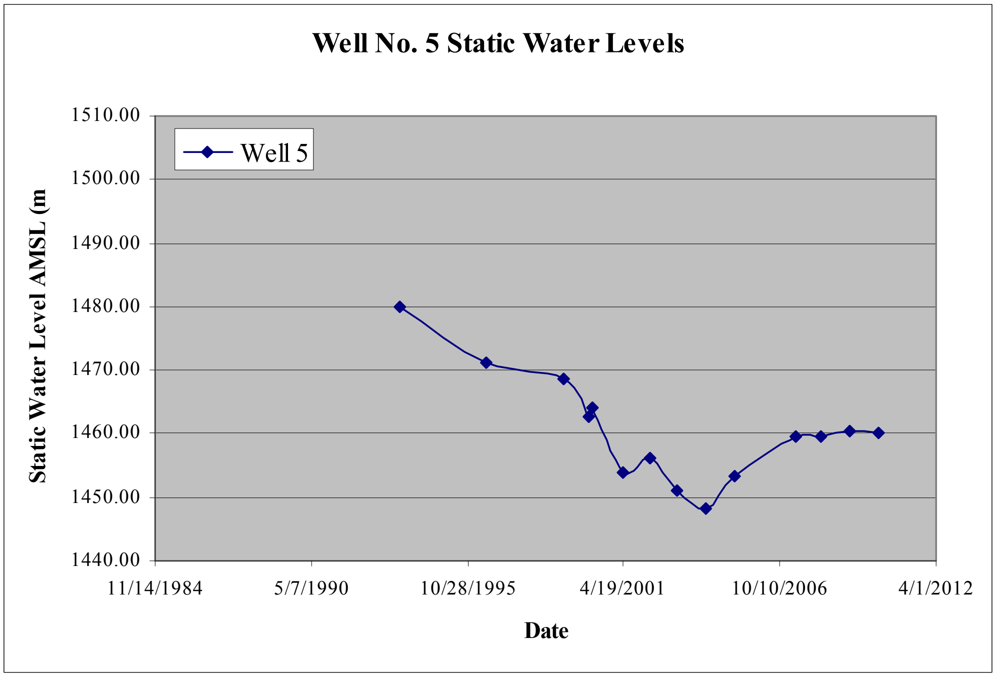


Figure 33. Well No. 5 Static Water Levels

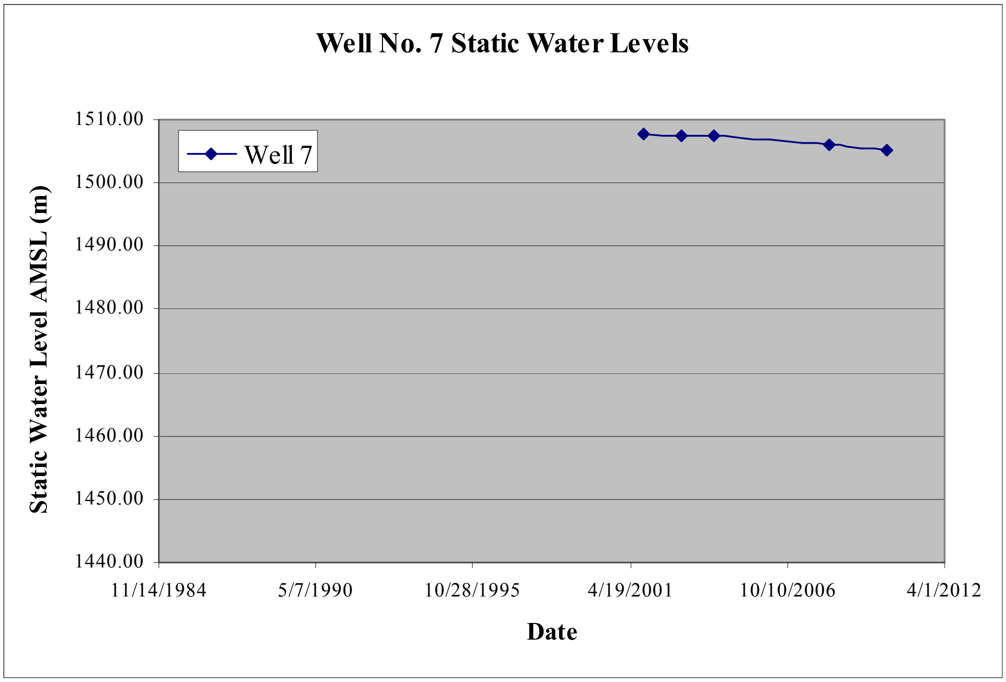


Figure 34. Well No. 7 Static Water Levels

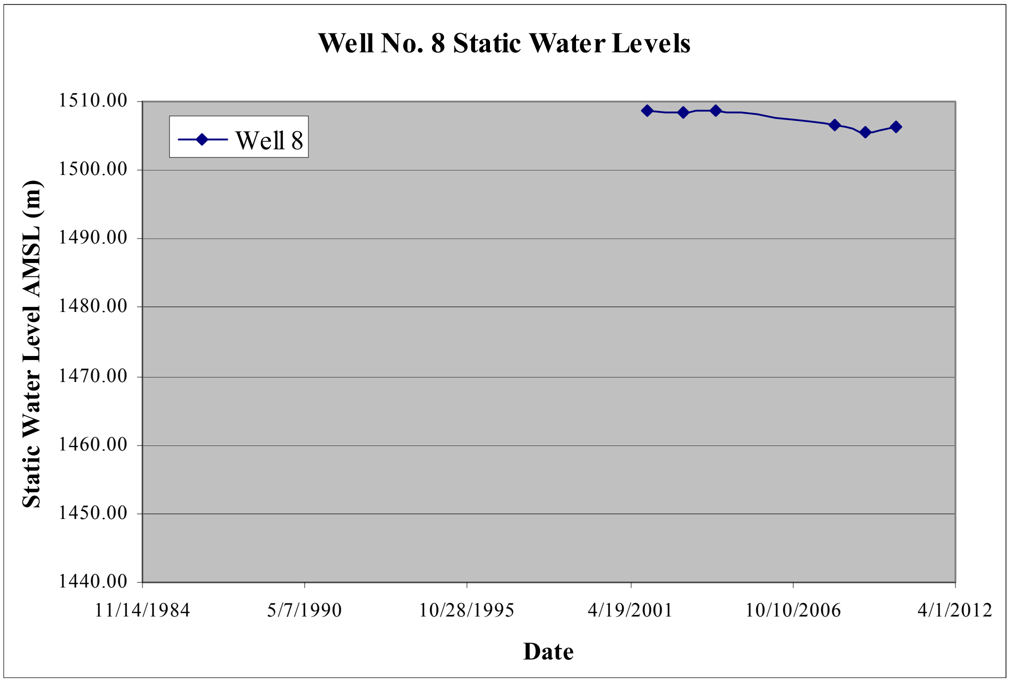


Figure 35. Well No. 8 Static Water Levels

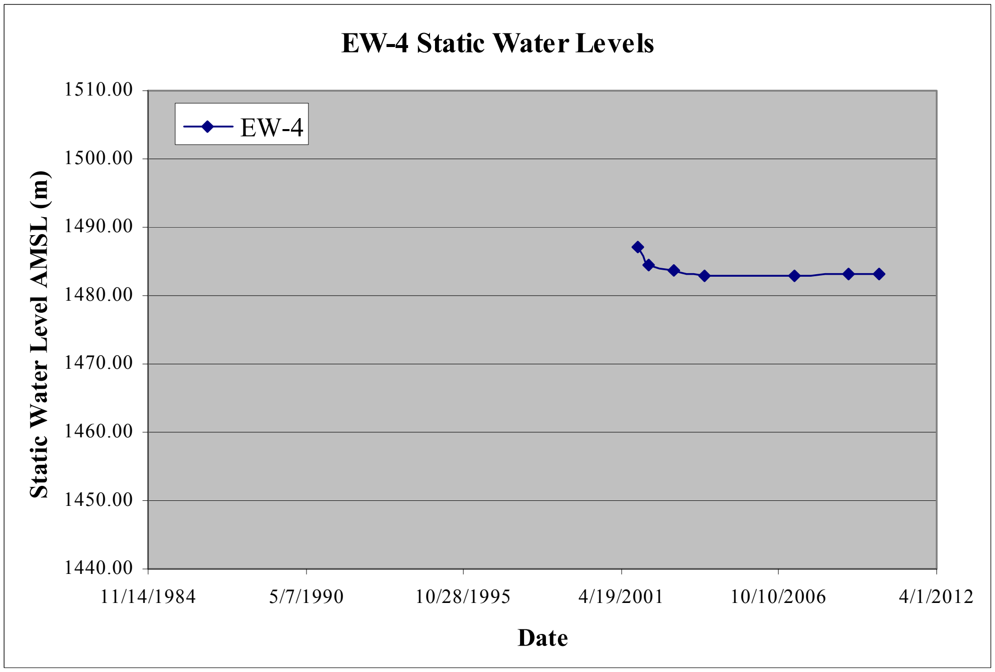


Figure 36. EW-4 Water Levels

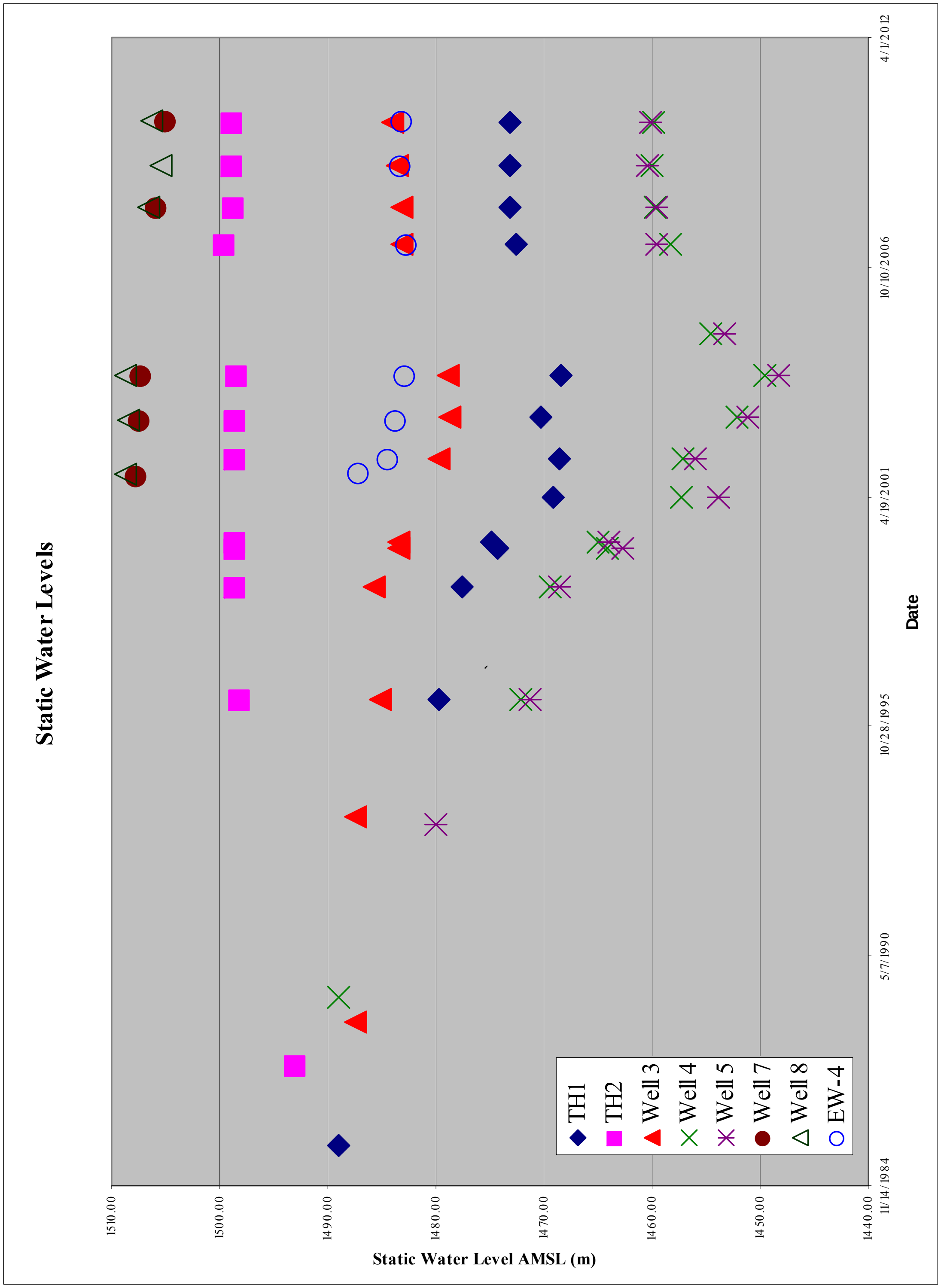


Figure 37. Static Water Levels

Figure 37 presents the static water level for all of the test holes and wells considered. Well Nos. 4 and 5 have very similar trending; as does Well Nos. 7 and 8. Test Hole No. 1, Well No. 3 and EW-4 also show some similar trending; these wells also show some relationship to Well Nos. 4 and 5, but without the steep drawdown indicating some degree of hydraulic connectivity. Test Hole No. 2 does not appear to share trending with any of the other wells.

6.2 Summary of Spring Information

There are three springs located at the northern part of Hungry Valley, as identified on the topographic map of the area (U.S. Department of the Interior, 2005): Little Hungry Spring, Hungry Spring, and Butler Spring. Little Hungry Spring has been previous shown to be of similar geochemistry to the groundwater of Hungry Valley. Hungry Spring appears to be recharged from mountain front recharge; and Butler Springs may be recharged from mountain front recharge or may be part of the regional flow system. The spring characteristics are summarized in the table below:

Table 6. Summary of Spring Coordinates, Elevations, and Flows (3/16/2009)

SPRING NAME	EASTING	NORTHING	DATUM	ELEVATION (meters (feet))	FLOW (m^3/day (GPM and Acre-Feet / Year))
Little Hungry Spring	266267	4403349	NAD 83	1,458.2 (4,784)	1.36 (0.25) (0.40)
Hungry Spring	267021	4403787	NAD 83	1,465.8 (4,809)	3.11 (0.57) (0.91)
Butler Spring	267985	4405570	NAD 83	1,408.8 (4,622)	14.12 (0.68) (1.10)

The following figures, Figure 38 through 43, present photographs of the springs of Hungry Valley:

Figure 38. Little Hungry Spring and Catchments

Figure 39. Little Hungry Spring Additional Catchment Farther to the North

Figure 40. Hungry Spring and Catchments

Figure 41. Butler Spring and Catchment

Figure 42. Butler Spring

Figure 43. Butler Spring Drainage Area Below Spring Elevation

6.3 Water Level Map

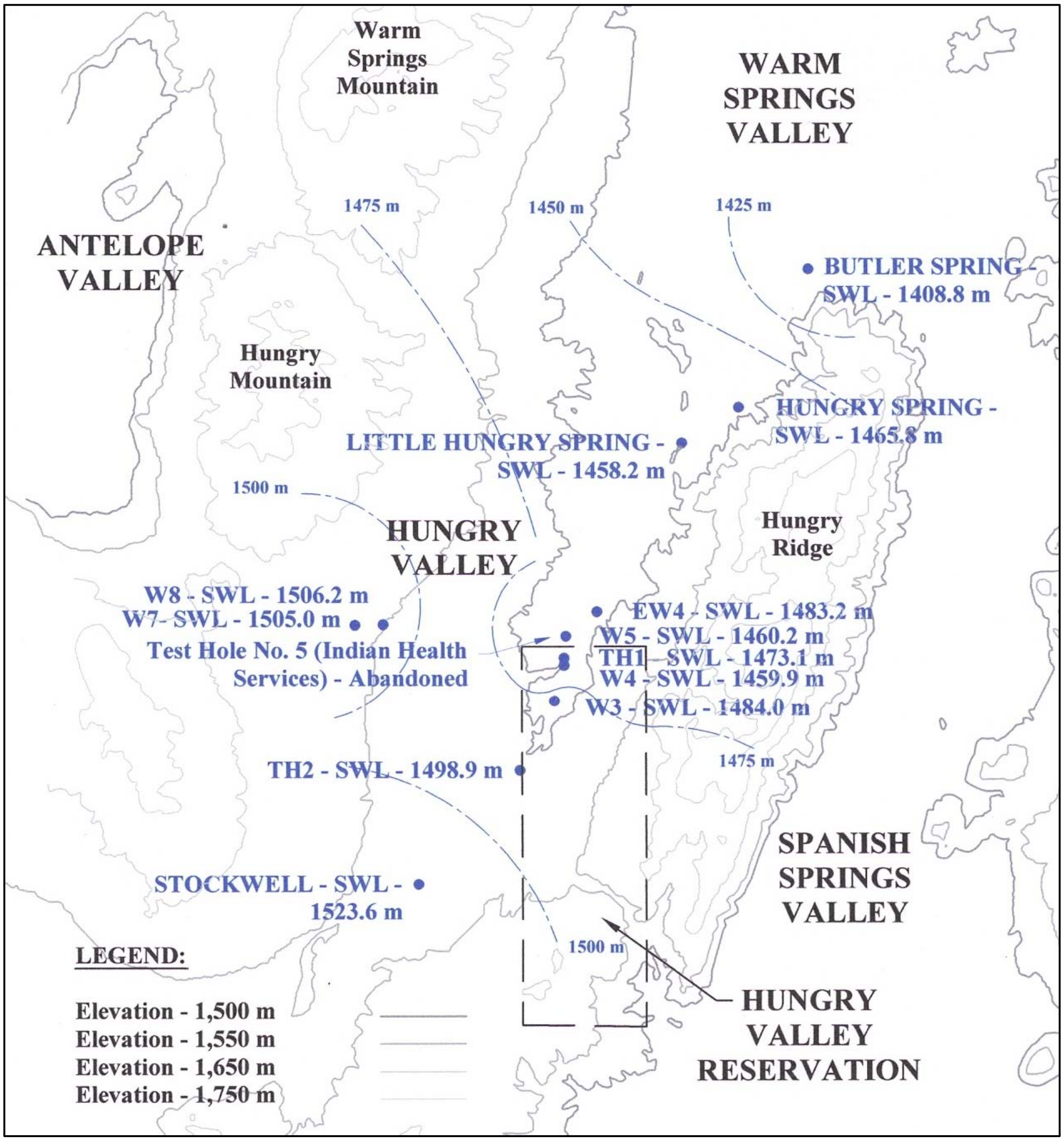


Figure 44. Water Level Map Derived from Measured Well Static Water Levels (3/20/2010 for Test Hole Nos. 1 and 2, and Well Nos. 3, 4, and 5; 4/2/2010 for Well Nos. 7, 8, and EW-4) and Springs (3/16/2009, also includes the Stock Well SWL) (Adapted from U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, 2005)

The above water level map presents a general idea of the groundwater elevations throughout Hungry Valley and the direction of flow. The groundwater contours were interpolated in the Groundwater Modeling System (GMS) software package. Interpolation was performed using the Inverse Distance Weighted Option with constant nodal function method and including all data points. As can be seen, elevations are higher in the south and decrease moving north through the valley with eventual discharge at the Little Hungry Spring (and possibly Butler Spring). This would support underflow within the basin from Hungry Valley into Warm Springs Valley. However, it has been previously discussed that the presence of faults may inhibit flow between the valleys. Additionally the static water levels are higher on the west side of the valley which supports the previous discussion that indicates the aquifers to not be hydraulically connected or the presence of a structural block between the connected aquifers but limiting flux.

Because the wells are screened at different depths they may be drawing groundwater from different aquifers. Also, the period of recovery is generally unknown at the time the measurements were taken. Finally, the static water levels were not all taken in the same year; however, trending indicates similar water levels to those presented would be expected.

The difference in static water levels between Well Nos. 4 and 5 and Test Hole No. 1 have been previously discussed. This is supported by the water level map. The static water levels for Well Nos. 4 and 5 do not appear to fit into the overall regional flow system; as there are higher static water levels both south (Well No. 3) and north (Well No. EW-4) of these wells.

6.4 Water Budget

The following table presents an estimated water budget for Hungry Valley taken from reported sources (as listed in the table). The water budget indicates the only source of inflow is recharge. Pumping and spring flow accounts for approximately 20% of the estimated recharge; and evapotranspiration of groundwater is considered negligible. Therefore, it is estimated that approximately 80% of the recharge leaves Hungry Valley as underflow to Warm Springs Valley.

Table 7. Estimated Water Budget

INFLOWS TYPE	INFLOW ESTIMATE (m^3/day (acre-feet / year))	REFERENCE
Recharge	946 (280)	Nevada Sierra Planners, 1999
OUTFLOWS TYPE	**OUTFLOW ESTIMATE (m^3/day (acre-feet / year))**	**REFERENCE**
Pumping (for consumptive use)	193 (57.1)	Hungry Valley Pumping Average Taken 2000 – 2009 (excluding 2005)
Spring Flow	1.35 (0.4)	Little Hungry Spring Estimate (Hungry Springs and Butler Spring appear to originate from mountain recharge areas)
Intra-Basin Underflow to Warm Springs Valley	752 (222.5)	Estimated from Difference Between Inflow and Outflow
Evapotranspiration	0 (0)	No Phreatophytes at the Valley Floor and Non Shallow Water Table

Note: To the northwest of Well No. 4 there are waste water effluent ponds. As these ponds are lined, they were not included in the estimated water budget (RSIC, Wellhead Protection Program, 2006).

6.5 Geochemistry

The following tables present geochemistry data for Hungry valley as follows:

- Table 8 – Springs
- Table 9 – Wells
- Table 10 – Blended Pumped Water

The following table presents geochemistry data from the springs of Hungry Valley collected during two site visits in 2009. The conductivity/pH meter utilized during the March site visit only had one calibration standard; so a second site visit was made in April.

Table 8. Hungry Valley Spring Water Geochemistry
(Data Collected in 2009)

LOCATION	DATE / TIME	CONDUCTIVITY (µS/cm)	TEMPERATURE (°C (°F))	pH
Little Hungry Spring	3/16/2009 / 13:40	785	10.7 (51.2)	
	4/15/2009 / 14:45	710	10.0 (50.1)	8.56
Hungry Spring	3/16/2009 / 13:59	555	12.9 (55.2)	
	4/15/2009 / 14:10	696	12.9 (55.2)	8.76
Butler Spring	3/16/2009 / 14:24	658	11.7 (53.1)	
	4/15/2009 / 15:10	585	12.2 (54.0)	7.89

The following table presents geochemistry data for the RSIC test holes and wells.

Table 9. Hungry Valley Well Water Geochemistry

The data for Test Hole Nos. 1 – 2 and Well Nos. 3 – 5 is reproduced from <u>Hydrogeological Assessment of the Hungry Valley Groundwater Basin</u> (Harrigan and Ball, 1996)

The data for Well Nos. 7, 8 and EW-4 is from V Point Planners, Table 1.2, 2002 (Note that the data sheet references EW No. 3, however, this appears to be Well EW-4)

The data for EW-4 (conductivity and temperature) was collected on 3/16/2009

The data for pH, Temperature and EC is reproduced from <u>Analysis of Hungry Valley Groundwater Pumping and Management, Washoe County, Nevada</u> (Shanafield et al, 2005) for Test Hole No. 1 and Well Nos. 4 and 7

Note: Where multiple data values exist, they are shown in order of the references listed

CONSTITUENT (Note: Units are mg/L unless otherwise noted)	**TEST HOLE NO. 1**	**TEST HOLE NO. 2**	**WELL NO. 3**	**WELL NO. 4**	**WELL NO. 5**	**WELL NO. 7**	**WELL NO. 8**	**EW-4**
Alkalinity Bicarbonate	272.0	171.0	300.0	259.0	361			
Alkalinity Carbonate	124.0	0	48.0	115.0	55.0			
Alkalinity						120	110	322
Arsenic	<0.003	0.006	<0.003	<0.003	<0.003	0.011	0.013	0.002
Barium	N.T.	<0.04	0	0.01	0	0.023	0.019	0.006
Cadmium	N.T.	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium	1.40	54.0	2.0	1.0	1.0	31	27	1.3
Chloride	11.0	11.0	11.0	7.0	8.0	4.7	4.8	18
Chromium	N.T.	<0.02	<0.005	<0.005	<0.005	0.009	0.005	0.016
Copper	N.T.	<0.02	0	0.01	0	<0.001	<0.001	<0.001
Fluoride	1.10	0.40	1.71	0.74	1.44	0.17	0.2	1.3
Iron	0.37	0.12	0.20	0.47	0.17	0.056	0.016	1.0

Table 9. Hungry Valley Well Water Geochemistry (continued)

CONSTITUENT (Note: Units are mg/L unless otherwise noted)	TEST HOLE NO. 1	TEST HOLE NO. 2	WELL NO. 3	WELL NO. 4	WELL NO. 5	WELL NO. 7	WELL NO. 8	EW-4
Lead	N.T.	<0.05	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001
Magnesium	0.30	20.00	0	0	0	6.4	3.8	0.48
Manganese	<0.02	0.15	0.02	0.01	0.01	0.023	0.001	0.016
Mercury	N.T.	<0.005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Nitrate	0.20	0.10	0.20	0.40	0.10	1.4	0.46	<0.05
Potassium	1.50	8.5	2.0	1.0	1.0	5.6	5.3	2.3
Selenium	N.T.	<0.005	0.002	<0.001	<0.001	0.003	0.002	<0.005
Silver	N.T.	<0.01	<0.005	<0.005	<0.005	<0.001	<0.001	<0.002
Sodium	190.0	150.0	168.0	202.0	196.0	23	18	200
Sulfate	26.0	370.0	37.0	25.0	35.0	11	14	96
Zinc	N.T.	<0.01	0.11	0.01	0.01	0.011	0.009	<0.005
T.D.S.	491.0	778.0	427.0	500.0	494.0	210	200	560
Total Hardness ($CaCO_3$)	5.0	217.0	5.0	3.0	3.0	104	83	5
pH	9.2	8.3	9.08	9.54	9.39	7.82	7.92	9.46
	6.74			8.85		9.3		

Table 9. Hungry Valley Well Water Geochemistry (continued)

CONSTITUENT (Note: Units are mg/L unless otherwise noted)	TEST HOLE NO. 1	TEST HOLE NO. 2	WELL NO. 3	WELL NO. 4	WELL NO. 5	WELL NO. 7	WELL NO. 8	EW-4
Temperature (°C (°F))	22 (72)	20 (68)				20.3 (68.5)	19.9 (67.8)	20.2 (68.4)
								13.2 (55.7)
	14.5 (58.1)			19.3 (66.7)		13.7 (56.7)		
Turbidity (NTU)			1.1	2.7	0.90			
E.C. (µS/cm)			727.0	827	803	290	270	853
								890
	5745			729		883		

The following data was collected during the aquifer (pump) tests performed in 2008 from the blended (and unfiltered) water in the treatment plant, pumped from Well Nos. 4 and 7:

Table 10. Hungry Valley Well Water (Blended) Geochemistry from Aquifer (Pump) Tests in 2008

DATE / TIME	CONDUCTIVITY – 1ST METER (µS/cm)	CONDUCTIVITY – 2ND METER (µS/cm)	TEMPERATURE – 1ST METER (°C (°F))	TEMPERATURE – 2ND METER (°C (°F))	pH
3/18/2008 / 17:50	618	626	20.7 (69.3)	21.6 (70.9)	9.31
3/18/2008 / 21:30	802	726	20.5 (68.8)	21.4 (70.5)	9.29
3/19/2008 / 7:01	406	354	19.9 (67.8)	20.9 (69.6)	9.16
3/19/2008 / 10:08	376	779	20.2 (68.4)	21.1 (70.0)	9.22
3/19/2008 / 11:40	802	751	20.5 (68.9)	21.5 (70.7)	9.22
3/19/2008 / 15:03	690	752	20.1 (68.2)	21.0 (69.8)	9.17

The data presented in Tables 8 – 10 indicates the following in relation between the springs and wells:

- The conductivity of the springs ranges from 555 – 785 µS/cm; with Little Hungry Spring having the highest readings. Whereas, the conductivity of Well No. 3 is 727 µS/cm, Well Nos. 4 and 5 average 787 µS/cm, Well Nos. 7 and 8 average 481 µS/cm, and Well EW-4 is 872 µS/cm.
- The average temperature of the springs is 11.7°C. The average temperate at Test Hole Nos. 1 and 2, and Well Nos. 4 and EW-4, are 18.3°C, 20.3°C, 19.3°C and 16.7°C, respectively. The average temperature at Well Nos. 7 and 8 is 18.0°C.
- The average pH of the springs is 8.5. The pH of Test Hole Nos. 1 and 2, and Well Nos. 3 and EW-4, are 8.0, 8.3, 9.1 and 9.5, respectively. The average pH of Well Nos. 4 and 5 is 9.3; and the average pH of Well Nos. 7 and 8 is 8.3.

The data presented in Tables 8 – 10 indicates the following in relation between the wells:

- The blended water from the 2008 aquifer (pump) test indicates that the pH is above 9. This is above the State of Nevada Secondary Standard for pH, which is the range of 6.5 to 8.5 (NAC 445A.455, 2012). Note that secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects or aesthetic effects in drinking water (EPA, National Secondary Drinking Water Regulations, 2012).
- Test Hole No. 1 has the highest value for conductivity, nearly 650% higher than the next highest data point.

- Test Hole No. 2 shows very high total hardness and total dissolved solids (T.D.S) as compared to the other wells. Test Hole No. 2 has a considerable number of layers and thicknesses of clay throughout its depth (see Lithologic Log in the Appendix). Also, its static water trend does not follow that of the other wells.
- Well Nos. 7 and 8 contain arsenic; whereas, the other wells do not appear to contain an appreciable concentration.
- Well No. 7 has a higher nitrate concentration compared to the other wells, although well below regulatory standards for nitrate.

6.5.1 Isotopes

An isotope analysis was conducted in 2003 by the UNR Graduate Program of Hydrologic Sciences. The results were provided in a Letter from Dr. Scott Tyler (Tyler, 2003):

> The stable isotopes of water (deuterium and oxygen-18) that were sampled from several wells and springs shows quite clearly that most of the ground water in Hungry Valley was probably recharged during the colder climates of the late Pleistocene, over 10,000 years ago. We were not able to pump most of the wells to get the best quality samples, however the isotope data are pretty consistent and show that deep ground water is well connected. The isotope data from Hungry Spring clearly shows that modern recharging water is isotopically heavier than the ground water supplies of the Colony. Again, this suggested that recharge to the ground water system supplying the Colony is small and that much of the ground water in the valley is quite old.

The isotopic analysis pertains to the groundwater currently present in the water bearing layers of Hungry Valley. Recharge is discussed in the following section, Section 6.6, and perennial yield is discussed in Section 6.7.

6.6 Recharge

The conceptual hydrogeologic model previous presented indicates that recharge occurs primarily in the mountains of Hungry Valley. To a lesser extent recharge occurs in the valley; however, diffuse recharge to the aquifers is limited by the thick sequences of fine grained silts and clays (Shanafield et al, 2005). The thick clay layer near the surface of many of the wells may retard surface recharge. Evaporation also plays a role in limiting recharge.

Nevada-Sierra Planners, in their 1999 Phase I Hydrogeologic Investigation of the Groundwater Supply at Hungry Valley (Gebhardt et al, 1999) estimated recharge using a standard chloride mass balance approach with comparison to estimates from other sources. A contributing area of approximately 25.9 square kilometers (10 square miles) was selected. The total amount of recharge was estimated at 946 m^3/day (280 acre-feet per year) assuming an average recharge rate of 4.2% of precipitation.

As part of the environmental impact statement for the Oil-Dri Corporation of Nevada's proposed Reno Clay Plant Project, an estimate of recharge for a sub-basin area of 11.7

square kilometers (2,900 acres) was presented and resulted in a recharge rate of 237 m^3/day (70 acre-feet per year) (BLM, 2001).

A third estimate for recharge is taken from Fundamental Concepts of Recharge in the Desert Southwest: A Regional Modeling Perspective, 2004. This document gives a mean potential recharge of 20,276 m^3/day (6,000 acre-feet per year) for the Warm Springs Area using the Maxey-Eakin Method (Flint et al, 2004). Note that Hungry Valley is only a small portion of the Warm Springs Area and sits topographically higher.

If the 25.9 square kilometer contributing area assumed by Nevada-Sierra Planners is applied to the other estimates, then the various estimates can be compared and this is presented in Table 11.

Table 11. Recharge Estimates (Assuming a 25.9 square kilometers (10 Square Mile) Contributing Area)

ORGANIZATION	YEAR	ESTIMATE (m^3/day (area-feet per year))
Nevada-Sierra Planners (standard chloride mass balance approach with comparison to estimates from other sources)	1999	946 (280)
BLM (Oil-Dri Corporation of Nevada's proposed Reno Clay Plant Project)	2001	524 (155)
USGS (Maxey-Eakin Method)	2004	821 (243)

6.7 Perennial Yield

The perennial yield of the Warm Springs Valley Hydrographic Basin is 10,138 m^3/day (3,000 acre-feet per year); however, committed groundwater exceeds 21,966 m^3/day (6,500 acre-feet per year) (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, Order 1205, 2010)

The Nevada State Water Plan (Nevada Division of Water Planning and the Department of Conservation and Natural Resources, 1999) defines Perennial Yield as:

> The amount of usable water of a ground water reservoir that can be withdrawn and consumed economically each year for an indefinite period of time. It cannot exceed the sum of the Natural Recharge, the Artificial (or Induced) Recharge, and the Incidental Recharge without causing depletion of the groundwater reservoir. Also referred to as Safe Yield" (Nevada State Water Plan, 1999).

The perennial yield by definition is determined by estimates of recharge as indicated in the reference above. Additionally, the perennial yield estimate is not specific to Hungry Valley; rather it is an estimate for the larger Warm Springs Valley Hydrographic Basin.

6.8 Evapotranspiration

Evapotranspiration refers to the combination of transpiration and evaporation. Transpiration occurs by deep-rooted plants, known as phreatophytes, that extend roots to the water table; and evaporation occurs where the water table is shallow (Moll, 2000).

Evapotranspiration occurs from local precipitation. However, evapotranspiration of groundwater does not appear to be significant to Hungry Valley due to the general absence of phreatophytes and a non shallow water table (generally greater than ~10 m on the east side of the valley and greater than ~40 m on the west side of the valley depth to groundwater). Additionally, many of the well logs indicate the presence of a thick clay layer near the land surface, which is likely to severely limit evaporation or transpiration from the aquifer. As there is rarely surface flow from the valley, it can be assumed that the vast majority of annual precipitation is lost annually to evapotranspiration from vegetation.

Section 7 – Construction of a Steady-State MODFLOW Model

The mathematical model simulates groundwater flow by means of a partial-differential equation that approximates the physical processes that occur in the system; and requires equations that describe the heads or flows along the boundaries of the model to define the boundary conditions (Anderson and Woessner, 2002).

Two approaches can be used to construct a MODFLOW simulation in Groundwater Modeling System (GMS): the grid approach or the conceptual model approach. The conceptual model approach was used for this project. This approach involved using the GIS tools in the MAP module to develop a conceptual model of Hungry Valley. The location of sources / sinks (Little Hungry Spring), layer parameters (hydraulic conductivity and vertical anisotropy), and model boundaries (no flow, constant flux, and constant head), were defined at the conceptual model level. Once the model was complete, the grid was generated and the conceptual model was converted to the grid model (Aquaveo, GMS Tutorials, MODFLOW – Conceptual Model Approach, Version 6.5.6). The Steady-State MODFLOW Model was created using the graphical user interface GMS 8.2, Version 8.2.2.12874, Build Date: 2/28/2012.

The model development for this thesis work consisted of the following:

- Development of a steady-state model of the aquifer; and calibration of the model to known static water levels prior to well field development (this Section)

- Development of a transient simulation to model the aquifer stresses due to well field development (Section 8)

7.1 Assumptions

Several assumptions were utilized in the development of the Steady-State MODFLOW Model.

Most significantly, the aquifer is represented as a single unit. This is a significant simplification of the apparent complex hydrogeology of Hungry Valley. Because of the elevation difference of the observed static water levels, the difference in geochemistry (Well Nos. 7 and 8 contain arsenic and Well Nos. 4 and 5 do not), and the differences in calculated transmissivities; it appears that the aquifer at Well Nos. 4 and 5 and the aquifer at Well Nos. 7 and 8 are not fully and completely connected. Additionally, each well is screened at different elevations and potentially interfaces with different aquifers at each given location. Finally, several faults and a structural block are referenced in the literature. Figure 45 below gives one depiction of faulting in the area; however, while the literature generally notes faulting there does not appear to be a consensus as to location. To address the available information, a partial structural block has been inserted to simulate separate aquifers; allowing some flow interaction throughout the layer. However, the model does not account for the possibility of aquifers at different elevations or of the possibility of water in bedrock below the aquifers. The top layer of the model is simulated as a single unconfined layer.

The Figure below is taken from Figure 1. General Location of Dry Valley, West-Central Nevada; and depicts faulting "modified from U.S. Geological Survey (2003)" in Hungry Valley (USGS Scientific Investigations Report 2004-5155). Superimposed on this figure are a drainage divide derived from Plate 1. Generalized Hydrogeologic Map of the Warm Springs – Lemmon Valley Area, Washoe County, Nevada and Lassen County, California (Rush and Glancy, 1966) (indicated in light blue); the selected model coverage area, and the location of the Hungry Valley Reservation and existing wells and springs pertinent to this thesis project.

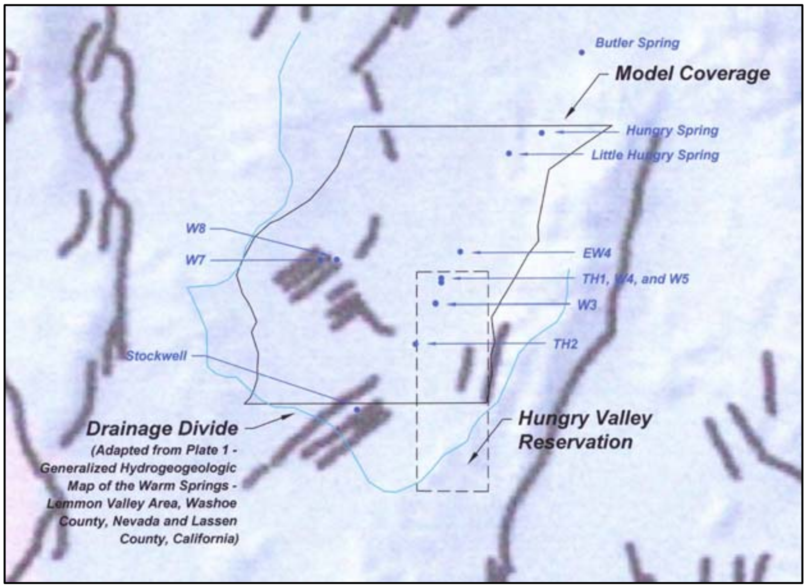


Figure 45. Model Area (Adapted from Figure 1 – General Location of Dry Valley, West-Central Nevada (USGS Scientific Investigations Report 2004 – 5155); with Drainage Divide from Plate 1 – Generalized Hydrogeologic Map of the Warm Springs – Lemmon Valley Area, Washoe County, Nevada and Lassen County, California (Rush and Glancy, 1966))

The model domain (discussed in Section 7.4 below) was chosen primarily based upon available data. Mountain front recharge was selected to the east and west of the model coverage area based on the conceptual hydrogeologic model presented in Section 4. Because of the similar peak elevations of Hungry Mountain and Hungry Ridge, the recharge estimate was divided evenly between the east and west boundaries of the model domain.

To the south appears to be a groundwater divide between Hungry Valley and Lemon Valley. This drainage divide is shown in Figure 45 above as a light blue line. The model domain does not coincide exactly with this groundwater divide; because of the limited data in the area, a straight line was chosen. This groundwater divide appears to be the result of a topographic high between Hungry Valley and Lemmon Valley.

The northern coverage area of the model terminates at Little Hungry Spring because little data are available beyond this northern boundary. A specified head boundary condition was placed in the depression noted between the elevation lines of 1,500 m on the topographic map (U.S. Department of the Interior, 2005). A specified head boundary may represent the water table (Anderson and Woessner, 2002) and was selected based on the elevation of Little Hungry Spring. The Steady-State MODFLOW Model requires at least one specified head boundary to give the model a reference elevation from which to calculate heads (Anderson and Woessner, 2002). The land surface elevations change rapidly in the narrow northern drainage area and vary with outcroppings. The depression noted between the elevation lines of 1,450 m on the topographic map (U.S. Department of the Interior, 2005) was modeled as 1,460 m to smooth the linearly interpolated land surface elevations and to more accurately represent the surface elevation at Little Hungry Spring. Additionally, the elevation of several of the 100 m square grid blocks in this area was changed by a few meters to prevent them from flooding (i.e. modeled head values greater than modeled surface elevation); these grid blocks are identified in Section 7.11.

Finally, it was the goal of the steady state model of the aquifer to be calibrated to known static water levels prior to well field development. Only the static water levels of Well Nos. 3 and 4 are known prior to the start of pumping in 1991. The static water levels for Well Nos. 7 and 8 and the flow at Little Hungry Spring are taken from 2001 and 2009 data, respectively. This leads to a level of uncertainty as to the actually static water levels throughout Hungry Valley prior to well field development.

7.2 Selection of Units

The units selected for the modeling effort were Length – Meters and Time – Days.

7.3 Import Topographic Map Image and Register

The modeling effort began with the import of the U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, 1:100,000-Scale Topographic Map, Reno, Nevada, 2005 (U.S. Department of the Interior, 2005). This map was registered utilizing the three hash marks nearest the project site in the North American Datum 83.

7.4 Coverage and Boundary Conditions

The development of the model began with the identification of the project site coverage. The project modeled the groundwater flow in the basin sediments bounded by Hungry Mountain to the west and Hungry Ridge to the east. The coverage was chosen at the 1,650 m topographic level. This coverage was chosen because it appears to delineate the extent of the basin sediments; based on the geological maps of the area and the conceptual hydrogeological model (see Section 4.3). Additionally, this coverage was chosen because of the consideration of mountain front recharge and the availability of data in the coverage area.

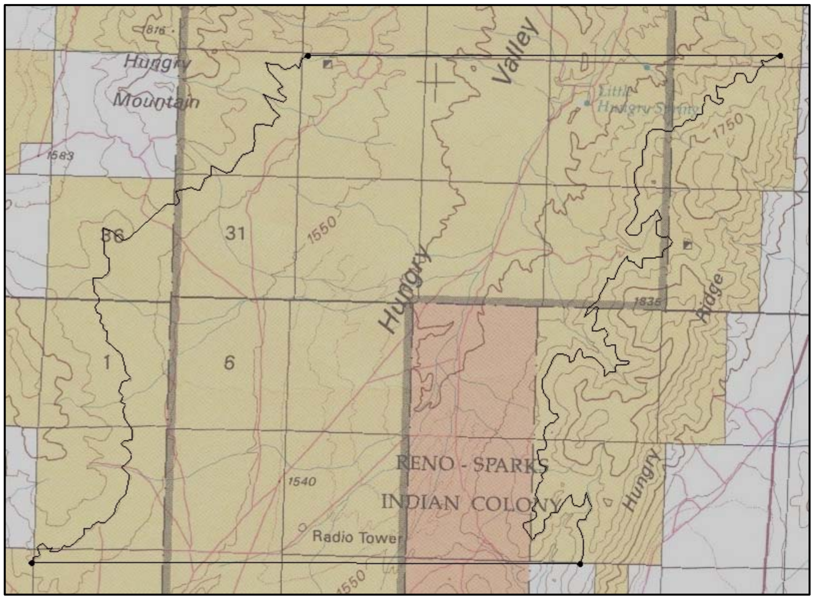


Figure 46. Model Coverage Delineation @ 1,650 m Elevation

This was simplified to a series of straight arcs:

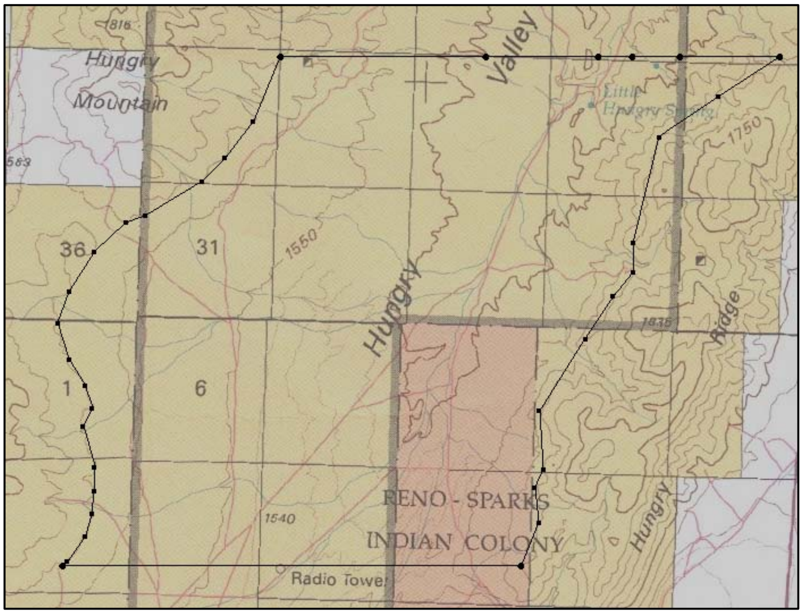


Figure 47. Simplified Model Coverage Delineation @ 1,650 m Elevation

The model domain perimeter is approximately 26.4 kilometers (16.4 miles) and the area is approximately 34.7 square kilometers (13.4 square miles or 8,576 acres).

The selection of boundary conditions largely determine the flow pattern of the Steady-State MODFLOW Model because there are no stresses applied to the aquifer (e.g. pumping) (Anderson and Woessner, 2002).

The boundary conditions utilized for this project are listed in Table 12.

Table 12. Boundary Conditions

BOUNDARY AREA	BOUNDARY CONDITION	COMMENTS
North*	Specified Head, Set @ 1,450 m for Elevation of 1,500 m and Lower; No Flow Elsewhere	The water balance (without pumping) indicates that nearly all of the recharge, approximately 944.7 m^3/day or 279.6 Acre-Feet per Year moves northward through Hungry Valley into Warm Springs Valley as underflow within the basin (as each valley is part of the larger Warm Springs Valley Hydrographic Area) Head @ Little Hungry Spring – 1458.2 m (see Table 6)
South	No Flow	Groundwater divide based on the topography between Hungry Valley and Lemon Valley
West**	Specified Flow, Set @ 473.1 m^3 / day	Estimated Recharge from Nevada Sierra Planners, 1999 – Specified Flow @ 50% of Estimated Recharge of 280 Acre-Feet per Year = 140 Acre-Feet / year = 172,687.5 m^3 / year
East**	Specified Flow, Set @ 473.1 m^3 / day	Estimated Recharge from Nevada Sierra Planners, 1999 – Specified Flow @ 50% of Estimated Recharge of 280 Acre-Feet per Year = 140 Acre-Feet / year = 172,687.5 m^3 / year

* The possible inhibited underflow of groundwater from Hungry Valley to Warm Springs Valley is discussed in Section 5. However, the northern boundary for this modeling effort ends well short of the Hungry Valley / Warm Springs Valley interface; and therefore, the northern boundary condition was modeled as indicated above. See Figure 50 for the modeled specified head boundary.

** The conceptual hydrogeologic model (see Figure 9) indicates both areal surface recharge and mountain front recharge. Because of the limited amount of precipitation the region receives and the presence of thick clay layers near the surface at most boreholes, the areal surface recharge was not included in this modeling effort.

7.5 Sources and Sinks

The only source in the model area appears to be recharge (see Section 6.6). The only sink in the model area prior to well field development appears to have been Little Hungry

Spring; Hungry Spring and Butler Spring appear to originate from mountain recharge areas outside the model area. The flow estimate for Little Hungry Spring is listed in the table below:

Table 13. Sources and Sinks

SOURCES	FLOW ESTIMATE (m^3/day (acre-feet/year))	COMMENTS
Recharge	946 (280)	See Section 6.6
SINKS	**FLOW ESTIMATE (field measurement taken March 2009) (m^3/day (acre-feet/year))**	**COMMENTS**
Spring Flow	1.35 (0.4)	Little Hungry Spring

Spring flow is affected by many factors, including: geology, climate, and groundwater (Freeze and Cherry 1979; McCabe 1998) (Fleishman et al, 2006). Therefore, the flow estimate for Little Hungry Spring in Table 13 should only be considered an estimate given the time of year and precipitation trends.

Little Hungry Spring is modeled in MODFLOW as a Drain.

The following figure shows the boundary conditions and sources / sinks for the conceptual model:

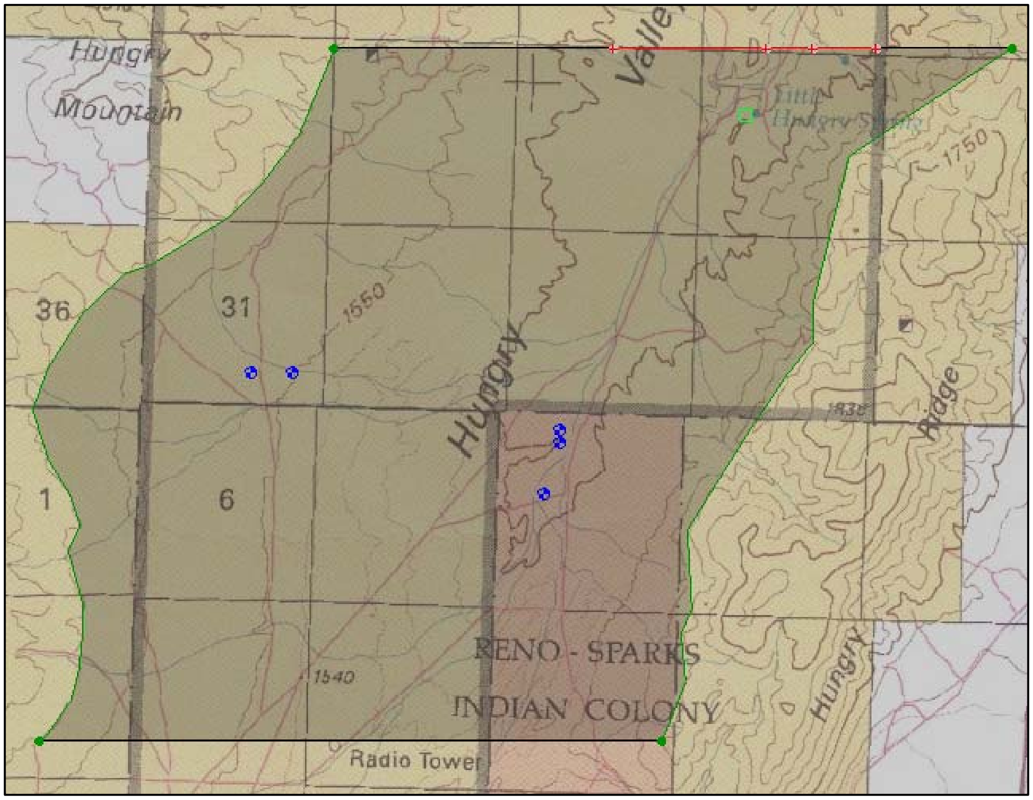


Figure 48. Boundary Conditions and Sources / Sinks for the Conceptual Model

Boundary conditions for the conceptual model:

- The black lines at the south, and sides of the north boundary, are no flow boundaries
- The green lines on either side of the model coverage are specified flow boundaries

- The red line at the center of the north side of the coverage is a specified head boundary.

The only sink in the conceptual model is Little Hungry Spring; shown as a green square. Additionally, the five production wells are included for spatial orientation; their pumping rates have been set to zero for the Steady-State MODFLOW Model.

7.6 Model Layers

The model was constructed using three layers:

- Layer 1 – Clay (low Hydraulic Conductivity)
- Layer 2 – Aquifer (high Hydraulic Conductivity)
- Layer 3 – Inactive Layer to Simulated Bedrock

Layer 3 was included at model development to allow the visualization of the Hungry Valley cross-section. Additionally, the thin alluvium layer at the surface (generally much less than 10 m (30 feet)) thickness was not included.

The layers were created in the MODFLOW model utilizing the two-dimensional geostatistics (interpolation) in the GMS 2D SCATTER POINT module. The module was used to interpolate from a set of 2D scatter points to the grid (Aquaveo, GMS Tutorials, Geostatistics – 2D, Version 6.5.6). The elevations were estimated at 1,460 m, 1,500 m, 1,550 m, 1,600 m and 1,650 m.

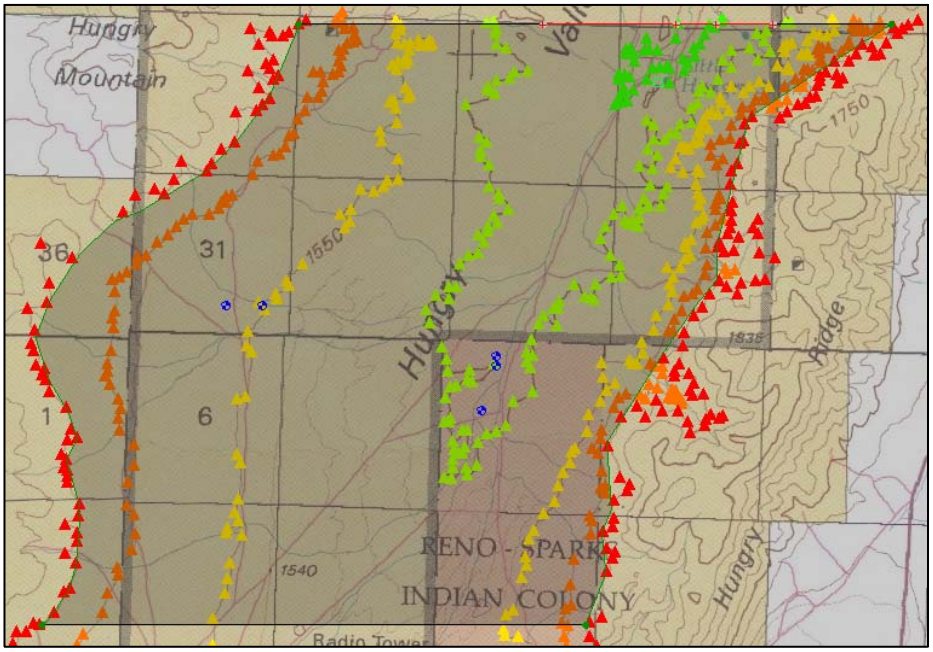


Figure 49. 2D Scatter Point Set

The data for the 2D Scatter Point Set is listed in Table 14.

Table 14. 2D Scatter Point Set

LAYER	ELEVATION – FROM WEST TO EAST (meters)								
Surface	1,650	1,600	1,550	1,500	1,460	1,500	1,550	1,600	1,650
Layer 1	1,610	1,540	1,470	1,370	1,320	1,370	1,420	1,470	1,520
Layer 2	1,510	1,440	1,390	1,305	1,255	1,305	1,355	1,405	1,455
Layer 3	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250

The depression noted between the elevation lines of 1,450 m on the topographic map (U.S. Department of the Interior, 2005) was modeled as 1,460 m to more accurate model the static water level at Little Hungry Spring. Little Hungry Spring originates out of the side of an outcropping that sits topographically higher than the surrounding area. Utilizing 1,450 m resulted in flooding of the grids adjacent to Little Hungry Spring.

The interpolation method used was linear. This method was chosen to avoid steep changes in elevation. A cross section of the northern boundary model layers is shown in Figure 50; also shown is the modeled specified head.

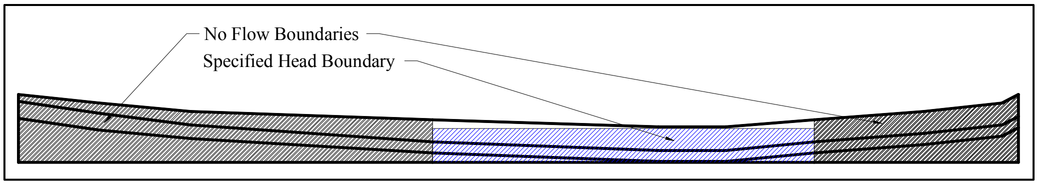


Figure 50. Specified Head Boundary Condition; Data from Table 14 and Specified Head Boundary Set @ 1450 m

7.6.1 Model Layer No. 1

Layer 1 is modeled as a clay layer. The layer thickness, from borehole data and based on screened intervals, ranges from approximately 130 m at Well Nos. 4 and 5 to 40 m at Well Nos. 7 and 8. The surface elevations were derived from the U.S. Department of the Interior, Bureau of Land Management, Surface Management Status, Reno, Nevada, 1:100,000-Scale Topographic Map, 2005 (U.S. Department of the Interior, 2005).

7.6.2 Model Layer No. 2

Layer 2 is modeled as the aquifer. The layer thickness, from borehole data and based on screened intervals, ranges from approximately 65 m at Well Nos. 4 and 5 to 100 m at Well Nos. 7 and 8. The layer thickness is kept constant at 65 m to the east and 100 m to the west; but is linearly increased between Well Nos. 4 and 5 and Well Nos. 7 and 8. The layer thickness is constant north to south.

7.6.3 Model Layer No. 3

Layer 3 is presented to graphically depict depth to lower elevation of the model or simulated bedrock, which is estimated at 1,250 m from the conceptual hydrogeologic model. Although, borehole data for Test Hole No. 1 indicates that the sediments may extend 300 m below the ground surface.

7.7 Layer Types

The storativities (see Section 8.5) of aquifer (pump) tests indicate the aquifer to be confined for Well Nos. 4, 5, 7 and 8. Layer No. 1 (unconfined layer) was set as ‘convertible’ in MODFLOW indicating an unconfined aquifer. Layer No. 2 (aquifer layer) was set to ‘confined’ in MODFLOW indicating a confined aquifer.

7.8 Model Grid

The model grid was chosen at 100 m square primarily due to the spacing of the wells.

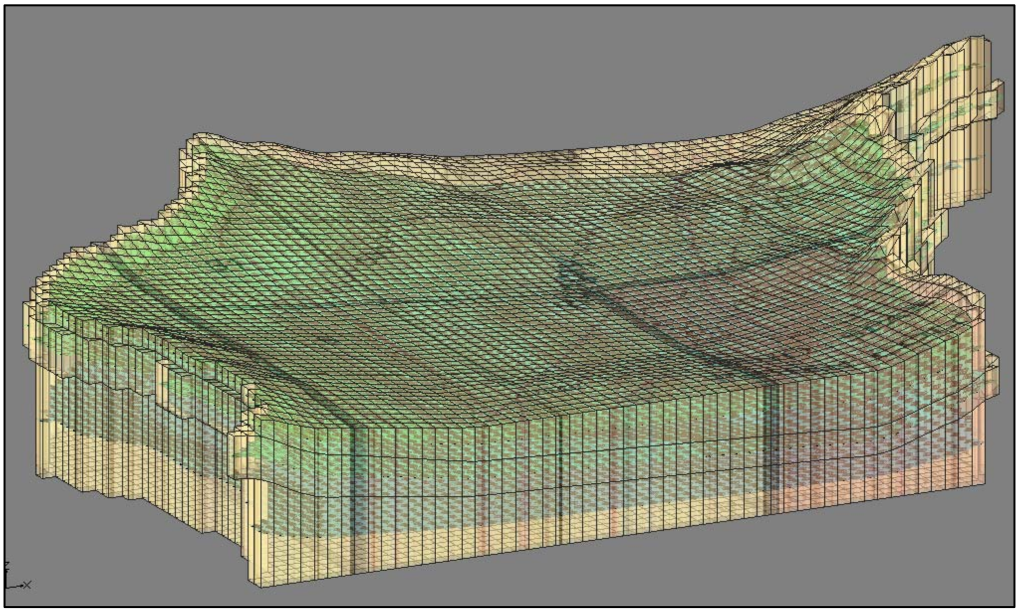


Figure 51. Interpolated 3D Image of the Model Coverage (looking South to North)

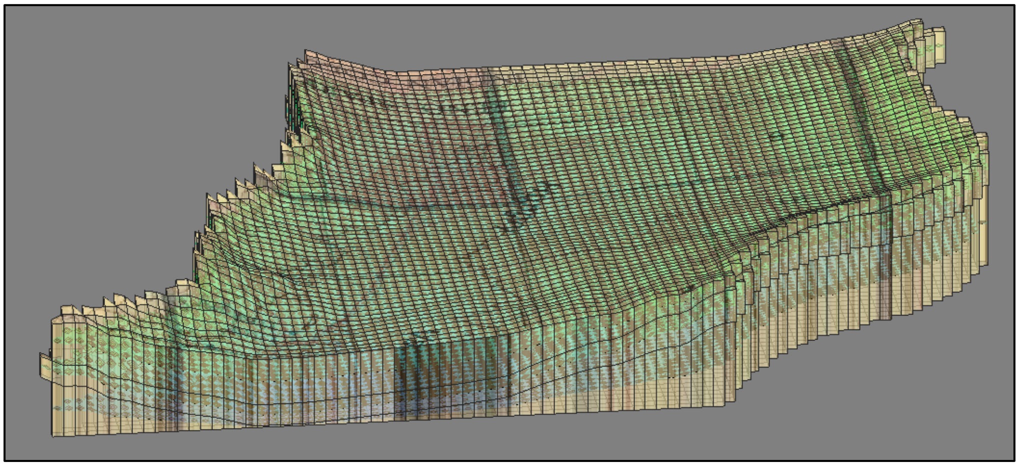


Figure 52. Interpolated 3D Image of the Model Coverage (looking North to South)

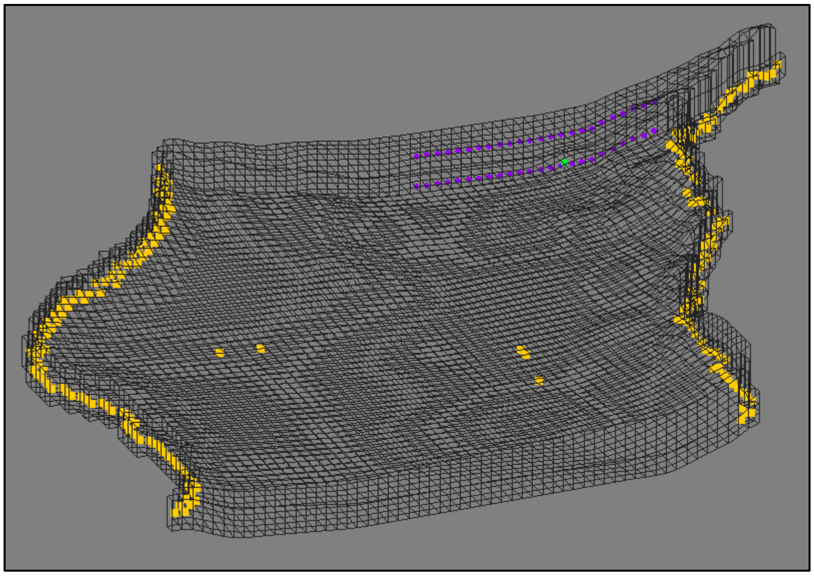


Figure 53. Interpolated 3D Image of the Model Coverage
(indicating boundary conditions and sources / sinks; with Layer 3 inactive)

7.9 Vertical Anisotropy and Hydraulic Conductivity

For this modeling effort the vertical anisotropy was set at a constant of ‘1’ for both Layer Nos. 1 and 2. The hydraulic conductivities for Layer No. 1 (unconfined layer) and the different areas of Layer No. 2 (aquifer layer) were estimated from calculated transmissivities from aquifer (pump) tests. The hydraulic conductivity was calculated by dividing the transmissivity by the saturated thickness of the aquifer as estimated from the lithologic log of the Well Driller’s Reports. The transmissivity “is a measure of the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient of 1” (Fetter, 2001).

Transmissivities were estimated by Nevada-Sierra Planners on aquifer (pump) tests performed by Wateresource Consulting Engineers in 1985 and 1987 for Test Hole Nos. 1 and 2. The results are listed in Table 15.

Transmissivities for Well Nos. 4, 5, 7 and 8, were calculated from aquifer (pump) tests conducted by students from the UNR Graduate Program of Hydrologic Sciences, Field Methods Classes. The results are listed in Tables 16 and 17.

Table 15. Summary of Test Hole Nos. 1 and 2 Transmissivities

(from Nevada-Sierra Planners (Gebhardt et al, 1999))

WELL	PUMPING RATE DURING TEST (gpm)	YEAR	TRANSMISSIVITY (m^2/d)	TRANSMISSIVITY (ft^2/d)
Test Hole No. 1	Unknown	1985, 1987	7.8	84
Test Hole No. 2	Unknown	1985, 1987	31.9	343

Table 16. Summary of Well Nos. 4 and 5 Transmissivities (from Previous UNR Class Field Work)				
WELL	**PUMPING RATE DURING TEST (gpm)**	**YEAR**	**TRANSMISSIVITY (m^2/d)**	**TRANSMISSIVITY (ft^2/d)**
Pumped: Well No. 4 **Observed: Well No. 5**	130	2000	20.3 – 29.9	218 – 322
Pumped: Well No. 5 **Observed: Well No. 4**	130	2001	13.9 – 21.4	150 – 230
Pumped: Well No. 5 **Observed: Well No. 4**	130	2002	11.1 – 17.4	120 – 187
Pumped: Well No. 5 **Observed: Well No. 4**	130	2003	18.3	197
Pumped: Well No. 5 **Observed: Well No. 4**	65	2004	8.8	95
Pumped: Well No. 4 **Observed: Well No. 5**	90	2008	14.0 – 21.5	151 – 231
AVERAGE	113		17.0	183
Hydraulic Conductivity (averaged) is estimated from 17.0 m^2/d / 65 m = 0.26 m/d				

Table 17. Summary of Well Nos. 7 and 8 Transmissivities (from Previous UNR Class Field Work)				
WELL	**PUMPING RATE DURING TEST (gpm)**	**YEAR**	**TRANSMISSIVITY (m^2/d)**	**TRANSMISSIVITY (ft^2/d)**
Pumped: Well No. 7 **Observed: Well No. 8**	125	2008	332.6 – 485.9	3580 – 5230
AVERAGE	125		409.3	4405
Hydraulic Conductivity (averaged) is estimated from 409.3 m^2/d / 100 m = 4.09 m/d				

As can be seen by the hydraulic conductivity estimates in Tables 16 and 17; the productivity of the aquifer is limited. Additionally, from previous aquifer (pump) tests, the “Drawdown / Time” curve appears to approach a horizontal asymptote indicating a leaky confined aquifer (Tyler, Summary of RSIC Hungry Valley Pump Testing, 2002). Note in the figure below there are minor variations in the calculated transmissivities for Well Nos. 4 and 5. These calculated transmissivities were estimated by different student groups over several years and the variations in tranmissivities may be the result of differences in aquifer (pump) test conditions.

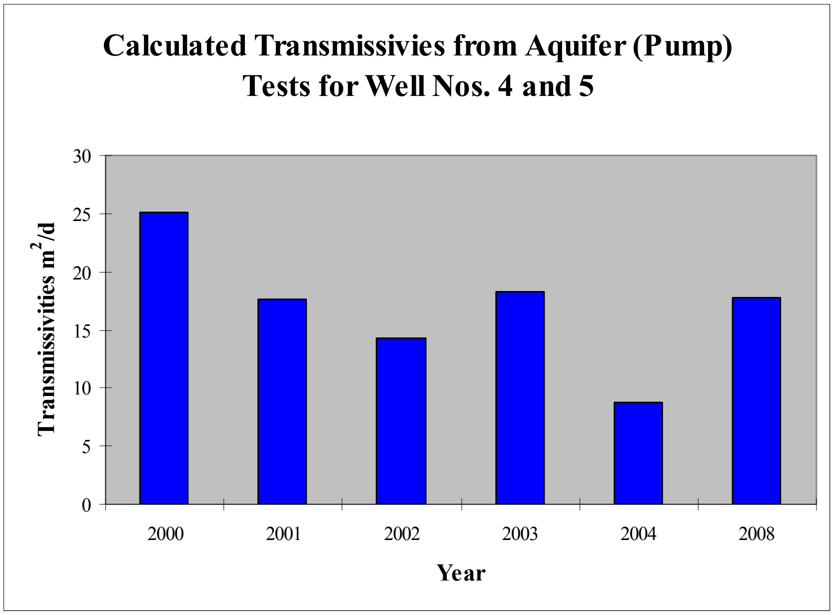


Figure 54. Summary of Calculated Transmissivities from Aquifer (Pump) Tests for Well Nos. 4 and 5 from Previous UNR Class Field Work

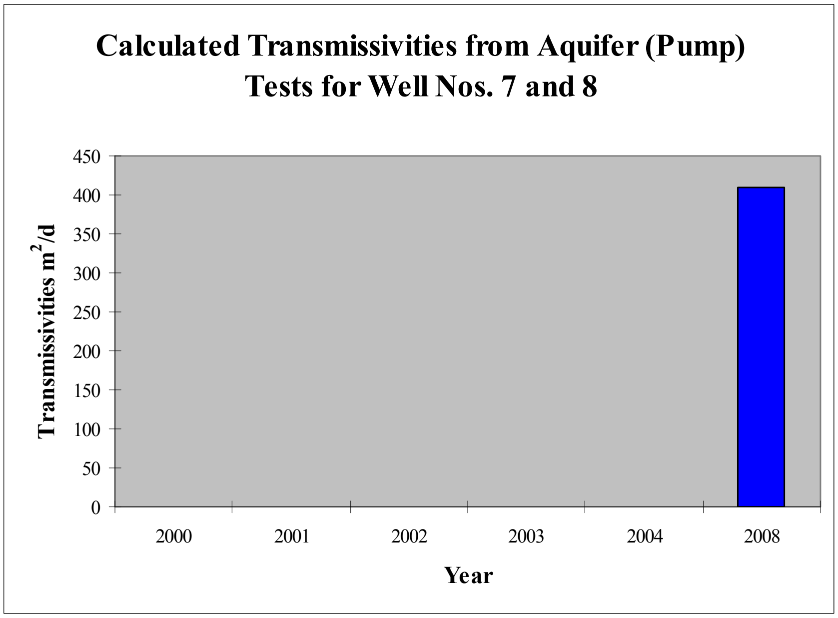


Figure 55. Summary of Calculated Transmissivities from Aquifer (Pump) Tests for Well Nos. 7 and 8 from Previous UNR Class Field Work

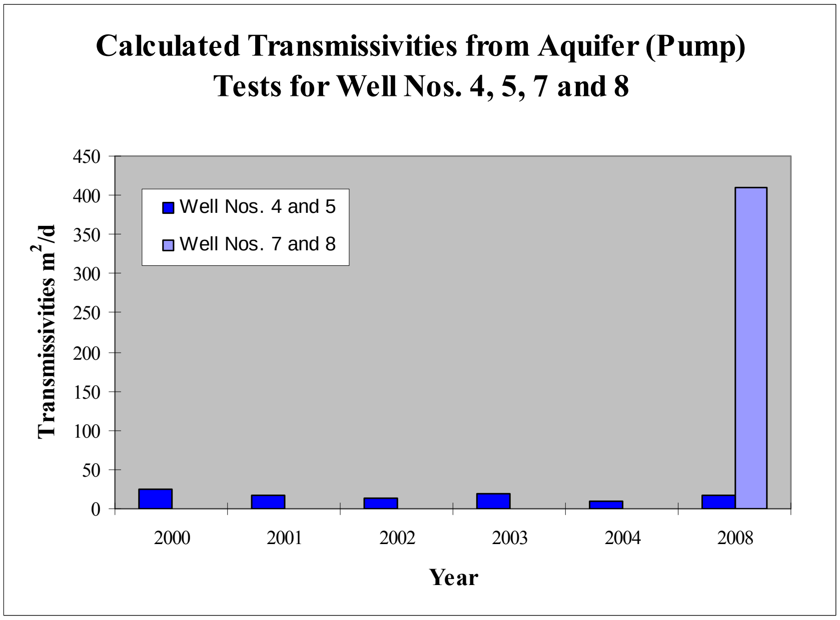


Figure 56. Summary of Calculated Transmissivities from Aquifer (Pump) Tests for Well Nos. 4, 5, 7 and 8 from Previous UNR Class Field Work

Additionally, during modeling, a third area with a different hydraulic conductivity was inserted between the two pumping areas. This third area was necessary to raise static water levels at Well Nos. 7 and 8 higher than would be possible with only elevation and aquifer parameters. This area was inserted following the surface of the terrain between elevations of 1,500 m and 1,550 m (U.S. Department of the Interior, 2005); and contains both a northern and southern section. This area of lower hydraulic conductivity is used to simulate a structural block as discussed in Section 7.1 and in the reference Hydrogeological Assessment of the Hungry Valley Groundwater Basin (Harrigan and Ball, 1996):

> The reference describes an exposure of consolidated rocks southwest of Well No. 3; with another outcrop west of and adjacent to Well No. 4. The exposure of consolidated rocks is traceable for about 914 m (3,000 feet) northeasterly from south of Test Hole No. 2 to west of Well No. 4. "This presents evidence of a structural block of unknown limit in length or depth of concealment by alluvium or sedimentary material beyond the exposed limits."

7.10 Model Closure Criterion

MODFLOW utilizes an indirect method to determine when iteration is to be terminated during the model run. This indirect method specifies that when changes in computed head values, from one iteration to the next iteration, are less than that of a specified closure criterion, iteration is stopped. Additionally, MODFLOW incorporates a maximum permissible number of iterations (Harbaugh, 2005).

The GMG Solver was utilized for the Steady-State MODFLOW Model with the following parameters:

- Maximum Inner Iterations: 50
- Inner Convergence Residual: 0.001
- Maximum Outer Iterations: 250
- Outer Convergence Residual: 0.001

7.11 Model Calibration

The calibration process for this modeling effort proceeding in a trial and error approach by varying the specified head boundary at the north end of the coverage and the hydraulic conductivity (Aquaveo, GMS Tutorials, MODFLOW – Model Calibration, Version 6.5.6).

The specified head boundary was adjusted to approximate the head at Little Hungry Spring, while not flooding the interior cells of the model. Some flooding occurred in cells adjacent to Little Hungry Spring. Their elevations were changed to prevent flooding of the grid cell that occurs when the modeled head value is greater than the modeled surface elevation (I = 10, J = 64, K = 1, 1460 m to 1461 m; I = 11, J = 63, K = 1, 1460 m to 1463 m; I = 11, J = 64, K = 1, 1461.9 m to 1462 m; and I = 12, J = 63, K = 1, 1461.7 m to 1464 m).

Little Hungry Spring was modeled in MODFLOW as a drain using two different approaches. The first approach was placing the bottom of the drain elevation at 1320 m which is the top of the confined Layer No. 2. The drain conductance was set at 0.0098 m^2/day and the drain was specified for interaction from only Layer No. 2. The second approach placed the bottom of the drain elevation at 1457 m. This is less than the ground surface elevation measured in the field of 1458.2 m; however, the Steady-State MODFLOW model generates a static water level of only 1457.5 m at the drain. So, the bottom of the drain was placed below this elevation to allow groundwater to drain from the system. Additionally, the drain conductance was set at 2.65 m^2/day and the drain was specified for interaction from both Layer Nos. 1 and 2. This allows for interaction between both Layers and would indicate the presence of faulting at the spring as previously discussed in Section 5. The selection of the drain parameters has a negligible affect elsewhere in the model and the remainder of the discussion for the Steady-State MODFLOW model considers the second approach to the implementation of the drain parameters.

The hydraulic conductivity was then adjusted to approximate the pre-well field development static water levels at Well Nos. 3, 4, 7 and 8. Hydraulic conductivity values are listed in Table 18 and shown for Layer No. 2 in Figure 57.

Table 18. Hydraulic Conductivity		
LAYER	**HYDRAULIC CONDUCTIVITY USED IN THE MODFLOW MODEL (m/d)**	**RANGES OF HYDRAULIC CONDUCTIVITIES FOR UNCONSOLIDATED SEDIMENTS FROM THE LITERATURE (FETTER, 2001) (m/d)**
Layer No. 1	0.0001	Clay - 0.000864 to 0.000000864 Silt, Sandy Silts, Clayey Sands, Till - 0.0864 to 0.000864 Silty Sands, Fine Sands – 0.864 to 0.00864
Layer No. 2 (west)	0.45	
Layer No. 2 (center, north)	0.06	
Layer No. 2 (center, south)	0.0001	
Layer No. 2 (east)	0.25	

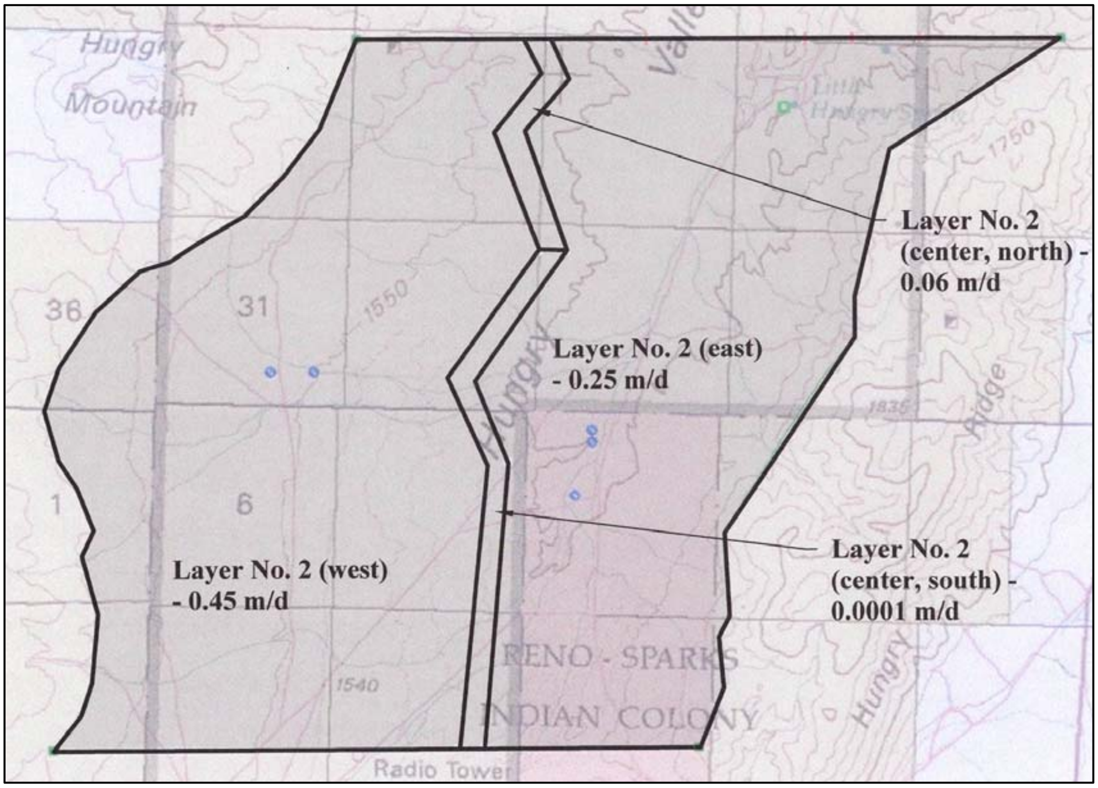


Figure 57. Areas of Hydraulic Conductivity for the Steady-State MODFLOW Model for Layer No. 2

It can be seen from Table 18 that the modeled hydraulic conductivity for Layer No. 2, for the East side of Hungry Valley, is in good agreement with the value from aquifer (pump) tests. The estimated hydraulic conductivity was 0.26 m/d versus the modeled value of 0.25 m/d. However, the modeled hydraulic conductivity for the West side of Hungry Valley, while greater than that on the East side, is a magnitude lower than that determined from the aquifer (pump) test. The estimated hydraulic conductivity was 4.09 m/d versus the modeled value of 0.45 m/d. Only a single estimate of hydraulic conductivity is available for the Well Nos. 7 and 8 (West side of Hungry Valley).

Well No. 5 was not included in the calibration effort because of its close proximity to Well No. 4 and the two wells demonstrated hydraulic conductivity to each other.

7.12 Modeling Results

Contour maps of the modeled area for Layer Nos. 1 and 2 are presented in Figures 58 and 59, respectively.

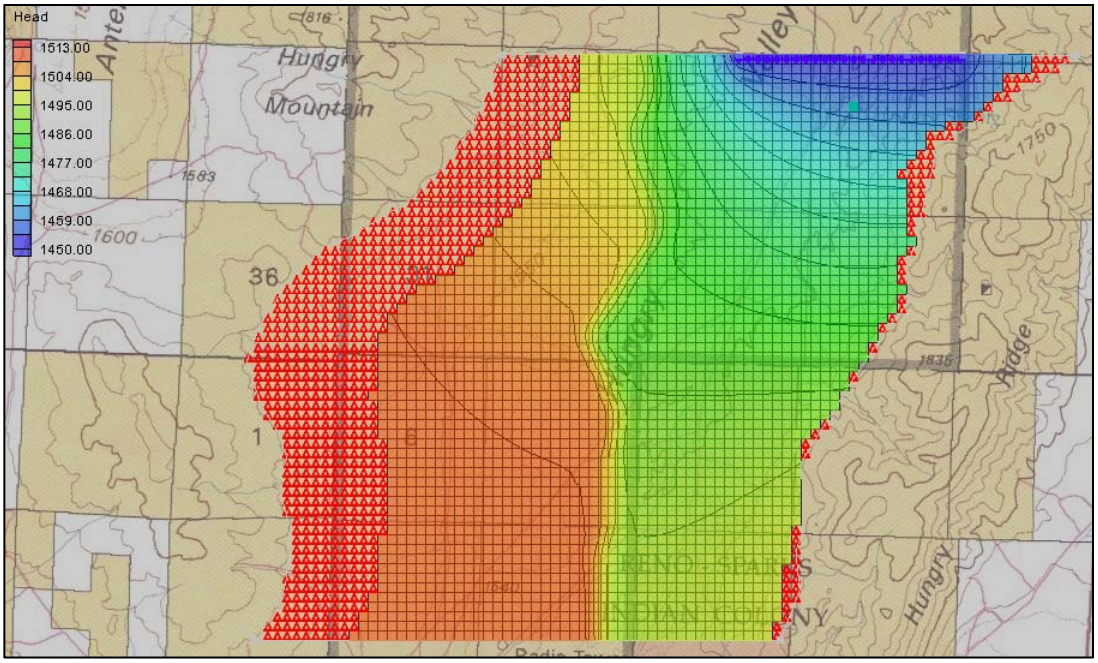


Figure 58. Stead-State MODFLOW Model Contours for Layer No. 1

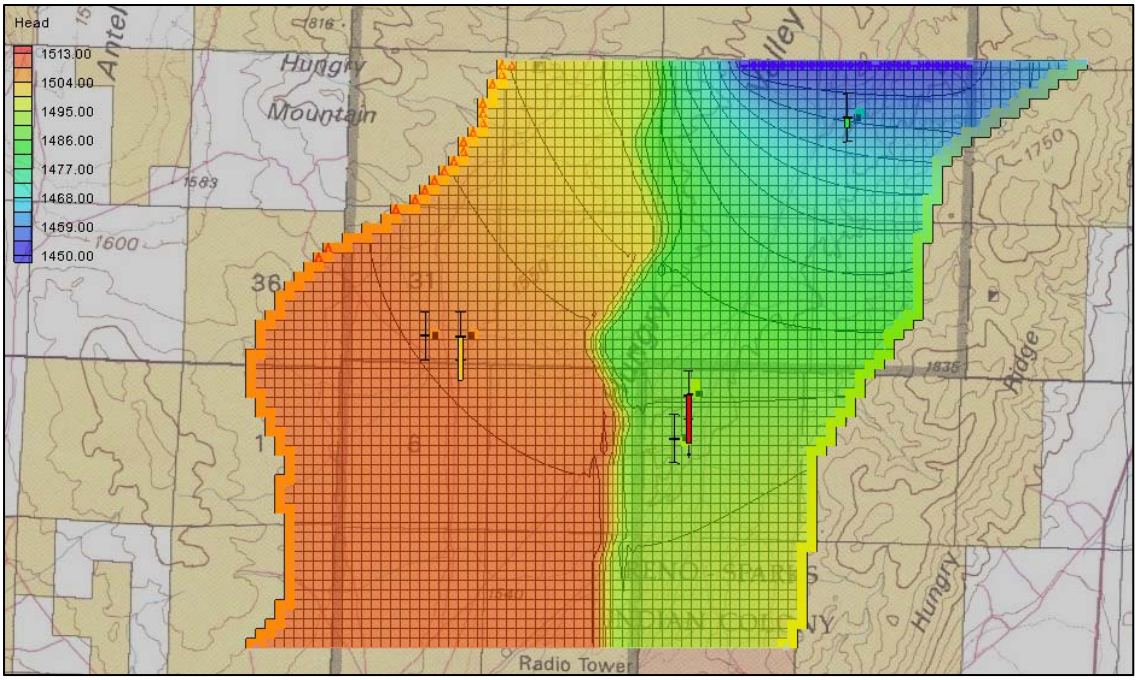


Figure 59. Steady-State MODFLOW Model Contours and Calibration Targets for Well Nos. 3, 4, 7 and 8, and Little Hungry Spring, for Layer No. 2

Figure 59 also includes a calibration target next to Well Nos. 3, 4, 7 and 8; and Little Hungry Spring. The center of the calibration target corresponds to the observed value. The top of the target is the observed value plus the interval, 1 m; and the bottom of the target is the observed value minus the interval. The colored bar represents the error and is green if the computed value is less than +/- 1 m of the observed value. If the bar is outside the target but the error is less than +/- 2 m, the bar is yellow. If it is greater than +/- 2 m, the bar is red; as is the case for Well No. 4 (Aquaveo, GMS Tutorials, MODFLOW – Model Calibration, Version 6.5.6).

Figure 60 is a plot of the Computed vs. Observed Valves for the five observation points.

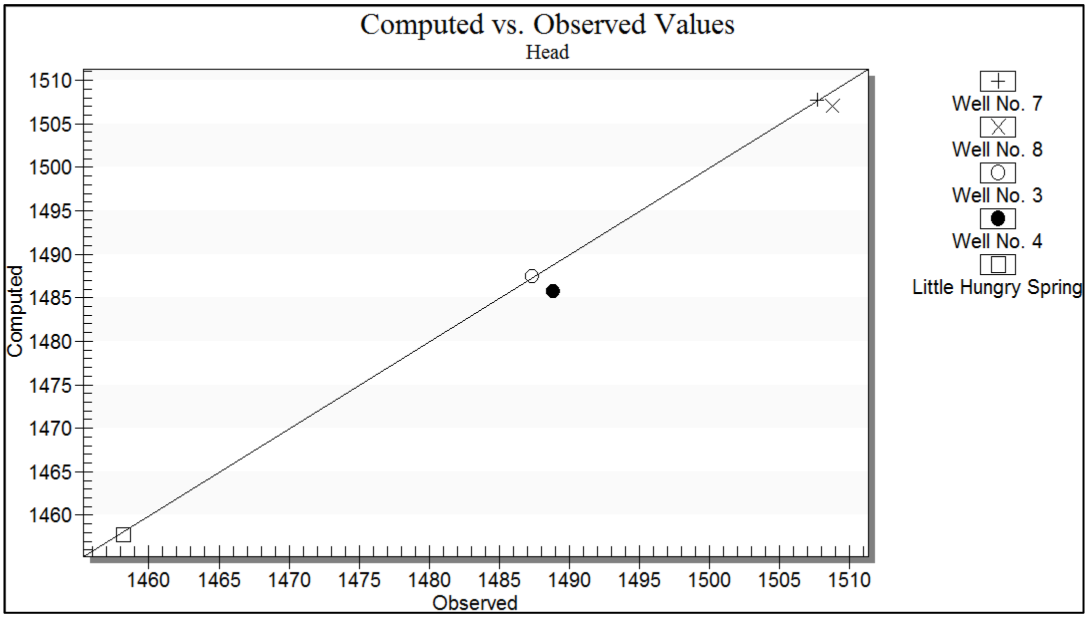
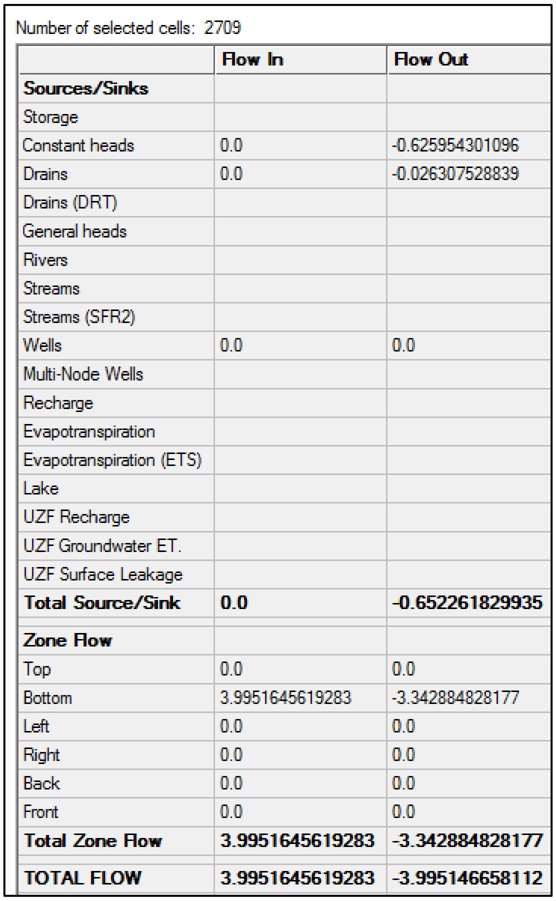


Figure 60. Steady-State MODFLOW Model Computed vs. Observed Valves for Well Nos. 3, 4, 7 and 8, and Little Hungry Spring, for Layer No. 2

7.12.1 Flow Budget

The flow budget feature of MODFLOW provides an accounting of flow into and out of the model. Figures 61 and 62 present the flow budgets for Layer No. 1 and Layer No. 2, respectively, of the Steady-State MODFLOW Model in m^3/day.



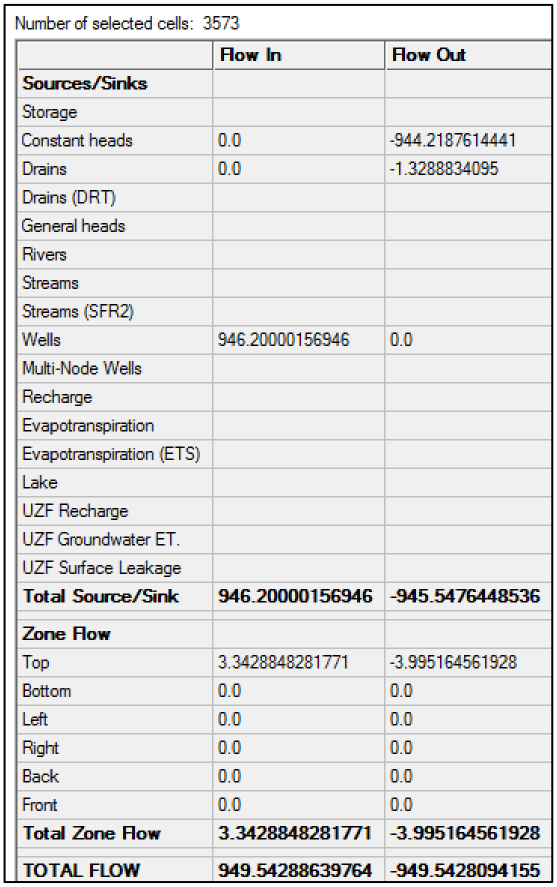
Number of selected cells: 2709

	Flow In	**Flow Out**
Sources/Sinks		
Storage		
Constant heads	0.0	-0.625954301096
Drains	0.0	-0.026307528839
Drains (DRT)		
General heads		
Rivers		
Streams		
Streams (SFR2)		
Wells	0.0	0.0
Multi-Node Wells		
Recharge		
Evapotranspiration		
Evapotranspiration (ETS)		
Lake		
UZF Recharge		
UZF Groundwater ET.		
UZF Surface Leakage		
Total Source/Sink	**0.0**	**-0.652261829935**
Zone Flow		
Top	0.0	0.0
Bottom	3.9951645619283	-3.342884828177
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**3.9951645619283**	**-3.342884828177**
TOTAL FLOW	**3.9951645619283**	**-3.995146658112**

Figure 61. MODFLOW Flow Budget for Layer No. 1 (units are m^3/day)

The flow budget for Layer No. 1 indicates some flow interaction between this layer and the confined layer below (Layer No. 2), the discharge at Little Hungry

Spring and movement of groundwater north through Hungry Valley into Warm Springs Valley.



Number of selected cells: 3573

	Flow In	**Flow Out**
Sources/Sinks		
Storage		
Constant heads	0.0	-944.2187614441
Drains	0.0	-1.3288834095
Drains (DRT)		
General heads		
Rivers		
Streams		
Streams (SFR2)		
Wells	946.20000156946	0.0
Multi-Node Wells		
Recharge		
Evapotranspiration		
Evapotranspiration (ETS)		
Lake		
UZF Recharge		
UZF Groundwater ET.		
UZF Surface Leakage		
Total Source/Sink	**946.20000156946**	**-945.5476448536**
Zone Flow		
Top	3.3428848281771	-3.995164561928
Bottom	0.0	0.0
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**3.3428848281771**	**-3.995164561928**
TOTAL FLOW	**949.54288639764**	**-949.5428094155**

Figure 62. MODFLOW Flow Budget for Layer No. 2 (units are m^3/day)

The flow budget for Layer No. 2 indicates flow into the model from the constant flux boundary condition (mountain front recharge), some flow interaction between this layer and the layer above (Layer No. 1), the discharge at Little Hungry Spring, and the majority of flow moving north through Hungry Valley into Warm Springs Valley.

From the flow budget for both Layer Nos. 1 and 2, the total recharge to the model is 946.20 m^3/day and the spring flow is 1.36 m^3/day (with approximately 2% from Layer No. 1 and remainder from Layer No. 2). The difference between the recharge and spring flow is 944.84 m^3/day; which is intra-basin underflow to Warm Springs Valley as indicated in the estimated water budget presented in Section 6.

7.12.2 Root Mean Squared Error (RMSE)

Note that calibration metric or objective function (see Section 7.10) refers to the difference in computed head values and not the difference between computed head values and observed head values. A measure of the difference between computed head values and the observed head values is RMSE (Anderson and Woessner, 2002). RMSE is defined as $[(1/n)\sum(h_{(measured)} - h_{(computed)})^2]^{0.5}$. The relative error (RE) considers the RMSE normalized to the total head drop in the system and is defined as RMSE/(Maximum Head – Minimum Head).

Table 19. Comparison of Model with Pre-Well Field Development Static Water Levels

WELL NO. (I, J, and K Coordinates from Model Grid)	GROUND SURFACE ELEVATION (meters)	ESTIMATED GROUND SURFACE ELEVATION FROM MODEL – SURFACE ELEVATION / BOTTOM OF LAYER 1 / BOTTOM OF LAYER 2 (meters)	STATIC WATER LEVEL (date measurement taken) (meters)	ESTIMATED STATIC WATER LEVEL FROM MODEL (meters)	DIFFERENCE – GROUND SURFACE ELEVATION (meters)	DIFFERENCE – STATIC WATER LEVEL (meters)
Well No. 3 (I = 43, J = 50, K = 2)	1495.6	1500.0 1370.0 1305.0	1487.4 (10/10/1988)	1487.5	- 4.4	- 0.1
Well No. 4 (I = 38, J = 51, K = 2)	1488.9	1500.0 1370.0 1305.0	1488.9 (5/15/1989)	1485.6	- 11.1	3.3
Well No. 7 (I = 32, J = 24, K = 2)	1556.9	1562.4 1487.3 1402.4	1507.7 (10/17/2001)	1507.8	- 5.5	- 0.1
Well No. 8 (I = 32, J = 28, K = 2)	1550.8	1550.0 1470.0 1390.0	1508.8 (11/5/2001)	1506.9	0.8	1.9
Little Hungry Spring (I = 9, J = 68, K = 2)	1458.2	1460.0 1320.0 1255.0	1458.2 (3/16/2009)	1457.5	- 1.8	0.7
RMSE FOR ALL DATA POINTS (meters)					5.94	1.73
RE (Relative Error)					9.4%	2.7%

Table 20. Comparison of Model with Spring Flow

SPRING (I, J, and K Coordinates from Model Grid)	FLOW (date measurement taken) (m^3 / day)	ESTIMATED FLOW FROM MODEL (m^3 / day)	DIFFERENCE – FLOW (m^3 / day)
Little Hungry Spring (I = 9, J = 68, K = 2)	1.35 (3/16/2009)	1.355	- 0.005

Note: The conductance utilized for Little Hungry Springs is 2.65 m^2/d; bottom elevation set @ 1475 m

The modeled ground surface elevations are moderately in agreement with the known elevations with a RMSE = 5.9 m and RE = 9.4%. The modeled elevations are generally higher than known elevations. The modeled elevation with the highest difference is Well No. 4.

The modeled static water levels are in good agreement with the observed values with a RMSE = 1.7 m and RE = 2.7%. The pre-well field development static water levels for Well Nos. 3 and 7, and Little Hungry Spring have been closely approximated by the model. However, the model underestimates Well Nos. 4 and 8; with the difference for Well No. 4 being the highest value at 3.3 m. Note that prior to well field development the static water level appears to be higher at Well No. 4 than at Well No. 3 by 1.5 m; indicating that groundwater movement was to the South. Additionally, the static water level at Well No. 8 was higher than at Well No. 7 by 1.1 m; indicating a groundwater movement to the West. However, the minor differences in elevation may be the result of the datum for static water level measurement as well as determination of ground surface elevation. By inspection of the topographic map referenced in Section 7.1, the reported ground surface elevation of Well No. 8 of 1550.8 m appears in good agreement with the topographic map. However, the reported ground surface elevation of Well No. 7 of 1556.9 appears lower than what would be interpolated from the topographic map and this would underestimate the observed static water levels at Well No. 7. The current modeled water levels for Well Nos. 3, 4, 7 and 8 indicate groundwater flow to the center of Hungry Valley and then north into Warm Springs Valley.

The modeled spring flow at Little Hungry Spring is in good agreement with the observed spring flow.

7.13 Sensitivity Analysis

A sensitivity analysis was performed on the Steady-State MODFLOW Model by increasing the hydraulic conductivity; and lowering the recharge and the specified head boundary condition. The sensitivity analysis was performed to better understand the uncertainty of the input parameters selected in the development of the Steady-State MODFLOW Model. The resulting RMSE from comparing the computed head values and spring flow to the observed values is summarized in Table 21.

Table 21. Steady-State MODFLOW Model – Sensitivity Analysis – RMSE

PARAMETER	ORIGINAL VALUE	REVISED VALUE	PERCENT OF ORIGINAL VALUE	RMSE – STATIC WATER LEVELS (meters)	DIFFERENCE – SPRING FLOW (m^3 / day)
Steady-State MODFLOW Model				1.73	- 0.005
Layer No. 1 Hydraulic Conductivity	0.0001 m/d	0.00015 m/d	150%	1.73	- 0.020
		0.0005 m/d	500%	1.85	- 0.109
Layer No. 2 Hydraulic Conductivity (west)	0.45 m/d	0.60 m/d	133%	3.12	0.031
		0.675 m/d	150%	3.74	0.043
Layer No. 2 Hydraulic Conductivity (center, north)	0.06 m/d	0.08 m/d	133%	3.07	0.025
		0.09 m/d	150%	3.67	0.037
Layer No. 2 Hydraulic Conductivity (center, south)	0.0001 m/d	0.00015 m/d	150%	1.72	- 0.017
		0.0005 m/d	500%	1.83	- 0.093
Layer No. 2 Hydraulic Conductivity (east)	0.25 m/d	0.375 m/d	150%	11.37	No Flow
		0.400 m/d	160%	12.64	No Flow
Recharge	946.2 m^3/day	473.1 m^3/day	50%	22.62	No Flow
Specified Head Boundary Condition – Lower the Two Center Segment End Points (of four total segment end points)	1450 m	1440 m	99.3%	5.70	No Flow

The model appears to be relatively insensitive to increases in Layer No. 1 and Layer No. 2 (center, south) hydraulic conductivity. However, with increasing hydraulic conductivity there is an increase in spring flow. Increases in Layer No. 2 (west) and Layer No. 2 (center, north) hydraulic conductivity results in lower static water levels and a decrease in spring flow. Increase in Layer No. 2 (east) hydraulic conductivity results in a moderate decrease in static water levels, with a major decrease in static water level at Well No. 4, and no spring flow.

The model appears to be sensitive to recharge; decreasing the recharge results in a major decrease in static water levels and no spring flow. The model also appears to be sensitive to the specified head boundary condition. Lowering the specific head boundary moderately lowers the static water levels and results in no spring flow. As a result of the sensitivity analysis, the Layer No. 2 (center, south) hydraulic conductivity was changed from 0.0001 m/d to 0.00015 m/d for the transient simulation.

Section 8 – Construction of a Transient MODFLOW Model

A Transient MODFLOW Model was developed utilizing historical pumping rates and compared with observed water levels. This model will be used to predict the effects of future stresses (e.g. pumping) on the aquifer (Section 9).

Because this is a time-dependent problem, a transient simulation was utilized; the Steady-State MODFLOW Model developed in the previous section was used as the initial condition and the model generated a set of heads at each time step selected (Anderson and Woessner, 2002).

The Transient MODFLOW Model was created using the graphical user interface GMS 8.2, Version 8.2.2.12874, Build Date: 2/28/2012.

8.1 Assumptions

Recharge is simulated as a constant at 946.2 m^3/day or 345,363 m^3/year; as utilized in the Steady-State MODFLOW Model. Pumping at Well Nos. 4, 5, 7 and 8 are averaged on an annual basis based on pumping rates received from the RSIC. This simplification does not illustrate the seasonal pumping schedule for the wells.

Pumping wells are assumed to fully penetrate the aquifers (i.e. Layer No. 2).

The transient simulation produces a set of heads at each time step or stress period (as defined in MODFLOW), typically January 1ST of each year modeled. However, the observed static water level data are from different days of the year; therefore, for comparison purposes, the closest data point was chosen.

8.2 Stress Periods

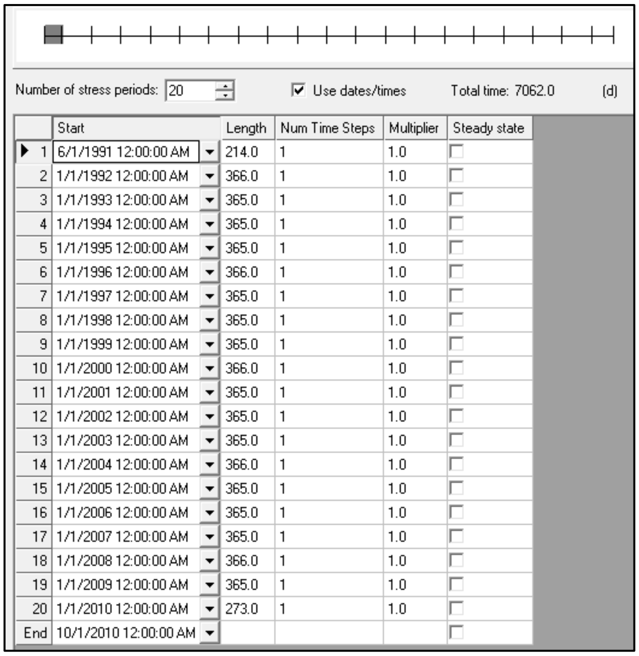
For the transient simulation, stress periods were assigned on annual basis from June 1991 through September 2010 as detailed in Table 22 and shown in Figure 63.

Table 22. Stress Periods

#	DATE	TIME	# OF DAYS	# OF TIME STEPS
1	6/1/1991	12:00:00 AM	214	1
2	1/1/1992	12:00:00 AM	366	1
3	1/1/1993	12:00:00 AM	365	1
4	1/1/1994	12:00:00 AM	365	1
5	1/1/1995	12:00:00 AM	365	1
6	1/1/1996	12:00:00 AM	366	1
7	1/1/1997	12:00:00 AM	365	1
8	1/1/1998	12:00:00 AM	365	1
9	1/1/1999	12:00:00 AM	365	1
10	1/1/2000	12:00:00 AM	366	1
11	1/1/2001	12:00:00 AM	365	1
12	1/1/2002	12:00:00 AM	365	1
13	1/1/2003	12:00:00 AM	365	1

Table 22. Stress Periods (continued)

#	DATE	TIME	# OF DAYS	# OF TIME STEPS
14	1/1/2004	12:00:00 AM	366	1
15	1/1/2005	12:00:00 AM	365	1
16	1/1/2006	12:00:00 AM	365	1
17	1/1/2007	12:00:00 AM	365	1
18	1/1/2008	12:00:00 AM	366	1
19	1/1/2009	12:00:00 AM	365	1
20	1/1/2010	12:00:00 AM	273	1
End	10/1/2010	**Total**	7,062	20



Number of stress periods: 20

☑ Use dates/times

Total time: 7062.0 (d)

	Start	Length	Num Time Steps	Multiplier	Steady state
1	6/1/1991 12:00:00 AM	214.0	1	1.0	☐
2	1/1/1992 12:00:00 AM	366.0	1	1.0	☐
3	1/1/1993 12:00:00 AM	365.0	1	1.0	☐
4	1/1/1994 12:00:00 AM	365.0	1	1.0	☐
5	1/1/1995 12:00:00 AM	365.0	1	1.0	☐
6	1/1/1996 12:00:00 AM	366.0	1	1.0	☐
7	1/1/1997 12:00:00 AM	365.0	1	1.0	☐
8	1/1/1998 12:00:00 AM	365.0	1	1.0	☐
9	1/1/1999 12:00:00 AM	365.0	1	1.0	☐
10	1/1/2000 12:00:00 AM	366.0	1	1.0	☐
11	1/1/2001 12:00:00 AM	365.0	1	1.0	☐
12	1/1/2002 12:00:00 AM	365.0	1	1.0	☐
13	1/1/2003 12:00:00 AM	365.0	1	1.0	☐
14	1/1/2004 12:00:00 AM	366.0	1	1.0	☐
15	1/1/2005 12:00:00 AM	365.0	1	1.0	☐
16	1/1/2006 12:00:00 AM	365.0	1	1.0	☐
17	1/1/2007 12:00:00 AM	365.0	1	1.0	☐
18	1/1/2008 12:00:00 AM	366.0	1	1.0	☐
19	1/1/2009 12:00:00 AM	365.0	1	1.0	☐
20	1/1/2010 12:00:00 AM	273.0	1	1.0	☐
End	10/1/2010 12:00:00 AM				☐

Figure 63. Stress Periods in MODFLOW

8.3 Well Discharge

From the historical pumping records as provided by the RSIC, it appears that Well No. 4 started production in June 1991. This was followed by Well No. 5 in 1996 and Well Nos. 7 and 8 in April 2005. Figure 64 graphical depicts a summary of total pumping from 1991 through 2009.

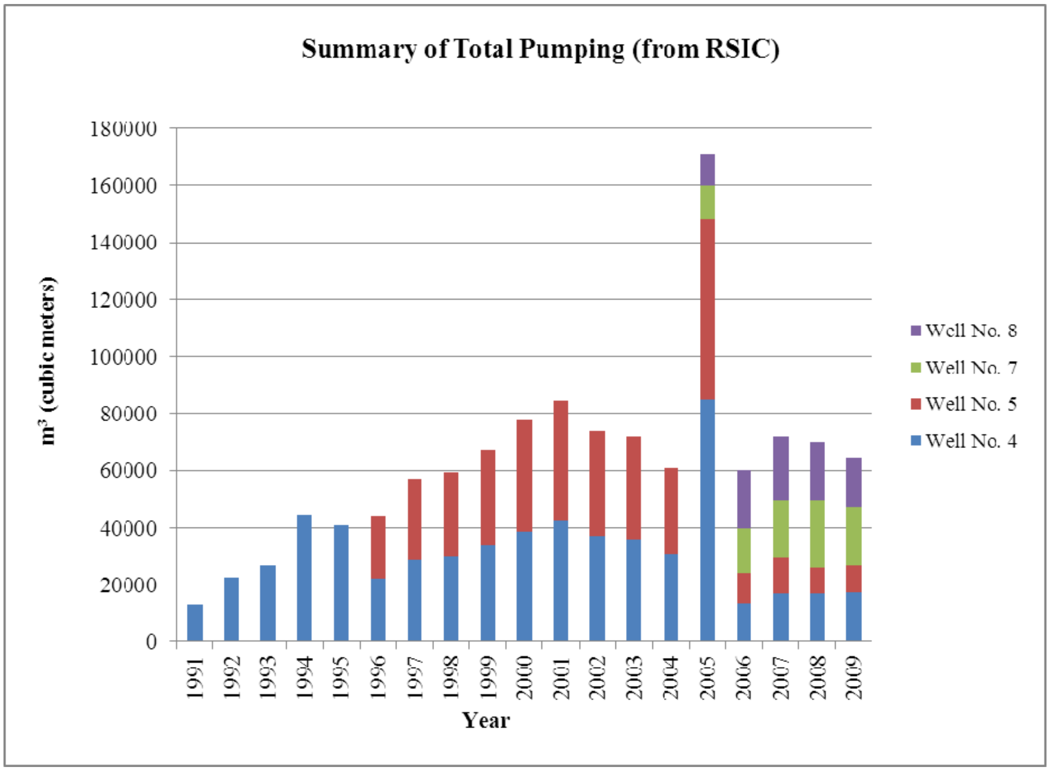


Figure 64. Summary of Total Pumping (from RSIC); 1991 - 2009

Historical pumping records are listed in Tables 23 through 27.

Table 23. Summary of Total Pumping from RSIC

(millions of gallons)

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991						0.09	0.48	0.76	0.43	0.69	0.54	0.46
1992	0.57	0.37	0.45	0.49	0.64	0.55	0.60	0.60	0.43	0.31	0.50	0.45
1993	0.37	0.41	0.50	0.67	0.61	0.65	0.79	0.78	0.73	0.50	0.52	0.51
1994	0.43	0.45	0.59	0.55	0.88	1.53	2.42	2.09	1.21	0.63	0.44	0.45
1995	0.46	0.60	0.54	0.69	0.92	0.91	1.12	1.45	1.63	1.06	0.72	0.71
1996	0.61	0.51	0.73	0.97	1.18	1.50	1.49	1.40	1.16	1.03	0.33	0.70
1997	0.84	0.75	1.01	1.23	1.73	1.22	1.88	1.86	1.36	1.36	0.91	0.89
1998	0.78	0.86	0.88	0.98	1.24	1.46	2.40	1.96	1.77	1.25	1.02	1.06
1999	0.85	0.83	1.21	1.26	1.71	2.02	1.88	2.06	1.77	1.77	1.22	1.21
2000	1.45	1.30	1.37	1.64	1.83	2.01	2.61	2.43	2.05	1.51	1.21	1.06
2001	1.13	1.00	1.36	2.50	1.74	1.92	2.02	3.46	2.67	1.95	1.36	1.20
2002	1.20	1.13	1.05	1.39	1.54	1.98	2.41	2.61	1.75	1.62	1.49	1.35
2003	1.45	1.18	1.28	1.25	1.61	1.90	2.07	1.94	1.97	1.58	1.43	1.35
2004	1.40	1.40	1.84	1.65	1.34	1.97	2.70	1.15	0.88	0.62	0.57	0.57
2005	4.43	3.45	4.54	5.06	4.24	6.64	7.99	3.78	1.49	1.24	1.20	1.11
2006	0.92	0.75	1.43	0.96	1.53	1.59	1.83	1.82	1.50	1.35	1.08	1.07
2007	1.18	0.99	1.45	1.49	1.74	1.89	2.17	2.16	1.82	1.67	1.22	1.19
2008	1.17	1.09	1.32	1.37	1.56	1.81	1.98	2.29	1.82	1.57	1.25	1.23
2009	1.07	1.04	1.07	1.36	1.69	1.60	2.02	1.86	1.84	1.20	1.14	1.04
2010	1.01	0.90	1.06	0.98	1.51	1.85	2.04	2.11	1.66			

Note: No data points were available for 2/2002 and 11/20002; these were estimated by averaging the data points on either side

Table 24. Summary of Pumping for Well No. 4 (from RSIC)

(millions of gallons)

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991						0.09	0.48	0.76	0.43	0.69	0.54	0.46
1992	0.57	0.37	0.45	0.49	0.64	0.55	0.60	0.60	0.43	0.31	0.50	0.45
1993	0.37	0.41	0.50	0.67	0.61	0.65	0.79	0.78	0.73	0.50	0.52	0.51
1994	0.43	0.45	0.59	0.55	0.88	1.53	2.42	2.09	1.21	0.63	0.44	0.45
1995	0.46	0.60	0.54	0.69	0.92	0.91	1.12	1.45	1.63	1.06	0.72	0.71
1996	0.31	0.26	0.36	0.49	0.59	0.75	0.75	0.70	0.58	0.52	0.16	0.35
1997	0.42	0.38	0.50	0.62	0.87	0.61	0.94	0.93	0.68	0.68	0.45	0.45
1998	0.39	0.43	0.44	0.49	0.62	0.73	1.20	0.98	0.89	0.63	0.51	0.53
1999	0.42	0.41	0.61	0.63	0.86	1.01	0.94	1.03	0.88	0.88	0.61	0.61
2000	0.72	0.65	0.68	0.82	0.92	1.01	1.30	1.22	1.02	0.76	0.60	0.53
2001	0.56	0.50	0.68	1.25	0.87	0.96	1.01	1.73	1.34	0.98	0.68	0.60
2002	0.60	0.56	0.52	0.69	0.77	0.99	1.20	1.31	0.87	0.81	0.75	0.68
2003	0.72	0.59	0.64	0.62	0.81	0.95	1.03	0.97	0.98	0.79	0.71	0.68
2004	0.70	0.70	0.92	0.82	0.67	0.98	1.35	0.58	0.44	0.31	0.29	0.28
2005	2.53	0.98	2.12	2.98	3.06	3.61	4.23	1.68	0.35	0.33	0.30	0.29
2006	0.19	0.15	0.28	0.01	0.22	0.31	0.65	0.81	0.04	0.32	0.38	0.12
2007	0.00	0.00	0.67	0.42	0.34	0.54	0.49	0.47	0.39	0.43	0.35	0.30
2008	0.29	0.24	0.37	0.31	0.33	0.34	0.43	0.65	0.49	0.38	0.30	0.34
2009	0.29	0.34	0.36	0.62	0.75	0.42	0.56	0.46	0.31	0.27	0.18	0.00
2010	0.20	0.16	0.14	0.15	0.41	0.46	0.40	0.46	0.34			

Note: For 1996 through 2004 only a 'Master Meter' reading is given, so the total gallons pumped is split between Wells No. 4 and 5

Table 25. Summary of Pumping for Well No. 5 (from RSIC)

(millions of gallons)

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991												
1992												
1993												
1994												
1995												
1996	0.31	0.26	0.36	0.49	0.59	0.75	0.75	0.70	0.58	0.52	0.16	0.35
1997	0.42	0.38	0.50	0.62	0.87	0.61	0.94	0.93	0.68	0.68	0.45	0.45
1998	0.39	0.43	0.44	0.49	0.62	0.73	1.20	0.98	0.89	0.63	0.51	0.53
1999	0.42	0.41	0.61	0.63	0.86	1.01	0.94	1.03	0.88	0.88	0.61	0.61
2000	0.72	0.65	0.68	0.82	0.92	1.01	1.30	1.22	1.02	0.76	0.60	0.53
2001	0.56	0.50	0.68	1.25	0.87	0.96	1.01	1.73	1.34	0.98	0.68	0.60
2002	0.60	0.56	0.52	0.69	0.77	0.99	1.20	1.31	0.87	0.81	0.75	0.68
2003	0.72	0.59	0.64	0.62	0.81	0.95	1.03	0.97	0.98	0.79	0.71	0.68
2004	0.70	0.70	0.92	0.82	0.67	0.98	1.35	0.58	0.44	0.31	0.29	0.28
2005	1.90	2.47	2.42	1.97	0.99	2.26	2.75	1.08	0.25	0.19	0.19	0.18
2006	0.21	0.18	0.29	0.29	0.37	0.30	0.12	0.03	0.45	0.24	0.09	0.31
2007	0.46	0.37	0.06	0.24	0.39	0.25	0.46	0.40	0.28	0.21	0.12	0.15
2008	0.19	0.16	0.13	0.19	0.23	0.30	0.29	0.22	0.19	0.20	0.17	0.14
2009	0.18	0.12	0.15	0.00	0.00	0.23	0.27	0.30	0.38	0.21	0.26	0.36
2010	0.20	0.21	0.27	0.17	0.25	0.30	0.40	0.35	0.26			

Note: For 1996 through 2004 only a ‘Master Meter’ reading is given, so the total gallons pumped is split between Wells No. 4 and 5

Table 26. Summary of Pumping for Well No. 7 (from RSIC)

(millions of gallons)

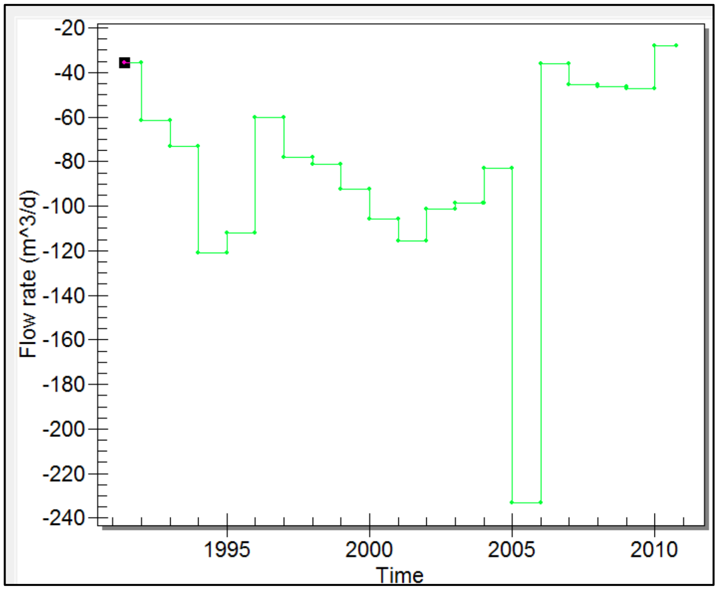
MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991												
1992												
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003												
2004												
2005				0.06	0.11	0.41	0.51	0.52	0.43	0.39	0.37	0.34
2006	0.17	0.14	0.35	0.13	0.27	0.39	0.81	0.98	0.05	0.33	0.44	0.12
2007	0.17	0.09	0.42	0.39	0.41	0.66	0.59	0.56	0.54	0.60	0.49	0.42
2008	0.36	0.33	0.52	0.43	0.46	0.48	0.60	0.91	0.69	0.53	0.42	0.45
2009	0.34	0.37	0.43	0.74	0.94	0.50	0.67	0.49	0.41	0.32	0.21	0.00
2010	0.24	0.14	0.17	0.34	0.49	0.54	0.44	0.53	0.42			

Table 27. Summary of Pumping for Well No. 8 (from RSIC)

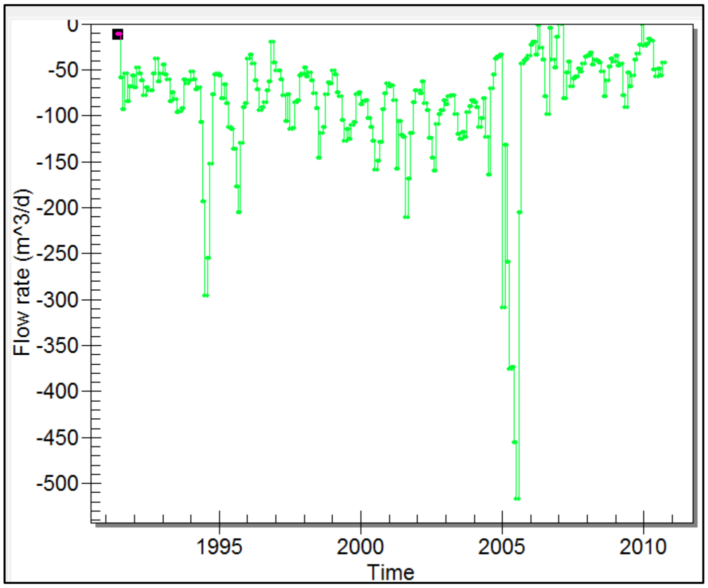
(millions of gallons)

MONTH YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991												
1992												
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000												
2001												
2002												
2003												
2004												
2005				0.05	0.08	0.36	0.50	0.50	0.46	0.33	0.34	0.30
2006	0.35	0.28	0.51	0.53	0.67	0.59	0.25	0.00	0.96	0.46	0.17	0.52
2007	0.55	0.53	0.30	0.44	0.60	0.44	0.63	0.73	0.61	0.43	0.26	0.32
2008	0.33	0.36	0.30	0.44	0.54	0.69	0.66	0.51	0.45	0.46	0.36	0.30
2009	0.26	0.21	0.13	0.00	0.00	0.45	0.52	0.61	0.74	0.40	0.49	0.68
2010	0.37	0.39	0.48	0.32	0.36	0.55	0.80	0.77	0.64			

Pumping input data for MODFLOW are shown in Figures 65 through 68 below.

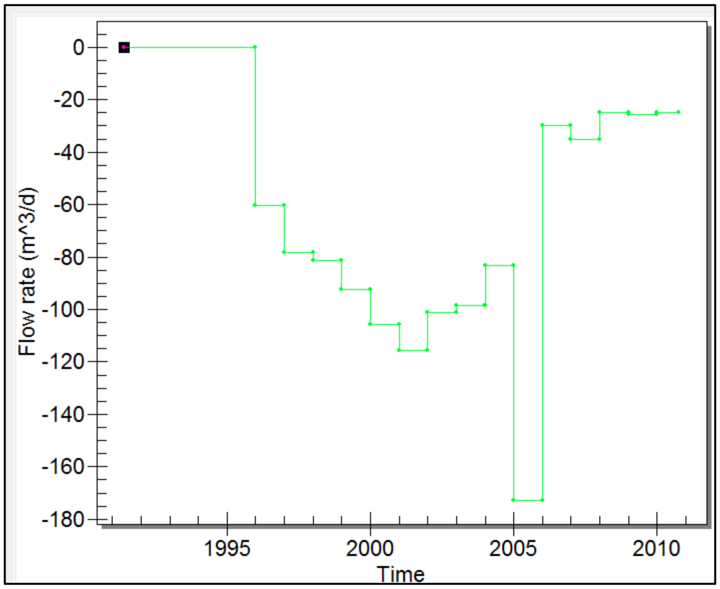


(a) Annual Average (as used in the model)

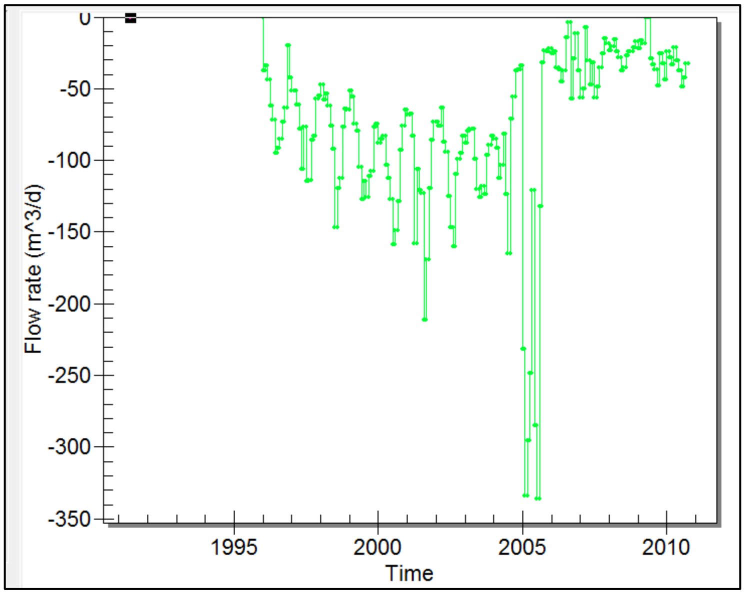


(b) Monthly Average

Figure 65. Well No. 4 Pumping Input MODFLOW Data

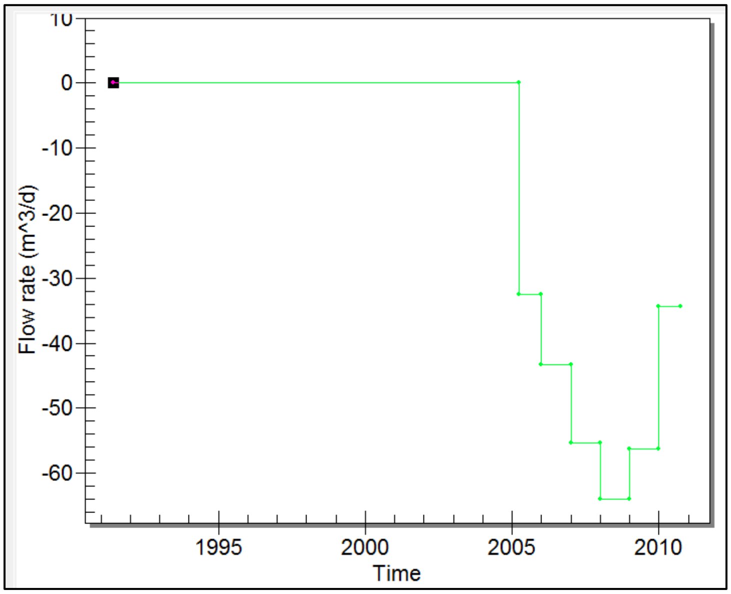


(a) Annual Average (as used in the model)

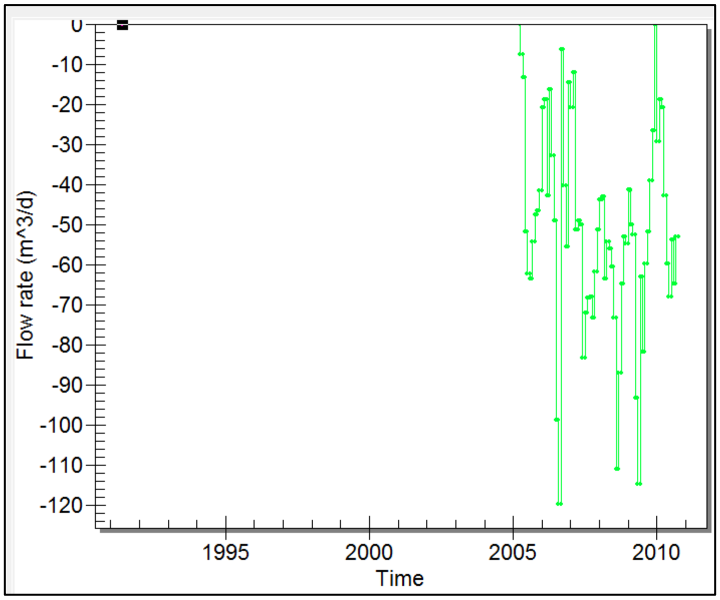


(b) Monthly Average

Figure 66. Well No. 5 Pumping Input MODFLOW Data

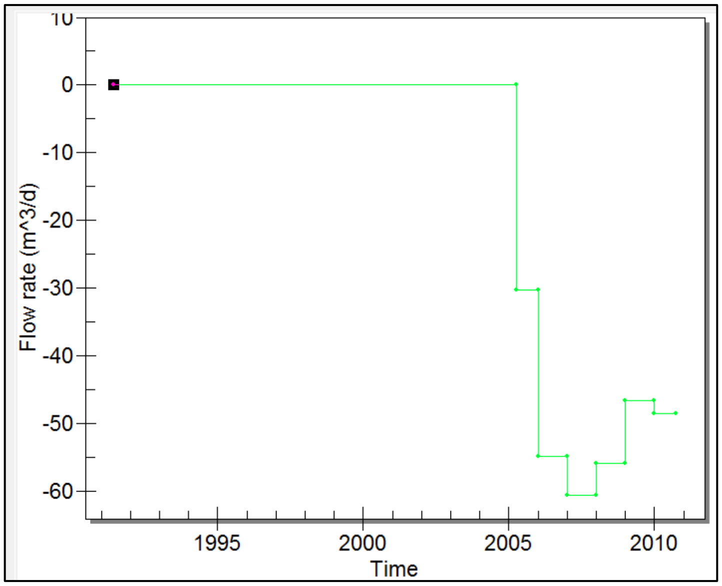


(a) Annual Average (as used in the model)

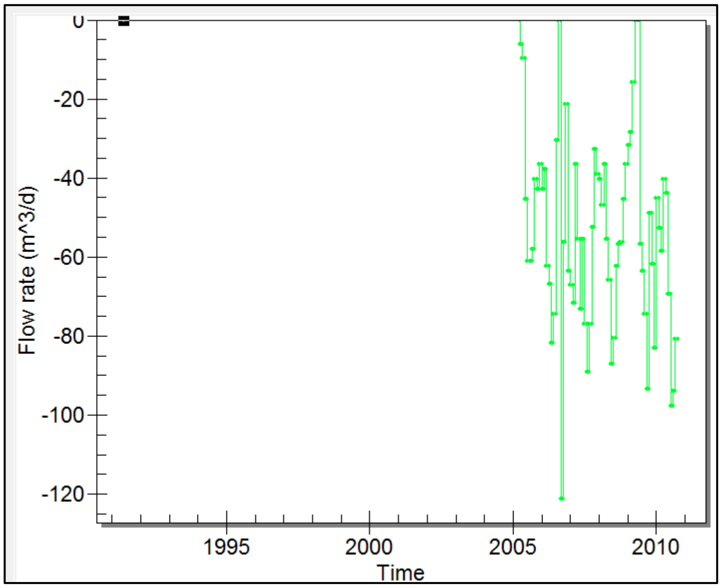


(b) Monthly Average

Figure 67. Well No. 7 Pumping Input MODFLOW Data



(a) Annual Average (as used in the model)



(b) Monthly Average

Figure 68. Well No. 8 Pumping Input MODFLOW Data

8.4 Specific Yield

Because Layer No. 1 was set as ‘convertible’ in MODFLOW a specific yield needs to be assigned. “In an unconfined unit, the level of saturation rises or falls with changes in the amount of water in storage. As the water level falls, water drains from the pore spaces. This storage or release is due to the specific yield (S_y) of the unit” (Fetter, 2001). This can also be described as gravity drainage as a result of the decline of the water table.

The specific yield of unconfined aquifers range from 0.02 to 0.30 (Fetter, 2001); and a median value of 0.16 was chosen for the transient simulation. This value for the specific yield provides for interaction between layers, and a release of water from Layer No. 1 (unconfined layer) to Layer No. 2 (aquifer layer). This interaction was noted during the March 2002 aquifer (pump) test conducted by UNR (Tyler, Summary of RSIC Hungry Valley Pump Testing, 2002).

8.5 Specific Storage

Because Layer No. 2 was set as ‘confined’ in MODFLOW, indicating a confined aquifer, a specific storage needs to be assigned.

“The specific storage (S_S) is the amount of water per unit volume of a saturated formation that is stored or expelled from storage owing to compressibility of the mineral skeleton and the pore water per unit change in head” (Fetter, 2001). This can also be described as water released from storage as a result of the decline in head. The specific storage is 0.000328 m^{-1} (0.0001 ft^{-1}) or less (Fetter, 2001). The specific storage was estimated from previous aquifer (pump) tests, using Storativity (S) = bS_S, where b is the aquifer thickness.

Storativities for Well Nos. 4, 5, 7 and 8, were calculated from aquifer (pump) tests conducted by students from the UNR Graduate Program of Hydrologic Sciences, Field Methods Classes. The results are listed in Tables 28 and 29; and shown graphically in Figures 69 and 70.

Table 28. Summary of Well Nos. 4 and 5 Storativities

(from Previous UNR Class Field Work)

WELL	**PUMPING RATE DURING TEST (gpm)**	**YEAR**	**STORATIVITY (dimensionless)**
Pumped: Well No. 4	130	2000	4.8×10^{-4}
Observed: Well No. 5			
Pumped: Well No. 5	130	2001	3×10^{-4}
Observed: Well No. 4			
Pumped: Well No. 5	130	2002	3×10^{-4} to 4×10^{-4}
Observed: Well No. 4			
Pumped: Well No. 5	130	2003	3×10^{-4} to 4×10^{-4}
Observed: Well No. 4			
Pumped: Well No. 5	65	2004	2.37×10^{-4}
Observed: Well No. 4			
Pumped: Well No. 4	90	2008	1.3×10^{-4} to 2.1×10^{-4}
Observed: Well No. 5			
AVERAGE	113		3.15×10^{-4}

Specific storage is estimated from 3.15×10^{-4} / 65 m = 4.846×10^{-6} m^{-1}

Table 29. Summary of Well Nos. 7 and 8 Storativities

(from Previous UNR Class Field Work)

WELL	**PUMPING RATE DURING TEST (gpm)**	**YEAR**	**STORATIVITY (dimensionless)**
Pumped: Well No. 7	125	2008	3×10^{-4} to 4×10^{-4}
Observed: Well No. 8			
AVERAGE	125		3.5×10^{-4}

Specific storage is estimated from 3.5×10^{-4} / 100 m = 3.5×10^{-6} m^{-1}

The specific storage (1/m) values utilized for Layer No. 2 for the transient simulation are listed in Table 30.

Table 30. Specific Storage

LAYER	SPECIFIC STORAGE
Layer No. 2 (west)	3.5×10^{-6} m^{-1}
Layer No. 2 (center, north)	4.846×10^{-6} m^{-1}
Layer No. 2 (center, south)	4.846×10^{-6} m^{-1}
Layer No. 2 (east)	4.846×10^{-6} m^{-1}

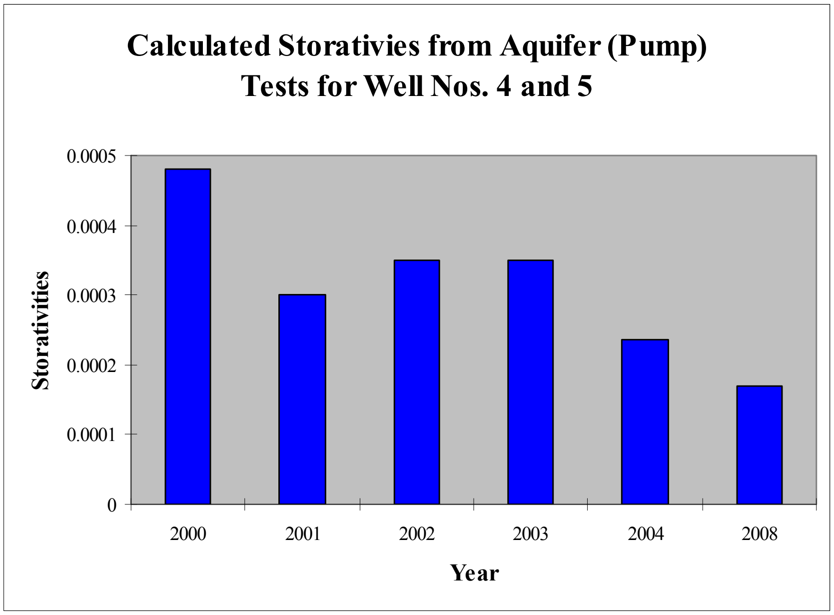


Figure 69. Summary of Calculated Storativities from Aquifer (Pump) Tests for Well Nos. 4 and 5 from Previous UNR Class Field Work

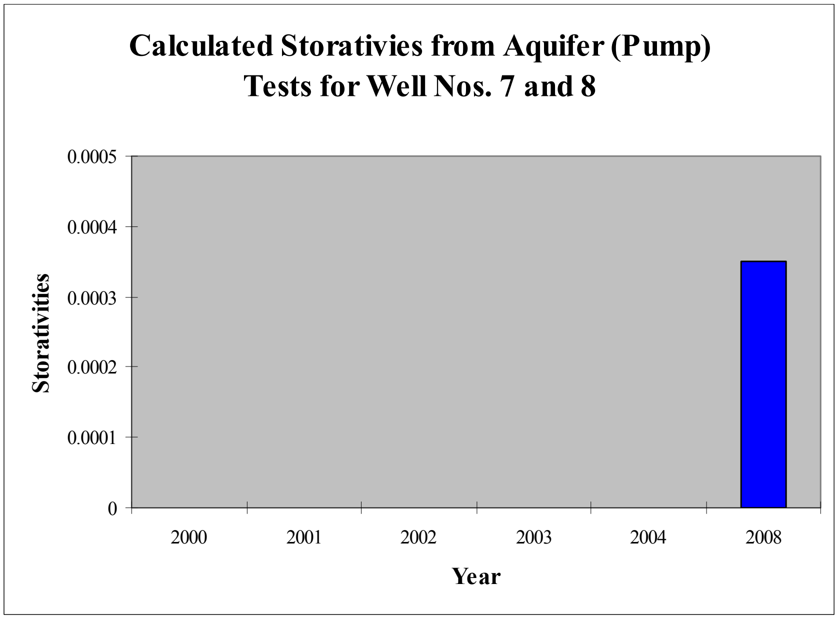


Figure 70. Summary of Calculated Storativities from Aquifer (Pump) Tests for Well Nos. 7 and 8 from Previous UNR Class Field Work

<u>8.6 Model Closure Criterion</u>

The model closure criterion was the same as utilized for the Steady-State MODFLOW Model (see Section 7.10).

<u>8.7 Model Calibration</u>

The transient simulation was run utilizing the well discharge data from RSIC, the specific yield estimated from the literature, and the specific storage derived from aquifer (pump) tests. No additional model calibration was performed.

8.8 Modeling Results

Figures 71 through 74 graphically present the transient simulation predicted drawdown due to pumping from June 1991 through September 2010 for Well Nos. 3, 4, 7 and 8 compared with observed static water levels. Well No. 5 is not included in the modeling results because of its proximity and hydraulic connectivity to Well No. 4. Note that the modeling results present an average head over the 100 m grid cell.

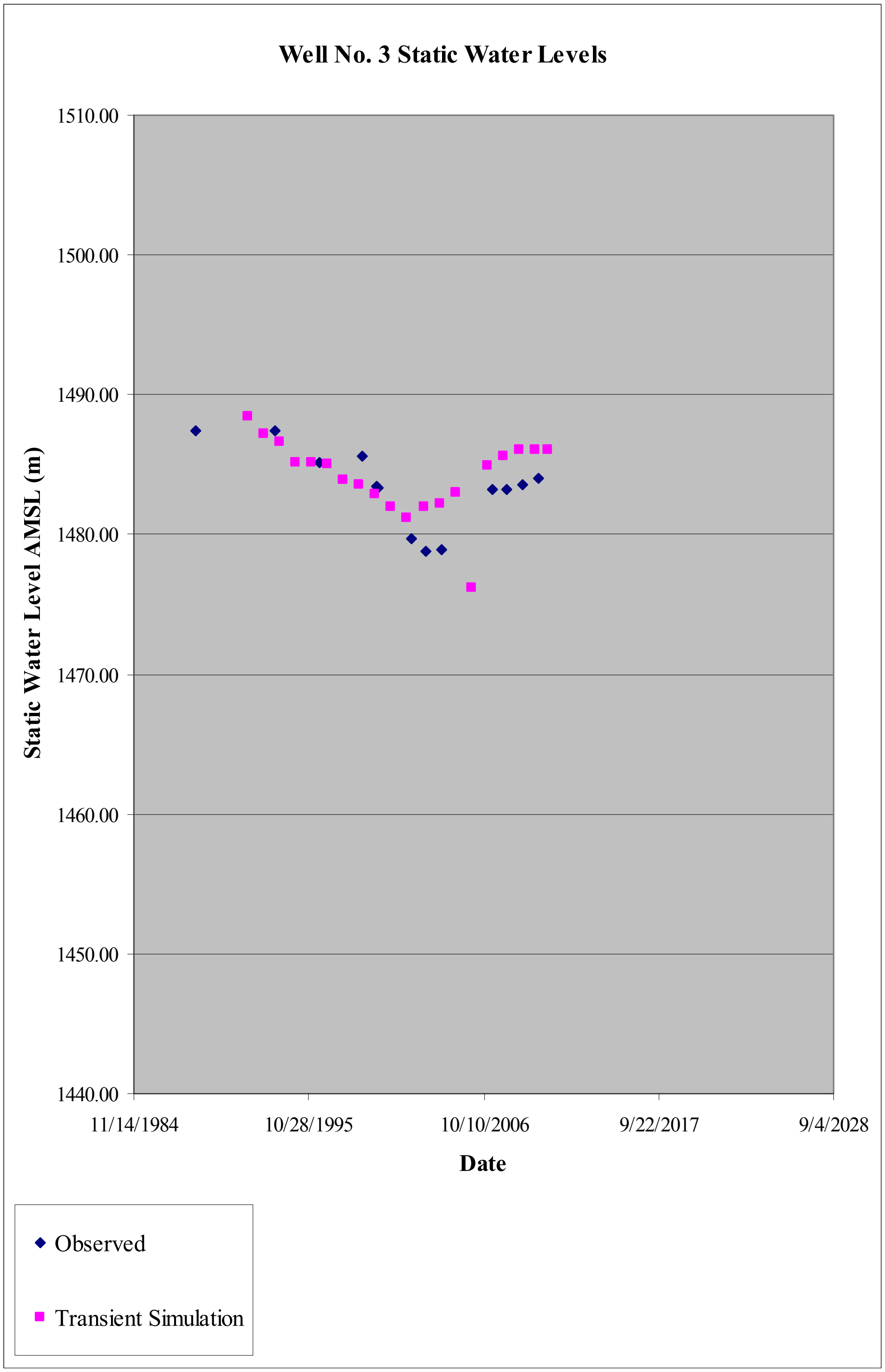


Figure 71. Transient Simulation Predicted Drawdown due to Pumping for Well No. 3

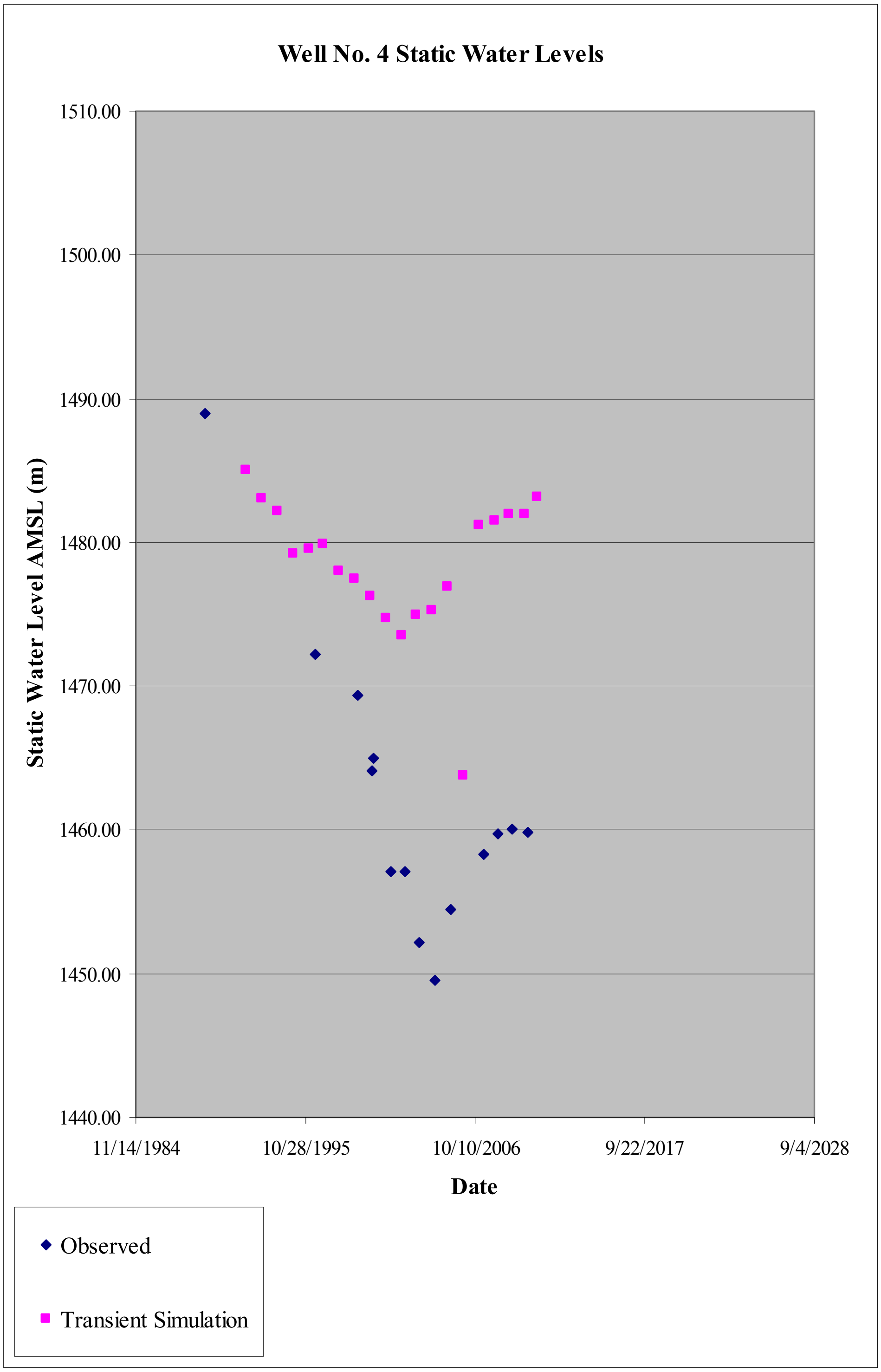


Figure 72. Transient Simulation Predicted Drawdown due to Pumping for Well No. 4 (Note: Well No. 5 is not included in the modeling results because of its proximity and hydraulic connectivity to Well No. 4)

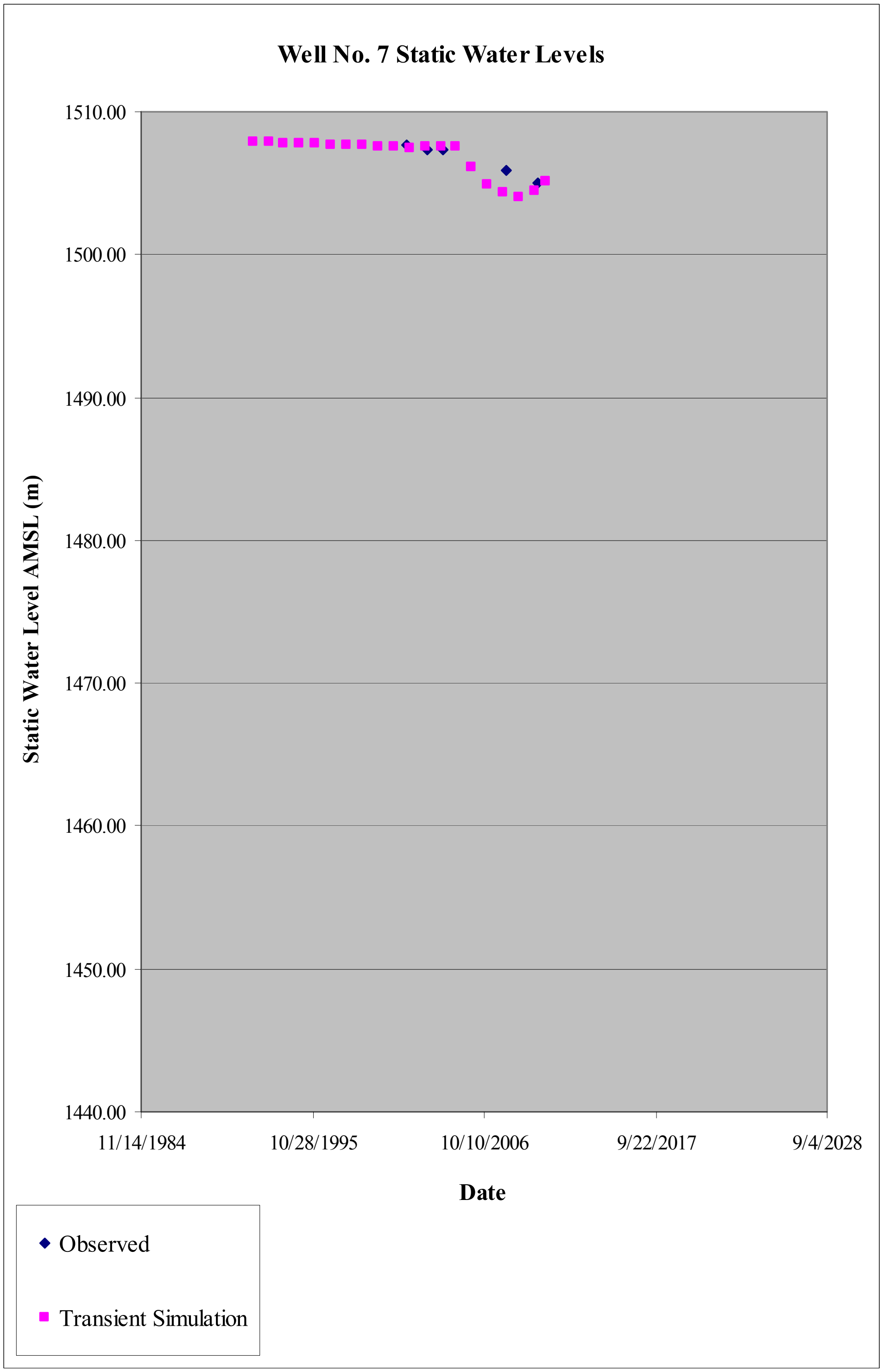


Figure 73. Transient Simulation Predicted Drawdown due to Pumping for Well No. 7

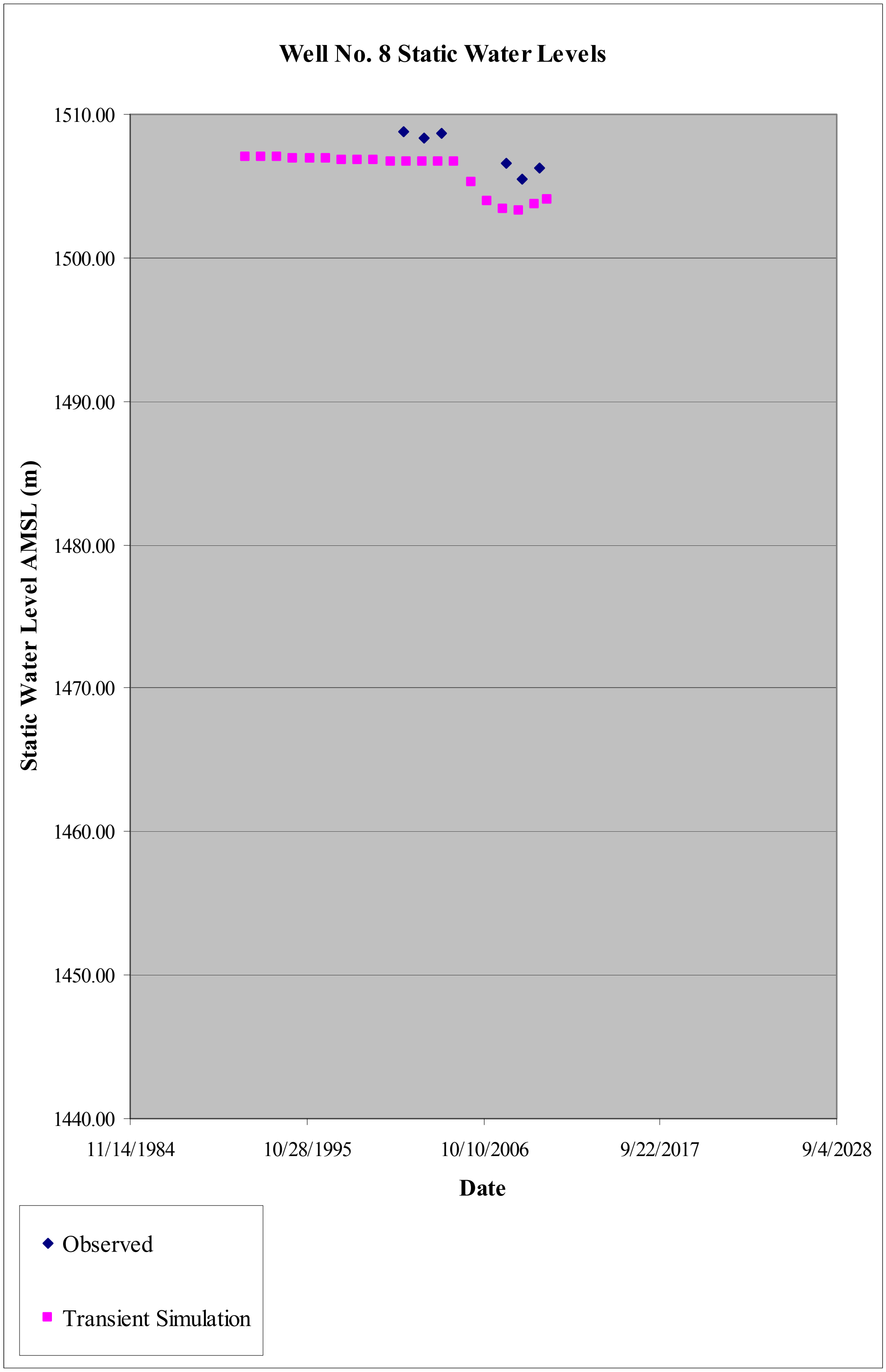


Figure 74. Transient Simulation Predicted Drawdown due to Pumping for Well No. 8

From Figures 71 through 74 the following observations are noted:

- For Well No. 3 the model appears to over-predict from 2003 and later.
- For Well No. 4 the model appears to considerably over-predict from 1996 and later. However, the model does appear to follow the general trend of the observed static water levels.
- For Well No. 7 the model appears to under-predict at 2008, but has good agreement in 2010.
- For Well No. 8 the model appears to under-predict throughout.
- Pumping for 2005 may be an outlier for Well Nos. 3 and 4.

The transient behavior of the model over-predicts the static water levels for Well No. 4 and this is discussed further in the following section.

Figures 75 through 77 present contour maps for the period following the beginning of pumping (1/1/1992), period of highest pump (1/1/2006), and the end of the transient simulation (10/1/2010) for Layer No. 2.

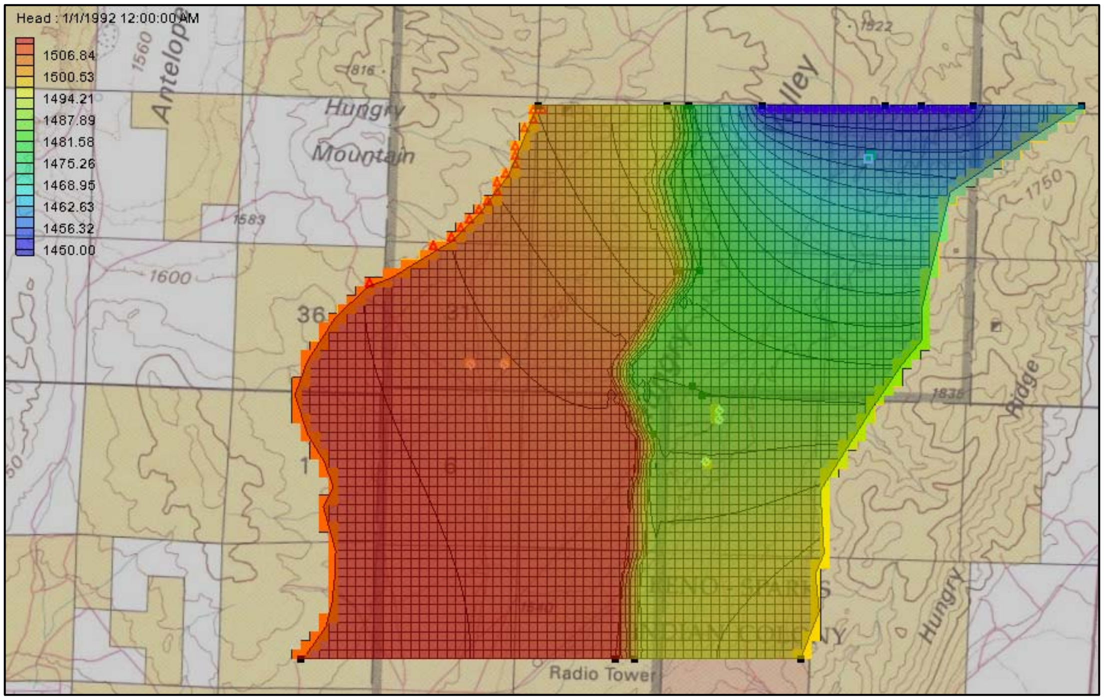


Figure 75. Transient Simulation Model Contours for Layer No. 2 at 1/1/1992

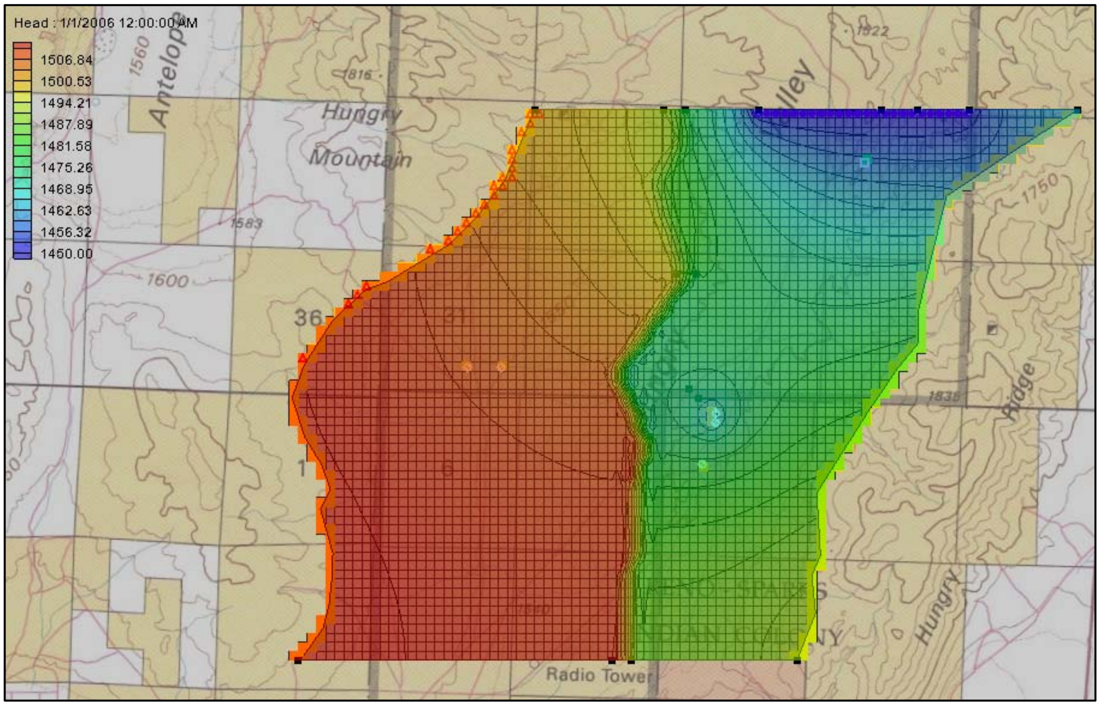


Figure 76. Transient Simulation Model Contours for Layer No. 2 at 1/1/2006

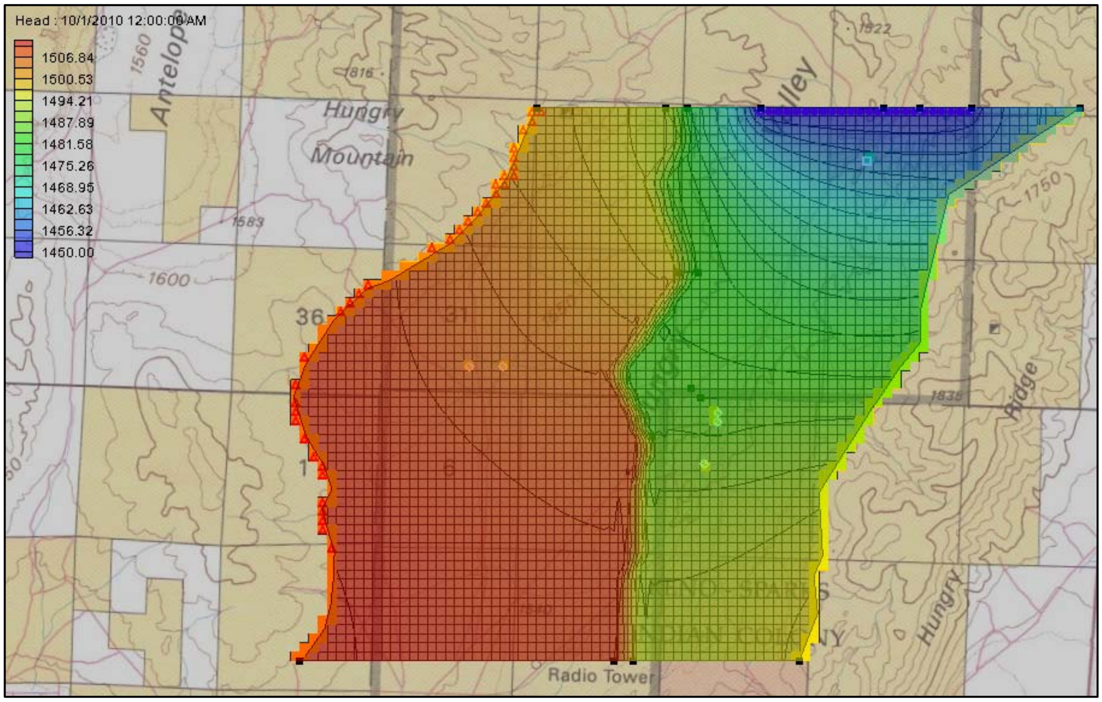


Figure 77. Transient Simulation Model Contours for Layer No. 2 at 10/1/2010

It can be seen from Figure 76 the effect of increased pumping of Well Nos. 4 and 5. In Section 7, Little Hungry Spring was modeled in MODFLOW as a drain using two different approaches. The first approach was placing the bottom of the drain elevation at 1320 m, the drain conductance was set at 0.0098 m^2/day and the drain was specified for interaction from only Layer No. 2. The second approach placed the bottom of the drain elevation at 1457 m, the drain conductance was set at 2.65 m^2/day and the drain was specified for interaction from both Layer Nos. 1 and 2. Figures 78 and 79 compare the transient simulation static water level at the drain cell and the spring flow for the two approaches.

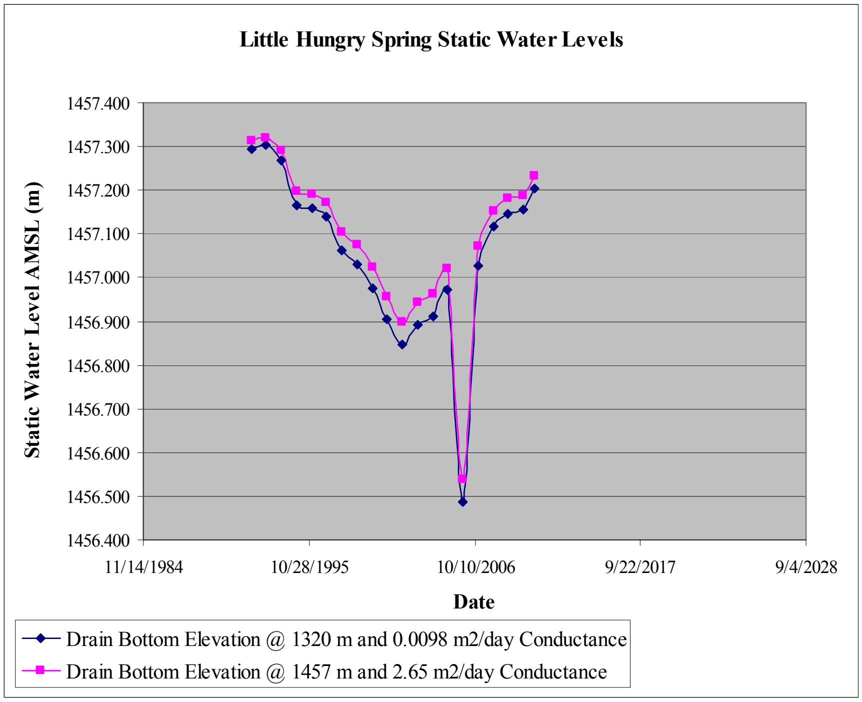


Figure 78. Transient Simulation Comparison of Little Hungry Spring Static Water Level Elevation

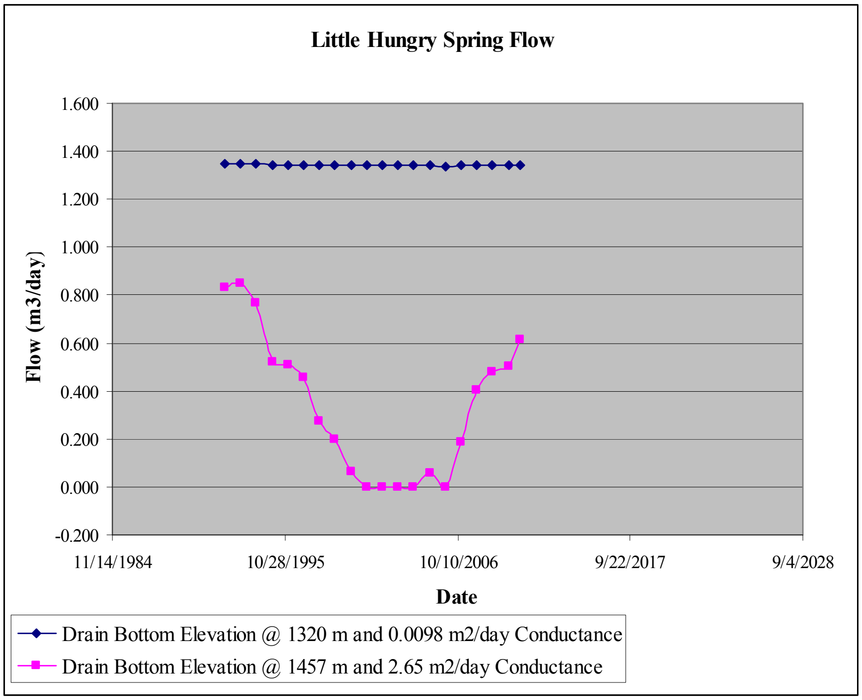


Figure 79. Transient Simulation Comparison of Little Hungry Spring Flow

It can be seen from Figure 78 that the static water level at the drain cell is similar between the two approaches and varies very little, between 1456.4 and 1457.4 m. It can be expected that the static water level at Little Hungry Spring is consistent with the observed value because it was the basis used to establish the specified head boundary.
The approach where the drain is placed at an elevation of 1320 m produces a slightly lower static water level. The flow as a result of the transient simulation at Little Hungry Spring is very different given the two approaches as seen in Figure 79. For the drain placed at 1320 m, the flow is nearly unchanged throughout the simulation. However, for the second approach with the drain placed at 1457 m, the spring flow is strongly influenced by the changing static water levels and is lower than that predicted from the first approach. This appears to be the result of the interaction between Layer Nos. 1 and 2 where the groundwater must pass through the layer of lower hydraulic conductivity to reach the drain elevation and leave the system. Note that where the static water level at the drain cell falls below 1457 m, there is not flow from the drain.

The modeled intra-basin flow to Warm Springs Valley is slightly affected by the pumping rate with an average of 899.8 m^3/day and a standard deviation of 16.7 m^3/day. The majority of the groundwater that leaves the system through pumping is from storage.

8.8.1 Root Mean Squared Error (RMSE)

A measure of the difference between computed head values and the observed head values is RMSE. The assumption made in this thesis effort is that the observed head values represent the static water levels in the aquifers that are not influenced directly by pumping. Table 31 presents the RMSE for the transient simulation. Note that the stress periods established for the transient simulation do not correspond with the date upon which static water levels have been observed. For purposes of calculating RMSE, the nearest data points were compared.

Table 31. Comparison of Transient Model with Observed Static Water Levels

WELL NO.	I, J, and K COORDINATES FROM MODEL GRID	RMSE – STATIC WATER LEVEL (meters)
Well No. 3	I = 43, J = 50, K = 2	2.08
Well No. 4	I = 38, J = 51, K = 2	19.34
Well No. 7	I = 32, J = 24, K = 2	0.78
Well No. 8	I = 32, J = 28, K = 2	2.32
Little Hungry Spring	I = 9, J = 68, K = 2	1.04
RMSE FOR ALL DATA POINTS (meters)		11.43
RE (Relative Error)		21.6%

Table 32. Comparison of Transient Model with Spring Flow

SPRING	(I, J, and K Coordinates from Model Grid)	DIFFERENCE – FLOW (m^3 / day)
Little Hungry Spring	(I = 9, J = 68, K = 2)	0.871

From the information presented in Tables 31 and 32, it can be seen that the model predicts the observed static water levels with the exception of Well No. 4 and spring flow. The model over-predicts the static water levels for Well No. 4 beginning in 1996; and to a lesser extent Well No. 3 beginning in 2003. Because the model assumes a single constant thickness aquifer at Test Hole No. 1 and Well Nos. 3, 4 and 5, any effort to adjust input parameters affects the entire aquifer. As has been previously discussed, the primary water bearing aquifer is at the first screened interval for Well Nos. 4 and 5; Test Hole No. 1 is screened below this interval, Well No. 3 is screened above this interval, and Well EW-4 is screened both above and below the interval. This modeling approach does not account for the physical layout of the aquifer and placement of the well screens. In Section 8.10, the model is modified to improve the transient behavior for Well No. 4. The model under-predicts the flow at Little Hungry Spring.

8.9 Sensitivity Analysis

A sensitivity analysis was performed on the model, varying the specific yield of Layer No. 1 and the specific storage for the east and west sections of Layer No. 2. The sensitivity analysis was performed to better understand the uncertainty of the input parameters selected in the development of the Transient MODFLOW Model. The results from comparing the computed head values and spring flow to the observed values are summarized in Tables 33 and 34.

Table 33. Transient Simulation MODFLOW Model – Sensitivity Analysis for Comparison of Model with Pre-Well Field Development Static Water Levels

WELL NO. (I, J, and K Coordinates from Model Grid)	PARAMETER	ORIGINAL VALUE	REVISED VALUE	PERCENT OF ORIGINAL VALUE	RMSE – STATIC WATER LEVELS (meters)
Well No. 3 (I = 43, J = 50, K = 2)	Transient Simulation (prior to sensitivity analysis)				2.08
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	2.25
			0.30	187.5%	2.17
	Layer No. 2 Specific Storage (west)	3.5x10^{-6} m^{-1}	1.75x10^{-6} m^{-1}	50%	2.08
			3.28x10^{-4} m^{-1}	9371.4%	2.16
	Layer No. 2 Specific Storage (east)	4.85x10^{-6} m^{-1}	2.42x10^{-6} m^{-1}	50%	2.16
			3.28x10^{-4} m^{-1}	6762.9%	4.05
Well No. 4 (I = 38, J = 51, K = 2)	Transient Simulation (prior to sensitivity analysis)				19.34
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	18.86
			0.30	187.5%	19.61
	Layer No. 2 Specific Storage (west)	3.5x10^{-6} m^{-1}	1.75x10^{-6} m^{-1}	50%	19.34
			3.28x10^{-4} m^{-1}	9371.4%	19.48
	Layer No. 2 Specific Storage (east)	4.85x10^{-6} m^{-1}	2.42x10^{-6} m^{-1}	50%	19.41
			3.28x10^{-4} m^{-1}	6762.9%	21.13
Well No. 7 (I = 32, J = 24, K = 2)	Transient Simulation (prior to sensitivity analysis)				0.78
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	1.44
			0.30	187.5%	0.73
	Layer No. 2 Specific Storage (west)	3.5x10^{-6} m^{-1}	1.75x10^{-6} m^{-1}	50%	0.80
			3.28x10^{-4} m^{-1}	9371.4%	0.75
	Layer No. 2 Specific Storage (east)	4.85x10^{-6} m^{-1}	2.42x10^{-6} m^{-1}	50%	0.77
			3.28x10^{-4} m^{-1}	6762.9%	0.73

Table 33. Transient Simulation MODFLOW Model – Sensitivity Analysis for Comparison of Model with Pre-Well Field Development Static Water Levels (continued)					
WELL NO. **(I, J, and K Coordinates from Model Grid)**	**PARAMETER**	**ORIGINAL VALUE**	**REVISED VALUE**	**PERCENT OF ORIGINAL VALUE**	**RMSE – STATIC WATER LEVELS (meters)**
Well No. 8 **(I = 32, J = 28, K = 2)**	Transient Simulation (prior to sensitivity analysis)				2.32
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	3.15
			0.30	187.5%	2.26
	Layer No. 2 Specific Storage (west)	$3.5\text{x}10^{-6}$ m^{-1}	$1.75\text{x}10^{-6}$ m^{-1}	50%	2.34
			$3.28\text{x}10^{-4}$ m^{-1}	9371.4%	1.16
	Layer No. 2 Specific Storage (east)	$4.85\text{x}10^{-6}$ m^{-1}	$2.42\text{x}10^{-6}$ m^{-1}	50%	2.32
			$3.28\text{x}10^{-4}$ m^{-1}	6762.9%	2.18
Little Hungry Spring **(I = 9, J = 68, K = 2)**	Transient Simulation (prior to sensitivity analysis)				1.04
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	1.20
			0.30	187.5%	1.01
	Layer No. 2 Specific Storage (west)	$3.5\text{x}10^{-6}$ m^{-1}	$1.75\text{x}10^{-6}$ m^{-1}	50%	1.02
			$3.28\text{x}10^{-4}$ m^{-1}	9371.4%	0.95
	Layer No. 2 Specific Storage (east)	$4.85\text{x}10^{-6}$ m^{-1}	$2.42\text{x}10^{-6}$ m^{-1}	50%	1.02
			$3.28\text{x}10^{-4}$ m^{-1}	6762.9%	1.00

Table 34. Transient Simulation MODFLOW Model – Sensitivity Analysis for Comparison of Model with Spring Flow

SPRING (I, J, and K Coordinates from Model Grid)	PARAMETER	ORIGINAL VALUE	REVISED VALUE	PERCENT CHANGE	DIFF. – SPRING FLOW (m^3 / day)
Little Hungry Spring (I = 9, J = 68, K = 2)	Transient Simulation (prior to sensitivity analysis)				0.851
	Layer No. 1 Specific Yield	0.16	0.02	12.5%	1.338
			0.30	187.5%	0.854
	Layer No. 2 Specific Storage (west)	3.5×10^{-6} m^{-1}	1.75×10^{-6} m^{-1}	50%	0.874
			3.28×10^{-4} m^{-1}	9371.4%	0.679
	Layer No. 2 Specific Storage (east)	4.85×10^{-6} m^{-1}	2.42×10^{-6} m^{-1}	50%	0.859
			3.28×10^{-4} m^{-1}	6762.9%	0.814

It appears from the sensitivity analysis that lowering the specific yield of Layer No. 1 will result in a moderate lowering of RMSE for Well No. 4; while increasing the RMSE for Well Nos. 3, 7 and 8. Lowering the specific yield also results in flooding in some grid cells and a decrease in flow from Little Hungry Spring. The model appears to be relatively insensitive to increasing the specific yield; with just a slight lowering of RMSE for Well Nos. 7 and 8. Additionally, it appears that increasing the specific storage to the upper limit for Layer No. 2 West will moderately decrease the RMSE for Well Nos. 7 and 8; while not significantly affecting Well Nos. 3 and 4. This also increases the flow at Little Hungry Spring. Finally, the model appears to be insensitive to changes in the specific storage for Layer No. 2 East; with only a moderate increase in RMSE for increasing the specific storage at Well Nos. 3 and 4.

The model as developed does not adequately represent the field conditions for Well No. 4. From the sensitivity analysis in this section, it appears that only minor improvements can be achieved in the RMSE by varying the transient simulation parameters. However, from the sensitivity analysis for the Steady-State MODFLOW Model (see Section 7), the model appears to be sensitive to the hydraulic conductivity and recharge.

8.10 Adjusting the Model Parameters to Improve the RMSE for Well No. 4

Three approaches were utilized to adjust the model to improve the RMSE for Well No. 4:

- Adjusting the hydraulic conductivity for Layer No. 2 (East) from 0.25 m/d to 0.45 m/d (see Section 7, Sensitivity Analysis)
- Adjusting the recharge on the East side of the Hungry Valley from 473.1 m^3/d to 400 m^3/d (see Section 7, Sensitivity Analysis)
- Isolating Well Nos. 4 and 5 with a Section of Low Hydraulic Conductivity, 0.0075 m/d (i.e., simulating a partially isolated aquifer)

The results of this analysis are presented in Table 35.

Table 35. Results of Adjusting Model Parameters to Improve the RMSE for Well No. 4

WELL NO. / SPRING	I, J, and K COORDINATES FROM MODEL GRID	RMSE – STATIC WATER LEVEL (Transient Simulation) (meters)	RMSE – STATIC WATER LEVEL (Recharge (East) Reduced from 473.1 m^3/d to 400 m^3/d) (meters)	RMSE – STATIC WATER LEVEL (Adjusting Layer No. 2 (East) Hydraulic Conductivity from 0.25 m/d to 0.45 m/d) (meters)	RMSE – STATIC WATER LEVEL (Isolating Well Nos. 4 and 5 w/Section of 0.0075 m/d) (meters)
Well No. 3	I = 43, J = 50, K = 2	2.08	1.67	4.81	2.81
Well No. 4	I = 38, J = 51, K = 2	19.34	18.34	15.86	10.03
Well No. 7	I = 32, J = 24, K = 2	0.78	0.83	2.93	0.79
Well No. 8	I = 32, J = 28, K = 2	2.32	2.42	4.78	2.34
Little Hungry Spring	I = 9, J = 68, K = 2	1.04	1.29	2.66	1.04
SPRING	**I, J, and K COORDINATES FROM MODEL GRID**	**DIFF. – FLOW (m^3 / day)**	**DIFF. – FLOW (m^3 / day)**	**DIFF. – FLOW (m^3 / day)**	**DIFF. – FLOW (m^3 / day)**
Little Hungry Spring - Flow	I = 9, J = 68, K = 2	0.87	No Flow	No Flow	0.42

From Table 35 it appears isolating Well Nos. 4 and 5 with an area of lower hydraulic conductivity has the largest effect of improving the RMSE for the modeling of the Well No. 4 observed static water levels; while minimizing the effects on the remainder of the model. The model underestimates the observed static water levels prior to 2003, has good agreement for 2003 to 2005, and then overestimates for the remainder of the transient simulation. The isolated area has Well Nos. 4 and 5 in the center and comprises 12 – 100 m grid cells or 0.12 square kilometers (approximately 30 acres). Figure 80 graphically presents the revised transient simulation predicted drawdown due to pumping from June 1991 through September 2010 for Well No. 4 compared with observed static water levels. Figure 81 presents a revised contour map at the end of the transient simulation (10/1/2010) for Layer No. 2.

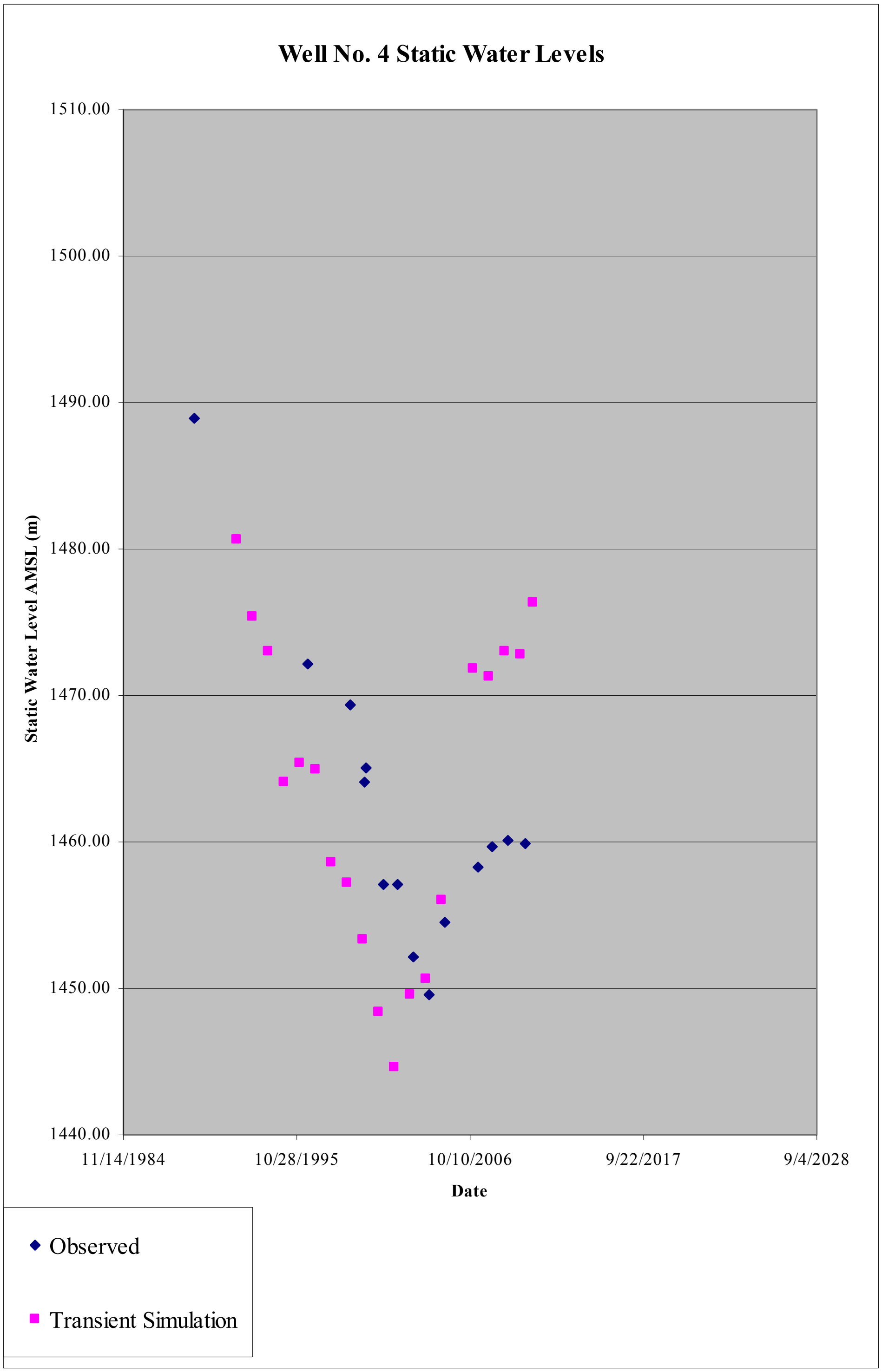


Figure 80. Revised Transient Simulation Predicted Drawdown due to Pumping for Well No. 4 (Note: Well No. 5 is not included in the modeling results because of its proximity and hydraulic connectivity to Well No. 4)

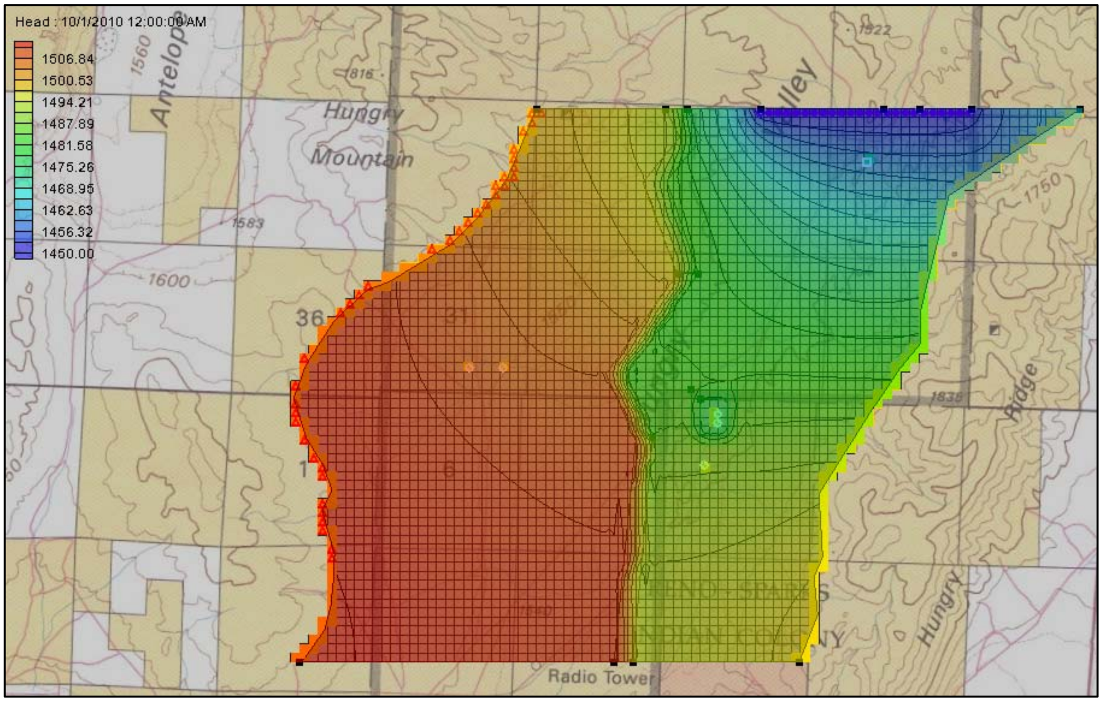


Figure 81. Revised Transient Simulation Model Contours for Layer No. 2 at 10/1/2010

Section 9 – Optimization

Optimization strategies can be developed through Linear Programming or a trial and error approach. Some examples of Linear Programming include:

- EPA/542/R-99/011B, Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems, Volume II: Application of Hydraulic Optimization
- A Model for Managing Sources of Groundwater Pollution, Water Resources Research, Steven M. Gorelick, Vol. 18, No. 4, Pages 773-781, August 1982

"In cases where only a few well locations are considered, the benefits of hydraulic optimization are diminished. In those cases, a good modeler may achieve near-optimal (or optimal) solutions by performing trial-and-error simulations" (EPA/542/R-99/011B, 1999). A trial and error approach was utilized. This is further simplified as Well Nos. 4 and 5 are considered to have the same pumping rate as are Well Nos. 7 and 8. This effectively reduces the number of wells for this optimization approach to two.

9.1 Objective

The objective of the optimization is to maintain the static water levels as high as possible.

9.2 Constraints

9.2.1 Arsenic

The first constraint is to ensure that arsenic levels remain below drinking water standards. Levels of arsenic in drinking water are set by the US Environmental Protection Agency through the Safe Drinking Water Act (Walker, FS-01-08). Drinking water standards for arsenic are listed in 40 CFR 141.11(a). The Maximum Contaminant Level (MCL) for arsenic is 0.010 mg/L (State of Nevada, Nevada Division of Environmental Protection, Bureau of Safe Drinking Water, April 2011).

The level of arsenic in Well Nos. 4 and 5 is < 0.003 mg/L (Harrigan and Ball, 1996); and the level of arsenic in Well Nos. 7 and 8 is 0.011 mg/L and 0.013 mg/L, respectively (RSIC, Wellhead Protection Program, 2006). The level of arsenic in Little Hungry Spring is unknown. Note that arsenic concentrations in water can vary tremendously from well to well (Walker, FS-01-08).

Given the above levels of arsenic and assuming that the pumping rate at Well No. 4 is equal to Well No. 5, and that the pumping rate at Well No. 7 is equal to Well No. 8; in order to keep the arsenic level below the MCL, a maximum of 77% can be pumped from Well Nos. 7 and 8 combined.

Table 36 lists the percentage of pumping for Well Nos. 4 and 5 combined and Well Nos. 7 and 8 combined from the summary of pumping provided by the RSIC. The table also provides an estimate of the arsenic level of the blended water supply.

Table 36. Percentage of Pumping by Well

YEAR	**WELL NOS. 4 AND 5** (percentage of pumping)	**WELL NOS. 7 AND 8** (percentage of pumping)	**ESTIMATE ARSENIC LEVEL FOR BLENDED WATER SUPPLY** (mg/l)
2006	40.2	59.8	0.0084
2007	41.1	58.9	0.0083
2008	37.3	62.7	0.0086
2009	41.5	58.5	0.0083

By inspection of the results of the transient simulation (presented in Section 8), the observed static water levels appear to have stabilized during the period of 2006 to 2009 or are recovering. Therefore, a pumping schedule of 60% for Well Nos. 7 and 8 combined and 40% for Well Nos. 4 and 5 combined appears to impact the static water levels evenly, maintain arsenic below the MCL, and is consistent with the operational history of the wells.

9.2.2 Cost of Groundwater Pumping

The second constraint is to reduce the cost of groundwater pumping. The document Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems, Volume II: Application of Hydraulic Optimization discusses the cost of groundwater pumping:

> Minimizing the total pumping rate is appropriate when the cost of pumping, treating, or discharging the water is rate-sensitive and is the dominant cost factor. Minimizing the number of active wells is appropriate if the number of pumps (e.g., electrical demand from pumping water) is the dominant cost factor. Minimizing the number of new wells is appropriate if the capital cost of installing a new well is the dominant cost factor (EPA/542/R-99/011B, 1999).

Reducing the cost of groundwater pumping can be achieved by reducing the pumping rate at each of the wells; thereby minimizing well losses. Additionally, lowering of the pumping rate and pumped volume should result in an eventual rebound in the static water level.

From the 2008 aquifer (pump) test performed by the UNR Graduate Program of Hydrologic Sciences, the maximum drawdown due to pumping for Well No. 4 was 92.1 m (302.1 feet) at an average pumping rate of 490.6 m^3/day (90 gallons per minute) and for Well No. 7 was 56.8 m (186.5 feet) at an average pumping rate of 681.4 m^3/day (125 gallons per minute). Therefore, it appears that Well Nos. 4 and 5 have the highest lift during pumping and should benefit the most

> from a decrease in pumping rate. In the previous section, it was shown that pumping from Well Nos. 7 and 8 could be increased to 77% of the total pumping requirement and remain at or below the MCL for arsenic. This increased pumping from Well Nos. 7 and 8 would also appear to result in minimizing the cost of overall groundwater pumping.

Therefore, for optimization it is necessary to increase pumping from Well Nos. 7 and 8 while maintaining the static water levels as high as possible. From Table 36, for the period from 2006 through 2009, the pumping strategy has been approximately 60% for Well Nos. 7 and 8 combined and 40% for Well Nos. 4 and 5 combined. Additionally, considering a degree of safety concerning arsenic, it is recommended to pump no more than 70% from Well Nos. 7 and 8, even though the maximum was calculated to be 77%. The optimization is then performed increasing pumping from Well Nos. 7 and 8 from 60% to 70% using a 2% increment. These transient simulations will complete 2010 (using the averaged pumping rate from January through September of 2010) and predict drawdown through 2015. The pumping rate for 2011 through 2015 is the average pumping from 2000 through 2009 (excluding 2005); which is 70,432 m^3/year (57.1 acre-feet per year) or 192.96 m^3/day. The results of this optimization approach are summarized in Table 37 below.

Table 37. Optimization Results

WELL NOS. 4 AND 5 PUMPING (percentage of pumping)	WELL NOS. 7 AND 8 PUMPING (percentage of pumping)	CHANGE IN STATIC WATER LEVEL FOR THE PERIOD 1/1/2011 THROUGH 1/1/2016			
		WELL NO. 3 (meters)	WELL NO. 4 (meters)	WELL NO. 7 (meters)	WELL NO. 8 (meters)
40	60	- 0.8	- 4.3	- 1.1	- 0.9
38	62	- 0.6	- 3.6	- 1.2	- 1.1
36	64	- 0.5	- 2.9	- 1.3	- 1.2
34	66	- 0.4	- 2.2	- 1.5	- 1.3
32	68	- 0.3	- 1.5	- 1.6	- 1.4
30	70	- 0.1	- 0.8	- 1.7	- 1.5

The optimization approach indicates that 70% pumping from Well Nos. 7 and 8 and 30% pumping from Wells Nos. 4 and 5 results in maximizing static water levels while meeting the arsenic and cost of groundwater pumping constraints. This pumping strategy results in essentially stabilized static water levels (i.e. neither recovering nor declining) for Well Nos. 3 and 4 and a slight decreasing static water levels for Well Nos. 7 and 8.

9.3 Predicted Drawdowns for Future Growth

Future water demand was discussed in the Phase I Hydrogeological Investigation of the Groundwater Supply at Hungry Valley; prepared by Nevada-Sierra Planners:

> Using the high growth scenario from 1997 population data, which averages to a 5.6% annual growth, the water demand increases from 48 annual acre feet (AAF) pumped in 1997 to 72 AAF in the year 2027. This water demand is calculated for the existing population and land uses and combined with the projected increase of population expressed as new, single-family houses at Hungry Valley. There is raw land at Hungry Valley for this development as well as other potential uses (Gebhardt et al, 1999).

Using a pumping rate of 70,432 m^3/year (57.1 acre-feet per year) for 2011 and projecting to 88,811 m^3/year (72 acre-feet per year) for 2027 results in a 1,147 m^3/year (0.93 acre-feet per year) increase. Using the optimized pumping scenario from Section 9.2 of 70% pumping for Well Nos. 7 and 8 and 30% pumping for Well Nos. 4 and 5, the model was utilized to predict the resulting static water levels (see Figures 82 through 85). The results indicate a decreasing water level for all wells as the pumping rate increases. Table 38 lists the change in static water level for the period from 1/1/2011 through 1/1/2028. As can be seen from the table, the largest decrease in static water levels occurs at Well No. 4.

Table 38. Change in Static Water Level for the Period 1/1/2011 through 1/1/2028 For the Future Growth Transient Simulation	
WELL NO.	**CHANGE IN STATIC WATER LEVEL (meters)**
Well No. 3	- 0.8
Well No. 4	- 3.7
Well No. 7	- 3.1
Well No. 8	- 2.9

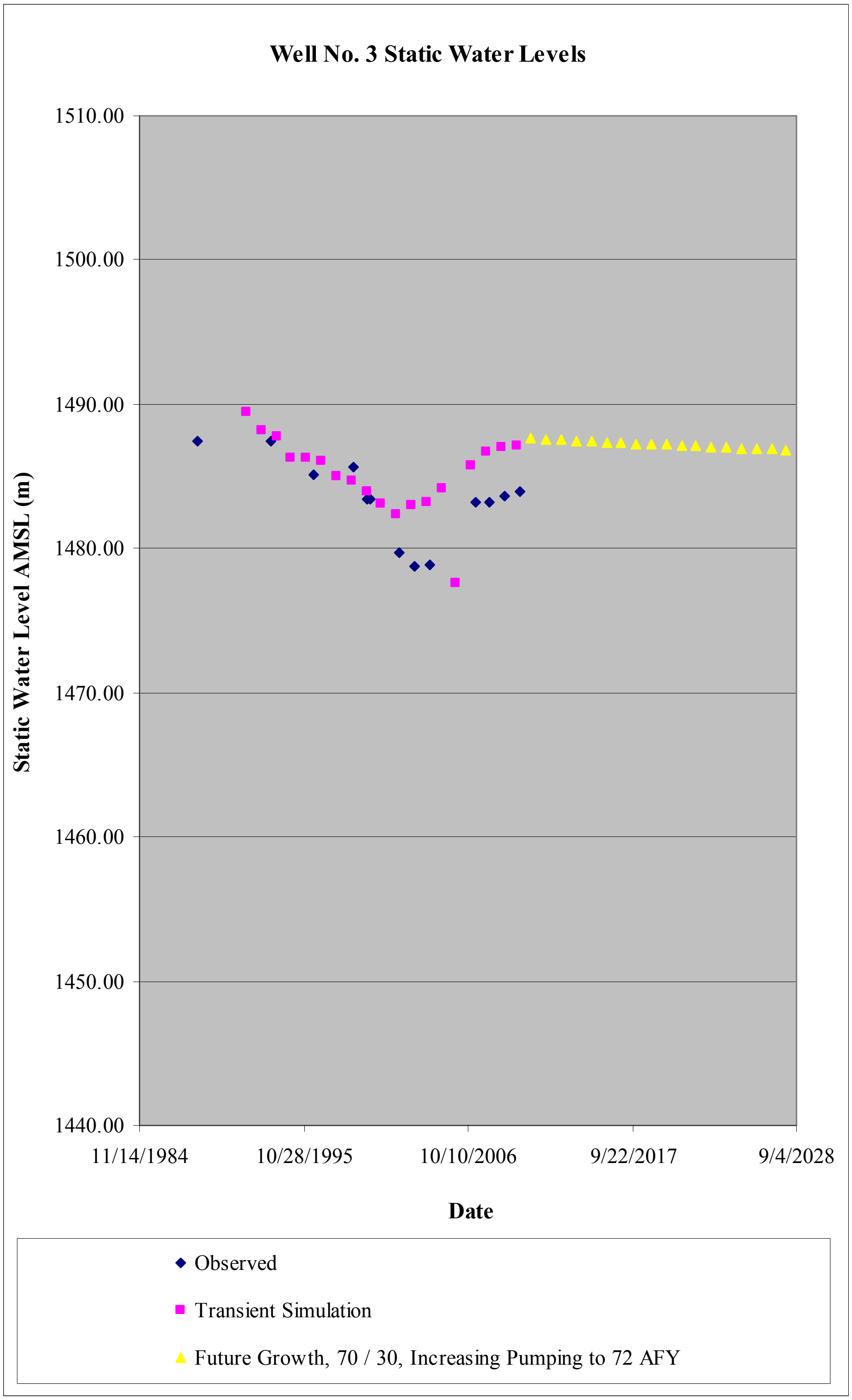


Figure 82. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 4 and 5 for Well No. 3

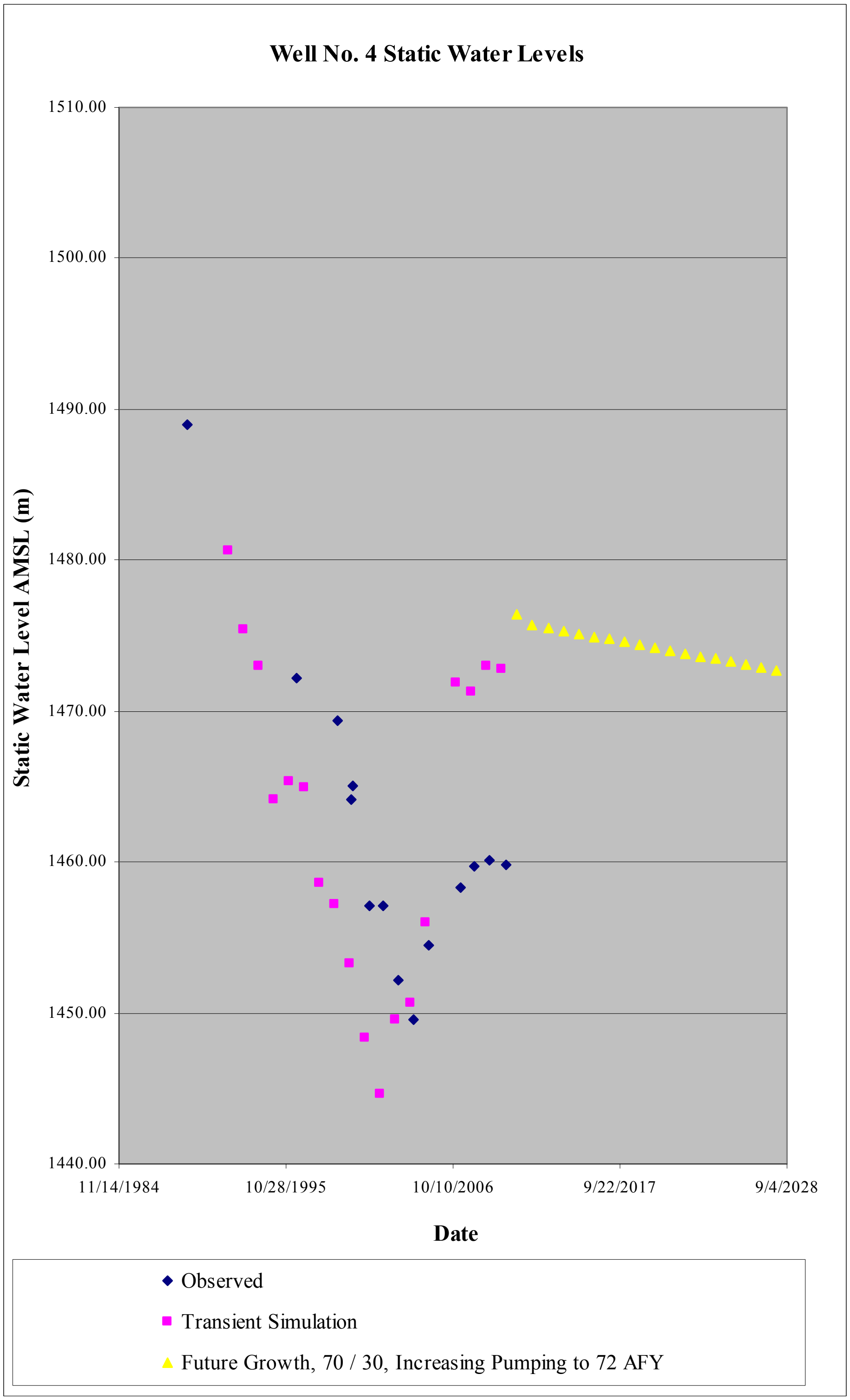


Figure 83. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 4 and 5 for Well No. 4

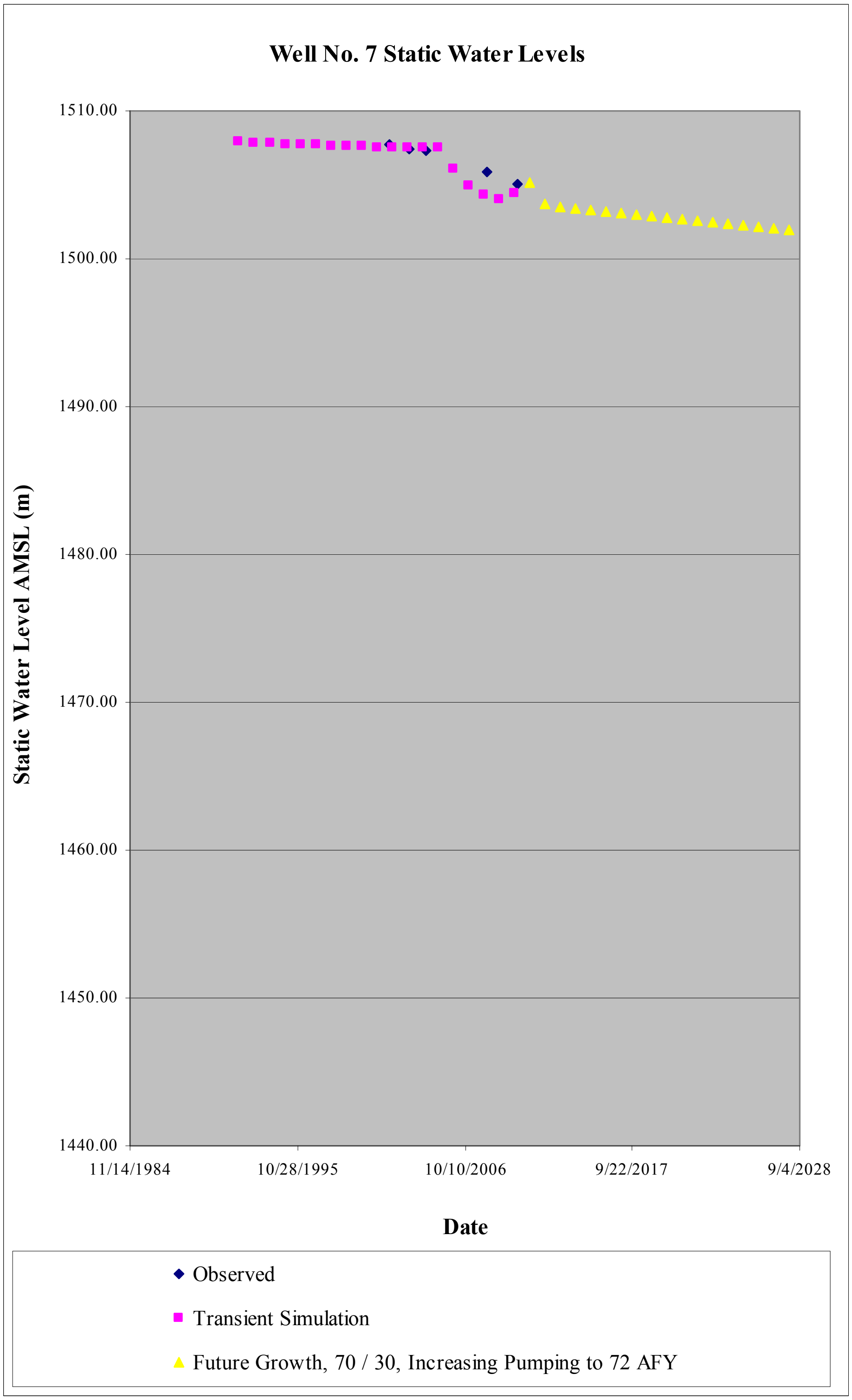


Figure 84. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 4 and 5 for Well No. 7

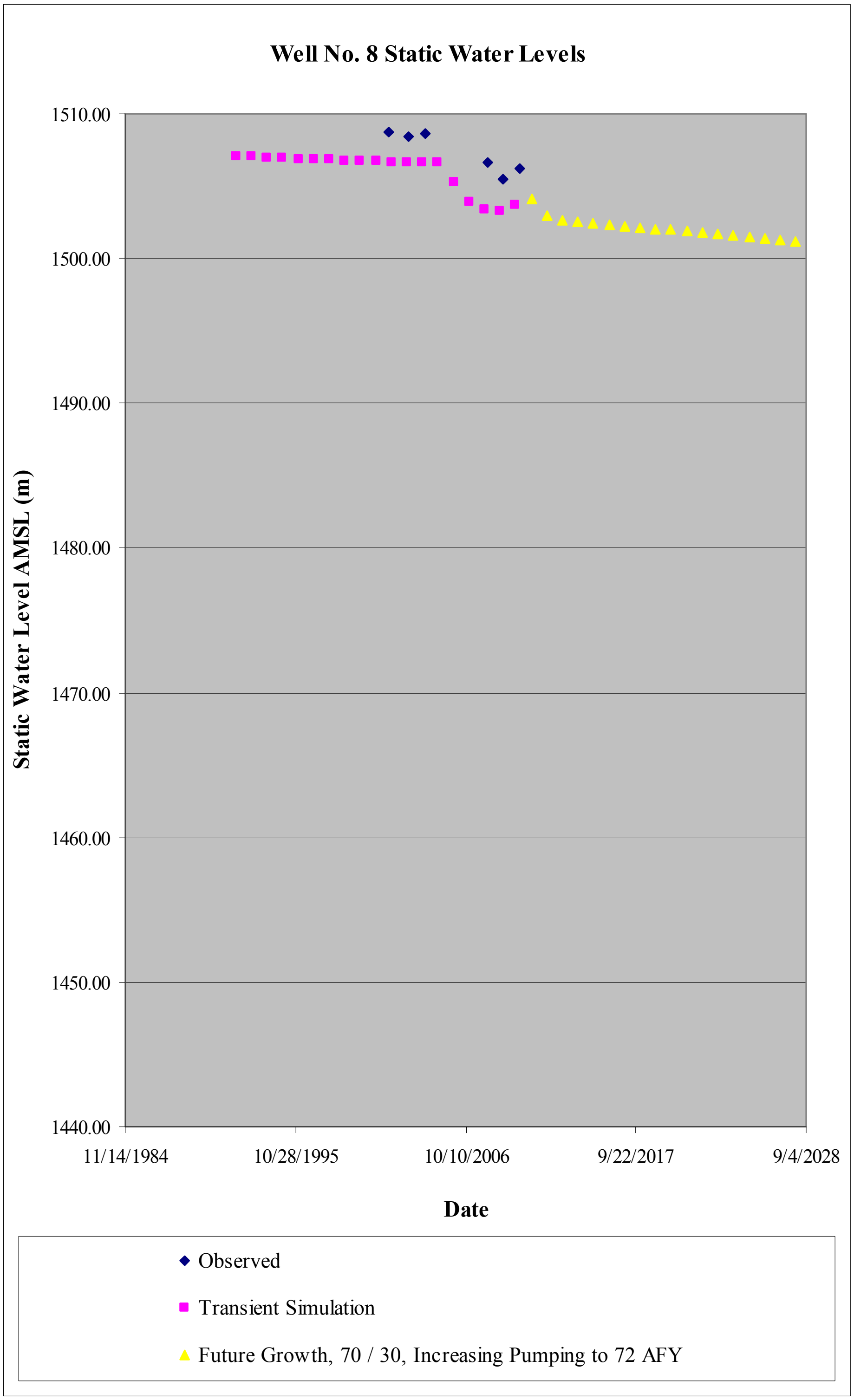


Figure 85. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 4 and 5 for Well No. 8

9.3.1 Utilizing Well No. 3 as a Production Well

To address the decrease in static water level at Well No. 4 due to the future growth estimate a transient simulation was run using Well No. 3 as a production well. Using the optimized pumping scenario from Section 9.2 of 70% pumping for Well Nos. 7 and 8 and 30% pumping for Well Nos. 3, 4 and 5, the model was utilized to predict the resulting static water levels (see Figures 86 through 89). It has been indicated by the RSIC that Well No. 3 is limited to 35 gallons/minute (gpm). Under this scenario the maximum pumping rate at Well No. 3 would be 24.32 m^3/day or approximately 4.5 gpm on average.

The results indicate a decreasing static water level for Well No. 3 and improvement of the static water levels for Well No. 4, as expected. There does not appear to be any affect at Well Nos. 7 and 8. Table 38 provides a comparison of future growth pumping both with and without Well No. 3 as a production well for the period from 1/1/2011 through 1/1/2028.

Table 39. Comparison of the Change in Static Water Level for the Period 1/1/2011 through 1/1/2028 For the Future Growth Transient Simulation Between No Pumping at Well No. 3 and Utilizing Well No. 3 as a Production Well

WELL NO.	CHANGE IN STATIC WATER LEVEL (No Pumping at Well No. 3) (meters)	CHANGE IN STATIC WATER LEVEL (Utilizing Well No. 3 as a Production Well) (meters)
Well No. 3	- 0.8	- 1.9
Well No. 4	- 3.7	- 0.1
Well No. 7	- 3.1	- 3.1
Well No. 8	- 2.9	- 2.9

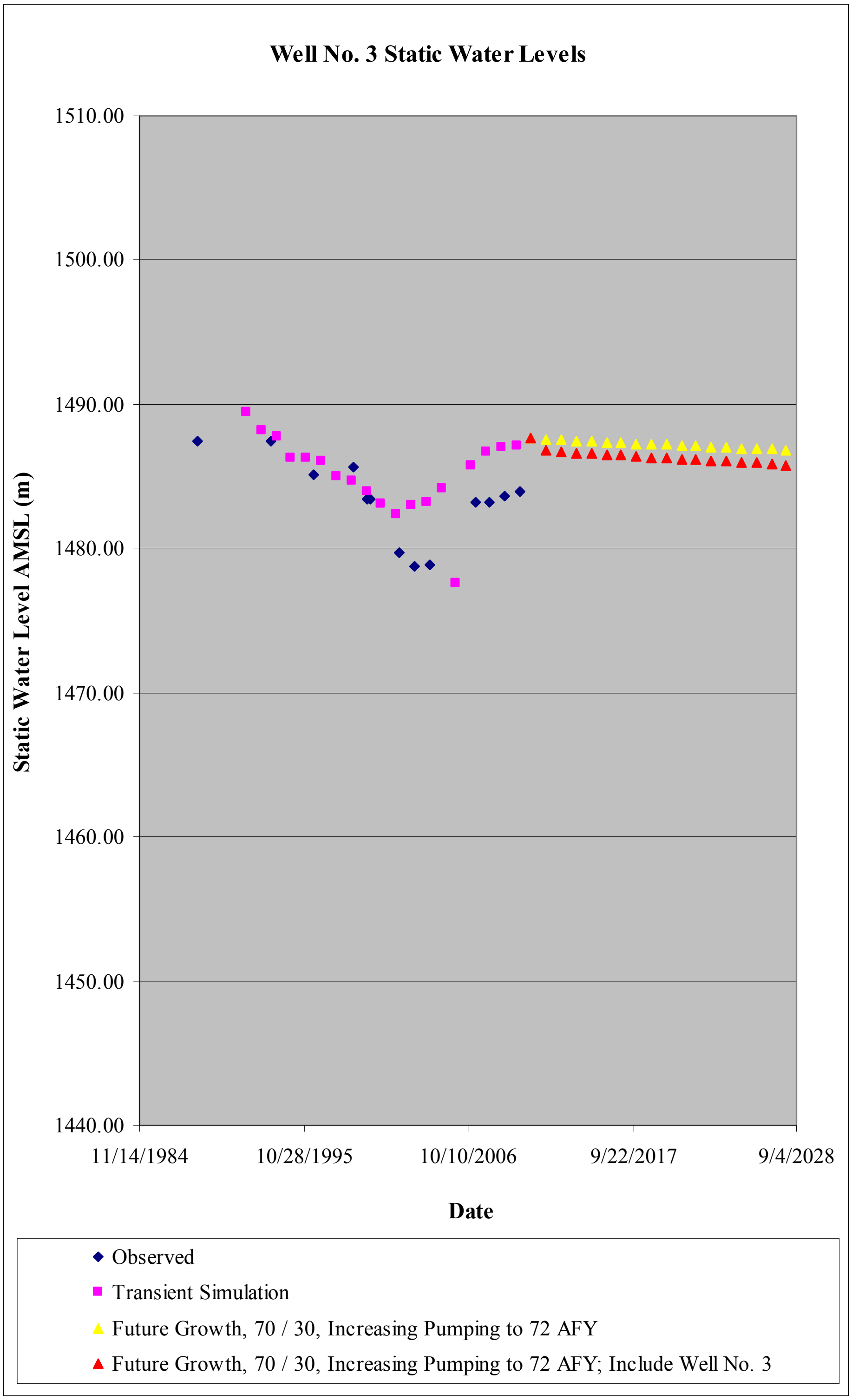


Figure 86. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 3, 4 and 5 for Well No. 3

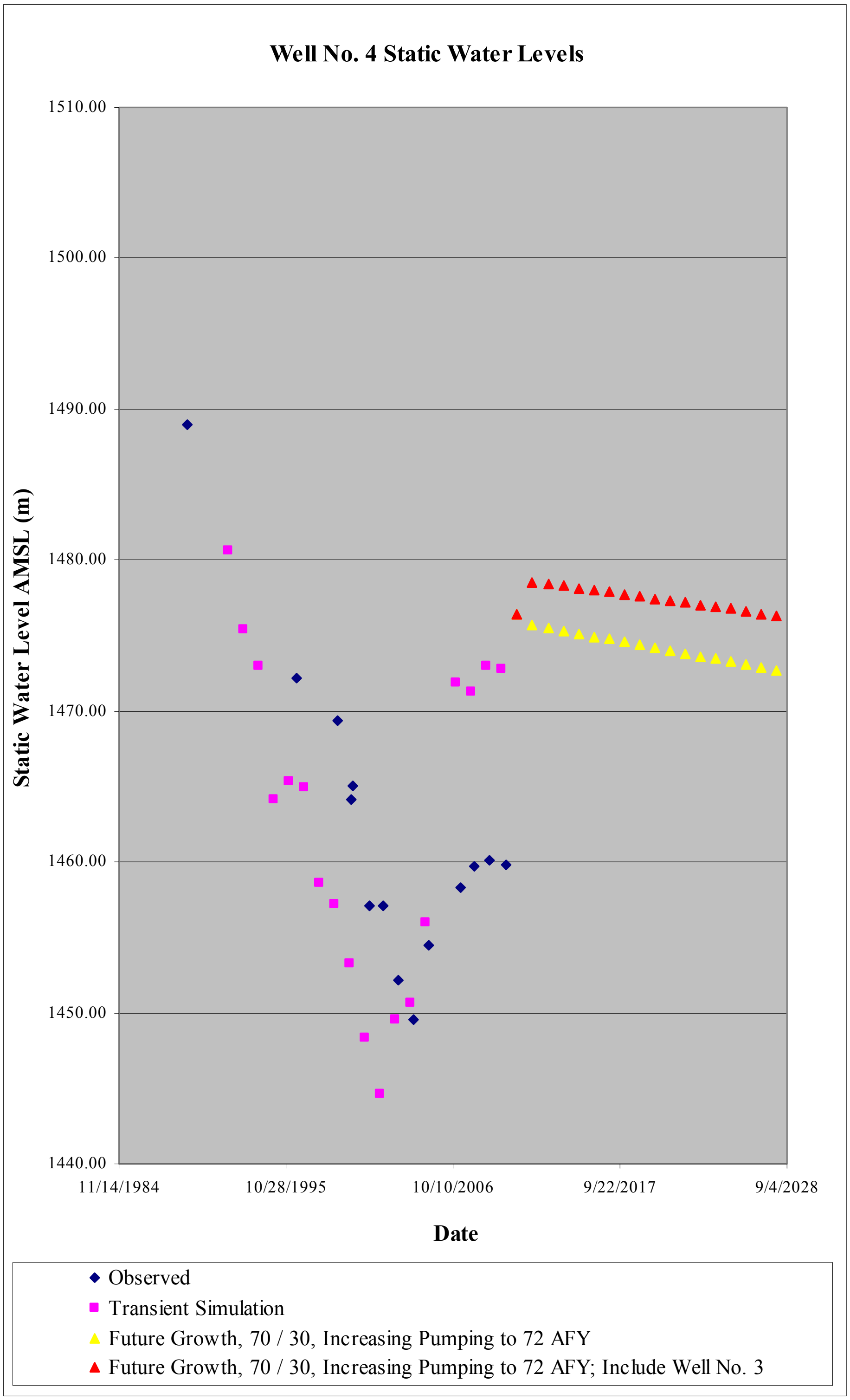


Figure 87. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 3, 4 and 5 for Well No. 4

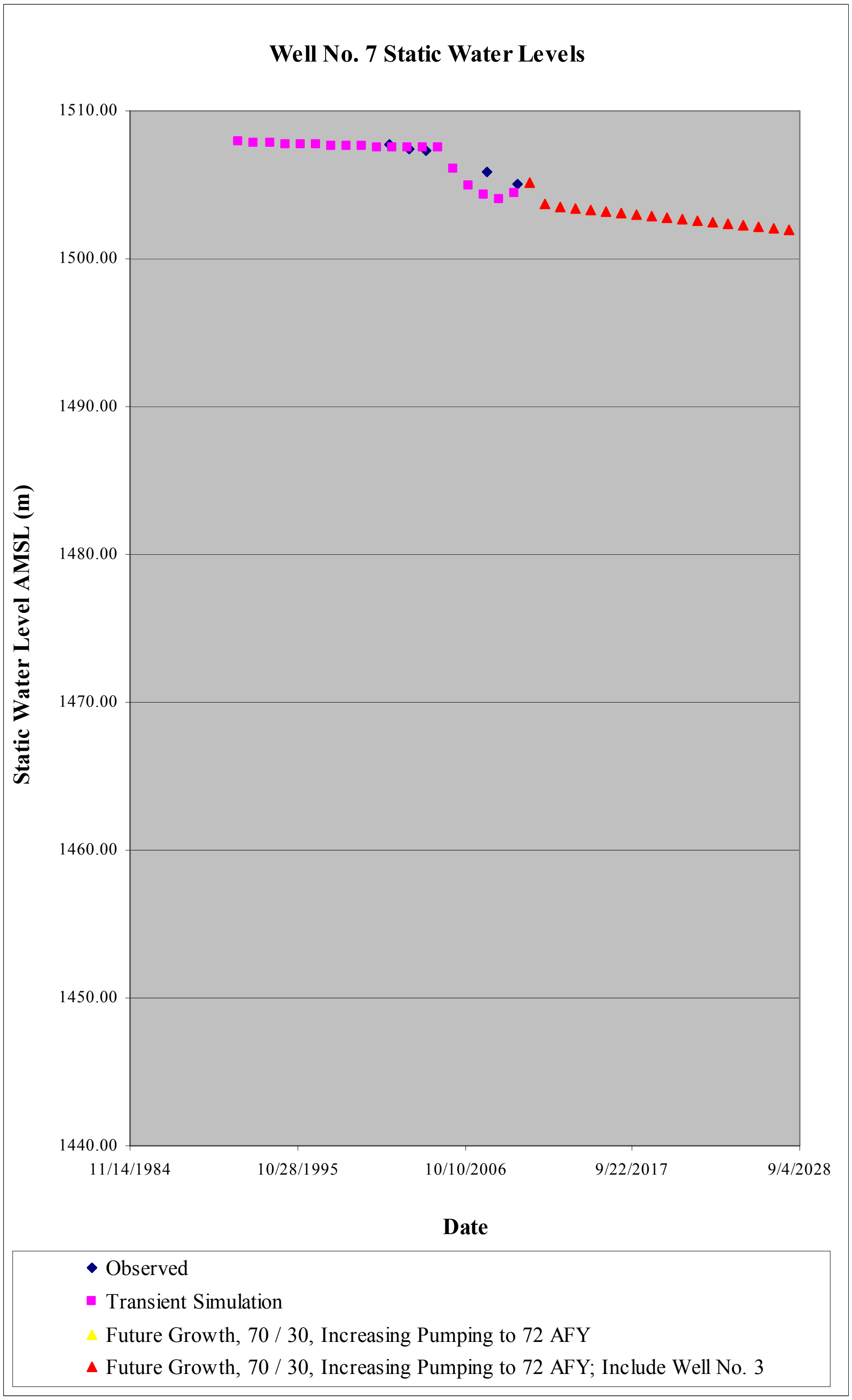


Figure 88. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 3, 4 and 5 for Well No. 7

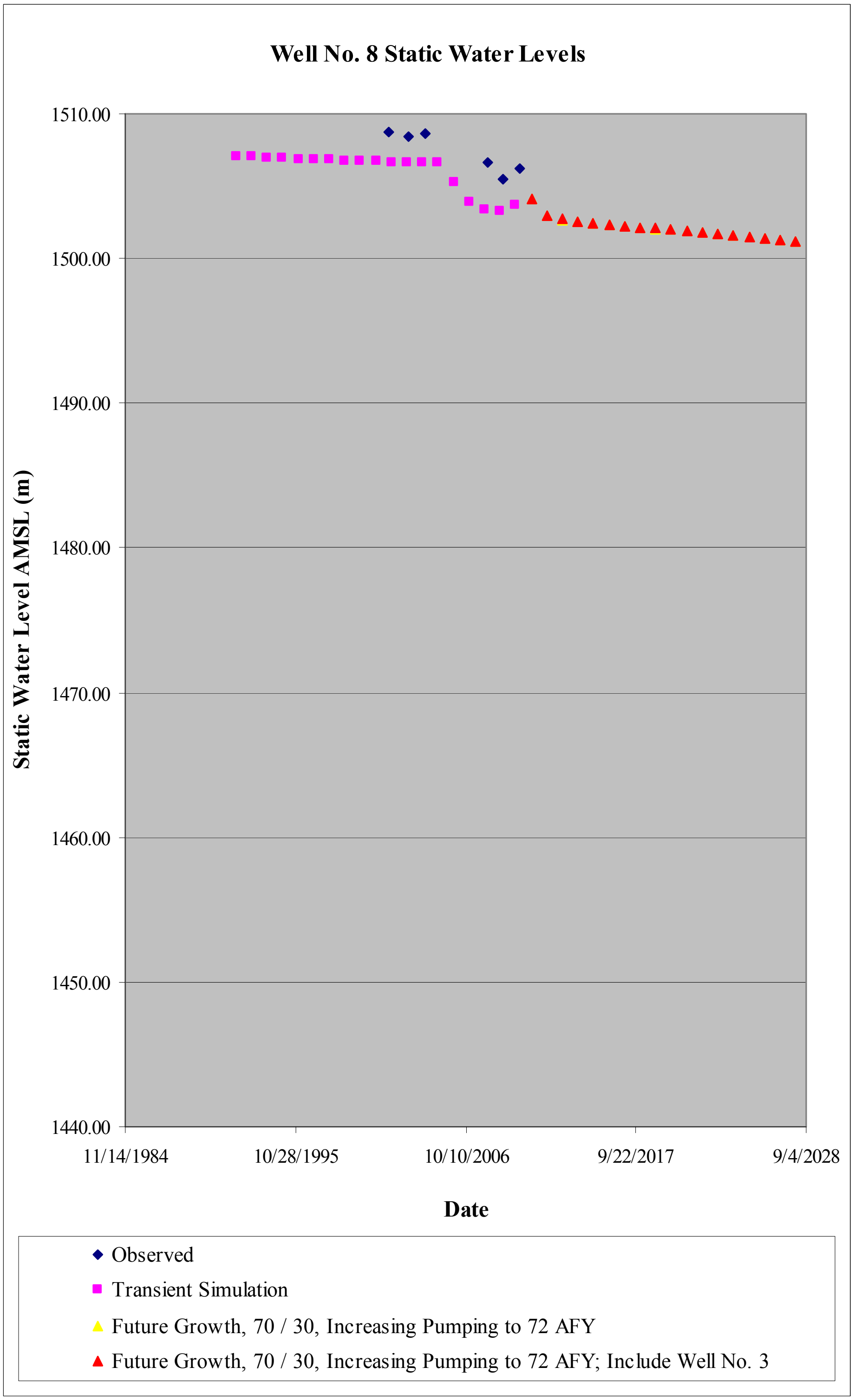


Figure 89. Transient Simulation Predicted Drawdown for Future Growth: 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 3, 4 and 5 for Well No. 8

Section 10 – Conclusions and Recommendation for Further Research

It is usually possible to find a number of different combinations of the input parameters that will produce a calibrated model which approximates field measured heads and fluxes (Anderson and Woessner, 1992) (Moll, 2000). This thesis effort is just one of the possible approaches to modeling the complex hydrogeology in Hungry Valley. Additionally, as this was the first effort at developing a model for Hungry Valley, several assumptions (e.g. a single layer aquifer system) were made at the outset that, through the analysis presented in the previous sections, now appear inadequate. The following conclusion section summarizes the model efforts; and following that section, are recommendations for further research and approaches to modeling the complex hydrogeology of Hungry Valley.

The results for Well No. 4 are also indicative of the results for Well No. 5. As previously discussed in this thesis, these wells are in near proximity to each other and are completed in the same unit. These wells are pumped similar and display similar results.

10.1 Conclusions

10.1.1 Steady-State Model

The steady-state model is only an approximation of the conditions prior to well field development because little data is available prior to the commencement of pumping; only the static water levels from the Well Driller’s Report are available for Well Nos. 3 and 4. Data for the north end of the model coverage area (Little Hungry Spring) and the east side of the model area (Well Nos. 7 and 8) were not available until several years after pumping had commenced. The steady-state model appears to support the structural block and/or faulting referenced in the literature. This structural block was necessary in the steady-state model to raise the static water levels on the east side of the valley.

The modeled ground surface elevations are moderately in agreement with the known elevations with a RMSE = 5.9 m and Relative Error (RE) = RMSE / (Maximum Head – Minimum Head) = 9.4%. The modeled elevations are generally higher than known elevations and may be the result of discretization with a grid spacing of 100 m. The modeled static water levels are in good agreement with the observed values with a RMSE = 1.7 m and RE = 2.7%. The modeled spring flow at Little Hungry Spring is also in good agreement with the observed spring flow. Note there were two different approaches to modeling the spring.

The model was constructed with a single Layer No. 1. However, Layer No. 2 was divided into four areas for input of the hydraulic conductivity. The model appears to be relatively insensitive to increases in Layer No. 1 and Layer No. 2 (center, south) hydraulic conductivity. Increases in Layer No. 2 (west) and Layer No. 2 (center, north) hydraulic conductivities result in a decrease in static water levels and spring flow. Increases in Layer No. 2 (east) hydraulic conductivity results in a moderate decrease in static water levels and no spring flow.

The model appears to be sensitive to decreasing the recharge and lowering the specific head boundary which results in a significant decrease in static water levels and no spring flow.

10.1.2 Transient Simulation

The transient simulation was run utilizing the well discharge data from RSIC, the specific yield estimated from the literature, and the specific storage derived from aquifer (pump) tests.

The transient simulation model does not take into account the monthly schedule of pumping. That is, from RSIC data, approximately 60% of pumping occurs in the summer months, April through September. This is shown in Figure 90. Conversely the majority of observed static water levels were taken in early spring each year, typically March. Because the model is setup for inputting pumping as a constant based on the average of total pumping for year, the heads produced by the transient simulation are given for January 1ST of each year. This may overestimate drawdown at the wells for the low pumping months, October through March. From the transient simulations, it can be seen that the model appears to overestimate drawdown at Well No. 8; and also Well No. 7 starting in

2005. Additionally, the model also appears to overestimate drawdown at Well No. 3 until about 2000 and Well No. 4 until about 2003, when the model begins to underestimate drawdown for these wells.

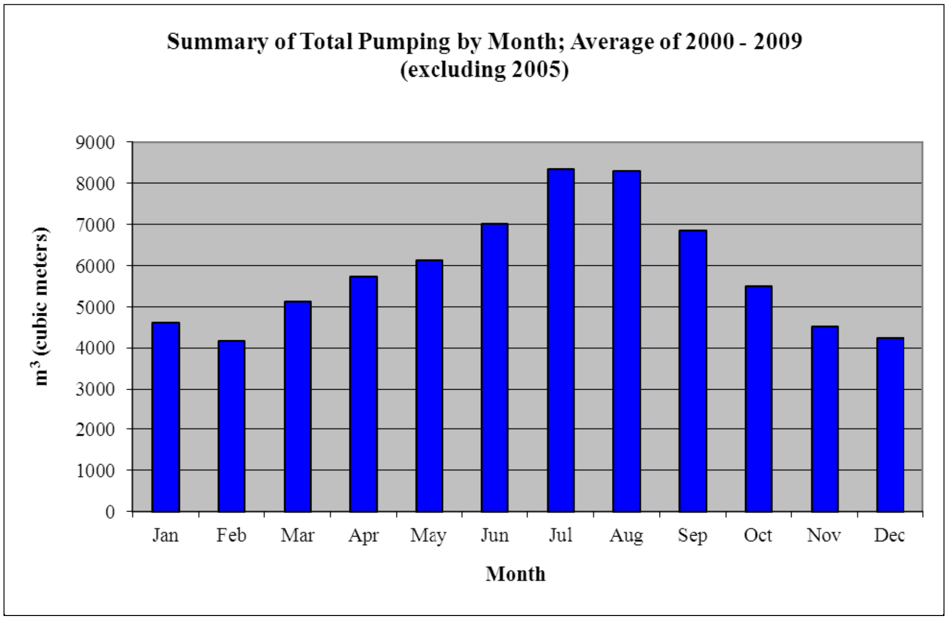


Figure 90. Summary of Total Pumping by Month; Average of 2000 through 2009 (excluding 2005)

The recharge rate was considered constant from 1991 through 2010. Figure 91 presents the precipitation by year for the period 2000 through 2010 for Reno-Tahoe Airport (O'Hara, 2011). It can be seen from Figure 91 that precipitation varies from year to year; this may affect recharge rates from year to year based on infiltration rates.

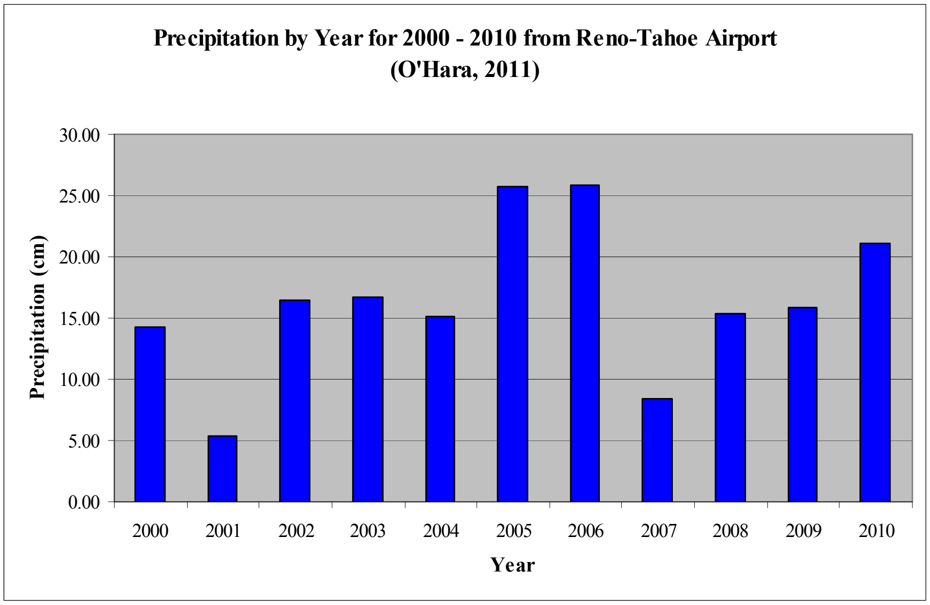


Figure 91. Precipitation by Year for 2000 - 2010

The predicted head from the transient simulation is an average over the 100 square meter grid block. This is discussed in EPA/542/R-99/011B, Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems, Volume II: Application of Hydraulic Optimization:

> Groundwater flow models based on finite differences (e.g., MODFLOW) typically calculate head for a representative volume (i.e., an entire grid block) (EPA/542/R-99/011B, 1999).

In some cases this may be appropriate for the modeling effort as the wells were allowed to recover prior to static water level measurements (e.g. aquifer (pump) tests conducted by UNR Field Methods Class). However, the recovery time prior to static water level measurements for all observed values is unknown.

As mentioned previously, the stress periods established for the transient simulation do not correspond with the date upon which static water levels have been observed. For purposes of calculating RMSE, the nearest data points were compared. The combined RMSE for the initial transient simulation comparison with observed static water levels for Well Nos. 3, 4, 7 and 8, and Little Hungry Spring, is 11.43 m and the RE = 21.6%. However, recognizing that the transient simulation did not have good agreement with the observed static water levels at Well No. 4 and considering only the remaining three wells and Little Hungry Spring, the RMSE = 1.91 m and the RE = 3.6%. This appears to indicate a good correlation between the transient simulation and the observed static water levels; with the exception of Well No. 4.

The flow at Little Hungry Spring was modeled by two different approaches. The first approach modeled the spring as a drain directly from the confined layer and the flow remained relatively unchanged throughout the transient simulation. However, the second approach considered the spring near ground surface elevation and the flow was substantially less than that observed in 2009. Additionally, for a couple of years, there was no flow from the spring as the static water level fell below the drain elevation.

The model was constructed with a single Layer No. 1. However, Layer No. 2 was divided into two areas for input of the specific storage. It appears from the sensitivity analysis that lowering the specific yield of Layer No. 1 will result in a moderate lowering of RMSE for Well No. 4 while increasing the RMSE for Well Nos. 3, 7 and 8. Lowering the specific yield also results in flooding in some grid cells and a decrease in flow from Little Hungry Spring. The model appears to be relatively insensitive to increasing the specific yield. Additionally, it appears that increasing the specific storage to the upper limit for Layer No. 2 West will moderately decrease the RMSE for Well Nos. 7 and 8 while not significantly affected Well Nos. 3 and 4. This also increases the flow at Little Hungry Spring. Finally, the model appears to be insensitive to changes in the specific storage for Layer No. 2 East; with only a moderate increase in RMSE for increasing the specific storage at Well Nos. 3 and 4.

The following figure, Figure 92, shows the initial transient simulation predicted drawdown due to pumping for Test Hole No. 1 and Well No. 4. Note that the observed static water levels for Test Hole No. 1 were not used in the transient simulation because Test Hole No. 1 and Well No. 4 are in close proximity and are located in the same 100 m grid cell of the MODFLOW model. However, as can be seen from the figure, they have different observed static water levels. The initial transient simulation more closely approximated the observed heads of Test Hole No. 1. To improve the transient simulation's representation of Well No. 4 (and, concurrently, Well No. 5), three approaches were utilized to adjust the model to improve the RMSE for Well No. 4: Adjusting the hydraulic conductivity for Layer No. 2 (East); adjusting the recharge on the East side of the Hungry Valley; and isolating Well Nos. 4 and 5 with a section of low hydraulic conductivity. This last option was proposed to approximate the layering at Test Hole No. 1 and Well Nos. 4 and 5, as noted from the lithologic logs from the Well Driller's Reports. It appears isolating Well Nos. 4 and 5 with an area of lower hydraulic conductivity has the largest effect of improving the RMSE for the modeling of the Well No. 4 observed static water levels; while minimizing the effects on the remainder of the model. This new transient simulation resulted in a combined RMSE = 6.17 m (as compared to 11.43 for the original transient simulation) and a RE = 11.7%.

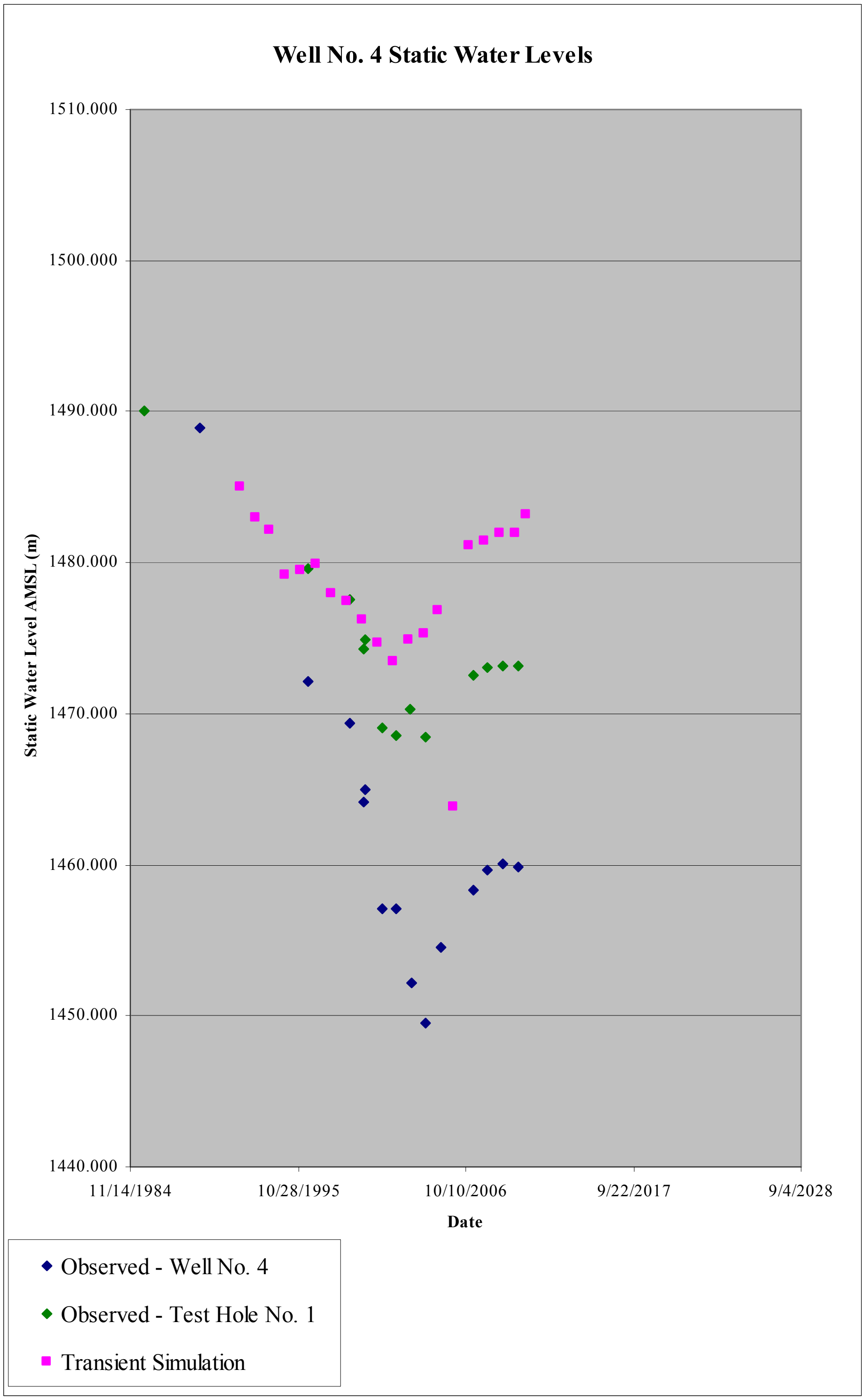


Figure 92. Transient Simulation Predicted Drawdown due to Pumping for Test Hole No. 1 and Well No. 4 (Note: Well No. 5 is not included in the modeling results because of its proximity and hydraulic connectivity to Well No. 4)

10.1.3 Optimization and Future Growth

The first optimization constraint is to ensure that arsenic levels remain below drinking water standards. Given the existing measured arsenic levels in Well Nos. 4, 5, 7 and 8; in order to keep the arsenic level below the MCL, a maximum of 77% can be pumped from Well Nos. 7 and 8 combined. By inspection, the observed static water levels appear to have stabilized during the period of 2006 to 2009 or are recovering. Therefore, a pumping schedule of 60% for Well Nos. 7 and 8 combined and 40% for Well Nos. 4 and 5 combined appears to stabilize the static water levels, maintain arsenic below the MCL, and is consistent with the operational history of the wells.

The second optimization constraint is to minimize the cost of groundwater pumping by minimizing the lift that is required during pumping. Because Well Nos. 4 and 5 have the highest lift, it would appear that decreasing their pumping rate would have the most beneficial cost benefit.

The optimization was performed increasing pumping from Well Nos. 7 and 8 from 60% to 70% using a 2% increment. The optimization indicated that 70% pumping from Well Nos. 7 and 8 and 30% pumping from Well Nos. 4 and 5 resulted in maximizing static water levels while meeting the arsenic and cost of groundwater pumping constraints.

Future water demand was estimated by Nevada-Sierra Planners to be 88,811 m^3/year (72 acre-feet per year) by 2027; using a pumping rate of 70,432 m^3/year (57.1 acre-feet per year) for 2011 and projecting to 88,811 m^3/year (72 acre-feet per year) for 2027 results in a 1,147 m^3/year (0.93 acre-feet per year) increase. Using the pumping scenario of 70% pumping for Well Nos. 7 and 8 and 30% pumping for Well Nos. 4 and 5, the transient simulation indicates a decreasing static water level for all wells as the pumping rate increases. The largest decrease in static water level of 3.7 meters for the period of 1/1/2011 through 1/1/2028 occurs at Well No. 4. To address the decrease in static water level at Well No. 4 due to the future growth estimate; a transient simulation was run using Well No. 3 as a production well. The pumping scenario for the transient simulation was 70% pumping for Well Nos. 7 and 8 and 30% pumping for Well Nos. 3, 4 and 5. The largest decrease in static water level now at occurs at Well No. 7 at 3.1 meters.

10.2 Recommendations for Further Research

10.2.1 Steady-State Model

Recommendations for further modeling effort would be to investigate the appropriateness of the modeled structural block. One consideration would be to analyze Little Hungry Spring for the presence of arsenic to see if groundwater is moving easterly to the center of the valley and north into Warm Springs Valley as modeled. Otherwise, separate aquifers may be a more accurate representation of the hydrogeology. Additionally, the hydrogeologic conditions at the north end of the model coverage could be more thoroughly investigated; as the steady-state model is strongly influenced by the specified head boundary. Finally, the steady-state model appears to be sensitive to the amount of recharge applied; another estimate of this parameter may be warranted for just the modeled area (e.g. Maxey-Eakin method).

10.2.2 Transient Simulation

It is recommended that the model be modified to more appropriately represent the physical layout of the aquifer and placement of the well screens for Test Hole No. 1 and Well Nos. 3, 4 and 5 in lieu of the assumption of a single aquifer layer. The different aquifer layers and their interaction with the layers of clay, above and below, would appear to need to be more thoroughly investigated and modeled for an improved correlation with observed static water levels.

Additionally, a finer model grid would provide a more accurate representation of the head at the well and may improve the model's ability to accurately represent the land surface elevations. Also, the future use of MODFLOW's multi-node well package would allow the head to be calculated averaged over the entire grid cell and at the scale of the borehole.

Finally, the modeling approach of Little Hungry Spring may be revisited to improve the correlation with the observed flow. More data points for observed flow (i.e. different seasons) would provide addition insight into the spring flow characteristics.

10.2.3 Optimization and Future Growth

Future water growth up to 88,811 m^3/year (72 acre-feet per year) by 2027 appears to be obtainable with the current well field with some minor decrease in current static water levels. The largest decrease in static water levels occurs at Well No. 4 and can be minimized by using Well No. 3 as a production well or investigating the possibility of a sixth production well. An area of interest for a future production well is the southwest portion of the valley near the foothills where mountain front recharge occurs.

Future studies, including collecting static water levels will allow the validation of the groundwater flow model.

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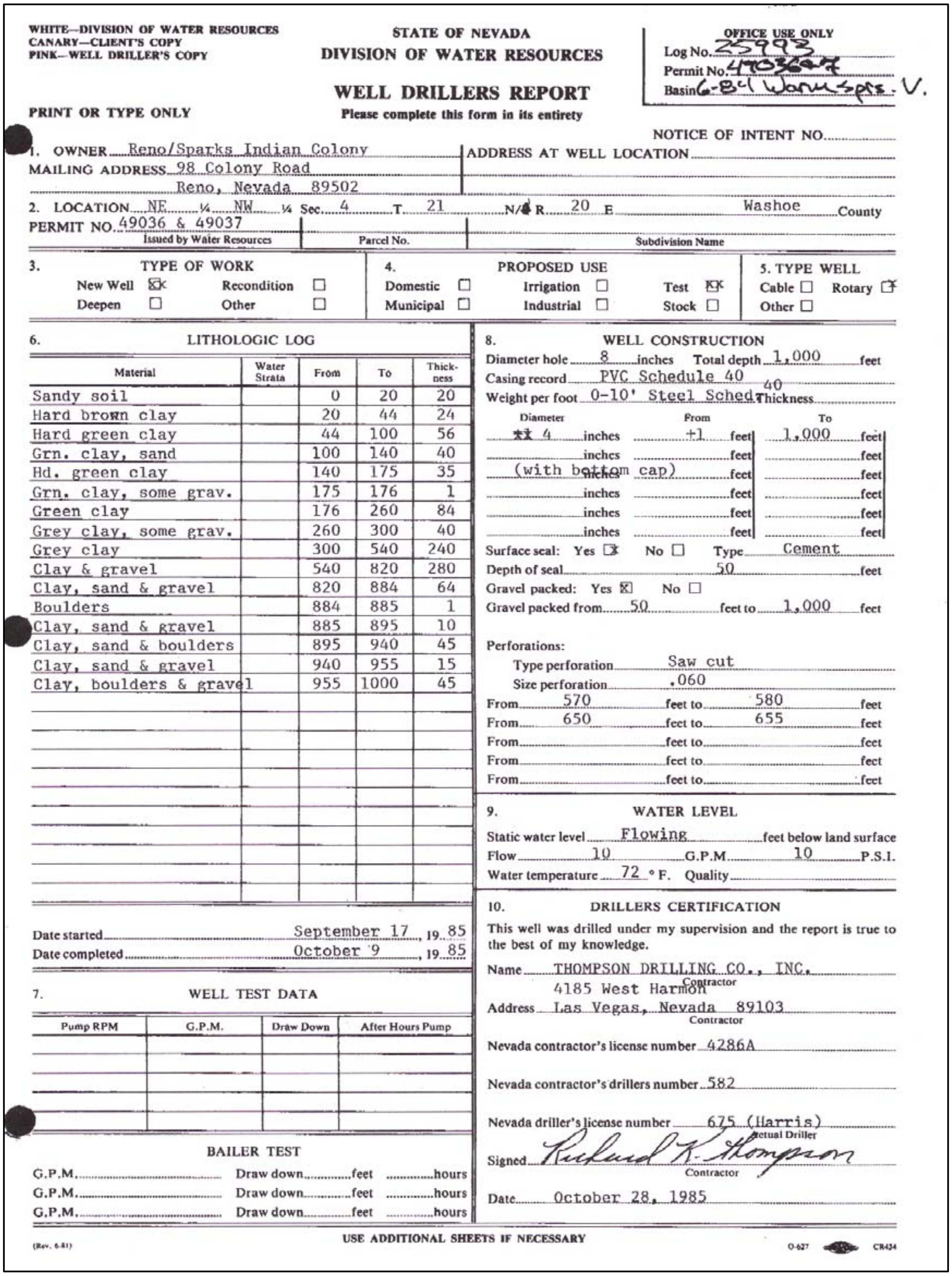
Section 12 – Appendices

12.1 Well Logs



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CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLERS REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 25993
Permit No. 49036&7
Basin 6-84 Warm Sprs. V.

NOTICE OF INTENT NO.

1. OWNER Reno/Sparks Indian Colony
MAILING ADDRESS 98 Colony Road
Reno, Nevada 89502

ADDRESS AT WELL LOCATION

2. LOCATION NE ¼ NW ¼ Sec. 4 T. 21 N/S R. 20 E Washoe County
PERMIT NO. 49036 & 49037
Issued by Water Resources
Parcel No.
Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☒
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Sandy soil		0	20	20
Hard brown clay		20	44	24
Hard green clay		44	100	56
Grn. clay, sand		100	140	40
Hd. green clay		140	175	35
Grn. clay, some grav.		175	176	1
Green clay		176	260	84
Grey clay, some grav.		260	300	40
Grey clay		300	540	240
Clay & gravel		540	820	280
Clay, sand & gravel		820	884	64
Boulders		884	885	1
Clay, sand & gravel		885	895	10
Clay, sand & boulders		895	940	45
Clay, sand & gravel		940	955	15
Clay, boulders & gravel		955	1000	45

Date started September 17, 19 85
Date completed October 9, 19 85

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

8. WELL CONSTRUCTION
Diameter hole 8 inches Total depth 1,000 feet
Casing record PVC Schedule 40
Weight per foot 0-10' Steel Sched 40 Thickness

Diameter	From	To
4 inches	+1 feet	1,000 feet
inches	feet	feet
(with bottom cap) inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type Cement
Depth of seal 50 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 50 feet to 1,000 feet

Perforations:
Type perforation Saw cut
Size perforation .060
From 570 feet to 580 feet
From 650 feet to 655 feet
From feet to feet
From feet to feet
From feet to feet

9. WATER LEVEL
Static water level Flowing feet below land surface
Flow 10 G.P.M. 10 P.S.I.
Water temperature 72 ° F. Quality

10. DRILLERS CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

Name THOMPSON DRILLING CO., INC.
Contractor
Address 4185 West Harmon
Las Vegas, Nevada 89103
Contractor

Nevada contractor's license number 4286A

Nevada contractor's drillers number 582

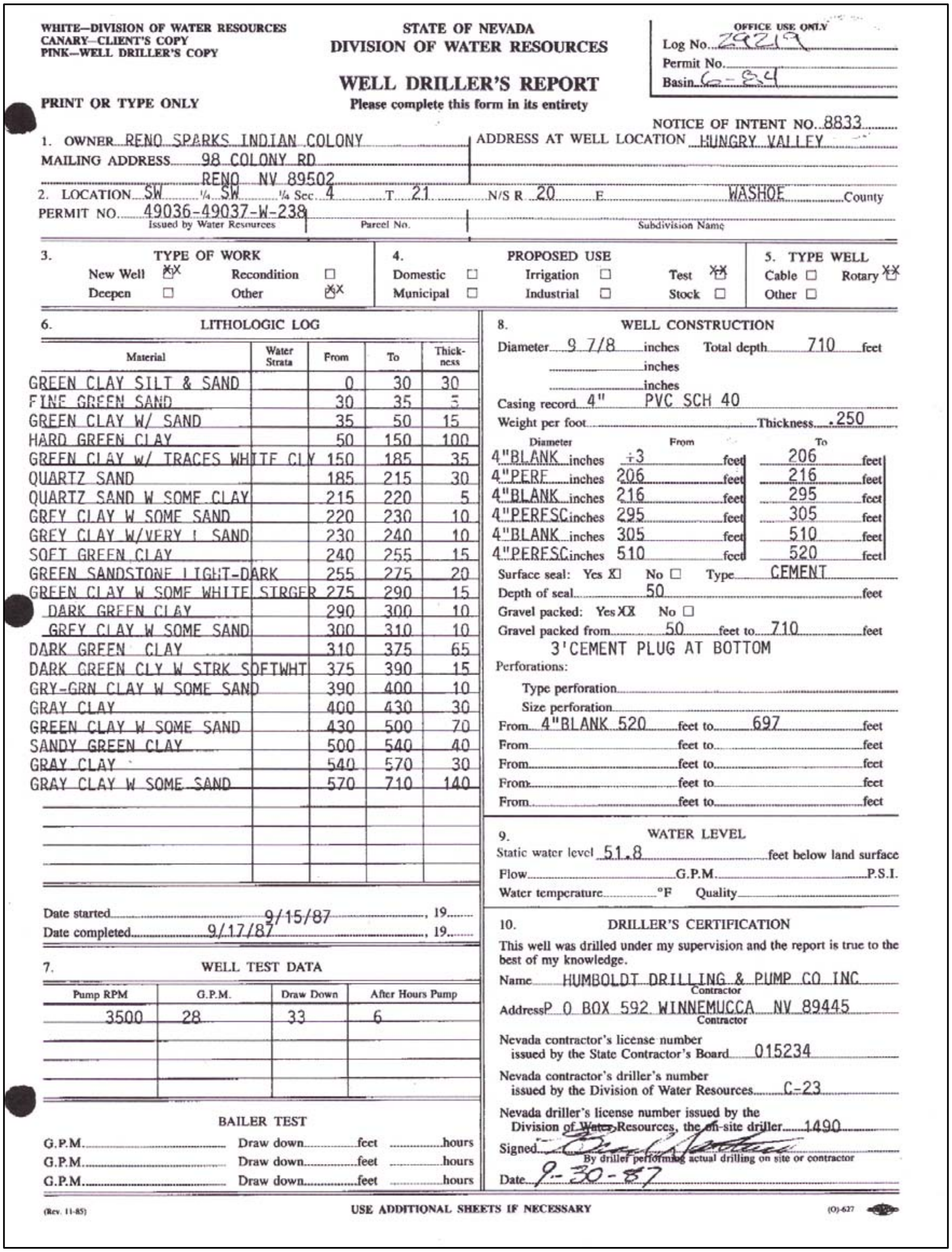
Nevada driller's license number 675 (Harris)
Actual Driller

Signed Richard K. Thompson
Contractor

Date October 28, 1985

(Rev. 6-81) USE ADDITIONAL SHEETS IF NECESSARY O-627 CR434

Figure 93. Well Log No. 25993, Test Hole No. 1, Date Completed 10/9/1985



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NOTICE OF INTENT NO. 8833

1. OWNER RENO SPARKS INDIAN COLONY
MAILING ADDRESS 98 COLONY RD
RENO NV 89502
ADDRESS AT WELL LOCATION HUNGRY VALLEY

2. LOCATION SW ¼ SW ¼ Sec. 4 T. 21 N/S R 20 E WASHOE County
PERMIT NO. 49036-49037-W-238
Issued by Water Resources
Parcel No.
Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☒

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☒
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thick-ness
GREEN CLAY SILT & SAND		0	30	30
FINE GREEN SAND		30	35	5
GREEN CLAY W/ SAND		35	50	15
HARD GREEN CLAY		50	150	100
GREEN CLAY w/ TRACES WHITE CLY		150	185	35
QUARTZ SAND		185	215	30
QUARTZ SAND W SOME CLAY		215	220	5
GREY CLAY W SOME SAND		220	230	10
GREY CLAY W/VERY L SAND		230	240	10
SOFT GREEN CLAY		240	255	15
GREEN SANDSTONE LIGHT-DARK		255	275	20
GREEN CLAY W SOME WHITE STRGER		275	290	15
DARK GREEN CLAY		290	300	10
GREY CLAY W SOME SAND		300	310	10
DARK GREEN CLAY		310	375	65
DARK GREEN CLY W STRK SOFTWHT		375	390	15
GRY-GRN CLAY W SOME SAND		390	400	10
GRAY CLAY		400	430	30
GREEN CLAY W SOME SAND		430	500	70
SANDY GREEN CLAY		500	540	40
GRAY CLAY		540	570	30
GRAY CLAY W SOME SAND		570	710	140

Date started 9/15/87, 19
Date completed 9/17/87, 19

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
3500	28	33	6

BAILER TEST
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

8. WELL CONSTRUCTION
Diameter 9 7/8 inches Total depth 710 feet
inches
inches
Casing record 4" PVC SCH 40
Weight per foot Thickness .250

Diameter	From	To
4"BLANK inches	+3 feet	206 feet
4"PERF inches	206 feet	216 feet
4"BLANK inches	216 feet	295 feet
4"PERFSC inches	295 feet	305 feet
4"BLANK inches	305 feet	510 feet
4"PERFSC inches	510 feet	520 feet

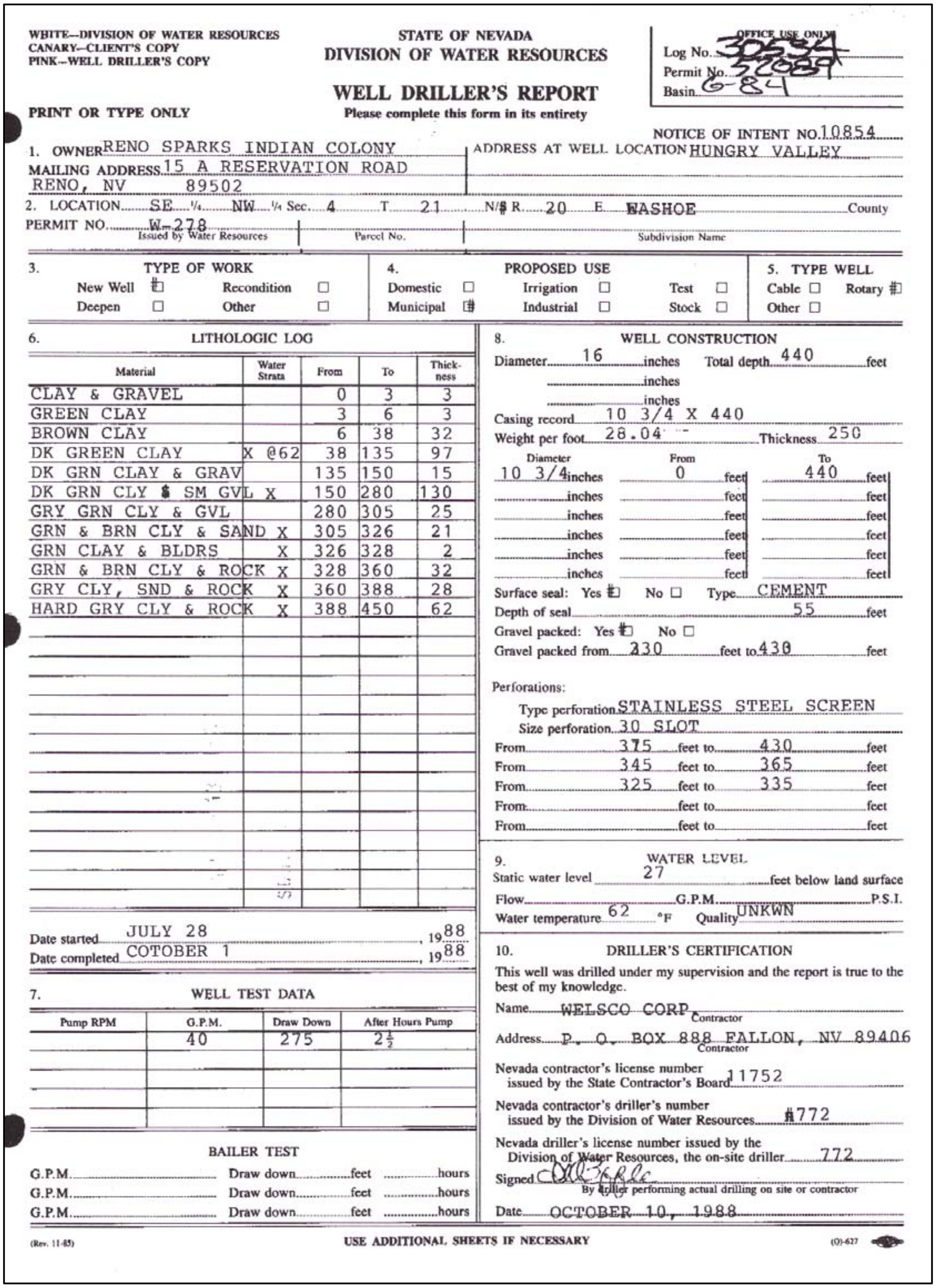
Surface seal: Yes ☒ No ☐ Type CEMENT
Depth of seal 50 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 50 feet to 710 feet
3'CEMENT PLUG AT BOTTOM
Perforations:
Type perforation
Size perforation
From 4"BLANK 520 feet to 697 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

9. WATER LEVEL
Static water level 51.8 feet below land surface
Flow G.P.M. P.S.I.
Water temperature °F Quality

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name HUMBOLDT DRILLING & PUMP CO INC
Contractor
Address P O BOX 592 WINNEMUCCA NV 89445
Contractor
Nevada contractor's license number issued by the State Contractor's Board 015234
Nevada contractor's driller's number issued by the Division of Water Resources C-23
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1490
Signed
By driller performing actual drilling on site or contractor
Date 9-30-87

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

Figure 94. Well Log No. 29219, Test Hole No. 2, Date Completed 9/17/1987



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PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

OFFICE USE ONLY
Log No. 30534
Permit No. 52089
Basin 6-84

PRINT OR TYPE ONLY

NOTICE OF INTENT NO. 10854

1. OWNER RENO SPARKS INDIAN COLONY
MAILING ADDRESS 15 A RESERVATION ROAD
RENO, NV 89502
ADDRESS AT WELL LOCATION HUNGRY VALLEY

2. LOCATION SE ¼ NW ¼ Sec. 4 T 21 N/S R 20 E WASHOE County
PERMIT NO. W-278 Issued by Water Resources | Parcel No. | Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☐
Municipal ☒ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
CLAY & GRAVEL		0	3	3
GREEN CLAY		3	6	3
BROWN CLAY		6	38	32
DK GREEN CLAY	X @62	38	135	97
DK GRN CLAY & GRAV		135	150	15
DK GRN CLY $ SM GVL	X	150	280	130
GRY GRN CLY & GVL		280	305	25
GRN & BRN CLY & SAND	X	305	326	21
GRN CLAY & BLDRS	X	326	328	2
GRN & BRN CLY & ROCK	X	328	360	32
GRY CLY, SND & ROCK	X	360	388	28
HARD GRY CLY & ROCK	X	388	450	62

Date started JULY 28, 1988
Date completed COTOBER 1, 1988

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	40	275	2½

BAILER TEST
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

8. WELL CONSTRUCTION
Diameter 16 inches Total depth 440 feet
inches
inches
Casing record 10 3/4 X 440
Weight per foot 28.04 Thickness 250

Diameter	From	To
10 3/4 inches	0 feet	440 feet

Surface seal: Yes ☒ No ☐ Type CEMENT
Depth of seal 55 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 230 feet to 430 feet

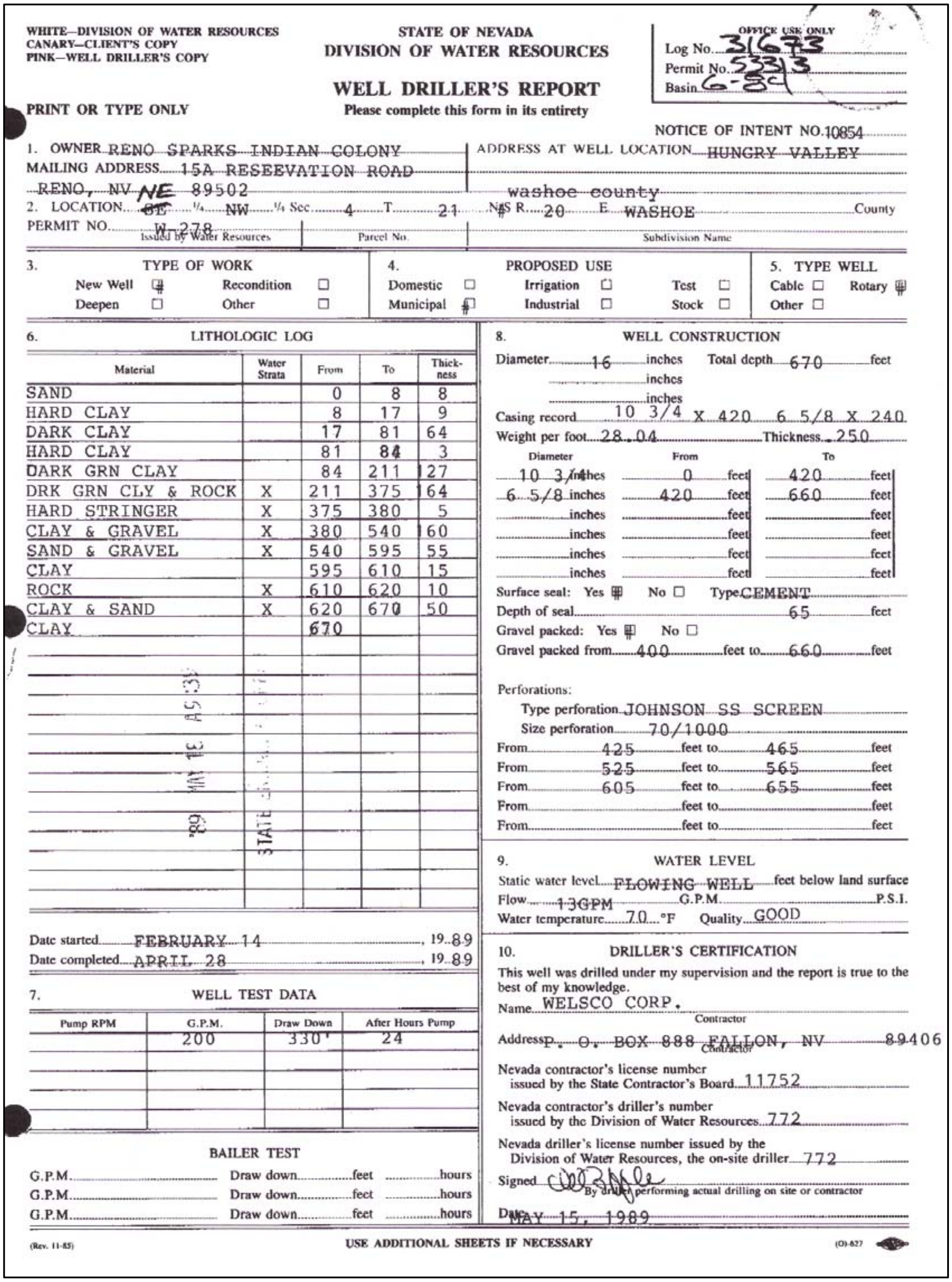
Perforations:
Type perforation STAINLESS STEEL SCREEN
Size perforation 30 SLOT
From 375 feet to 430 feet
From 345 feet to 365 feet
From 325 feet to 335 feet
From feet to feet
From feet to feet

9. WATER LEVEL
Static water level 27 feet below land surface
Flow G.P.M. P.S.I.
Water temperature 62 °F Quality UNKWN

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name WELSCO CORP. Contractor
Address P. O. BOX 888 FALLON, NV 89406 Contractor
Nevada contractor's license number issued by the State Contractor's Board 11752
Nevada contractor's driller's number issued by the Division of Water Resources #772
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 772
Signed
By driller performing actual drilling on site or contractor
Date OCTOBER 10, 1988

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

Figure 95. Well Log No. 30534, Well No. 3, Date Completed 10/1/1988



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STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT
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OFFICE USE ONLY
Log No. 31673
Permit No. 53313
Basin 6-84

PRINT OR TYPE ONLY

NOTICE OF INTENT NO. 10854

1. OWNER RENO SPARKS INDIAN COLONY
MAILING ADDRESS 15A RESEEVATION ROAD
RENO, NV NE 89502

ADDRESS AT WELL LOCATION HUNGRY VALLEY
washoe county

2. LOCATION ~~SE~~ ¼ NW ¼ Sec. 4 T. 21 N/S R. 20 E WASHOE County
PERMIT NO. W-278 (Issued by Water Resources) Parcel No. Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☐
Municipal ☒ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thick-ness
SAND		0	8	8
HARD CLAY		8	17	9
DARK CLAY		17	81	64
HARD CLAY		81	84	3
DARK GRN CLAY		84	211	127
DRK GRN CLY & ROCK	X	211	375	164
HARD STRINGER	X	375	380	5
CLAY & GRAVEL	X	380	540	160
SAND & GRAVEL	X	540	595	55
CLAY		595	610	15
ROCK	X	610	620	10
CLAY & SAND	X	620	670	50
CLAY		670		

'89 MAY 18 A9:35
STATE [illegible]

Date started FEBRUARY 14, 1989
Date completed APRIL 28, 1989

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	200	330'	24

BAILER TEST
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

8. WELL CONSTRUCTION
Diameter 16 inches Total depth 670 feet
inches
inches
Casing record 10 3/4 X 420 6 5/8 X 240
Weight per foot 28.04 Thickness .250

Diameter	From	To
10 3/4 inches	0 feet	420 feet
6 5/8 inches	420 feet	660 feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type CEMENT
Depth of seal 65 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 400 feet to 660 feet

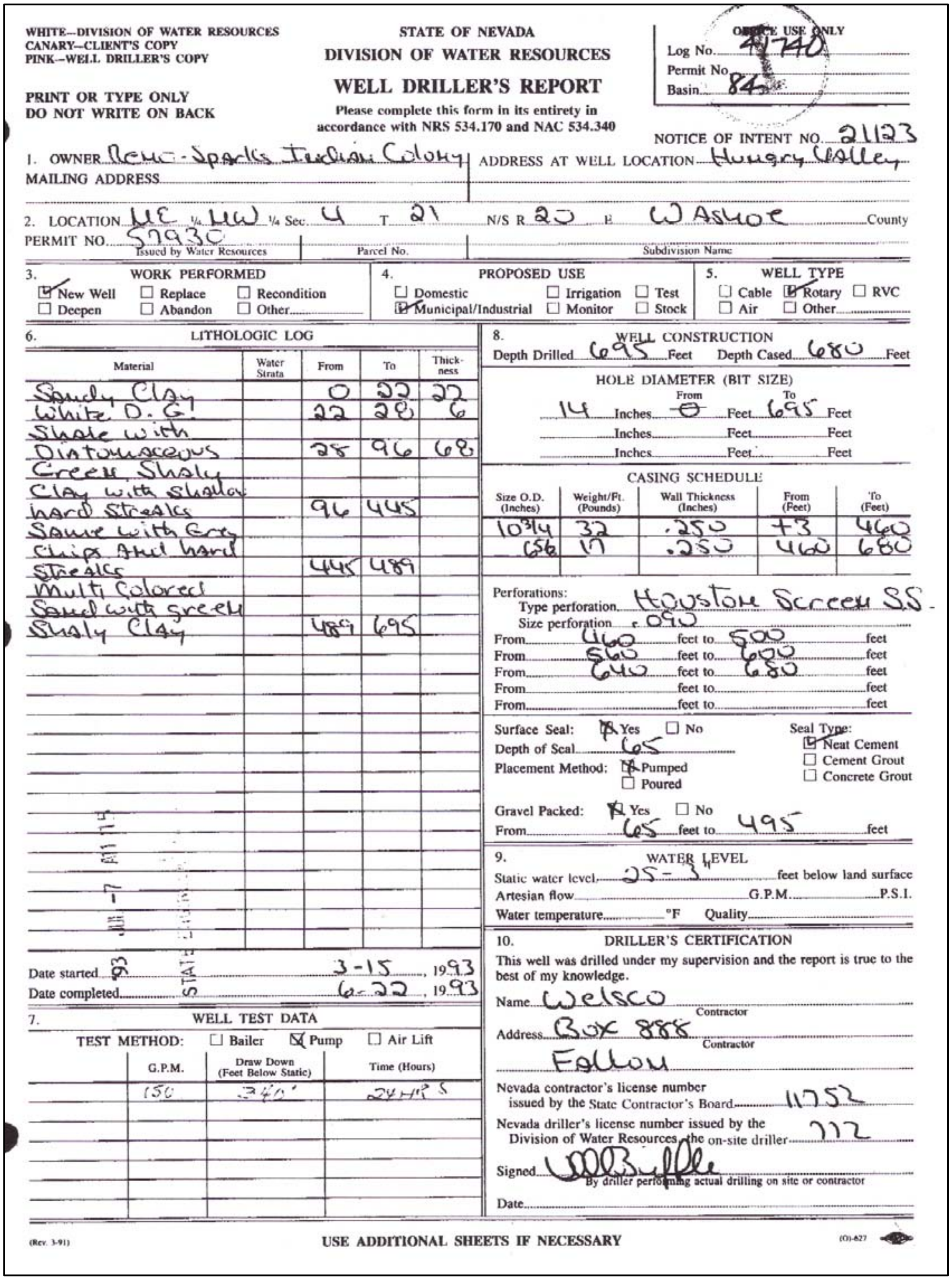
Perforations:
Type perforation JOHNSON SS SCREEN
Size perforation 70/1000
From 425 feet to 465 feet
From 525 feet to 565 feet
From 605 feet to 655 feet
From feet to feet
From feet to feet

9. WATER LEVEL
Static water level FLOWING WELL feet below land surface
Flow 13GPM G.P.M. P.S.I.
Water temperature 70 °F Quality GOOD

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name WELSCO CORP. (Contractor)
Address P. O. BOX 888 FALLON, NV 89406 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 11752
Nevada contractor's driller's number issued by the Division of Water Resources 772
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 772
Signed (By driller performing actual drilling on site or contractor)
Date MAY 15, 1989

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

Figure 96. Well Log No. 31673, Well No. 4, Date Completed 4/28/1989



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STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 41740
Permit No.
Basin 84

NOTICE OF INTENT NO. 21123

1. OWNER Reno-Sparks Indian Colony
ADDRESS AT WELL LOCATION Hungry Valley
MAILING ADDRESS

2. LOCATION NE ¼ NW ¼ Sec. 4 T 21 N/S R 20 E Washoe County
PERMIT NO. 57930 (Issued by Water Resources)
Parcel No.
Subdivision Name

3. WORK PERFORMED
☑ New Well ☐ Replace ☐ Reconditionmagnetic
☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☑ Municipal/Industrial ☐ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☑ Rotary ☐ RVC
☐ Air ☐ Other

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Sandy Clay		0	22	22
White D.G.		22	28	6
Shale with Diatomaceous		28	96	68
Green Shaly Clay with shallow hard streaks		96	445	
Same with Grey Chips and hard streaks		445	489	
Multi Colored Sand with green Shaly Clay		489	695	

93 JUN -7 AM 11 14
STATE

Date started 3-15, 1993
Date completed 6-22, 1993

7. WELL TEST DATA
TEST METHOD: ☐ Bailer ☒ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
150	340'	24 HRS

8. WELL CONSTRUCTION
Depth Drilled 695 Feet Depth Cased 680 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
14 Inches	0 Feet	695 Feet
Inches	Feet	Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
10¾	32	.250	+3	460
6⅝	17	.250	460	680

Perforations:
Type perforation Houston Screen SS.
Size perforation .090
From 460 feet to 500 feet
From 560 feet to 600 feet
From 640 feet to 680 feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 65
Placement Method: ☒ Pumped ☐ Poured
Seal Type: ☑ Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: ☒ Yes ☐ No
From 65 feet to 495 feet

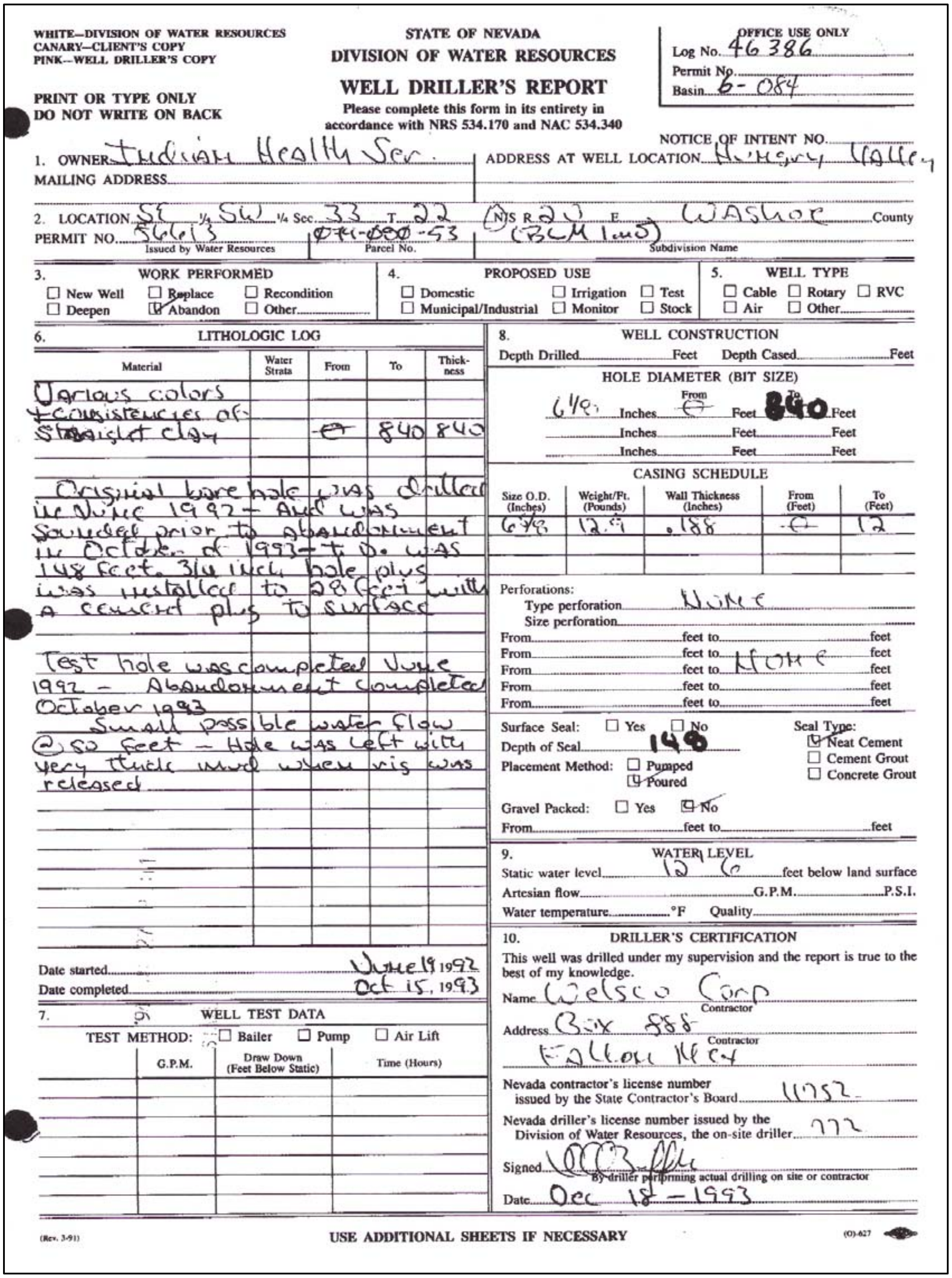
9. WATER LEVEL
Static water level 25-3 feet below land surface
Artesian flow G.P.M. P.S.I.
Water temperature °F Quality

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Welsco (Contractor)
Address Box 888 Fallon (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 11752
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 712
Signed (By driller performing actual drilling on site or contractor)
Date

(Rev. 3-91) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

Figure 97. Well Log No. 41740, Well No. 5, Date Completed 6/22/1993



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STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 46386
Permit No.
Basin 6-084

NOTICE OF INTENT NO.

1. OWNER Indian Health Ser.
ADDRESS AT WELL LOCATION Hungry Valley
MAILING ADDRESS

2. LOCATION SE 1/4 SW 1/4 Sec. 33 T. 22 [✓ N] S R. 20 E. Washoe County
PERMIT NO. 56613 (Issued by Water Resources)
074-090-53 (Parcel No.)
(BLM land) (Subdivision Name)

3. WORK PERFORMED
☐ New Well ☐ Replace ☐ Recondition
☐ Deepen ☑ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☐ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC
☐ Air ☐ Other

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Various colors & consistencies of straight clay		0	840	840

Original bore hole was drilled in June 1992 - And was sounded prior to abandonment in October of 1993 - T.D. was 148 feet. 3/4 inch hole plug was installed to 28 feet with a cement plug to surface

Test hole was completed June 1992 - Abandonment completed October 1993

Small possible water flow @ 50 feet - Hole was left with very thick mud when vis was released

Date started June 19 1992
Date completed Oct 15, 1993

7. WELL TEST DATA
TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)

8. WELL CONSTRUCTION
Depth Drilled ______ Feet Depth Cased ______ Feet

HOLE DIAMETER (BIT SIZE)
6 1/8 Inches From 0 Feet To 840 Feet
Inches Feet Feet
Inches Feet Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
6 5/8	12.9	.188	0	12

Perforations:
Type perforation None
Size perforation
From ______ feet to ______ feet
From ______ feet to None feet
From ______ feet to ______ feet
From ______ feet to ______ feet
From ______ feet to ______ feet

Surface Seal: ☐ Yes ☐ No
Depth of Seal 148
Placement Method: ☐ Pumped ☑ Poured
Seal Type: ☑ Neat Cement ☐ Cement Grout ☐ Concrete Grout
Gravel Packed: ☐ Yes ☑ No
From ______ feet to ______ feet

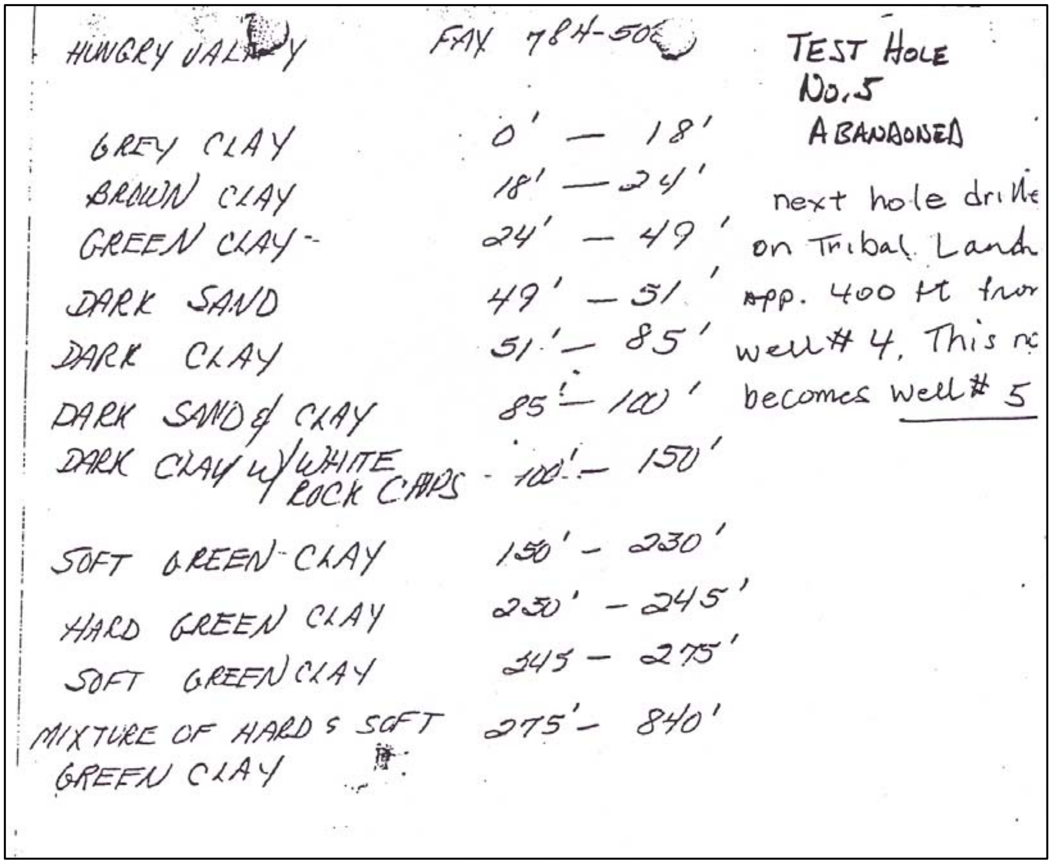
9. WATER LEVEL
Static water level 12 6 feet below land surface
Artesian flow ______ G.P.M. ______ P.S.I.
Water temperature ______ °F Quality ______

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Welsco Corp (Contractor)
Address Box 888 (Contractor)
Fallon Nev
Nevada contractor's license number issued by the State Contractor's Board 11752
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 772
Signed (By driller performing actual drilling on site or contractor)
Date Oct 18 - 1993

(Rev. 3-91) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

Figure 98. Well Log No. 46386, Test Hole No. 5 (Indian Health Services),

Date Completed 10/15/1993



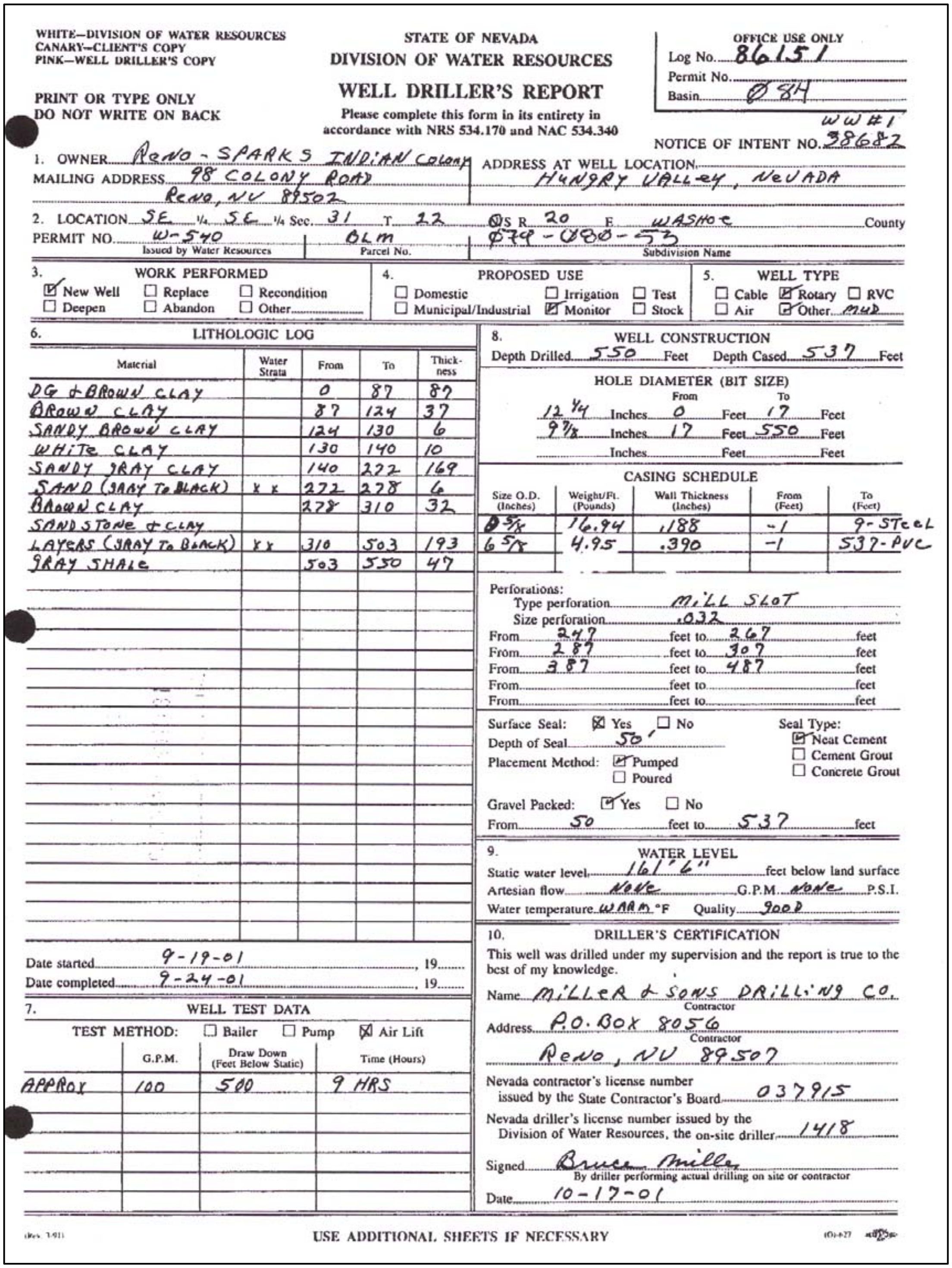
HUNGRY VALLEY FAX 784-50

TEST HOLE
No. 5
ABANDONED

GREY CLAY	0' — 18'
BROWN CLAY	18' — 24'
GREEN CLAY	24' — 49'
DARK SAND	49' — 51'
DARK CLAY	51' — 85'
DARK SAND & CLAY	85' — 100'
DARK CLAY W/WHITE ROCK CHIPS	100' — 150'
SOFT GREEN CLAY	150' - 230'
HARD GREEN CLAY	230' - 245'
SOFT GREEN CLAY	245 — 275'
MIXTURE OF HARD & SOFT GREEN CLAY	275' — 840'

next hole drille
on Tribal Land
app. 400 ft fro
well # 4. This n
becomes Well # 5

Figure 99. Well Log No. 46386, Test Hole No. 5 (Indian Health Services), Field Notes, Date Completed 10/15/1993



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STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 86151
Permit No.
Basin 084

WW #1
NOTICE OF INTENT NO. 38682

1. OWNER RENO - SPARKS INDIAN COLONY
MAILING ADDRESS 98 COLONY ROAD
RENO, NV 89502

ADDRESS AT WELL LOCATION HUNGRY VALLEY, NEVADA

2. LOCATION SE 1/4 SE 1/4 Sec. 31 T. 22 [✓ N] S R. 20 E WASHOE County
PERMIT NO. W-540 (Issued by Water Resources) | BLM (Parcel No.) | 079-080-53 (Subdivision Name)

3. WORK PERFORMED
☑ New Well ☐ Replace ☐ Reconditon
☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☑ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☑ Rotary ☐ RVC
☐ Air ☑ Other MUD

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thick-ness
DG & BROWN CLAY		0	87	87
BROWN CLAY		87	124	37
SANDY BROWN CLAY		124	130	6
WHITE CLAY		130	140	10
SANDY GRAY CLAY		140	272	169
SAND (GRAY TO BLACK)	X X	272	278	6
BROWN CLAY		278	310	32
SANDSTONE & CLAY				
LAYERS (GRAY TO BLACK)	X X	310	503	193
GRAY SHALE		503	550	47

Date started 9-19-01, 19
Date completed 9-24-01, 19

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☒ Air Lift

	G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
APPROX	100	500	9 HRS

8. WELL CONSTRUCTION
Depth Drilled 550 Feet Depth Cased 537 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
12 1/4 Inches	0 Feet	17 Feet
9 7/8 Inches	17 Feet	550 Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
8 5/8	16.94	.188	-1	9-STEEL
6 5/8	4.95	.390	-1	537-PVC

Perforations:
Type perforation MILL SLOT
Size perforation .032
From 247 feet to 267 feet
From 287 feet to 307 feet
From 387 feet to 487 feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 50'
Placement Method: ☑ Pumped ☐ Poured
Seal Type: ☑ Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: ☑ Yes ☐ No
From 50 feet to 537 feet

9. WATER LEVEL
Static water level 161' 6" feet below land surface
Artesian flow NONE G.P.M. NONE P.S.I.
Water temperature WARM °F Quality GOOD

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

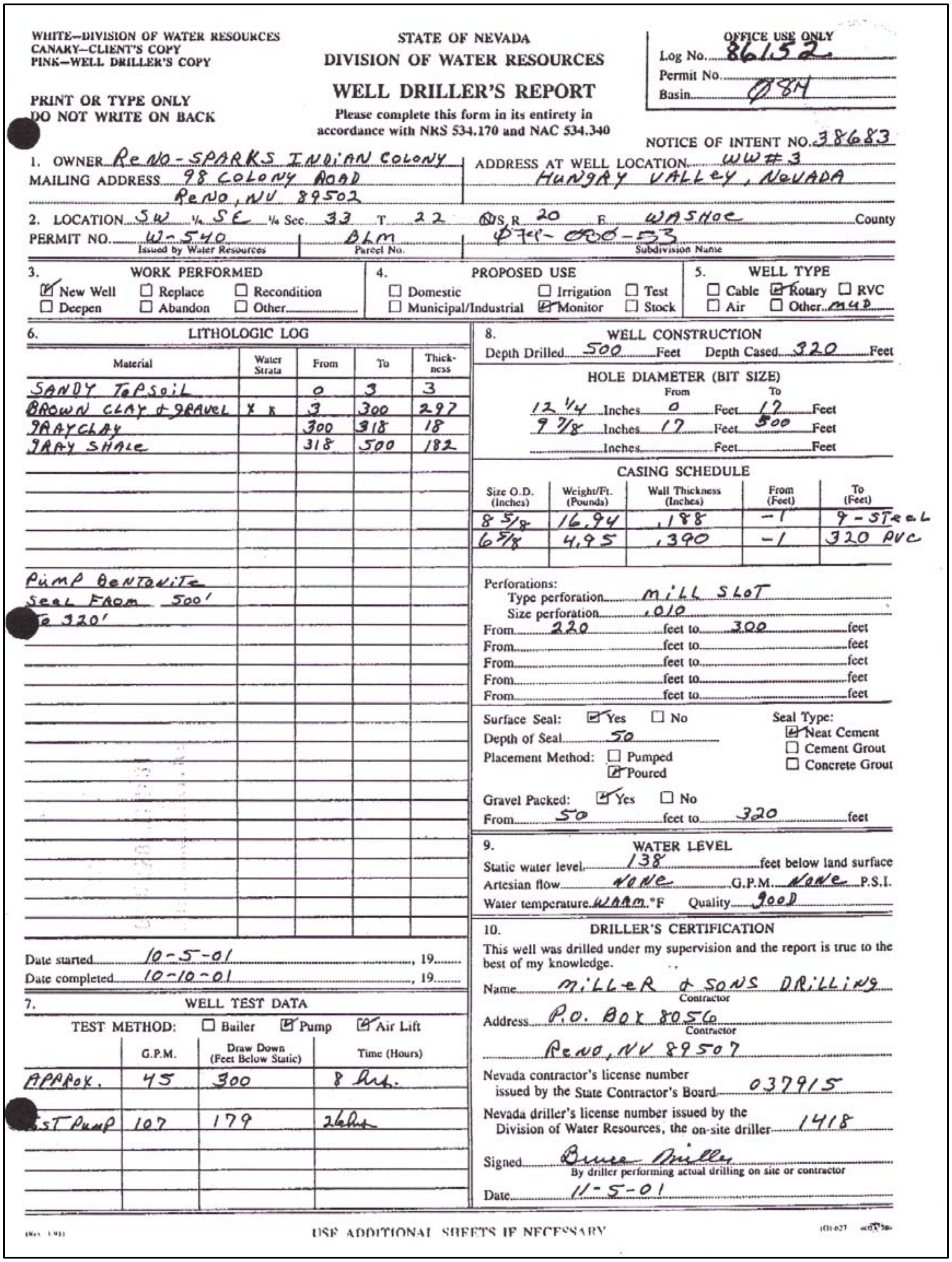
Name MILLER & SONS DRILLING CO. (Contractor)
Address P.O. BOX 8056 (Contractor)
RENO, NV 89507

Nevada contractor's license number issued by the State Contractor's Board 037915
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1418

Signed Bruce Miller
By driller performing actual drilling on site or contractor
Date 10-17-01

(Rev. 3-91) USE ADDITIONAL SHEETS IF NECESSARY (0)+27

Figure 100. Well Log No. 86151, Well No. 7 (WW-1), Date Completed 9/24/2001



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STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 86152
Permit No.
Basin 084

NOTICE OF INTENT NO. 38683

1. OWNER RENO-SPARKS INDIAN COLONY
MAILING ADDRESS 98 COLONY ROAD
RENO, NV 89502

ADDRESS AT WELL LOCATION WW # 3
HUNGRY VALLEY, NEVADA

2. LOCATION SW ¼ SE ¼ Sec. 33 T. 22 N/S R. 20 E. WASHOE County
PERMIT NO. W-540 (Issued by Water Resources)
BLM (Parcel No.)
079-000-53 (Subdivision Name)

3. WORK PERFORMED
☑ New Well ☐ Replace ☐ Recondition
☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☑ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☑ Rotary ☐ RVC
☐ Air ☐ Other MUD

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thick-ness
SANDY TOPSOIL		0	3	3
BROWN CLAY & GRAVEL	X X	3	300	297
GRAYCLAY		300	318	18
GRAY SHALE		318	500	182

PUMP BENTONITE
SEAL FROM 500'
[illegible]o 320'

Date started 10-5-01, 19
Date completed 10-10-01, 19

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☑ Pump ☑ Air Lift

	G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
APPROX.	45	300	8 hrs.
[illegible]ST PUMP	107	179	26hrs

8. WELL CONSTRUCTION
Depth Drilled 500 Feet Depth Cased 320 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
12 ¼ Inches	0 Feet	17 Feet
9 7/8 Inches	17 Feet	500 Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
8 5/8	16.94	.188	-1	9 - STEEL
6 5/8	4.95	.390	-1	320 PVC

Perforations:
Type perforation MILL SLOT
Size perforation .010
From 220 feet to 300 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

Surface Seal: ☑ Yes ☐ No
Depth of Seal 50
Placement Method: ☐ Pumped ☑ Poured

Seal Type:
☑ Neat Cement
☐ Cement Grout
☐ Concrete Grout

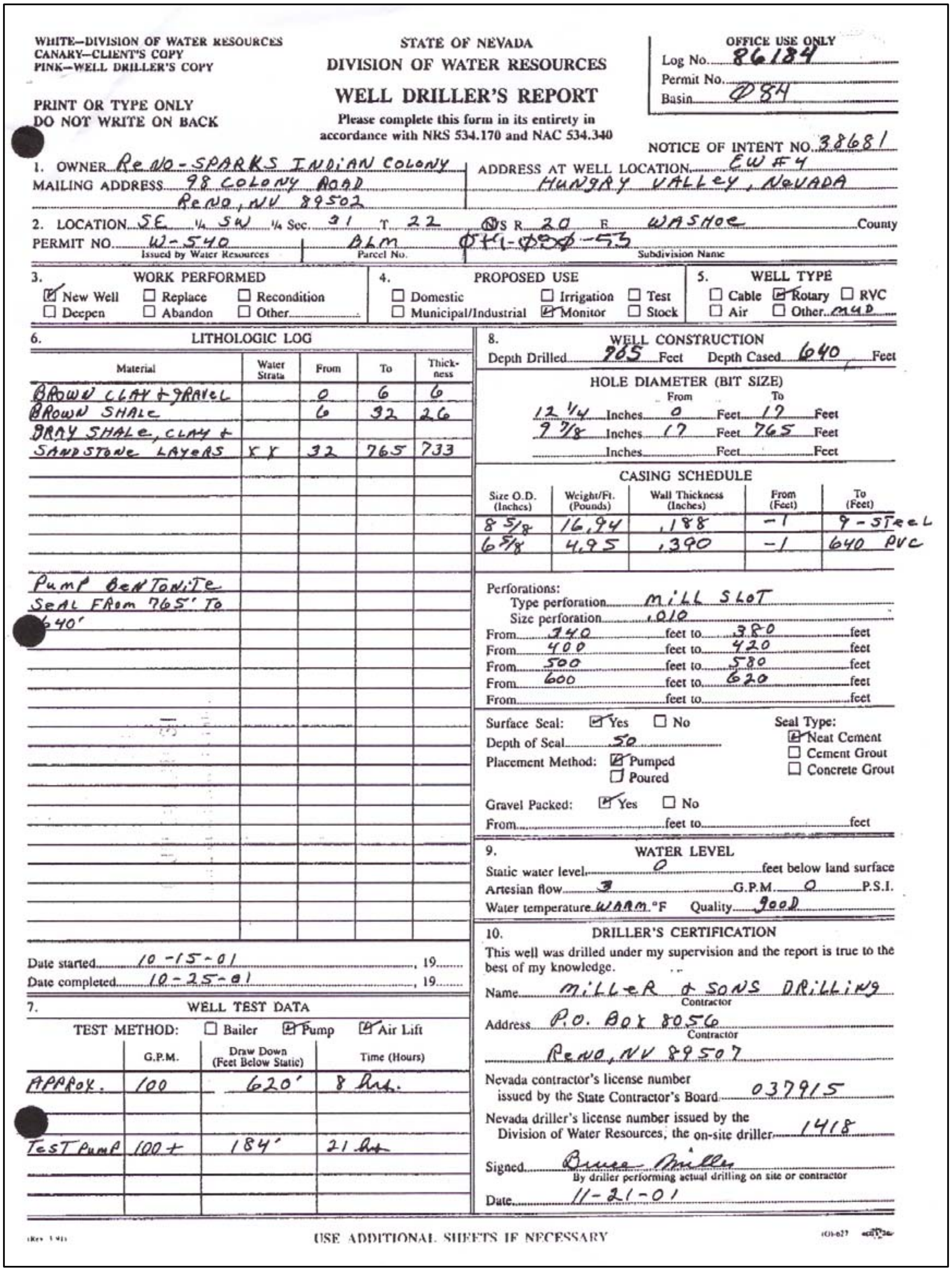
Gravel Packed: ☑ Yes ☐ No
From 50 feet to 320 feet

9. WATER LEVEL
Static water level 138 feet below land surface
Artesian flow NONE G.P.M. NONE P.S.I.
Water temperature WARM °F Quality GOOD

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name MILLER & SONS DRILLING (Contractor)
Address P.O. BOX 8056 (Contractor)
RENO, NV 89507
Nevada contractor's license number issued by the State Contractor's Board 037915
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1418
Signed Bruce Miller
By driller performing actual drilling on site or contractor
Date 11-5-01

(Rev. 1/91) USE ADDITIONAL SHEETS IF NECESSARY (01-027)

Figure 101. Well Log No. 86152, Well No. 8 (WW-3), Date Completed 10/10/2001



WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

PRINT OR TYPE ONLY
DO NOT WRITE ON BACK

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 86184
Permit No.
Basin 084

NOTICE OF INTENT NO. 38681

1. OWNER Reno-Sparks Indian Colony
MAILING ADDRESS 98 Colony Road
Reno, NV 89502

ADDRESS AT WELL LOCATION EW #4
Hungry Valley, Nevada

2. LOCATION SE ¼ SW ¼ Sec. 31 T. 22 [✓ N] S R. 20 E. Washoe County
PERMIT NO. W-540 (Issued by Water Resources) | BLM (Parcel No.) 041-030-53 | Subdivision Name

3. WORK PERFORMED
☑ New Well ☐ Replace ☐ Recondition
☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☑ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☑ Rotary ☐ RVC
☐ Air ☐ Other mud

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Brown clay & gravel		0	6	6
Brown shale		6	32	26
Gray shale, clay & sandstone layers	x x	32	765	733
Pump bentonite seal from 765' to 640'				

Date started 10-15-01, 19
Date completed 10-25-01, 19

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☑ Pump ☑ Air Lift

	G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
Approx.	100	620'	8 hrs.
Test pump	100 +	184'	21 hr

8. WELL CONSTRUCTION
Depth Drilled 765 Feet Depth Cased 640 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
12 ¼ Inches	0 Feet	17 Feet
9 7/8 Inches	17 Feet	765 Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
8 5/8	16.94	.188	-1	9 - steel
6 5/8	4.95	.390	-1	640 PVC

Perforations:
Type perforation mill slot
Size perforation .010
From 340 feet to 380 feet
From 400 feet to 420 feet
From 500 feet to 580 feet
From 600 feet to 620 feet
From feet to feet

Surface Seal: ☑ Yes ☐ No
Depth of Seal 50
Placement Method: ☑ Pumped ☐ Poured
Seal Type: ☑ Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: ☑ Yes ☐ No
From feet to feet

9. WATER LEVEL
Static water level 0 feet below land surface
Artesian flow 3 G.P.M. 0 P.S.I.
Water temperature warm °F Quality good

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Miller & Sons Drilling (Contractor)
Address P.O. Box 8056 (Contractor)
Reno, NV 89507

Nevada contractor's license number issued by the State Contractor's Board 037915

Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1418

Signed Bruce Miller (By driller performing actual drilling on site or contractor)

Date 11-21-01

(Rev. 1-91) USE ADDITIONAL SHEETS IF NECESSARY

Figure 102. Well Log No. 86184, EW-4, Date Completed 10/25/2001

12.2 Hydrogeologic Units and Stratigraphy Modeling

The current well field development in Hungry Valley has been in the basin-fill aquifer. The basin-fill aquifer has been described as low-permeability alluvial sediments consisting of clays and silts with limited sand lenses (Gebhardt et al, 1999). To better understand or conceptualize the hydrogeologic units of Hungry Valley, the well logs were used for stratigraphy modeling in GMS MODFLOW, utilizing the Borehole Module. Due to the rough estimates of the lithologic logs and simplifications (e.g. generally eliminating cross-sections of approximately 6 meters or less (20 feet or less)) used in the modeling, these pictorial representations should not be considered as an accurate representation of the stratigraphy of the Hungry Valley. Rather the following figures are used to estimate the thickness of the various hydrogeologic units and their possible lateral extent.

The following legend was used for stratigraphy modeling:

Table 40. Legend for Stratigraphy Modeling

UNIT NO.	UNIT DESCRIPTION	COLOR LEGEND
1	Sand	
2	Clay	🟥
3	Clay and Sand	🟦
4	Clay and Gravel / Rock	🟦
5	Rock	⬛

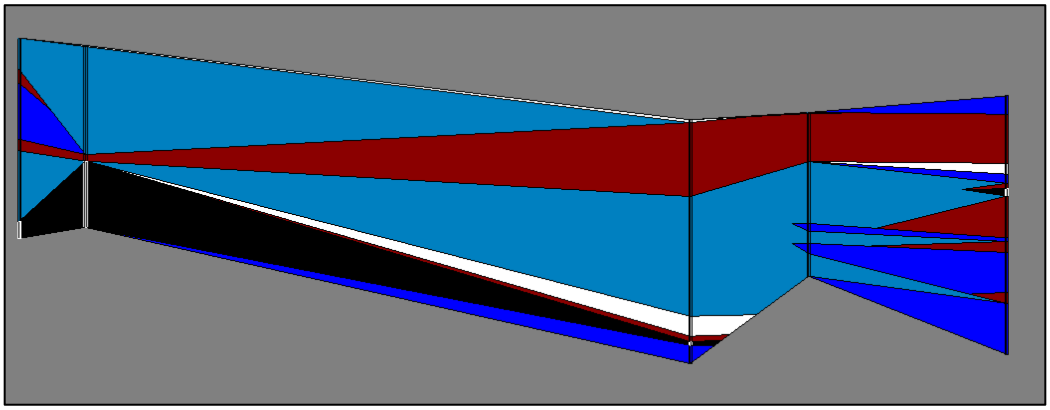


Figure 103. Stratigraphy Modeling; from Left to Right:
Well No. 7 – Well No. 8 – Well No. 4 – Well No. 3 – Test Hole No. 2

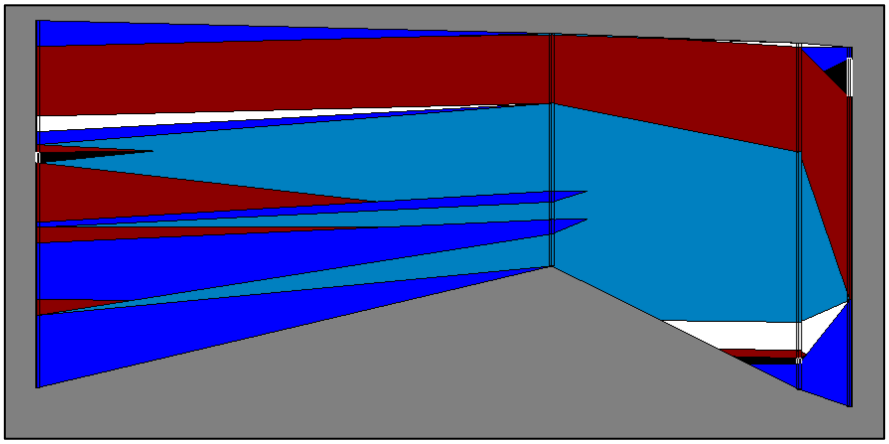


Figure 104. Stratigraphy Modeling; from Left to Right:
Test Hole 2 – Well No. 3 – Well No. 4 – Well No. 5

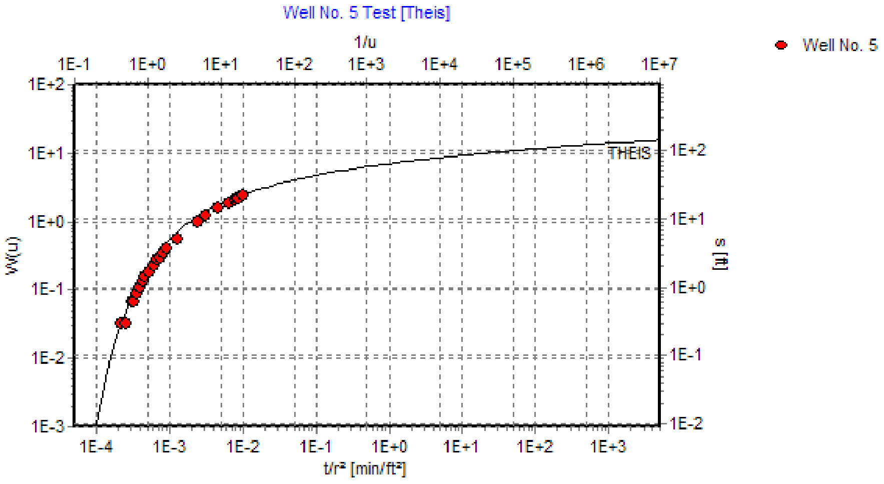
Note that all of the eastern wells (Test Hole No. 2 and Well Nos. 3, 4 and 5) are characterized by a thick clay layer near the surface; while the two west wells (Well Nos. 7 and 8) are not. Sand lenses (indicated in "white") are rarely seen in any of the lithologic logs.

Test Hole No. 2 has a considerable number of layers and thicknesses of clay throughout its depth. This test hole was previously described as not displaying either quantity or quality of water to encourage further exploration in the area south of the test hole (Harrigan and Ball, 1996).

12.3 Aquifer (Pump) Test, March 18 through March 20, 2008

A 24-hour pump test and 24 hour recovery analysis was performed by UNR students as part of GEOL 702Z Hydrologic Field Methods on March 18 – 20, 2008 at the Reno Sparks Indian Colony (RSIC) Well Field in Hungry Valley, Nevada.

The pump test was begun at approximately 3:34 PM (daylight savings) on March 18, 2008. Well Nos. 4 and 7 served as the pumped wells; with Wells Nos. 5 and 8, and Test Hole No. 1, used as monitoring wells. Water levels were recorded manually from the transducers (Series 900 RTU) for Wells Nos. 3, 4, 7 and 8. A transducer/data logger was installed in Test Hole No. 1. Pumping rate was monitored from the flow meter (+GF+ Signet Flow) located in the treatment plant.

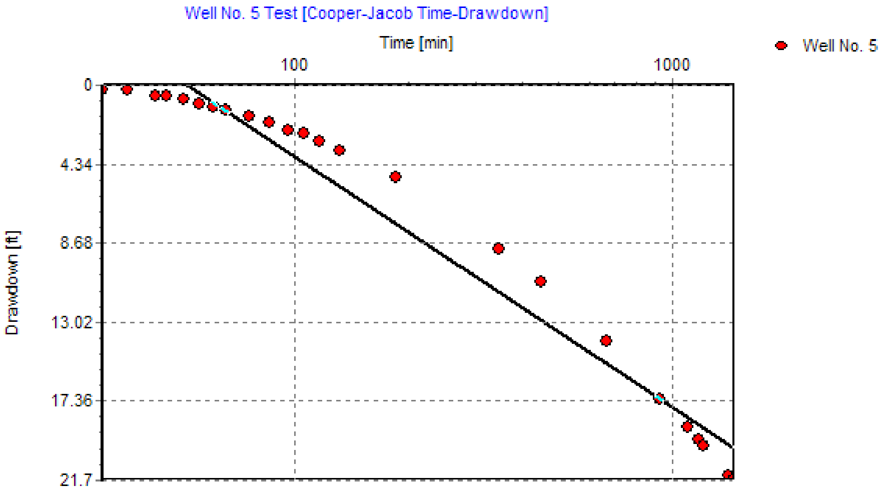


Transmissivity: 1.51E+2ft²/ d

Storativity: 2.11E-4

Conductivity: 1.26E+0 ft/ d

Figure 105. Aquifer (Pump) Test, Observation Well No. 5 (for Pumped Well No. 4) Curve Fitting via Theis Method



Transmissivity: 2.31E+2ft²/ d

Storativity: 1.32E-4

Conductivity: 1.92E+0 ft/ d

Figure 106. Aquifer (Pump) Test, Observation Well No. 5 (for Pumped Well No. 4) Curve Fitting via Cooper-Jacob Method

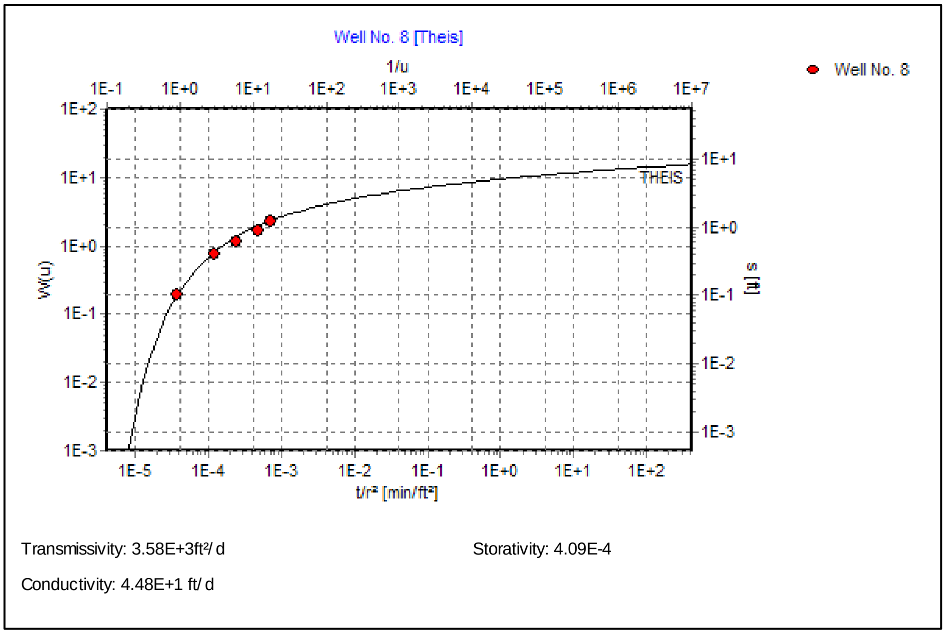


Figure 107. Aquifer (Pump) Test, Observation Well No. 8 (for Pumped Well No. 7) Curve Fitting via Theis Method

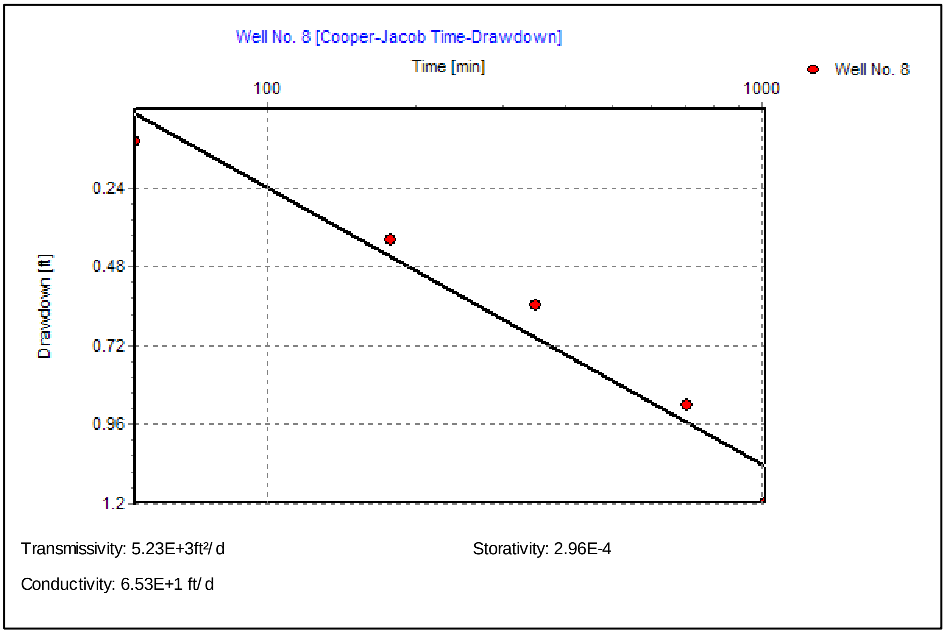


Figure 108. Aquifer (Pump) Test, Observation Well No. 8 (for Pumped Well No. 7) Curve Fitting via Cooper-Jacob Method