Prepared for:
California Regional Water Quality Control Board
Lahontan Region, Victorville, California

Final Report: Molycorp Supplemental Environmental Project Numerical Groundwater Flow Model Ivanpah Valley, San Bernardino County, California and Clark County, Nevada

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1.0 Introduction

Ivanpah Valley is a semi-arid, partially closed basin that lies within both San Bernardino County, California, and Clark County, Nevada. The valley is currently undergoing commercial, industrial, and some domestic development and is the proposed future site for the Clark County Ivanpah Airport, which is planned for the Nevada portion of the basin. Molycorp has evaporation ponds and water supply well fields along State Route 164 south of Ivanpah Lake in the California portion of the valley; Primm, Nevada, located just north of the state line, is well known for its casinos and resort golf courses. Groundwater use in Ivanpah Valley has increased over the past 40 years and could increase substantially in the future due to commercial and residential development of the valley. An understanding of the hydrology of Ivanpah Valley will thus become important for water management in the valley as the demands on groundwater increase over the next 20 years.

2.0 Purpose of the Groundwater Flow Model

The purpose of the groundwater flow model is to provide the California Regional Water Quality Control Board, Lahontan Region (Regional Board) with a calibrated numerical groundwater flow model for Ivanpah Valley that can be used to manage groundwater resources in the valley as development of the valley continues and the demand for groundwater increases. The groundwater flow model will provide the Regional Board with the following:

- Ability to estimate the impacts of continued groundwater withdrawal on existing and future well fields.
- Ability to model groundwater/surface water interactions.
- Ability to estimate the impacts of surface use, such as landfills, evaporation ponds, golf courses, and the proposed Ivanpah Airport on groundwater and surface water resources.
- Ability to estimate the impacts of residential and commercial development on the water resources of the valley.
- Ability to estimate the potential impacts of introduced contaminants on groundwater resources and wells used for domestic water supply.
- A better understanding of the hydrogeology of Ivanpah Valley.

The groundwater flow model is designed to be a tool that will allow the Regional Board to better manage the water resources of Ivanpah Valley and especially to manage the water resources of the California portion of Ivanpah Valley (Ivanpah South) with reference to groundwater use within the Nevada portion of the valley (Ivanpah North). Based on comments received as a result of a public presentation of the draft version of the report, changes were incorporated in the modeling that involved moving the recharge for the Primm Golf Course and the location of the Molycorp New Evaporation Ponds. Recent satellite photographs were used to locate these recharge features and some of the wells in Ivanpah South to better define the potential effects of these features on local drawdown and recharge in Ivanpah South. As a result of moving the recharge areas for the Primm Golf Course, the water balance for Ivanpah South and Ivanpah North changed somewhat from that presented in the draft version of the report. The overall water balance for Ivanpah Valley did not change.

3.0 Previous Studies

Previous studies of Ivanpah Valley have been conducted by both the California Division of Water Resources (DWR) and the Nevada DWR over a period extending from 1920 to 1972. The report of Waring (1920) on groundwater in Pahrump, Mesquite, and Ivanpah valleys was the first compilation of water well data for the valley. The most complete geologic map and report for Ivanpah Valley was prepared by the U.S. Geological Survey (USGS) (Hewett 1956). Glancy (1968) provided the first attempt at a hydrologic model for the Nevada portion of Ivanpah Valley. The California DWR (1956) compiled and presented water well data for many of the valleys along the California/Nevada border, including Ivanpah Valley. In 1972, the California DWR (Moyle 1972) compiled the water well and spring data for Ivanpah South. Studies by Molycorp (2000) of the new evaporation pond area in Ivanpah South and a groundwater model by Geomega (2000) for the Molycorp Mountain Pass Mine provide more current data on the valley sediments near Ivanpah Lake and the mountain ranges surrounding the Mountain Pass mine, respectively. A groundwater model for a portion of Ivanpah South by TRC (2000) was used to model contaminant plume movement near the Molycorp new evaporation ponds. Both the California DWR and the Nevada DWR websites provide current information on water use in the valley. Recent geologic mapping by Schmidt and McMackin (2006) and also the development of a flood hazard map (House 2006) for Ivanpah North have been published as part of the ongoing evaluation of Ivanpah North for the development of the proposed Ivanpah Airport.

4.0 Availability of Data

The availability of data has been limited to published studies and compilations of data for both the California and Nevada portions of Ivanpah Valley. Some of these studies are over 30 years old. More current data have come from: the Nevada and California DWR websites (Nevada DWR 2006; California DWR 2006); the groundwater model and report for the Mountain Pass mine prepared by Geomega (2000); Molycorp's (2000) evaluation of its new evaporation pond area near Ivanpah Lake, from the groundwater model developed for the Molycorp new evaporation pond area by TRC (2000); from the Primm Golf Course (Montgomery, Watson, Herza [MWH] 2006). No recent studies of the hydrology of Ivanpah Valley are available and there are no current compilations of water levels in all wells. Calibration of the groundwater flow model has thus relied on water level data measured over a number of years before major development of the valley and on transient stresses in the area from Primm, Nevada, south to the Molycorp new evaporation ponds measured and reported by TRC (2000).

5.0 Report Format

The report consists of six main sections:

1. A Summary of the Geology and Hydrology of Ivanpah Valley.
2. A Conceptual Hydrogeological Model for Ivanpah Valley.
3. Development of the Calibrated Groundwater Flow Model.
4. A Summary of the Hydrology of Ivanpah Valley.
5. Recommendations.
6. Response to Comments Received at a Public Presentation of the Draft Report.

The data presented in the Summary of the Geology and Hydrology of Ivanpah Valley have been gathered from published reports, websites, and by personal contact with major water users in the valley. The Conceptual Hydrogeological Model establishes the overall groundwater flow and groundwater balance for the valley. The section on the Calibrated Groundwater Flow Model presents the methodology of developing and calibrating the groundwater model and the results of the calibration. The Summary of the Hydrology of Ivanpah Valley combines concepts and data from the three previous sections of the report to provide an integrated view of the hydrology of Ivanpah Valley. The section on Recommendations focuses on data needed to develop a more detailed and accurate understanding of groundwater flow in the valley. The Response to Comments presents responses to written and verbal comments received as a result of a public presentation of the draft report and groundwater model in Victorville, California, during the summer of 2007.

6.0 Geology of Ivanpah Valley

Ivanpah Valley is a closed to semi-closed basin that lies across the California-Nevada border, as shown in **Figure 6-1**. Ivanpah Valley is typical of a basin that lies within the basin and range physiographic province in that it trends northward and is surrounded by mountain ranges that contain highly faulted sedimentary, igneous, and metamorphic rocks. The most complete geology of the basin is given by Hewett (1956) in U.S. Geological Survey Professional Paper 275, *Geology and Mineral Resources of the Ivanpah Quadrangle*, *California and Nevada*. Much of this section on the geology of the valley is taken from that report and has been supplemented by geologic data on valley sediments provided by Molycorp (2000). In addition, a surficial geology map of the Mesquite Quadrangle, which includes Ivanpah North has been published recently by Schmidt and McMackin (2006). The geologic summary presented in this section is designed to provide geologic information needed to justify the boundary conditions and groundwater recharge used in the conceptual hydrogeologic model, rather than provide a detailed geology of the valley. The reader is referred to Hewett (1956) for a more detailed discussion of the geology of Ivanpah Valley and the Ivanpah Quadrangle, and to Schmidt and McMackin (2006) for a geologic discussion of the surficial geology of Ivanpah North.

6.1 General Geology of the Valley

The geology of Ivanpah Valley is summarized in **Figure 6-2**. This geologic map is a simplification of the geology of the Ivanpah Quadrangle provided by Hewett (1956). The mountain ranges consist of Precambrian metamorphic and sedimentary rocks, Paleozoic and Mesozoic sedimentary rocks, and both igneous and volcanic rocks and sediments of Tertiary age. Most of the mountain ranges are transected by a myriad of faults consisting of both thrust faults and normal faults. Major faults, such as the Ivanpah fault and the Clark Mountain fault, cross the valley floor and can be traced in the mountain ranges on both sides of the valley. A major fault, referred to as the State Line fault, follows the approximate trace of the California-Nevada border (Hewett 1956). Ivanpah Valley was formed by downfaulting along basin and range faults that border the mountain ranges. The thickness of the valley sediments is not known with any certainty because no wells near the center of the basin penetrate the valley sediments. Wells along the valley margins have penetrated alluvial sediments ranging from 200 to around 750 feet in thickness. The valley sediments are probably around 8,000 feet thick and may have a maximum thickness in the range of 20,000 feet (Hewett 1956; Molycorp 2000).

6.2 Geology of the Mountain Ranges

The mountains consist of rocks ranging from Precambrian to Tertiary in age. The prominent Cima Dome at the south end of the valley (**Figure 6-2**) is composed of the Tertiary Teutonia quartz monzonite. This dome is an intrusive dome that is not faulted and contains many springs used for livestock watering.

Ivanpah Mountain: This northwest-trending range, which borders the valley on the southwest, contains Precambrian metamorphic and igneous rocks juxtaposed against Paleozoic and Mesozoic sedimentary rocks by the Clark Mountain fault. The Mesquite thrust lies to the west of the Clark Mountain fault and roughly parallels that fault. The Paleozoic and Mesozoic sedimentary rocks are intricately folded and faulted. Ore deposits are found both in the Precambrian metamorphic rocks (Molycorp Mountain Pass Mine) and in the sedimentary rocks. The main stratigraphic units found in the Precambrian of Ivanpah Mountain are the Kingston Peak, Bell Spring, and Crystal Spring formations along with the metamorphic gneisses. The Paleozoic rocks range from Cambrian to Pennsylvanian in age and consist of many of the major stratigraphic units found in the Paleozoic of southwest Nevada (see Hewett 1956 for details on each stratigraphic unit). The Mesozoic units are more limited and consist of the Triassic Moenkopi and Chinle formations and Jurassic volcanic and igneous units.

Spring Mountains: This mountain range is mostly in Nevada, but has an arm that trends northeast-southwest that crosses the California-Nevada border and separates Mesquite Lake from Ivanpah Valley (**Figure 6-1**). The range consists of highly faulted and folded Paleozoic and some Mesozoic sedimentary rocks. Northwest-trending normal faults and thrust faults are common throughout the range, making this range one of the most faulted ranges in Ivanpah Valley. Some of the faults are shown in **Figure 6-2**. Just across the border in southwestern Nevada, a Tertiary intrusive dome is present in this range at Devils Peak. Tertiary volcanic and volcaniclastic sedimentary rocks are also present throughout the range. The State Line fault transects the range and this fault, combined with the Ivanpah fault, probably produced the northeast-trending arm of Spring Mountain as a result of coupled fault movement. The extensive faulting found in this range allows for infiltration of precipitation and thus, recharge to the groundwater in this range. The Paleozoic stratigraphic units found in this range include the Kaibab limestone, Supai formation, Bird Spring formation, and Monte Cristo limestone of Mississippian and Pennsylvanian age along with the Devonian Goodsprings dolomite and the Cambrian Pioche shale and Prospect Mountain quartzite (see Hewett 1956 for details on these stratigraphic units).

Spring Range: This range lies to the northeast of the Spring Mountains across Goodsprings Valley. This range consists of the same Paleozoic sedimentary rocks as the nearby Spring Mountains. The range is also highly faulted with both northwest and northeast trending normal faults. The Roach fault transects this range and continues down Ivanpah Valley to the State Line fault (**Figure 6-2**). Like the Spring Mountains, groundwater recharge along faults is expected to be quite prevalent during periods of snow melt and heavy rainfall.

McCullough Range: The McCullough Range borders the eastern side of Ivanpah Valley and consists mainly of Precambrian gneisses and sedimentary rocks. The north end of the range has the Precambrian covered with Tertiary volcanic flows and volcaniclastic sedimentary rocks. The range is not faulted to any degree. The McClanahan fault (**Figure 6-2**) is the only major fault mapped in the range by Hewett (1956).

Lucy Grey Range: The Lucy Grey Range lies just to the west of the McCullough Range and consists of Precambrian gneisses and sedimentary rocks. The south end of the range contains normal faults. The Lucy Grey Range is separated from the McCullough Range by the McCullough fault; a narrow valley of alluvial fan sediments also separates the two ranges.

New York Mountains: The New York Mountains border Ivanpah Valley on the southeast and are across the valley from Ivanpah Mountain (**Figure 6-1**). North of the Clark Mountain fault, the New York Mountains consist mainly of Precambrian gneisses and sedimentary rocks overlain by Tertiary volcanic flow and volcaniclastic sedimentary rocks. South of the Clark Mountain fault, the range is mostly composed of the Tertiary Teutonia quartz monzonite with local windows of Precambrian rocks exposed within the massive intrusive body. Except for being transected by major faults like the Ivanpah fault and the Clark Mountain fault, the New York Mountains are not faulted.

6.3 Geology of the Valley

The geology of the sedimentary units in Ivanpah Valley is known only from driller's logs and boring logs published in reports by Molycorp (2000), Glancy (1968), the California DWR (1956) and Moyle (1972). The most detailed evaluation of the geology of the valley sediments was completed by Molycorp (2000) for their new evaporation pond situated within Ivanpah playa (Ivanpah Lake). Boring logs and the work of Molycorp (2000) indicate that Ivanpah Valley consists of alluvial sediments generated by alluvial fans that fed into the valley from the mountains that border the valley. Near the center of the valley, these alluvial fan sediments merge with fine-grained playa sediments. As shown by Molycorp (2000), the margins of the Ivanpah playa show an interfingering of playa clays with coarser alluvial sands.

A geologic model for the sedimentary units of Ivanpah Valley would have coarse alluvial sands and gravels grading basinward into a mixture of sands and silty clays that merge near the center of the valley with playa clays and evaporative sediments. As shown by Molycorp (2000), the playa clays are a mixture of clays, silts, caliche, gypsum, and evaporative salts. Drilling by Molycorp (2000) also revealed a volcanic ash layer 1 to 2 feet in thickness at a depth of about 70 feet below ground surface (bgs) in the area of the new evaporative pond. This volcanic ash was dated at 660,000 years before present and correlated with a Yellowstone volcanic event. Oil and gas drilling, referenced by Molycorp (2000), has intercepted a 130-foot thick salt layer at a depth of 1,100 feet bgs in Ivanpah Valley. This layer may act as an impermeable base for groundwater movement in the valley (Molycorp 2000).

The surficial geologic map of Ivanpah North, available in the report on the Mesquite Lake Quadrangle (Schmidt and McMackin 2006), shows alluvial fans descending from the mountain ranges and the interior mountain blocks, such as the Lucy Grey Range, toward the center of Ivanpah North and eventually to the playa lake (Roach Lake) at the lowest point in Ivanpah North. The complexity of these surficial alluvial sediments probably mirrors the complex interfingering and interlayering of the underlying alluvial sediments that comprise Ivanpah Valley above the thick salt layer.

6.4 Geologic History of Ivanpah Valley

The geologic history of the Ivanpah Quadrangle provides a better understanding of the evolution of Ivanpah Valley. The Precambrian gneissic rocks form the early basement rocks of the Ivanpah area. During late Precambrian time, sedimentary rocks of the Pahrump series were deposited on these basement rocks to a maximum thickness of about 7,000 feet. Early marine carbonates of the Crystal Spring and Beck Spring formations were eventually overlain by sandstone and conglomerate of the Kingston Peak formation.

Following a period of deformation, marine deposition resumed in the early Paleozoic with the Noonday dolomite. Throughout most of the Paleozoic, marine deposition in a shallow marine environment dominated the Ivanpah area. Approximately 6,000 to 7,000 feet of marine sedimentary rocks were deposited during the Paleozoic. Periods of non-deposition in the Paleozoic sequence suggest periods of uplift. During the Mesozoic, non-marine clastic sedimentary rocks were deposited over the marine units. During the late Mesozoic, volcanic rocks replaced the clastic rocks.

From the late Cretaceous (late Mesozoic) to early Tertiary, the Ivanpah area experienced considerable folding, thrust faulting, and orogenic uplift. This was the time period when most of the thrust faults mapped by Hewett (1956) in the mountain ranges that border Ivanpah Valley were formed. Five major thrust systems were formed along with numerous minor faults and folds ranging from open folds to tight recumbent folds (Hewett 1956). The upper block on the Mesquite thrust was moved 8 miles eastward. During the later part of this Laramide orogeny, igneous intrusions accompanied by a variety of metaliferous ore deposits were emplaced into the folded and faulted sedimentary rocks.

During early to middle Tertiary time, the whole area was uplifted and deeply eroded to form the Ivanpah erosional surface. Most of the debris generated by erosion was apparently carried out of the Ivanpah area (Hewett 1956). During the middle Tertiary, volcanic plugs and dikes accompanied by gold-bearing veins were emplaced. During the late Tertiary, a second period of deformation occurred in the Ivanpah area resulting in folding and eastward directed thrust faulting. Erosion of this deformed and uplifted highland resulted in deposition of the Resting Springs formation.

During the Quaternary, Ivanpah Valley was formed by Basin and Range style faulting. Ivanpah Valley, according to Hewett (1956) is an isosceles triangle hinged at its northwest base with the apex in the southeast down-dropped approximately 20,000 feet. The Ivanpah fault has about 8,000 feet of displacement and the McCullough fault approximately 20,000 feet of displacement. Lateral displacement on the State Line fault is about 2,000 feet. These major faults, along with numerous smaller basin margin faults, dropped Ivanpah Valley by about 20,000 feet during the Quaternary and resulted in the formation of the basin. Basin sediments consist of older alluvial sediments that are mainly gravel and sand overlain by younger alluvial sediments that grade from coarser sands and gravels along the mountain fronts to fine-grained silts and clays near the center of the valley. These sediments are interbedded with basalt flows and evaporative beds containing gypsum and other salts.

7.0 Hydrology of Ivanpah Valley

Ivanpah Valley is one of several closed to semi-closed basins along the Nevada-California border in southern California. Elevations in Ivanpah Valley range from around 2,600 feet above mean sea level (amsl) on the basin floor to 8,510 feet amsl in the adjacent mountains. Nearby Mesquite Valley ranges from 2,540 feet amsl on the basin floor to the same maximum of 8,510 feet amsl in the mountains. Jean Lake Valley, which is part of the northern part of Ivanpah Valley in Nevada, ranges from 2,780 feet amsl on the basin floor to 6,840 feet amsl in the adjacent mountains. Hidden Valley ranges from 2,990 to 4,290 feet amsl (**Figure 6-1**). Temperatures in the mountains can be in the range of 70 to 80 degrees Fahrenheit (°F) in the summer and 35 to 48 °F in the winter months (Geomega 2000). In the valleys, the temperature during the summer months can exceed 90 °F on a regular basis. Precipitation falls mainly in the mountains and recharge to the groundwater systems in all of these valleys occurs in the mountains or along the mountain fronts due to runoff infiltration.

7.1 Precipitation, Evapotranspiration, and Evaporation

Ivanpah Valley contains approximately 240 square miles in Ivanpah North and about 450 square miles in the Ivanpah South portion of the basin (Glancy 1968). For comparison, Jean Lake Valley occupies 100 square miles and Hidden Valley about 30 square miles. In Ivanpah Valley, the playas that have developed in the lowest part of the basin account for about 2.7 percent of the valley area. For Mesquite Valley and Jean Lake valleys the playas occupy about 2.1 percent of the valley, with Hidden Valley having a playa that occupies about 0.8 percent of the valley (Glancy 1968).

Precipitation records for areas near Ivanpah Valley have been summarized by Glancy (1968) and Geomega (2000). Important records that have been used in developing an equation for the relationship between precipitation and elevation (Geomega 2000) are summarized below:

Gage Location	Elevation (feet)	Average Annual Precipitation (inches)	Years of Record
Las Vegas, Nevada	2,162	4.11	1949-1996
Boulder City, Nevada	2,525	5.22	1931-1966
Searchlight, Nevada	3,540	6.74	1948-1996
Mountain Pass, California	4,739	8.44	1958-1996
Pahrump, Nevada	2,669	3.64	1959-1966
Red Rock Summit, Nevada	6,240	10.62	1945-1952
Roberts Ranch, Nevada	6,100	13.95	1945-1952
Lee Canyon, Summit, Nevada	9,200	20.3	1945-1965
Amboy, California	640	1.9	1948-1974
Silver Lake, California	922	2.48	1948-1953
Baker, California	940	2.13	1953-1990
Ivanpah Lake	2,605	3.0	Molycorp (2000)

The equation relating precipitation to elevation, developed by Geomega (2000), is:

Precipitation (inches) = 0.002 x Elevation (feet) + 0.276

The pan evaporation rate for standing water in Ivanpah Valley is about 100 inches per year (Geomega 2000), giving a ponded water or lake evaporation rate of about 70 inches per year. The evapotranspiration rate for phreatophytes ranges from 25 to 60 inches per year. The phreatophyte extinction depth averages around 20 feet (Geomega 2000), but can range up to about 60 feet for some species. Thus, precipitation falling on the valley floor in Ivanpah Valley can be expected to be transpirated in areas with vegetation growth. On the playas, precipitation would be expected to pond and evaporate due to the low permeability of the playa clays and the general lack of vegetation on the playas.

Precipitation falling in the mountain ranges and mountain-front runoff are thus the main sources of groundwater recharge. The runoff from the mountains follows ephemeral stream channels in the alluvial fan sediments and infiltrates quickly as it enters the alluvial fans that border the valley floor in Ivanpah Valley. Most mountain-front runoff infiltrates into the coarse alluvial sediments. During very heavy storms or prolonged rainfall, high levels of runoff generated in the mountains can flow all the way to the playas and cause flooding of the playas and the lower parts of the valley floors, as evidenced in the flood hazard map prepared for Ivanpah North by House (2006). Evaporation is negligible due to the short time involved and overcast conditions when heavy rains occur. Where the depth to groundwater exceeds 60 feet, evapotranspiration of groundwater can be expected to be absent. However, runoff that infiltrates can be expected to be partially transpirated. Thus, some runoff that infiltrates the coarse alluvial sediments becomes recharge to the shallow groundwater table beneath the alluvial fans; the remainder of the infiltrating runoff is transpirated.

7.2 Streams, Runoff, and Groundwater Recharge

Streams: Streams in Ivanpah Valley are ephemeral and only carry water for short periods of time. Streams descending from the mountain ranges onto the alluvial fans carry storm runoff and spring snow melt runoff. Water flowing in these streams generally infiltrates and recharges the shallow groundwater aquifer in the alluvial sediments. Some of the runoff that infiltrates into the alluvial sediments undoubtedly is transpirated by plants, but the exact percentage has not been quantified.

Runoff: Geomega (2000) attempted to estimate the percentage of precipitation in the mountainous area around Molycorp's Mountain Pass Mine that results in runoff. Their work showed that on an average annual basis about 7 percent of precipitation results in runoff. The range was from a low value around 0.72 percent during the dry months to a high value of 20.12 percent in months with frequent heavy storms.

Glancy (1968) estimated runoff for Ivanpah, Mesquite, Jean Lake, and Hidden valleys. For Ivanpah Valley, he estimated a runoff area of 74,300 acres in Ivanpah North that would yield an average annual runoff of 1,200 acre-feet of water. Using the same percentages and ratios for Ivanpah South would give a runoff acreage of 139,300 acres and an average annual runoff of 2,250 acre-feet of water. For Mesquite Valley, the total average annual runoff for both the California and Nevada portions of the valley was estimated by Glancy (1968) at 2,100 acre-feet of water. For Jean Lake Valley, the runoff acreage was 27,800 acres and the average annual runoff was 250 acre-feet of water; for Hidden Valley, the runoff acreage was 10,400 acres and the average annual runoff was estimated at 50 acre-feet of water. Glancy's (1968) acreages and precipitation rates were based on data available at that time for Ivanpah Valley and southern California.

Groundwater Recharge: Glancy (1968) estimated the recharge to groundwater in both the valley sediments and the sedimentary and metamorphic rocks of the mountain ranges using the methodology of Maxey and Eakin (1949). He estimated that groundwater recharge in Ivanpah North would be about 685 acre-feet per year (afy) and the groundwater recharge in Ivanpah South would be about 834 afy. For Jean Lake Valley, Glancy (1968) estimated groundwater recharge at 88 afy. For Hidden Valley, he determined that there would be little if any recharge because elevations are mostly below 5,000 feet amsl. The calculations of Glancy (1968) for

Ivanpah, Jean Lake, and Hidden valleys are reproduced in **Table 7-1**. The method of Maxey and Eakin (1949) was reviewed and evaluated by Avon and Durbin (1994) and found to be acceptable for desert basins in the Great Basin area of Nevada and adjacent California. The method of Maxey and Eakin (1949) is based on estimating recharge from a water balance for a basin. Recharge in the method of Maxey and Eakin (1949) combines recharge from mountain precipitation and from mountain-front runoff into a set of recharge efficiency factors applied to precipitation zones in the surrounding mountains, as illustrated in **Table 7-1**.

Table 7-2 presents a modification of the Maxey-Eakin (1949) method that incorporates the precipitation versus elevation equation of Geomega (2000) for determining the precipitation at specified elevations in the Ivanpah Valley area. This table also incorporates the recharge efficiency factors developed by Katzer and Donovan (2003) that are based on precipitation rates, rather than being a fixed set of factors applied to precipitation ranges as is the case with the Maxey and Eakin (1949). The equation of Katzer and Donovan (2003) relating precipitation and recharge is:

Recharge (Re) = 0.05 x (precipitation expressed in feet per year)^2.75

A comparison of **Tables 7-1** and **7-2** shows that by using a precipitation versus elevation equation that is more specific to the area around Ivanpah Valley, the estimated annual precipitation for all areas, except Hidden Valley, is greater. For Ivanpah North, the total average precipitation estimate increases from 81,256 acre-feet (Glancy 1968) to 119, 305 acre-feet. However, most of this increase in precipitation is below 5,000 feet, where recharge is considered to be negligible. The overall estimate of recharge is somewhat higher (752 acre-feet versus 685 acre-feet) for Ivanpah North using the precipitation verses elevation equation of Geomega (2000) and the recharge efficiency factors of Katzer and Donovan (2003). For Ivanpah South, the recharge is 1,184 acre-feet versus 834 acre-feet using Glancy (1968); for Jean Lake Valley, the estimated recharge increases to 119 from 88 acre-feet using Glancy (1968).

TRC (2000) used the method of Maxey and Eakin (1949) to estimate a starting value for recharge in their groundwater model for the Molycorp evaporation ponds in Ivanpah South. They distributed the starting recharge around the margins of the valley based on watershed area. Their final calibrated recharge for Ivanpah South (905 afy) was close to the estimated recharge found in Glancy (1968) and between the estimated recharge for Ivanpah South found in **Tables 7-1** and **7-2**.

7.3 Groundwater Discharge

Groundwater discharge in Ivanpah Valley occurs by the following methods: 1) spring discharge in the mountains, 2) groundwater pumpage in the valley and in some mines, and 3) groundwater underflow northward out of the valley to Las Vegas Valley (Glancy 1968). Because the water table is generally at least 60 to 80 feet deep (Molycorp 2000), evapotranspiration from the water table is not considered to be a source of groundwater discharge. Similarly, groundwater flowing toward the basin center and Ivanpah Lake/Roach Lake does not reach the surface and evaporate, as it does in Mesquite Valley (Glancy 1968; Molycorp 2000). Rainwater that falls on the playas in Ivanpah Valley evaporates after a few weeks (Molycorp 2000).

Spring Discharge: Spring flow rates have been measured at various times and reported by the California DWR (Moyle 1972) and Waring (1920). In the report by the California DWR (Moyle 1972), 31 springs in Ivanpah South were visited. Of these, 23 springs had flow rates ranging from 0.005 gallons per minute (gpm) to 2.25 gpm. Most springs had flow rates below 1.0 gpm. The elevations of the springs ranged from 4,080 to 5,480 feet amsl, placing them along the mountain fronts. Waring (1920) found that most springs had flow rates between 0.5 and 3.0 gpm, with a maximum flow rate of 6.0 gpm. Glancy (1968) did not report measured spring flow rates for Ivanpah North, but remarked that most springs had flow rates below 5 gpm and that water evaporated or was transpirated by plants near the spring exit. **Table 7-3** contains a summary of measured spring flow rates, as well as the location and elevation of known springs in Ivanpah Valley.

Groundwater Pumpage: Published or publicly available groundwater pumpage rates have been presented by various authors for Ivanpah Valley. Molycorp (2000) has suggested that the total groundwater pumpage for their wells, the wells in Primm, Nevada, the Colosseum Mine wells, and the Primm Golf Course wells is about 1,800 gpm (2,904 afy). The 2 Molycorp wells are rated at a total of 850 gpm (Glancy 1968). In 2005, the Primm Golf Course complex used 1,560 acre-feet of water; water use in 2002-2004 was 1,680 to 1,727 afy (MWH 2006). Between 1953 and 1998, the Molycorp wells pumped between 484 and 1,242 afy (TRC 2000). The Nevada DWR (2006) published on their website the following values for active annual duty water use in Ivanpah and Jean valleys:

Type of Use	Ivanpah North	Ivanpah South	Jean Valley
Quasi-Municipal	1420.39 afy	751 afy	0
Mining	397.73 afy	22.89 afy	39.87 afy
Industrial	150.0 afy	0	0
Domestic	15.93 afy	0	0
Commercial	10.26 afy	0	0
Stock Watering	10.46 afy	3.62 afy	10.35 afy
Wildlife	0	3.23 afy	0
TOTAL	**2004.77 afy**	**780.75 afy**	**50.22 afy**

The town of Jean used about 554 to 690 afy of groundwater during 1995-2000 (Parsons 2002) and disposed of gray water through infiltration basins. Jean wells near the Southern Nevada Correctional Facility can produce up to 182.4 afy. According to Parsons (2002), casino gray water in the town of Primm accounts for about 700 afy, most of which is returned to the valley aquifer through infiltration basins. Groundwater used in the Goodsprings, Nevada, area comes mainly from private wells in alluvium and carbonate rocks. According to Glancy (1968), Goodsprings used about 10 afy of groundwater in 1968. In 2006, water use at Goodsprings was approximately 120 afy, based on a population of 232 individuals (Goodsprings 2006) and water consumption at 463 gallons per capita per day (Nevada DWR 2006).

Molycorp's (2000) estimate of 2,904 afy of groundwater use in Ivanpah Valley is somewhat higher than that of the Nevada DWR, but in the general range for the sum of estimated groundwater use in the valley. This suggests that groundwater pumpage in Ivanpah North is around 2,000 afy, while that in Ivanpah South is probably close to around 780 afy. However, the value of 751 afy for quasi-municipal use in the data of Nevada DWR (2006) for Ivanpah South suggests that it may not include the 1,560 acre-feet of groundwater use by the Primm Golf Course complex. If that is the case, then groundwater use in Ivanpah South is closer to 2,340 afy, making the total groundwater use for Ivanpah Valley closer to 4,344 afy. As a note, the Primm Golf Course wells are in Ivanpah South near the Molycorp new evaporation ponds (**Figure 7-1**).

Groundwater Underflow: Ivanpah South is a closed basin with a groundwater divide near Cima, California. Glancy (1968) estimated that the groundwater underflow from Ivanpah Valley South to Ivanpah North was about 800 afy. He also estimated that the groundwater underflow from Ivanpah Valley to Las Vegas Valley was about 1,500 afy. Molycorp (2000) has suggested that the Ivanpah fault may act as a partial barrier to groundwater flow. They based this interpretation on a noticeable difference in water levels in monitor wells across the fault near their new evaporation ponds. Also, the State Line fault and the Clark Mountain fault (**Figure 6-2**) may act as partial barriers to groundwater flow. Thus, groundwater underflow in Ivanpah Valley needs to be evaluated with a numerical groundwater flow model. Groundwater underflow estimates based on approximate water balance calculations cannot take into account restrictions on groundwater flow by the major valley faults.

7.4 Water Balance for Ivanpah Valley

Glancy (1968) prepared a water balance for Ivanpah Valley based on the Maxey-Eakin (1949) method for estimating recharge to a desert basin and based on water levels in selected wells and a few estimates of hydraulic conductivity for basin sediments that were available in 1968. His water balance had a recharge of 834 afy for Ivanpah South and a recharge of 685 afy for Ivanpah North. His water balance also included groundwater underflow from Ivanpah South to Ivanpah North at 800 afy and groundwater underflow from Ivanpah Valley to Las Vegas Valley at about 1,500 afy, the total recharge to Ivanpah Valley. He also assumed that the perennial yield of the valley was about half of the recharge, or about 750 afy.

Today, Ivanpah Valley is much different from the relatively remote and uninhabited valley visited by Glancy in 1968. Primm, Nevada, has a major resort/golf course complex, along with casinos. Jean and Goodsprings pump far more water than in 1968. The Primm Golf Course pumps about 1,500 afy from Ivanpah South, and past recharge to Ivanpah South from the Molycorp evaporation ponds is no longer available. Gray water infiltration ponds at Primm and Jean, Nevada, may provide recharge to Ivanpah North. Also, the Molycorp wells have been pumping for over 30 years. Thus, the water balance provided by Glancy (1968) is probably not accurate and requires updating.

One of the principal goals of the groundwater model is to provide a water balance for Ivanpah Valley based on calibration of the numerical groundwater flow model to more current conditions in the valley. Today, groundwater use in Ivanpah Valley is probably around 4,340 afy, which is far more than the recharge estimated by Glancy (1968). Even allowing for recharge from gray water basins at Primm and Jean, Nevada, this may suggest that groundwater underflow from Ivanpah Valley to Las Vegas Valley has been reduced and that water is being removed from storage in the valley to accommodate the increased groundwater demand.

7.5 Aquifer Systems in Ivanpah Valley

Molycorp (2000) indicated that well data near their evaporation ponds suggests that the salt layer at 1,100 feet bgs probably serves as a base to the alluvial aquifer in Ivanpah Valley. They also suggested that the valley aquifer may be 2 aquifers that are interconnected, based in part on the observation that valley sediments have higher hydraulic conductivities at depths less than 100 to 130 feet bgs and that valley sediments become more consolidated at depths between 300 and 500 feet bgs. They divided the valley aquifer into a shallow aquifer and a deep aquifer, the shallow aquifer being at depths of up to about 100 to 130 feet bgs. The deep aquifer would then extend from around 100 to 130 feet bgs to the salt layer at about 1,100 feet bgs. The ground elevation near the Molycorp evaporation ponds is around 2,605 feet amsl, so this places the base of the shallow aquifer at a depth of about 2,470 to 2,500 feet amsl and the bottom of the deep aquifer at a depth of about 1,500 feet amsl.

Hydraulic conductivites for the valley aquifer were measured by Molycorp (2000) in slug tests conducted using the new evaporation pond monitoring wells, and by one pumping test that used well ME-8 as the pumping well. In addition, TRC (2000) reported slug test data from the monitoring wells at the old Molycorp evaporation pond and pumping test data from wells that predated the evaporation ponds. Transmissivities can be estimated from specific capacity data reported for some of the older wells. The hydraulic conductivity measurements are summarized in **Table 7-4** and the specific capacity tests reported by Glancy (1968) and the California DWR (Moyle 1972) are summarized in **Table 7-5**.

The slug tests measured by Molycorp (2000) indicate that hydraulic conductivities for the shallow aquifer near their evaporation ponds range from 1.0×10^{-3} to 1.0×10^{-5} centimeters per second (cm/s), or about 2.83 to 0.0283 feet per day. For the deep aquifer, which ranges from 170 to about 200 feet in the Molycorp (2000) monitor wells, the hydraulic conductivity decreases to around 1.0×10^{-6} cm/s (0.00283 feet per day). A pumping test near the new evaporation ponds using well ME-8 with well screens at 90 to 100 feet bgs and 250 to 260 feet bgs suggested a hydraulic conductivity of 2.39×10^{-2} cm/s (67.64 feet per day) and a storage coefficient of 0.001 for an assumed sand layer about 8 feet in thickness (Molycorp 2000). Pumping test results from pre-existing wells D-1 to D-4 and U-1 suggest sand layers in the aquifer with hydraulic conductivities of 1.35 x 10^{-3} cm/s to 3.88 x 10^{-4} cm/s (3.82 to 1.1 feet per day). Conversion of the slug test conductivities to transmissivities, assuming a tested zone about 25 feet thick (average screen length was 20 feet), would yield a transmissivity in the range of 0.7 to 70 feet squared per day for the shallow aquifer and 0.07 feet squared per day for the deep aquifer. For the pumping test, assuming an 8 foot thick sand zone (Molycorp 2000), the transmissivity would be about 541 feet squared per day at depths from 90 to 260 feet.

Specific capacity tests in various wells belonging to Union Pacific Railroad and Molycorp (**Table 7-5**) show that for productive sand zones at depths of 600 to 735 feet bgs, the transmissivity ranges from about 400 feet squared per day to a maximum of 13,400 feet squared per day, with most values in the range of 1,000 to 2,000 feet squared per day. The shallower Ruoff wells (16N/14E-01J02) at 160 feet bgs gave a transmissivity of 296 feet squared per day. Thus, productive sand zones in the depth range of 100 to 735 feet bgs can have transmissivities in the range of about 300 to 2,000 feet squared per day. Finer-grained sediments near the playa have transmissivities closer to 1.0 to 70 feet squared per day, depending on depth and the lithologic composition of the layer. Transmissivities were calculated from specific capacity tests using the equation for an unconfined aquifer from Driscoll (1989).

Following the results of the Molycorp (2000) aquifer tests, the alluvial aquifer in the groundwater model was divided into a shallow aquifer and a deep aquifer. The deeper more confined aquifer was set to range from about 200 feet bgs near the center of the valley to the depth of the salt layer at 1,100 feet bgs. The upper shallow and unconfined aquifer was set to range from the ground surface to a maximum depth of 200 feet bgs near the center of the valley. Thus, the elevation for the bottom of the shallow aquifer was set around 2,400 feet amsl in the model and the bottom of the deep aquifer was located at 1,500 feet amsl. The base of the groundwater flow regime in Ivanpah Valley was set at 1,500 feet amsl throughout the model under the assumption that the salt layer is continuous throughout the valley at that approximate elevation. The thickness of 200 feet for Layer 1 near the center of the valley, and thus in the vicinity of Ivanpah Lake, was chosen to accommodate the extra thickness of playa clays beneath Ivanpah Lake and still incorporate the change in hydraulic conductivities apparent in the slug test data of Molycorp (2000) that occurs around 100 to 130 feet bgs in the area of Ivanpah Lake.

The data of Molycorp (2000) apply only to Ivanpah South in the vicinity of the old and new evaporation ponds and to maximum depths of about 200 to 400 feet. Many of the productive wells in Ivanpah South are at deeper depths, screened in coarse alluvial sand and gravel zones, and somewhat removed from the Molycorp evaporation ponds. This suggests that the deeper alluvial aquifer has a complex geology and hydrogeology. The groundwater model developed for this study reflects some of the complexity of the deeper alluvial aquifer, but because of the limited amount of data on the deeper alluvial aquifer, the groundwater model will be somewhat preliminary in its ability to estimate groundwater flow paths in the deeper alluvial aquifer. Also, the general sparsity of well data and aquifer tests for Ivanpah North make the groundwater model a general estimate of groundwater flow paths for that part of the valley.

For the mountain ranges, hydraulic conductivities have been reported by Geomega (2000) for the area of Molycorp's Mountain Pass Mine. In addition, the groundwater model for the Mountain Pass Mine developed by Geomega (2000) used a range of hydraulic conductivities to achieve a calibrated flow model for the various bedrock units near the mine. These values are reproduced in **Table 7-6**.

7.6 Wells and Springs in Ivanpah Valley

Figure 7-1 shows the location of selected wells and springs in Ivanpah Valley and the surrounding mountain ranges (spring locations). **Figure 7-2** shows the location of monitoring wells around the Molycorp new and old evaporation ponds (Molycorp 2000). **Tables 7-7** and **7-8** summarize water level, location, ownership, and well depth data available on wells in Ivanpah Valley. The Molycorp (2000) well data have complete geologic logs available for the monitoring wells around the new evaporation ponds and have been summarized in **Table 7-7**. Some of the other wells in Ivanpah Valley have driller's logs available, and these are found in Glancy (1968), Moyle (1972), and TRC (2000). Well depths in the valley alluvium range from 9 feet (DWR-8) to 1,600 feet (DWR-22). Water level depths are also variable, with the deepest water level at 950 feet bgs (GL-17). Water level elevations range from around 2,500 feet amsl for wells near the valley center to 5,100 feet amsl for wells near the mountain fronts or within the mountain ranges.

Table 7-9 contains water level data over time from 1984 to 1999 for Molycorp wells near the old evaporation ponds. These data were compiled from a list of transient calibration targets used by TRC (2000) for their model of Ivanpah South. Wells in this table were used for transient calibration of the Ivanpah groundwater model. **Table 7-10** contains pumping stresses in Ivanpah South available from TRC (2000) that were also used in the transient calibration.

8.0 Conceptual Hydrogeologic Model for Ivanpah Valley

The preceding sections have summarized data and concepts related to groundwater in Ivanpah Valley available in published reports or readily available from agencies or water users in the valley. This section summarizes the important components of the conceptual hydrogeologic model that has been presented in the preceding sections.

Groundwater models are based on the conceptual hydrogeologic model for the system being modeled. For Ivanpah Valley, the following are key components of the conceptual hydrogeologic model:

1. Ivanpah Valley consists of two main basins – Ivanpah South (California portion) and Ivanpah North (Nevada portion).
2. Jean Lake Valley is part of Ivanpah North.
3. Hidden Valley is separate from Ivanpah North and a groundwater divide separates Jean Lake Valley and Hidden Valley.
4. The mountains that surround Ivanpah Valley form groundwater divides. As shown in **Figure 6-1**, the boundaries of the model domain outline the groundwater divides that surround Ivanpah Valley. The mountainous area along the northeast border of the valley with Las Vegas Valley is not a divide in that groundwater underflow is allowed to Las Vegas Valley.
5. Groundwater flow in Ivanpah South is from the mountains toward the center of the valley and then northward into Ivanpah North.
6. Groundwater flow in Ivanpah North is toward the center of the valley from the mountains and then northward toward Jean Lake Valley and into Las Vegas Valley.
7. Recharge in the mountains enters the bedrock in the mountains through fractures and faults and eventually reaches the valley aquifer through groundwater flow from the bedrock to the deeper alluvial aquifer.
8. Runoff from the mountain fronts provides recharge to the shallow alluvial aquifer along the mountain front.
9. Groundwater evapotranspiration does not occur in Ivanpah Valley due to the groundwater being deeper than 60 feet, the maximum extinction depth of phreatophytes.
10. Rain falling on the valley floor either is transpirated by plants or evaporates. Rain falling on the valley floor does not recharge groundwater.
11. The primary mechanism of groundwater discharge is through groundwater pumpage. A secondary discharge mechanism may be groundwater underflow to Las Vegas Valley.
12. The primary mechanisms for groundwater recharge are precipitation in the mountains, mountain-front runoff, and recharge from gray water basins. Precipitation recharge is in the range of 1,900 afy (**Table 7-2**), with about 752 afy in Ivanpah North and 1,184 afy in Ivanpah South. Jean Lake Valley receives about 119 afy.
13. Groundwater pumpage in Ivanpah North is about 2,000 afy.

14. Groundwater pumpage in Ivanpah South probably averages around 2,340 afy and consists of the 780 afy reported by Nevada DWR (2006) plus the pumpage of 1,560 afy by the Primm Golf Course wells. However, as shown in **Table 7-10**, pumpage from 1953 to 1986 was in the range of 484 to 1,242 afy, pumpage from 1986 to 1991 ranged from 900 to 1,600 afy, and pumpage from 1992 to 2005 ranged from 1,300 to 3,200 afy.

15. The alluvial aquifer of Ivanpah Valley consists of two interconnected aquifers: 1) an upper shallow unconfined aquifer about 200 feet in thickness near the center of the valley with a base around 2,400 feet amsl in the model, and 2) a deeper more confined aquifer that extends down to the salt layer from the base of the upper shallow aquifer. The salt layer at 1,100 feet bgs near Ivanpah Lake is considered to be the base of groundwater flow in the valley (Molycorp 2000). This salt layer with a top around 1,500 feet amsl is assumed to be continuous at this elevation throughout the valley.

The basic hydrogeologic model for Ivanpah Valley is a basin closed on the south near Cima, California, and open on the northeast. The valley is surrounded by mountains that act as groundwater divides and provide groundwater recharge through groundwater flow from the mountain bedrock into the deep alluvial aquifer. Groundwater flow is from south to north, from Ivanpah South to Ivanpah North, and then into Las Vegas Valley. Groundwater recharge comes from precipitation and mountain-front runoff, as well as gray water infiltration basins. Groundwater discharge is from springs along the mountain fronts, groundwater pumpage in the valley, especially near Primm, Nevada, and groundwater underflow to Las Vegas Valley. There are no perennial streams in Ivanpah Valley. Recharge to bedrock in the mountains follows the concepts outlined by Maxey and Eakin (1949). The alluvial aquifer of Ivanpah Valley is limited at depth by a thick salt layer at a elevation of about 1,500 feet amsl throughout the valley, and consists of a shallow aquifer about 200 feet in thickness near the center of the valley and a deep aquifer that extends from the base of the shallow aquifer to the top of the salt layer throughout the valley. The shallow and deep alluvial aquifers are in hydraulic communication.

9.0 Groundwater Flow Model

9.1 Introduction

A groundwater model was constructed and calibrated for Ivanpah Valley by Environmental Simulations, Inc. under subcontract to ENSR. The groundwater flow model was based on the conceptual hydrogeological model presented in Section 8.0 and previous sections of this report, and on a previous model of the area of Ivanpah South near the Molycorp new evaporation ponds developed by TRC (2000). The groundwater flow model covers the Ivanpah North, Ivanpah South, and Jean Valley groundwater basins in California and Nevada.

The model was calibrated to steady-state conditions assumed to be prevailing in the late 1960s and early 1970s. This time period was chosen because most of the available water levels were collected in the basin at or before that time. The model was then developed to simulate the transient period from 1972 through 2006. The transient model was calibrated to monitoring and pumping wells located near the Molycorp evaporation ponds because these were the only wells with available transient data (TRC 2000).

9.2 Model Construction

9.2.1 Code Selection

The groundwater model for Ivanpah Valley was constructed using the MODFLOW2000 model (Harbaugh et al. 2000) developed by the USGS. MODFLOW2000 is the latest version of the MODFLOW family of models. MODFLOW is the most popular groundwater flow model used in the United States and has become the standard for groundwater flow modeling in the country. The model was designed using Environmental Simulations' Groundwater Vistas software (Environmental Simulations, Inc. [ESI] 2005), which creates the MODFLOW2000 input files and allows for analysis of the results.

MODFLOW is capable of simulating steady-state or transient groundwater flow in one, two, or three dimensions. A wide variety of boundary conditions may be simulated, including constant head, constant flux (wells, recharge), and head-dependent flux (evapotranspiration, drains, rivers, streams, and general head) boundaries. The types of boundaries used in this model will be described below. MODFLOW can simulate aquifer systems that are unconfined, confined, or a combination of both.

MODFLOW was chosen for this study because it has all of the requisite capabilities to simulate flow in Ivanpah Valley and MODFLOW2000 was chosen in particular because it is the newest and most up-to-date version of MODFLOW. MODFLOW is also thoroughly documented (McDonald and Harbaugh 1988; Harbaugh et al. 2000), and has been extensively tested (Andersen 1993).

9.2.2 The Model Grid

The flow of groundwater can be described using mathematical equations that form the basis for all computer models used in the field of hydrogeology. Computer models may be subdivided into two broad categories, called numerical and analytical models. Analytical models are exact solutions of the groundwater flow equations, and numerical models are approximate solutions. Given the choice between an exact solution and an approximate one, it seems logical that one would choose an analytical model over a numerical model. However, analytical models are usually limited to ideal aquifers that are homogeneous with simple boundaries. Most real world aquifers are not that simple. Consequently, numerical models are used most often in practice.

Because numerical models are approximate, they typically compute hydraulic head (water levels) at fixed points within the aquifer. These points are called nodes or cells, and are often arranged in a rectangular pattern called a grid. There are many different types of numerical techniques that are used to solve the groundwater flow equations. MODFLOW2000 uses a technique called the finite-difference method.

The finite-difference technique requires that the aquifer system be divided into a set of discrete blocks or cells. These blocks are rectangular in shape and form the model grid. The process of creating the grid is called discretization. Water levels computed for a block represent the average water level over that rectangular region of the aquifer. Thus, adequate discretization is required to resolve features of interest, such as the location of the wells, faults, and basin boundaries in Ivanpah Valley.

An algebraic equation that describes groundwater flow is written for each block in terms of the surrounding blocks, and the complete set of linear equations is iteratively solved until the change in head between iterations meets a set criterion. An iterative solution is required because the model is an approximate solution to the groundwater flow equations.

The model grid developed for Ivanpah Valley covers approximately 1,330 square miles. The model domain measures approximately 52 miles from north to south and 25 miles from east to west. The southwest corner of the model grid is located at Easting 2,064,810 feet and Northing 12,784,462 feet. These coordinates are in UTM Zone 11N, NAD 1927, feet.

The model grid spacings vary from 660 feet (1/8 mile) to 4,538 feet. The model grid was finer in the vicinity of the Molycorp evaporation ponds and around the towns of Goodsprings, Jean, Primm, and Nipton. The model grid contains 145 rows, 82 columns, and 2 layers for a total of 23,780 cells. There are 13,668 active cells. The model simulates only the area up to the mountain blocks. Mountain block recharge and mountain-front runoff recharge were applied at the base of the mountain fronts using recharge cells. The model area is shown in **Figure 9-1**. No-flow cells are those outside the active portion of the model grid.

The model was divided into two layers. Layer 1 represents the upper portion of saturated material and was modeled as an unconfined aquifer. The elevation of the top of Layer 1 was interpolated from the USGS digital elevation model (DEM) for the area. The bottom of Layer 1 was assumed to be at an elevation of 2,400 feet amsl, allowing for a thickness of about 200 feet near the center of the valley. Layer 2 represents a confined aquifer with a bottom elevation of 1,500 feet amsl. The base of Layer 2 represents the top of the thick salt deposit (TRC 2000).

9.2.3 Boundary Conditions

Once the aquifer system has been discretized, it is implicitly assumed that groundwater outside the model grid can be ignored. The model, however, must account for areas where groundwater enters or leaves the system. These effects are included in a model using boundary conditions. Ideally, boundary conditions should represent identifiable regional hydrologic features at which some characteristic of groundwater flow is easily described (Franke et al. 1984).

In the case of the current model, the regional hydrologic boundaries for the Ivanpah Valley are the edges of the surrounding mountain blocks or the basin boundaries. The latter occurs, for example, where Ivanpah North borders Las Vegas Valley on the north. Groundwater enters closed basins in California and Nevada in three main ways: 1) recharge from the mountain blocks, 2) infiltration of stream flow, and 3) lateral movement of water from adjacent basins. Groundwater leaves the basins through evapotranspiration by phreatophytes and through direct evaporation from the playa lakes. In the current model, water enters the basin from recharge and stream infiltration that occurs in the mountain blocks. There is no loss of groundwater through evapotranspiration in the basin because of the depth to groundwater, and available data suggest that no groundwater enters from adjacent basins. There is some groundwater discharge into Las Vegas Valley on the north, however.

Numerical groundwater models, such as MODFLOW, use three types of boundary conditions to model ways in which water may enter or leave the model domain. These include the specified head, specified-flux, and head-dependent flux boundaries. A description of each type is given below as applied in the current model. Boundary conditions (including wells) are shown in **Figure 9-2** for Layer 1 and in **Figure 9-3** for Layer 2.

The specified-head boundary condition is called a constant head in MODFLOW. The head or water level at a constant head boundary is specified independently of the simulation results and is fixed at the specified elevation throughout the simulation. Constant head boundaries were not used in the Ivanpah Valley model.

Specified flux boundary conditions are implemented in MODFLOW using wells, recharge, or no-flow (i.e., flux equals zero) cells. Constant flux boundary conditions were used extensively in the Ivanpah Valley model to simulate flow of water into the basin from the mountain blocks. The flow rates were determined from the basin water budget presented in the conceptual model (Section 8.0). This recharge was distributed to Layer 1 in the model, as shown in **Table 9-1**. **Table 9-2** summarizes inflows and outflows for each time period and presents the surplus of water that flows northward to Las Vegas Valley. This table indicates that the increase of pumping in the valley has reduced the amount of water available for migration northward to Las Vegas Valley and today there is a net deficit of water in the basin. **Appendix B** contains the universal transverse mercator (UTM) coordinates for all wells used in the model.

At steady state (circa 1972), mountain block recharge and mountain-front runoff recharge combined were divided into 3 sources, 871 afy for Ivanpah North; 1,184 afy for Ivanpah South; and 119 afy for Jean Valley (**Table 7-2**). These same recharge rates were assumed to be constant during the transient portion of the simulation as well. The recharge was evenly applied to Ivanpah North and Jean Valley, as shown in **Figure 9-4A**. The recharge rates around the edge of Ivanpah South were based on the TRC (2000) model calibration, which varied the recharge rates geographically, based on the size of the drainage basins feeding into Ivanpah South.

Other sources of recharge included the Molycorp evaporation ponds starting around 1980, return flows from Primm Golf Course irrigation, and gray water infiltration ponds associated with municipal areas. The model assumed that 30 percent of water pumped for golf course irrigation was returned back to the water table because of the high evaporation rate in Ivanpah Valley. For municipal water use, it was assumed that 40 percent of the water pumped was returned to the aquifer as gray water infiltration. **Table 9-1** shows all of these components for the steady-state and transient periods.

All of these recharge sources were simulated with the MODFLOW2000 recharge package. **Figure 9-4A** shows the distribution of recharge zones in the model for the steady-state case and the legend relates these areas back to **Table 9-1**. The rates shown in **Figure 9-4A** are in feet per day (the units used in the model) for the steady-state time period. **Figure 9-4B** shows the recharge and return flow sources for the transient case and the legend relates these areas back to **Table 9-1**.

No-flow boundaries are placed in a model where the aquifer is not present or where leakage of water into the model is negligible. No-flow boundaries were placed along the mountain blocks in the model and at basin boundaries.

Head-dependent flux boundary conditions are a hybrid between the specified head and specified flux boundary conditions. In a head-dependent flux boundary, the flux (flow rate) of water into or out of the cell is computed by the model based upon the head calculated for the cell, the head specified for the boundary, and a conductance term. MODFLOW offers five different types of head-dependent flux boundary conditions, including the drain, river, stream, general-head, and evapotranspiration packages. Each type is slightly different. Only general head boundaries were used in the current model, as described below.

General-head boundaries (GHBs) are typically used at the lateral margins of a model to allow groundwater to enter or leave the model domain. GHBs were assigned in the current model to simulate outflow of groundwater to Las Vegas Valley. Heads were assigned to these GHB cells based on water level data from wells outside the basin. The conductance of the GHB cells was based on the transmissivity of the aquifer derived during model calibration. **Figures 9-2** and **9-3** show the location of the GHB cells in Layers 1 and 2, respectively.

The conductance value assigned to each GHB boundary cell is computed using the following equation:

$$C = (K\ w\ l)/D$$

Where C is the conductance value in units of feet squared per day, K is the hydraulic conductivity of the aquifer in units of feet per day, w is the width of the cell in feet, l is the saturated thickness of the cell (feet), and D is the distance to the external head assigned to the GHB (feet).

Ivanpah Valley is heavily faulted, as discussed in Section 6.0 and shown on **Figure 6-2**. Not all of these faults were simulated in the model, however. The Ivanpah fault, the State Line fault, and the Clark Mountain fault were represented in the model, as shown in **Figures 9-2** and **9-3**.

Faults in MODFLOW2000 are simulated using the Horizontal Flow Barrier Package (HFB) of Hsieh and Freckleton (1993). The HFB Package requires a conductance term similar to the GHB Package described above. These conductance values were determined through calibration to match water levels in the vicinity of each fault.

9.2.4 Model Parameters

Model parameters required by MODFLOW2000 for the model include horizontal and vertical hydraulic conductivity values for each cell in the model. Hydraulic conductivity determines the ease with which groundwater flows horizontally. Storage coefficients were also assigned for the transient portion of the model simulation. This section describes the final distribution of parameters in the model derived during calibration. The calibration process will be described in Section 9.3.

The usual philosophy in model construction and calibration is to start with a simple distribution of parameters and add complexity (heterogeneity) as required during calibration. In calibrating the Ivanpah Valley model, the hydraulic conductivity distribution was initially homogeneous by layer; additional hydraulic conductivity zones were added as necessary to match the observed water levels and changes in hydraulic gradient in the valley. The final eleven hydraulic conductivity zones are shown in **Figures 9-5** and **9-6** for Layers 1 and 2, respectively.

The hydraulic conductivity values range from a low of 1.3×10^{-5} feet per day in the southeastern corner of Ivanpah South to a high of 30 feet per day in the central portion of Ivanpah North and the northern portion of Ivanpah South. This is the same area in the TRC (2000) model where high hydraulic conductivity values (25 feet per day in that case) were placed. These high hydraulic conductivities were necessary to match the very low gradient in this portion of the valley. In the area of the Molycorp new Ivanpah evaporation ponds, hydraulic conductivities were low because of the extensive clay and evaporite minerals found beneath the Ivanpah playa. In Layer 1 of the model, the hydraulic conductivity below the Ivanpah playa was set at 0.3 feet per day and for Layer 2 the area below the playa was set at 0.0028 feet per day.

Hydraulic conductivity values were low in the southern portion of the model in order to match very high water levels in those locations. Initially, the conductance of the fault zones were reduced to try to match those water levels. However, it was still not possible to match the high water levels without also reducing the hydraulic conductivity in the south. The same was true around Jean Valley and in the area of Goodsprings to the north.

Storage coefficients were assumed to be homogeneous by layer. The specific yield in Layer 1 was calibrated to be 0.001 and the specific storage of Layer 2 was 1×10^{-5} per foot.

9.3 Model Calibration

9.3.1 Calibration Concepts

It is important to understand the terms and concepts used in describing the calibration effort. Many of these terms come from the statistical literature and some are unique to groundwater modeling. Calibration is the process of adjusting parameters in the model so that the model-computed water levels match water levels measured in wells. Calibrating a groundwater model is difficult because we have relatively little information on subsurface conditions. Most of the parameters in a model, such as hydraulic conductivity, are only known at a few points where measurements have been taken. Even at those “known” points, the measurement of subsurface properties is an inexact science. Thus, calibration is a necessary part of groundwater modeling where the initial estimates of aquifer properties, entered when the model is first created, are changed so that the model computes more realistic water level elevations.

During the calibration, the model-computed water levels are compared to those water levels measured in wells. These measured water levels are called calibration targets, or just targets. The targets represent water levels measured at a particular time during the simulation or they can represent steady-state conditions. In the case of the Ivanpah Valley model, steady-state conditions represent water levels measured prior to the early 1970s when water development in the valley was relatively minor. These water levels are not ideal, however, because they were measured over a wide range in dates and it is not clear how accurate these measurements were.

Accepted practice in groundwater modeling is to match water level elevations in a steady-state calibration and then water level changes during transient calibration. This was the approach taken in the Ivanpah Valley model. Measured water level elevations in feet above sea level were matched by the model for steady-state conditions and then changes in water levels for selected wells were matched transiently. There are two methods to match water level changes. The first is to compute the change in water level from steady-state heads to the point in time where a transient observation is made. This could not be done for the Ivanpah model because none of the wells with transient data had water level measurements in the steady-state period. The second method, and the one used in the current model, is to off-set the hydrographs during calibration so that the first or second point on the curve matches the model and subsequent measurements are compared.

After each simulation, the target water levels are compared to model-computed water levels. The model-computed water levels are subtracted from the field measurements to produce a residual. Positive residuals represent computed water levels that are lower than those measured in the field. Conversely, negative residuals are those where the model is computing water levels higher than the measured ones.

A statistical analysis is performed on the collection of residuals from all targets used in the model (Konikow 1978). Simple statistics such as the mean, standard deviation (sometimes called root mean-square, or RMS error), and absolute mean are commonly used. The mean residual should be close to zero, indicating that the positive and negative residuals are balanced. The absolute mean is computed by making all residuals positive and thus represents the average error in the calibration. These statistical measures are used to determine the quality of the calibration. Goals should be established for acceptable values of the mean, standard deviation, and absolute mean. These goals are discussed later in this chapter.

In addition to statistics computed for residuals, the distribution of residuals should be analyzed during calibration. It is desirable to have positive and negative residuals randomly scattered throughout the model. Clustering of positive or negative residuals over large areas is called spatial bias. One goal of calibration is to reduce spatial bias as much as possible. It is virtually impossible, however, to eliminate spatial bias because of the lack of subsurface data.

In traditional calibration techniques, a relatively small number of zones are used to calibrate the model. Each zone covers many cells in the model and within each zone, properties such as hydraulic conductivity are constant. The result is a piece-wise homogeneous aquifer configuration in which large areas of the each aquifer have homogeneous properties. This was the approach used in the Ivanpah Valley model and is similar to the approach used by TRC (2000) in their model of a portion of Ivanpah South.

9.3.2 Calibration Results

There are many ways to assess the quality of a calibration. The Ivanpah Valley model calibration was assessed by comparing the calibration statistics to the goals used by ESI in all company modeling projects and by a visual comparison of hydrographs at selected wells.

What constitutes an acceptable calibration is very subjective. Woessner and Anderson (1992) suggested that goals should be established before the calibration starts. However, no standards have ever been put forth by American Society for Testing and Materials or in the scientific literature that describe what these goals should be. Goals were established in the protocol for this model, and are based on goals used by ESI in all models and which have undergone peer review from U.S. Environmental Protection Agency and many state government agencies. These goals are summarized as follows:

- Residual standard deviation divided by range in head for all targets should be less than 0.10 (10 percent).
- Absolute residual mean divided by range in head for all targets should be less than 0.10 (10 percent).
- Residual mean divided by range in head for all targets should be less than 0.05 (5 percent).
- There will be limited spatial bias in the distribution of residuals.

As previously discussed, a residual is the difference between a measured water level and the model-computed water level. The residual is calculated as the observed head minus the model computed head. Thus, a negative residual occurs where the model-computed head is too high and a positive residual is where the model-computed head is too low.

The statistical analysis of the regional calibration is provided in **Table 9-3** for both the steady-state and transient calibrations together. The table shows the residual mean, residual standard deviation and absolute residual mean. The residual mean uses both positive and negative residuals and thus should be close to zero if the positive and negative residuals balance each other. The absolute residual mean is computed after all residuals are made positive and is thus an average error in the model. **Table 9-4** shows the mass balance (water balance) for each of the stress periods used in the groundwater model.

The statistics for the Ivanpah Valley model calibration meet the calibration goals described above. The residual mean divided by range in head is 0.01 percent, well below the goal of 5 percent. The standard deviation divided by range in head was 1.5 percent, again well below the goal of 10 percent. The absolute residual mean divided by range in head was 0.8 percent, significantly less than the goal of 10 percent. Therefore, all of these statistical measures are substantially better than the established goals.

In addition to statistics, another standard method of judging calibration quality is to plot the measured water levels versus the computed water levels. In a perfect calibration, the points would lie along a straight line at a 45-degree angle indicating that the computed water levels match the observed water levels exactly. In reality this never happens; however, the spread of data points about the perfect line is an overall indication of spatial bias in the model. **Figure 9-7** shows that there is no large-scale bias in the calibration with each broad area having the same degree of scatter about the 45-degree line. The higher water levels in the regional model represent the southern portion of the model domain, while the lower water levels are found in the northern portions of the model and the center of the valleys.

9.3.3 Groundwater Flow in Ivanpah Valley

Groundwater flows from the southern end of Ivanpah South to the northern end of Ivanpah North. **Figures 9-8A** and **9-9A** show the steady-state calibrated flow field for Layers 1 and 2, respectively. **Figure 9-8B** and **Figure 9-9B** show the calibrated flow field for the current condition in Ivanpah Valley. **Figures 9-8C** and **9-9C** show in detail the potentiometric surface configuration between the Molycorp evaporation ponds and Primm, Nevada. **Figures 9-8D** and **9-9D** show the flow vectors for groundwater under current conditions for Layers 1 and 2, respectively.

Gradients are quite steep in the southern end of Ivanpah South and then become very flat from the area of the Molycorp pumping wells all the way to Jean in the north. In fact, the water table drops about 1,700 feet from the southern edge of the model to the Molycorp wells and evaporation ponds. The water table only drops an additional 75 feet between the Molycorp wells and Jean, Nevada, a greater distance than from the Molycorp wells to the southern model boundary. Gradients are also steep from Goodsprings to Jean and in the Jean Valley.

Residual circles are posted on **Figures 9-8A** and **9-9B** to indicate the distribution of positive and negative errors in the model. Blue circles are where the model-computed water level is too low (positive residual) and red circles indicate areas where the model-computed water level is too high. The size of the circle is somewhat proportional to the error at the target. Larger circles indicate larger errors. The smaller circles, however, have been increased in size so that they can be seen on the map.

The distribution of residual circles is an indication of spatial bias. The distribution of circles shows that in some smaller geographic areas, such as the edges of Ivanpah South, there is some spatial bias. More residuals are high around the edge of Ivanpah South than are low. However, on a basin-wide distribution, there is a good scatter of high and low residuals, especially in the area of low gradient in the central portions of Ivanpah South and Ivanpah North.

Hydrographs for the eight wells used in the transient calibration are shown in **Figures 9-10** through **9-18**. Relatively little data were available for the transient calibration and all were around the Molycorp evaporation ponds. Data for the Molycorp new pond were sparse. Wells ME-3 and ME-4 (**Figures 9-10** and **9-11**) only had two data points. These measurements were before and after the pond was actively infiltrating water. The model does a reasonably good job of matching the decline in water levels over this time period.

Wells IER-2 and IER-3 are between the two Molycorp evaporation ponds and had seven measurements during this time period. Both hydrographs show a general decline in water levels, followed by a slight increase in water level, probably caused by a reduction in pumping by Molycorp. The match between model-computed water levels and measured water levels is acceptable but not exact. The model relied on assumed constant infiltration rates reported by TRC. It is likely that these rates are not very accurate and so the model can only be expected to match general trends.

Figures 9-14 through **9-17** are hydrographs for wells OIEP-5, -7, -8, and -9, respectively. Like wells IER-2 and IER-3, the model-simulated hydrograph generally matches the overall magnitude of the water level changes and the general trends, except for OIEP-8. The match at OIEP-8 is not very good.

The model was also used to evaluate the water budget over time. From **Table 9-2**, it is obvious that the amount of water available for transfer to the Las Vegas Valley should be decreasing with time. **Figure 9-18** is a plot of the model-wide water budget over time. The left side of the graph represents the steady-state period and the right side of the graph is 2006. It is interesting to note that as of 2006, the model predicts that there is still a transfer of water to Las Vegas Valley equal to the steady-state value (see GHB outflow on **Figure 9-18**). While pumping has increased significantly in the valley, it has been offset by recharge from the Molycorp evaporation ponds, during the period when they were operational, and by water coming out of storage.

A transient run was made 200 years into the future assuming current pumping and recharge levels. This run indicated that after 200 years, the flow to Las Vegas Valley was reduced by about 8 percent from the base values. The long-term transient results are very sensitive to choice of specific storage in the aquifer. Reducing the calibrated value by a factor of 10 predicts that flow to Las Vegas Valley would be reduced by 40 percent over 200 years. Reducing specific storage by a factor of 100 predicts that flow to Las Vegas Valley would be stopped and that a slight amount of water would flow from Las Vegas Valley to Ivanpah North after 200 years.

The long-term transient runs suggest that it may take a long time before the effects of increased pumping translate into reduced flow to the north. This happens because of the size of the valley and the time it will take for cones of depression to propagate to the extreme northern end of the valley.

One additional simulation was used to determine the effect of a 5-year drought on the basin. Recharge from precipitation in the mountains and mountain-front runoff was reduced by 50 percent for a period of 5 years. **Figure 9-19** shows the predicted drop in the water table at the end of the fifth year of drought. The maximum decline was 120 feet. However, all of the declines over 1 foot were at the margins of the valley. The water table declined less than 1 foot in the center of the valley. Water level declines in the southwestern part of Ivanpah South were in the range of 10 to 90 feet. North of Goodsprings in Ivanpah North, water level declines ranged from 10 to 70 feet. As shown in **Figure 9-19**, most of Ivanpah Valley was not affected by the decrease in precipitation recharge.

For reference, **Appendix A** and **Table A-1** present a sensitivity analysis conducted on the main input parameters of the groundwater model, mainly hydraulic conductivity, storage, and recharge. **Appendix B** gives the UTM coordinates of monitoring wells used as calibration targets and pumping wells used in the model, along with the UTM coordinates of the recharge basins used for return flow.

10.0 Summary of the Hydrology of Ivanpah Valley

By combining the empirical estimates for the hydrologic properties and processes of Ivanpah Valley with a numerical groundwater flow model, we are in a position to evaluate the flow mechanisms, water balance, and hydrologic properties of Ivanpah Valley in a manner that is not possible with empirical estimates alone. This section summarizes the results of the previous sections in an attempt to integrate the groundwater flow model with empirical data on the valley to achieve a better understanding of the hydrology of Ivanpah Valley.

10.1 Water Balance for Ivanpah Valley

The basin-wide water balance for Ivanpah Valley is summarized in **Table 9-2**. During the pre-1973 steady-state period, the basin had a surplus of about 1,329 afy of water due to precipitation recharge exceeding pumpage. Most of this water flowed northward into Las Vegas Valley. The increase in pumpage, particularly from about 1992 onward to 2005, resulted in a net deficit in water in the basin of about 1,304 afy by 2005. Even with return flows at 40 percent of pumpage, more water was withdrawn from the valley by 1998 than was returned by a combination of recharge and return flows. As shown in **Table 9-2**, the main source of the water deficit is the pumpage in Ivanpah South.

10.1.1 Water Balance for Ivanpah South

Groundwater pumpage in Ivanpah South has come from four main sources: 1) Molycorp's wells, 2) the Whiskey Pete well, 3) the Primm Golf Course wells, and 4) the Colosseum Mine well. As shown in **Table 9-1**, the Molycorp wells were active prior to 1973 during the steady-state period and up to 1998. After 1998, the pumpage has been minimal. The Whiskey Pete well and the Primm Golf Course wells are near the Molycorp new evaporation ponds (**Figure 7-1**) and did not come on-line until after 1992. This was a time of declining pumpage for the Molycorp wells. As shown in **Table 9-2**, total pumpage in Ivanpah South has been increasing since 1973 and has increased from less than 1,000 afy prior to 1980 to over 3,200 afy since 1999. Pumpage from the Colosseum Mine well has been relatively constant and in the range of 500 to 659 afy for most years that the well was active. The Primm Golf Course wells and the Whiskey Pete well have been increasing in pumpage since about 1994 due to the development of resort complexes in Primm, Nevada.

Return flows from the Primm Golf Course were set at 30 percent because of the high evaporation and transpiration rates for this area of southern California. Recharge from the Molycorp evaporation ponds was active from 1988 to 1998 and served to offset the pumpage from the Molycorp wells, the Whiskey Pete well, and the Primm Golf Course wells in terms of the overall water balance. This ceased in 1998. Precipitation recharge and return flows from the Colosseum Mine and the Primm Golf Course are the only major sources of recharge to groundwater resources in Ivanpah South since 1998. Ivanpah South entered a period of possible overdraft starting around 1998.

10.1.2 Water Balance for Ivanpah North

Pumpage in Ivanpah North, including Jean Valley, has also been increasing steadily since 1973. Pumpage since 1999 has been in the range of 2,000 afy with pumpage around Primm and Jean, Nevada, being the major areas of pumpage. Goodsprings has increased pumpage from around 10 to over 100 afy from 1973 to 1999. Pumpage around Jean and Primm is in the range of 600 afy at present. Total mining pumpage distributed along the west side of the valley in the major mining areas is around 300 to 400 afy and light industrial pumpage near Primm is around 150 afy at present (**Table 9-1**).

Returns from gray water basins in Ivanpah North increased substantially starting in 1994 due to the expansion of the casinos. Precipitation recharge has been relatively constant around 871 afy with 752 afy in Ivanpah North proper and 119 afy in Jean Valley. Overall, Ivanpah North has had a net surplus of water that has been steadily decreasing from pre-1972 (steady-state period) to the present. The surplus has been decreasing due to increased pumpage in Ivanpah North; currently Ivanpah North may have a slight deficit in groundwater. For Jean Valley, recharge from precipitation exceeds pumpage at present, so Jean Valley has a net surplus of water.

10.2 Aquifer Properties in Ivanpah Valley

The aquifer properties for Ivanpah Valley determined by model calibration to the steady-state condition prior to 1973 are shown in **Figures 9-5** and **9-6**. These hydraulic conductivities were the result of matching the hydraulic gradient in the valley using the recharge presented in **Table 9-1** and the well pumpage that was active during the steady-state period.

10.2.1 Layer 1

Figure 9-5 shows the modeled hydraulic conductivites for Layer 1 in the groundwater flow model. For Layer 1, the Ivanpah fault appears to separate the basin into two distinct hydrogeologic basins. South of the Ivanpah fault, the alluvial sediments in Layer 1 are quite fine-grained and have an average hydraulic conductivity of about 0.0275 feet per day. This is equivalent to a silty clay. This low hydraulic conductivity is dictated by the steep hydraulic gradient in the southern half of Ivanpah South.

North of the Ivanpah fault, the basin alluvium becomes more conductive and has an average hydraulic conductivity around 1.8 feet per day, which is equivalent to a silty sand. The low hydraulic gradient in the central and northern part of Ivanpah Valley requires a hydraulic conductivity in this range for calibration. This is reasonably consistent with drilling near the Molycorp evaporation ponds, which found abundant fine-grained sediments ranging from sands and silts to clays. Beneath the new evaporation ponds in Ivanpah playa, modeling by TRC (2000) found that a hydraulic conductivity in the range of 1.0×10^{-2} feet per day worked best for the playa clays. Because the groundwater model in this report includes only the top 200 feet of the alluvial aquifer beneath the Ivanpah playa in Layer 1, which is considerably less than that included in Layer 1 of the TRC (2000) model, a hydraulic conductivity around 0.3 feet per day was found to work best for the area beneath the evaporation ponds in the Ivanpah playa. The TRC (2000) model included more fine-grained and compacted material at depth in Layer 1 of its model than are included in Layer 1 of this model. The alluvial fans along the mountain fronts have hydraulic conductivities in the range of 6.5 feet per day, which would correspond to sands and gravelly sands. The valley between the Lucy Grey Range and the McCullough Range has an average hydraulic conductivity around 6.46×10^{-2} feet per day, which is in the range of silty clay. The valley north of Goodsprings also has an average hydraulic conductivity in this range. These hydraulic conductivities are those yielded by the groundwater model in order to match the hydraulic gradient in these areas.

10.2.2 Layer 2

Figure 9-6 shows the modeled hydraulic conductivities for Layer 2. Again, the Ivanpah fault separates Ivanpah Valley into two distinct hydrogeologic basins. South of the Ivanpah fault, hydraulic conductivites are low and average around 2.75×10^{-2} feet per day, the same value found for Layer 1. North of the Ivanpah fault, hydraulic conductivites increase to around 0.7 to 1.1 feet per day, which is equivalent to silty sand. Beneath Ivanpah and Roach lakes, and extending north of Roach Lake in the central part of Ivanpah Valley, there is a zone of high hydraulic conductivity (30 feet per day) in the model, which corresponds to sandy gravel or gravelly sand. This high hydraulic conductivity is dictated in the model by the very low hydraulic gradient in this part of the valley. Beneath the southern part of Ivanpah Lake in the area of the Molycorp new evaporation ponds, modeling by TRC (2000) suggested a clay zone that should have a hydraulic conductivity in the range of 4.0×10^{-3} to 9.0×10^{-3} feet per day. This model calibrated with a hydraulic conductivity around 2.8×10^{-3} feet per day in the area beneath the evaporation ponds. The northern part of Ivanpah North has a relatively high average hydraulic conductivity around 1.3 feet per day. The area between the Lucy Grey Range and the McCullough Range has a relatively low hydraulic conductivity of 2.0 x 10^{-2} feet per day, which is equivalent to clay.

The groundwater flow model, in an effort to match the high hydraulic gradient in the southern part of Ivanpah South and the relatively low hydraulic gradient in the central part of Ivanpah Valley and in Ivanpah North, has suggested that Ivanpah Valley is divided into two separate basins hydrogeologically by the Ivanpah fault. The area south of the Ivanpah fault has relatively fine-grained alluvial sediments. The area north of Ivanpah fault, and especially Ivanpah North has relatively coarser-grained alluvial sediments and a low hydraulic gradient. The model suggests that the central part of Ivanpah Valley, beneath playas at Ivanpah Lake and Roach Lake, may contain a sandy gravel zone at depths of around 200 feet or greater beneath the playas.

10.2.3 Comparison to Aquifer Test Data

For comparison, aquifer slug tests conducted by Molycorp in the shallow part of the aquifer (Layer 1) near their evaporation ponds yielded estimated hydraulic conductivities in the range of 1.06 x 10^{-3} cm/s (3.03 feet per day) to 4.06 x 10^{-5} cm/s (0.12 feet per day) (**Table 7-4**). The model estimated an average hydraulic conductivity of 1.8 feet per day in this area (**Figure 9-5**). The model included the TRC (2000) lower conductivity zone beneath the Molycorp evaporation ponds, although at a higher conductivity value than used by TRC (2000) because of the limited depth used for Layer 1 in the model, as discussed above in Section 10.2.1. The deep completions near the Molycorp evaporation ponds gave estimated hydraulic conductivities in the range of 1.6 x 10^{-6} cm/s (4.6 x 10^{-3} feet per day) to 3.1 x 10^{-6} cm/s (8.9 x 10^{-3} feet per day) from slug tests. A single pumping test in permeable sands in this area gave an estimated hydraulic conductivity of 2.39 x 10^{-2} cm/s (68.3 feet per day). The model estimated an average hydraulic conductivity in this area of about 30 feet per day with a bordering area of 1.1 feet per day (**Figure 9-6**). This is higher than the slug test range for hydraulic conductivity but between the slug test results and the pumping test results. The model incorporated the TRC (2000) low conductivity zone between the new and old Ivanpah evaporation ponds, as shown in **Figure 9-6**. Also, the specific capacity well test data for the Molycorp water wells (**Table 7-5**) suggests a large range in transmissivity for deep wells in the area of the evaporation ponds. Most likely, there is considerable interlayering and interfingering of sands, gravels, and clays in the area of the evaporation ponds and Ivanapah Lake. The groundwater model is averaging these complex hydrostratigraphic units in its attempt to match the groundwater gradients. The central zone of high hydraulic conductivity (30 feet per day) beneath Ivanpah Lake and Roach Lake found in the groundwater model is reflected in the high hydraulic conductivity and transmissivity values found in the well tests conducted on water supply wells in this area.

10.3 Groundwater Flow Patterns in Ivanpah Valley

10.3.1 Steady-State Condition

Groundwater flow in Ivanpah Valley under steady-state conditions is illustrated in **Figure 9-8A** for Layer 1 and in **Figure 9-9A** for Layer 2. Because both layers are in hydrostatic equilibrium under steady-state conditions, the potentiometric surfaces are essentially the same in both layers. The potentiometric surfaces for Ivanpah South are constrained by the Ivanpah fault and the Clark Mountain fault. Flow is from south to north toward and through the Clark Mountain and Ivanpah faults. At the faults, the potentiometric surfaces are bunched, reflecting the low permeability of the fault zones. North of the Clark Mountain fault, the potentiometric surfaces remain closely spaced until they reach the high conductivity zone shown in **Figure 9-5**, where the hydraulic conductivity increases approximately 100 times. Once in the high conductivity zone, the potentiometric surfaces become widely spaced, indicating a much lower gradient and driving force for groundwater flow. Groundwater flow in the northern part of Ivanpah South and the southern part of Ivanpah North, the central part of the valley, is northward toward and past the playas at Ivanpah Lake and Roach Lake. Around Jean, Nevada, groundwater flow in the central part of Ivanpah North converges with flow down the valley northwest of Goodsprings and water flowing northwestward from the area around the Lucy Grey Range. This convergence of flow then turns northeast and heads out of Ivanpah Valley and into Las Vegas Valley.

Groundwater gradients are steep in the valley northwest of Goodsprings, Nevada, due to the low hydraulic conductivity of the sediments. The groundwater gradients become more widely spaced once the central part of Ivanpah North is reached. Flow out of Ivanpah Valley and into Las Vegas Valley is approximately 1,332 afy (GHB Outflow, **Table 9-4**). This is close to the estimate of 1,500 afy of outflow estimated by Glancy (1968; Section 7.4).

10.3.2 Current Condition

Groundwater potentiometric surfaces for Layer 1 are shown in **Figure 9-8B**. For Layer 1, groundwater flow in Ivanpah South to the south of the Clark Mountain fault is similar under current conditions to the steady-state condition shown in **Figure 9-8A**. North of the Clark Mountain fault, flow conditions are also similar to the steady-state condition until the area of the Molycorp evaporation ponds is approached. From the Molycorp evaporation ponds to Primm, Nevada, pumpage by the well fields near the new evaporation ponds and gray water return flow at Primm affect groundwater flow, as shown in **Figure 9-8C**. The well fields for the Primm Golf Course wells and the Whiskey Pete well have a radius of influence of about 3,000 to 4,000 feet that is limited to the general area of the well field. Pumpage by these wells is offset to some degree by return flows from the Primm Golf Course, thus limiting the radius of influence of these wells. Similarly, around Primm groundwater flow in Layer 1 is influenced by return flow.

Groundwater potentiometric surfaces for Layer 2 are shown in **Figure 9-9B**. Like Layer 1, the groundwater flow patterns in Layer 2 are similar to those in Layer 1 for the model domain except around the pumping wells near the Molycorp evaporation ponds. As shown in **Figure 9-9C**, pumpage at the Molycorp wells and in the well field north of the evaporation ponds that contains the Primm Golf Course wells and the Whiskey Pete well affects local groundwater flow near the evaporation ponds and along the west side of the Ivanpah Lake playa between the evaporation ponds and Primm. The radius of influence of the wells in Layer 2 is more extensive than in Layer 1, with the 2,510 foot contour outlining the effective radius of influence of the pumping wells in Layer 2. The absence of offsetting return flows in Layer 2 and the location of the well screens in Layer 2 of the model account for the more extensive range of influence of these wells.

10.4 Surface Water/Groundwater Interaction

Ivanpah Valley is a semi-closed basin where stream flow occurs only during heavy precipitation events and rain or snowmelt from the surrounding mountains descends into the valley along otherwise dry drainages. Severe flooding of the Ivanpah Lake and Roach Lake playas can occur during major storms. Ephemeral stream channels can be overflowing with water for a period of a few hours to most of a 24-hour period. Mountain-front runoff thus provides the main source of stream flow in Ivanpah Valley and the main source of recharge to the shallow groundwater table. Precipitation in the mountains that infiltrates into the bedrock probably recharges the valley alluvium through bedrock groundwater that flows from springs and subsurface interaction between the bedrock and valley alluvial aquifers.

As discussed in Section 7.5, the shallow groundwater table in both Ivanpah North and Ivanpah South lies at depths of 60 to 80 feet. Thus, surface water and groundwater do not have a direct interaction in Ivanpah Valley. Rather, surface water flow during major storm events recharges the shallow groundwater in the valley through infiltration of the mountain-front runoff that generates the surface water flow. The amount of surface water that infiltrates and recharges groundwater, as opposed to surface water that infiltrates and is later evapotranspirated by plants or is simply evaporated, is difficult to quantify. The calibrated groundwater flow model has provided one approach to estimating the amount of groundwater recharge from precipitation in the mountains and mountain-front runoff. For the steady-state case, the recharge inflow is 2,098 afy (**Table 9-4**). In the groundwater model, this recharge was applied along the contact between the mountain fronts and the basin alluvial fans, as shown in **Figure 9-4A**. In reality, the recharge from mountain-front runoff would be distributed along the major ephemeral drainages basinward from the mountains, with most of the recharge occurring within a few miles of the mountain fronts. For the playas, storm water that reaches the playa would probably not recharge the shallow groundwater, but would evaporate. Using **Table 7-2**, where the total precipitation is 345,704 afy for Ivanpah Valley, a recharge to groundwater of 2,098 afy is about 0.61 percent of total precipitation available to the valley.

Another approach to estimating the amount of recharge to groundwater from mountain-front runoff would be that of Savard (1998), where streamflow infiltration and recharge to groundwater were estimated for Fortymile Canyon near Yucca Mountain in Nevada. Although Savard (1998) developed his equations for a specific area in south-central Nevada, the conceptual approach used and the equations developed are considered reasonable for Ivanpah Valley because of the similarity in hydrologic and geologic settings. Savard (1998) used actual stream gage data and estimated the amount of infiltration of stream flow and the recharge to groundwater using the streamflow loss data and changes in water levels in monitoring wells. For Fortymile Canyon, he developed the equation: Recharge = 0.968 x (Streamflow Loss) – 10,000 where the units are in cubic meters. Applying this equation to Ivanpah Valley, the estimated recharge to groundwater from mountain-front runoff can be determined for both runoff estimates using Geomega (2000) and Moore (1968). For Geomega (2000), the average estimated runoff of 7 percent of precipitation was used. **Table 10-1** presents the results of applying the equation of Savard (1998) to the runoff estimates of Geomega (2000) and Moore (1968). The calculations in **Table 10-1** were done in cubic meters and then the recharge was converted to acre-feet to be consistent with the use of acre-feet in other tables.

As shown in **Table 10-1**, the total groundwater recharge for Ivanpah Valley from streamflow infiltration that results from mountain-front runoff ranges from 2,705 afy using the 7 percent average approach from Geomega (2000) to 1,229 afy using the method of Moore (1968). The estimated recharge to Ivanpah Valley from the groundwater model is 2,098 afy, which is about midway between the two estimates in **Table 10-1**. This suggests that the major component of groundwater recharge in Ivanpah Valley is from streamflow infiltration. Thus, mountain-front runoff and the resulting streamflow that infiltrates into the valley alluvium probably provides the majority of recharge to groundwater in Ivanpah Valley.

10.5 Future Development and Water Resources in Ivanpah Valley

Ivanpah Valley may experience substantial commercial and residential development over the next 20 years due to the expansion of the Primm resort community and residential development in Jean and Goodsprings as the population of Clark County grows. In addition, Primm may become the location of the proposed Clark County Ivanpah Airport. The development of the valley may put new pressures on the groundwater resources of Ivanpah Valley.

10.5.1 Ivanpah Airport and Primm Expansion

The main project planned for the development of Ivanpah Valley is the proposed new Ivanpah Airport that would be built north of Primm, Nevada, in Ivanpah North. The airport Environmental Impact Statement is underway and, if approved, the airport would occupy about one-third of the Roach Lake playa northeast of Primm. This is an area prone to flooding during very heavy rainfall events (House 2006) and is also the area of high hydraulic conductivity in Layer 2 of the groundwater flow model. The Ivanpah Airport, if approved, would not be operational until around the year 2017.

Expansion of the resort community at Primm, Nevada, is a probable consequence of economic development and population growth in southern Nevada. Primm may, therefore, need to develop additional water supplies locally. If this additional municipal water should come from the well field in Ivanpah South near the Molycorp evaporation ponds, this would put additional stress on a water resource that may already be facing overdraft.

Both Primm and the proposed Ivanpah Airport may have additional gray water discharge. If this wastewater is discharged to infiltration basins in Ivanpah North, it may partially replenish groundwater withdrawn from the area around Primm. Another option would be to transfer the gray water to Ivanpah South and have the infiltration basins near the well field by the Molycorp evaporation ponds. This would serve to offset the pumpage currently drawing water in this area and may allow for additional pumpage of groundwater from this area to serve Primm.

10.5.2 Expansion of Goodsprings and Jean

Both Goodsprings and Jean, Nevada, may see increased residential development over the next 20 years as the population of Clark County grows. This will place demands on the water supply systems of both communities. As shown in **Figures 9-5** and **9-6**, Jean lies in an area of relatively conductive alluvial material. This should allow for increased groundwater use by Jean to meet the demands of an expanding population. If the population of Jean expands substantially, increased pumpage of groundwater may ultimately reduce the flow of groundwater to Las Vegas Valley.

Goodsprings, on the other hand, lies in an area of where the conductivity of the alluvial material is low and where the alluvial material is underlain at a shallow depth by carbonate bedrock (**Figures 9-5** and **9-6**). Increased groundwater demand in Goodsprings would probably have to be met by developing municipal wells in the carbonate bedrock beneath the valley alluvium.

10.5.3 Development of Ivanpah South

Ivanpah South is divided into two separate hydrogeologic basins by the Clark Mountain and Ivanpah faults, as shown in **Figures 9-5** and **9-6**. South of the Ivanpah fault, the conductivity of the valley alluvium is quite low, averaging around 2.75×10^{-2} feet per day. This will preclude any substantial development of groundwater resources in this part of the valley. Wells drilled and developed for stock water or local domestic use by ranches and farms should be possible, but commercial or municipal development of groundwater resources would probably not be possible.

North of the Ivanpah fault, however, the conductivity of the valley alluvium is much higher and averages around 1.8 feet per day in the top 100 to 130 feet and around 1.0 feet per day in Layer 2 south of Ivanpah Lake, as shown in **Figures 9-5** and **9-6**. From Ivanpah Lake north to the Nevada line and then farther north beneath Roach Lake, Layer 2 in the groundwater model has a zone of high hydraulic conductivity that averages around 30.0 feet per day. This is the area of the current Primm Golf Course wells and the Whiskey Pete well and is the best area in Ivanpah South for additional groundwater development. Currently, pumpage in this area may have overdrafted Ivanpah South. Any additional development of groundwater resources in this area should consider utilization of return flow to the aquifer through infiltration basins to at least partially offset the withdrawal of groundwater.

10.5.4 Groundwater Recharge and Valley Development

As discussed in Section 10.4, the main source of recharge to shallow alluvial groundwater in Ivanpah Valley is mountain-front runoff. This runoff flows down the ephemeral drainages and infiltrates into the valley alluvium, eventually providing the main source of groundwater recharge in the valley. If development of Ivanpah Valley should interfere with this recharge mechanism through diversion of this runoff for commercial or municipal use, or rerouting of this runoff to control flooding, then the recharge of groundwater in the valley could be altered, or possibly even compromised. Preservation of the recharge of groundwater by mountain-front runoff, especially within 5 miles of the mountain fronts, is critical to maintaining recharge to valley groundwater.

10.5.5 Basin Water Quality Patterns

Water quality in Ivanpah Valley varies with location within the basin. A compilation of water quality data from wells in Ivanpah Valley by Moyle (1972) showed that most wells had total dissolved solids (TDS) less than 500 milligrams per liter (mg/L) and water quality dominated by bicarbonate, which generally ranged from 100 to 300 mg/L. Sulfate was generally below 200 mg/L and calcium, sodium, and magnesium each were usually below 100 mg/L. Wells near the playas, especially Ivanpah Lake, could have sulfate up to 1,800 mg/L with TDS up to 13,000 mg/L. Some wells near the playas were dominated by sodium chloride, rather than calcium sulfate. Molycorp (2000) reported TDS near Molycorp's new evaporation ponds of up to 58,000 mg/L, with many values in the 5,000 to 20,000 mg/L range.

Glancy (1968) reported water quality analyses from selected wells in Ivanpah Valley. Most wells located at a distance from the playas had a specific conductance ranging from 464 to 845 microsiemens/cm (TDS of about 324 to 590 mg/L). The waters were bicarbonate dominated with bicarbonate in the range of 100 to 200 mg/L. Sulfate was generally below 100 mg/L and chloride was below 200 mg/L. Two wells near the playas, one near Ivanpah Lake and 1 near Primm had specific conductance values around 19,000 microsiemens/cm (TDS of about 13,000 mg/L) with sodium in the range of 4,600 to 5,000 mg/L. The well near Ivanpah Lake had sulfate around 13,000 mg/L with chloride at 191 mg/L. The well near Primm had sulfate at 1,060 mg/L and chloride at 7,800 mg/L.

Thus, water quality sampling in selected wells during the 1960s and 1970s suggests that groundwater quality in Ivanpah Valley, primarily Ivanpah South, increases in TDS, sulfate, chloride, and alkali metals from the basin margins toward the playas. The playas have very saline groundwater due to dissolution of evaporative salts (Molycorp 2000). As one moves away from the fine-grained clays with interbedded salts that characterize the playas, coarser gravel and sand zones are encountered that have much higher permeability than the playas and water quality that is generally suitable for either domestic or agricultural use.

The groundwater flow patterns presented in **Figure 9-8D** for the shallow alluvial aquifer and in **Figure 9-9D** for the deeper alluvial aquifer in the valley show that groundwater flows from the basin margins toward the basin center and then down the basin axis toward Jean and eventually out of the model domain and into Las Vegas Valley. In the southern part of Ivanpah South, the groundwater model suggests mainly parallel flow of groundwater down the valley toward the Clark Mountain fault in both the shallow and deeper aquifer zones. The groundwater gradient is relatively steep due to the low hydraulic conductivity of the aquifer sediments. In the northern part of Ivanpah South and in Ivanpah North, there is more convergence of groundwater flow toward the center of the basin with flow down the center of the basin being driven by a relatively low groundwater gradient. Pumpage of groundwater at the Molycorp wells, at Primm, and at the well field north of the Molycorp new evaporation ponds (Primm Golf Course and Whiskey Pete wells) affects groundwater flow in Layer 2 because these wells are screened mainly in this layer. Pumpage of groundwater at the well field north of the Molycorp new evaporation ponds affects groundwater flow in Layer 1 near the center of the valley.

Wells located in the coarser alluvial sediments along the basin margins would encounter groundwater with low TDS due to recharge of the groundwater by streams entering the valley from the adjacent mountains. Near the center of the baisn in both Ivanpah North and Ivanpah South, groundwater quality would be expected to increase in salinity (TDS) due to reactions along the flow path with aquifer solids. Within and near the playas at Ivanpah Lake and Roach Lake, groundwater quality would be expected to be quite saline, especially in the upper few hundred feet of the basin aquifer. In the deeper high conductivity zone in Layer 2, the water quality may be less saline and suitable for domestic and agricultural use, as is evidenced by the water being pumped by the Primm Golf Course wells and the Whiskey Pete well. Because of the convergence of groundwater flow paths near the center of Ivanpah South and Ivanpah North, saline groundwater and any groundwater contamination introduced near the center of Ivanpah Valley would not be expected to impact wells along the basin margin. Wells located in the southern part of Ivanpah South would be expected to have a water quality dependent on their location. Most samples of groundwater from this area show TDS values generally below 500 mg/L.

Groundwater quality in Ivanpah Valley is governed mainly by location within the valley. Within and near the playas, the groundwater quality can be quite saline, especially in the upper shallow aquifer. Along the center of the valley, but removed some distance from the playas, the water quality can be acceptable for agricultural and industrial use. Along the basin margins, the water quality is generally good and suitable for domestic use. Changes in water quality along the center of the valley would not be expected to affect water quality along the basin margins due to the nature of the groundwater flow paths illustrated in **Figures 9-8D and 9-9D**. However, changes in water quality along the margins of the valley may eventually affect water quality near the center of the valley. Contaminants introduced along the margins of the valley may accumulate near the center of the valley due to the convergence of the groundwater flow paths near the valley center and the low hydraulic gradient down the center of the valley. Also, any contaminants introduced into the shallow alluvial aquifer (Layer 1) near the center of the valley by wastewater infiltration basins, other types of infiltration or detention basins, or groundwater return flow from agricultural practices may eventually affect water quality in the long term near the center of the valley.

10.6 Recommendations

The following recommendations are suggestions to further enhance both the understanding of groundwater resources in Ivanpah Valley and to enhance the management of those water resources as development of the valley proceeds:

1. Complete a detailed hydrogeologic evaluation of the permeable zone in Layer 2 of the groundwater model that lies beneath Ivanpah Lake and Roach Lake and extends north of Roach Lake. This zone has the greatest potential for groundwater development in the valley and is currently the main source of groundwater being extracted from Ivanpah South.

2. Quantify the recharge and return flow mechanisms in both Ivanpah North and Ivanpah South to better understand the recharge to groundwater in the valley. This will help place limits on the amount of groundwater that can be withdrawn for future development in the valley.

3. Consider completing a water quality evaluation of the productive permeable zone and potentially productive zones in Ivanpah North and Ivanpah South indicated by the zone of high permeability in Layer 2 of the groundwater model. This would provide a basis for determining the quality of groundwater that would be available to support valley development.

4. Consider implementing annual monitoring of water levels and water quality in all wells in Ivanpah Valley. Make these data available to regulatory agencies in California and Nevada to better assess the impacts of future development in the valley.

5. Consider updating the groundwater model about every 3 to 5 years based on the level of development in the valley and the additional knowledge gained from hydrologic and hydrogeologic evaluations.

11.0 Response to Public Comments

As a result of a public presentation of the draft version of this report in Victorville, California, during the summer of 2007, a number of verbal and written comments were received. This section presents a response to those comments.

WRITTEN COMMENTS

(1) Pete Penoyer, USNP Mojave Preserve

Summary of key questions:

1. Why was the bedrock-alluvial valley contact modeled as a no-flow boundary? Fracture flow in bedrock can contribute groundwater flow to valley alluvium –was this modeled?
2. Was fracture flow or stream flow down Wheaton Wash to the valley modeled?
3. Faults that parallel the slope of bedrock or the bedrock water table can carry water –were these modeled?

Response: These three comments all center around the concept of modeling fracture flow in bedrock or stream flow in the mountains as part of modeling recharge to the basin. The approach taken in the modeling was a standard approach that applies recharge from the mountains as recharge to the alluvium at the mountain front/alluvial basin contact. Thus, precipitation falling in the mountains, streams flowing out of the mountains in response to precipitation, and fracture flow in the mountains carrying water from precipitation are all modeled as recharge at the mountain front/alluvial basin contact using recharge cells. The amount of recharge applied to each recharge cell is based on the conversion of precipitation in the mountains to recharge using the recharge efficiency factors and the methodology proposed by Maxey and Eakin (1949). In summary, recharge to the basin from precipitation in the mountains and the resulting groundwater flow in the mountains is treated by recharge cells at the mountain front/alluvial basin contact using the method of Maxey and Eakin.

(2) Pam Adams, LVMcCarran Airport

Summary of key points:

1. Comments were all editorial recommendations to remove suggestions that the proposed new Ivanpah Airport may cause growth in the valley that would result in an increase in demand on groundwater resources.

Response: Suggested changes made in revised text.

(3) Terry Katzer, Cordilleran Hydrology

Summary of key points:

1. Main points were that: 1) the acreages used by Glancy (1968) were wrong and on the low side for calculating precipitation recharge; 2) the precipitation database used by Glancy (1968) was outdated and not accurate; 3) that the 8 inch threshold for precipitation recharge should be at 4,500 feet amsl, not the conventional 5,000 feet amsl commonly used. This is part of point #1 because Glancy's acreages were low due to the fact that he did not consider precipitation or acreage below 5,000 feet amsl.

Response: A lengthy response to comments by Terry Katzer and Tim Durbin (comment #14 below) was prepared and is attached at the end of this section on public comments. The methodology for calculating recharge to alluvial basins in the Great Basin is in a state of flux at present. New ideas are being presented and some are being tested in the field. The authors of this report prefer to be conservative and therefore adopted the classical methodology of Maxey and Eakin (1949) and also took the conservative view that in southern California precipitation at low elevations is not likely to recharge groundwater under "normal" or average annual conditions. Under very exceptional periods of rainfall, this conservative approach may not hold. The authors also believe that field data should take precedence in a groundwater model over assumptions about how or where recharge might occur. For these reasons, which are elaborated in the response to Katzer and Durbin at the end of this section on comments, the authors of the report feel the conservative approach taken in the design and calibration of the groundwater model is valid and justified with the available field data.

(4) Tim Durbin, Consulting Hydrologists

Summary of key points:

1. Presented the same argument as Katzer that the acreages of Glancy (1968) were too low because they did not consider recharge from precipitation down to 4,500 feet amsl.

2. Provided a calculation of acreages using the USGS DEM method and showed that by including acreages down to 4,500 feet amsl, and additional 59,402 acres could be added for inclusion in recharge estimates, with 54,914 acres being in Ivanpah South.

   Response: Please see the response to Terry Katzer above and the more extensive response to Terry Katzer and Tim Durbin at the end of this section on public comments (comment #14).

(5) David Hay, TRC

Summary of key points:

1. The New Ivanpah Evaporation Ponds are about 2 miles too far southward in the model relative to correct positions.

2. The playa silts and clays beneath the Ivanpah Ponds and the Golf Course wells are around 400 feet thick, not the 100 feet used in the model. The division of the aquifers into an upper shallow aquifer about 100 feet thick and a deeper aquifer is not consistent with TRC drilling near the Ivanpah Ponds.

3. The New Ponds ceased operation in 1998 and the reference on pgs 9-7 and 10-4 to current recharge from these ponds is not correct.

4. Monitoring data for the Ivanpah Ponds indicate that quarterly monitoring of this area and new monitoring wells are not needed.

5. Conceptualization of the recharge stress/boundary condition is oversimplified in the model, wherein recharge is assumed to be constant with elevation, geomorphology, and time. The model should better quantify recharge for the Ivanpah Basin.

Response: 1) the New Ivanpah Evaporation Ponds were inadvertently placed about 2 miles south of the correct position by our GIS staff. This was corrected in the revised calibration and is reflected in this final report; 2) the thickness of top layer (Layer 1) beneath the Ivanpah Ponds and Golf Course wells is around 200 feet. This thickness was chosen for Layer 1 in the model to be consistent with data in TRC reports showing an upper zone with higher hydraulic conductivity and a lower zone with much lower hydraulic conductivities, based on slug tests in monitoring wells. The break between these zones as shown on **Figures 4-2** and **4-3** in the TRC (2000) modeling report is around 120 feet bgs. ENSR and ESI believe this is a better representation of the hydrostratigraphic layering of Ivanpah South because it honors the definite break in hydraulic conductivities that reflects a change from unconsolidated to more consolidated alluvial material. We utilized this layering for Ivanpah North because we had to no data to suggest otherwise in that part of the basin; 3) the water balance tables show that the New Ponds ceased operation in 1998 and this was included in the modeling. The text was apparently unclear about this and has been corrected; 4) the monitoring data available in Molycorp's reports to the Lahontan Water Quality Control Board show that the groundwater contamination near the Ivanpah New Ponds is localized. The recalibration of the model with the New Ponds in the correct location and Primm Golf Course return flow more accurately located using satellite imagery shows that pumpage from the Golf Course and Whiskey Pete wells should not affect the movement of contaminated groundwater near the New Ponds; 5) recharge in the model followed the standard methodology of Maxey and Eakin (1949) and was intended to be conservative. Reliance was placed on field data for hydraulic parameters in calibrating the model, rather than on assumptions about how and where recharge might occur. Please see the responses to Terry Katzer and Tim Durbin relative to this issue of recharge (Comment #14).

VERBAL COMMENTS AT THE PRESENTATION

1. The grid system. The model used UTM coordinates, but the tables in the report are in state plane grid system. Why the switch?

   Response**:** Groundwater Vistas uses only UTM coordinates. Data presented in the literature were in either state plane or township-range-section coordinates. These were all converted to state plane coordinates and then the state plane coordinates were converted to UTM for use in the groundwater model.

2. Faults. Only one fault in the model had a conductance assigned, the rest were treated as barriers –is that correct?

   Response: Yes. The other faults were treated as restrictions on groundwater flow, but not as barriers to flow.

3. Model recharge from the Primm Golf Course and the Primm gray water basins. The model used 30% for percentage of pumped water that is returned as recharge for the Primm Golf Course and 40% for the Primm gray water basins. Why these percentages?

   Response**:** The percentages chosen for estimated groundwater recharge from golf course irrigation and from gray water basins was intended to be conservative in that the upper limit for recharge from both types of water use was used. For golf course irrigation, it is the practice in southern California and in southern Nevada to maximize irrigation water use by achieving about 70% utilization of irrigation water (Green, R.L. (2005) *Trends in Golf Course Water Use and Regulation in California* available at http://ucrturf.ucr.edu). This means that 70% of the applied water is to go directly to the turf grass and balance losses by evapotranspiration. This leaves about 30% of the applied water to be lost either through evaporation or infiltration. Golf courses also have ponds, lakes, and other artificial water bodies to make the course more difficult. Because golf courses in desert environments are under pressure to maximize use of water, the loss of water to infiltration and evaporation would be kept at a minimum by irrigation at night. Thus, it was assumed that a maximum (conservative estimate) of about 30% of the irrigation water would return to shallow groundwater. For gray water basins, the main loss of water is through evaporation. It was assumed that 60% of water in a basin evaporates, leaving about 40% for infiltration.

4. The Ivanpah new ponds. They are located about 2 miles south of actual location in the model figures – need to be moved.

Response: The ponds have been moved to their correct locations in the revised model that is presented in the final report.

5. Primm Golf Course recharge cells – should be on the California side of the state line.

Response: These have been moved in the revised model. The water balance table has been modified accordingly.

6. Layer 1 beneath the Ivanpah new ponds in the model should be 200 to 300 feet thick, not the 100 feet indicated in the text of the report.

Response: The text of the report presented the model of TRC (2000) for the basin and incorporated the approximate division of the alluvial into an upper unconsolidated layer about 100 to 130 feet thick (Layer 1 in the model) and a much thicker lower consolidated zone (Layer 2 in the model). In the area of the Ivanpah new ponds, Layer 1 is approximately 200 feet thick. As discussed in the text and above under Written Comment #5, it was decided to limit the thickness of Layer 1 to around 200 feet beneath the playas, to reflect the change in hydraulic conductivity in the TRC (2000) data that occurs around 120 to 130 feet bgs.

7. Comment from TRC: the hydraulic conductivity around the Primm Golf Course wells should be 25 feet per day, based on slug tests.

Response: Available hydraulic data near the Primm Golf Course wells from published reports by Molycorp (**Table 7-4**) show that deep completions have slug test results ranging from 0.0089 feet/day (NIEP 4L) to 5.6 x10^{-6} feet/day (NIEP 9L). The Primm Golf Course wells are deep wells that range from 470 feet to 705 feet bgs. The model has the Primm Golf Course wells in a zone in Layer 2 with a hydraulic conductivity of 1.1 feet/day. These wells are located very close to the zone in Layer 2 that has a conductivity of 30 feet/day. Based on the available slug test data, it was decided to keep the wells in the zone with 1.1 feet/day. If the Primm Golf Course wells have a hydraulic conductivity of 25 feet/day based on slug tests, then they are surrounded to the east by lower conductivity sediments, based on the slug test data in the NIEP wells (**Table 7-4**). This would suggest that the golf course wells are screened in a high conductivity channel within the deeper sediments in the basin. This would be consistent with their water production and with the variability in transmissivity of pumping wells in the basin as shown in **Table 7-5**. Successful water production from the basin depends on finding these coarse alluvial channels in the otherwise fine-grained alluvial material. Because the NIEP wells (**Table 7-4**) show relatively low hydraulic conductivity values in the area east of the Primm Golf Course wells, extending the high conductivity (30 feet/day) zone in Layer 2 to the Primm Golf Course wells would not be justified. Also, placing a high conductivity zone beneath the wells would create a problem for the model because we don't know the extent of that alluvial channel. The presence of a high conductivity channel in the Primm Golf Course well area suggests that pumping from these wells will have a more limited areal extent in Layer 2 than shown by the modeling.

8. Comment: Primm gray water basins have been dry for past 2 years.

Response: The model water balance used available published data. If the gray water basins have been dry for the past 2 years, that water may be entering the groundwater system at some other location near Primm, such as a power plant discharge.

9. Comment from TRC: monitor wells on both sides of the State Line fault suggest different water levels and thus that fault may be partial barrier to flow.

Response: This may be correct. However, the calibration based on available well data suggests that the affect of the State Line fault on groundwater flow is not appreciable.

10. TRC comment: text of report suggests that Ivanpah new ponds are still recharging the shallow aquifer.

Response: This has been corrected in the revised report. The tables in the report show that the ponds ceased operation in 1998 and the text now reflects this.

11. Did we model fractured bedrock?

Response**:** No. Only Ivanpah basin was modeled. Recharge in the mountains that affected the valley was modeled with recharge cells along the mountain front. No attempt was made to model fractured bedrock because of the lack of data on the hydraulic properties of the fractures and the complexity of the fracturing.

12. The specific yield used in the model seems to be low.

Response: The specific yield used was based on data available in the USGS and Calif. Division of Water Resources reports and in the reports by TRC (2000) on the Ivanpah pond area.

13. Did we have any hydraulic data on faults?

Response: There are no published studies with hydraulic data for faults in the Ivanpah Valley area.

14. Response to Letters Received from Terry Katzer and Tim Durbin relative to the Water Balance Estimates in the Molycorp Supplemental Environmental Project Numerical Groundwater Flow Model for Ivanpah Valley.

Terry Katzer on July 16, 2007, and Tim Durbin on July 17, 2007, submitted letters to the Lahontan Water Quality Control Board summarizing their objections to the water balance presented in the Molycorp Supplemental Environmental Project Numerical Groundwater Flow Model for Ivanpah Valley (Ivanpah Valley Groundwater Model). Both letters stated that the authors were of the opinion that the recharge estimates from precipitation in the groundwater model and report were low because precipitation below 5,000 feet amsl had not been included in recharge estimates and because the acreages used by Glancy (1968) were low because acreages below 5,000 feet amsl had not been used and because Glancy's (1968) acreages were not based on the more recently available USGS digital elevation maps. Both authors were of the opinion that recharge to Ivanpah Valley was higher than used in the groundwater model and that use of the higher recharge estimates derived from considering acreages and precipitation below 5,000 feet amsl, especially in Ivanpah South, would show that Ivanpah Valley was not approaching an overdraft situation.

I will respond to those letters in two ways. First, I will present the main points of each letter and respond to each point, and then secondly I will present my argument that a calibrated groundwater flow model puts constraints on basin recharge based on field measurements of water levels, geology, and hydraulic properties and that these constraints are better than a "best guess" estimate derived using precipitation verses elevation graphs, estimates of area affected by different precipitation levels, and "recharge efficiency factors". Groundwater models are especially important when there are no other constraints on recharge estimates, which is the case currently for Ivanpah Valley.

I. RESPONSE TO KATZER AND DURBIN

Main Issues Provided by Katzer's July 16 Letter:

1. The acreages in Glancy (1968) are wrong and too low because of the method used by Glancy (1968) to estimate the acreages in each precipitation zone in the mountains.

Response: I would agree that the modern USGS DEM method is more accurate than the older method used by Glancy (1968). However, as I will discuss in my response to Tim Durbin's letter, most of the difference is in Ivanpah South and below 5,000 feet amsl, where precipitation probably does not yield groundwater recharge.

2. Glancy's (1968) precipitation verses elevation data are not correct and not consistent with more modern estimates of precipitation verses elevation for Las Vegas Valley.

Response: I would agree with this comment. But, as stated later in Katzer's letter, ENSR/ESI used precipitation verses elevation data from Geomega (2000) that is more specific to the Ivanpah Valley area. This is found in **Table 7-2** of our report.

3. Groundwater outflow from Ivanpah Valley is model generated, not derived from the inflow =outflow equation used by most hydrologists in estimating water balance.

Response: This is a misconception by Terry Katzer. There is no quantification of outflow from Ivanpah Valley because the vegetation does not intercept the shallow alluvial water table, which is 60 to 80 feet below the surface and thus too deep for most plants to reach. Thus, there is no estimate of outflow from Ivanpah Valley using the traditional method of phreatophyte evapotranspiration (E/T). This E/T discharge is the traditional outflow in most closed basin water balance models and is used to put a constraint on recharge. As Mr. Katzer states, the "recharge efficiency" factors are usually estimated by balancing precipitation and E/T discharge. In Ivanpah Valley, this can not be done. Thus, in Ivanpah Valley, we do not have an outflow or E/T constraint on recharge. Also, in his paper with Donovan (Donovan and Katzer 2000), Terry Katzer states that the recharge to Las Vegas Valley is 57,000 acre-feet/year and the discharge is 53,000 acre-feet/year. This is an imbalance caused by using 6,000 acre-feet/year of inflow from Ivanpah Valley. If the inflow from Ivanpah Valley were 2,000 acre-feet/year (4,000 acre-feet/year less), then recharge would equal discharge in Las Vegas Valley, which is what Donovan and Katzer assumed when they began their estimate of steady-state water balance. Subtracting 4,000 acre-feet/year from the 6,000 acre-feet/year from Ivanpah Valley leaves 2,000 acre-feet/year of inflow from Ivanpah Valley. This just happens to be what ENSR/ESI estimated using the groundwater model in this report for Ivanpah Valley.

4. The 8-inch precipitation threshold should be set a 4,500 feet amsl, as it was for Las Vegas Valley.

Response: The USGS standard, which began with Maxey-Eakin (1949), assumed that 5,000 feet amsl is the lowest elevation that precipitation can recharge groundwater. Evaluation of the Maxey-Eakin method by Avon and Durbin (1994) confirmed that the Maxey-Eakin method is reasonably correct. The use of 4,500 feet amsl for Las Vegas Valley by Donovan and Katzer (2000) is their own personal assumption. It should not be applied to Ivanpah Valley or any other valley without actual field data to support the decision. No such data exist for Ivanpah Valley. ENSR/ESI therefore preferred to use the USGS standard of having the 8-inch precipitation threshold at 5,000 feet amsl for Ivanpah Valley, which corresponded to Glancy (1968). As is stated in the response to Tim Durbin's letter, this is where the difference in recharge estimates for Ivanpah South occur. The ENSR/ESI water balance has no recharge below 5,000 feet. The Katzer/Dubin method does have recharge down to 4,500 feet and thus results in considerably more recharge to Ivanpah South.

5. Other methods used to estimate recharge were incorrect.

Response: Mr. Katzer misunderstood the reason for including the other methods. These additional methods of estimating recharge, summarized in **Table 10-1**, were used to simply illustrate the range of possible values for recharge that could be obtained by different methods and to put a constraint on the range of recharge values that could be used in the groundwater model.

Main Issues Provided by Tim Durbin's July 17 Letter:

Tim Durbin focused on the difference in acreage estimates between Glancy (1968) and using the USGS DEM method. He kindly provided a table illustrating the differences, so I will discuss the main area of difference.

Response: Tim Durbin's table and his letter pointed out that the main difference in acreage estimates for Ivanpah Valley between Glancy (1968) and the USGS DEM method were in Ivanpah South. His table shows that for Ivanpah South, the method of Glancy (1968) is low by 45,625 acres compared to the USGS DEM method for areas below 5,000 feet in Ivanpah South. The total difference for Ivanpah South is 54,914 acres, so the percent of error in Ivanpah South below 5,000 feet amsl is 83%. Thus most of the recharge difference between

Katzer/Durbin and ENSR/ESI lies in the area below 5,000 feet amsl. As stated earlier, ENSR/ESI followed Glancy (1968) and the USGS standard set by Maxey-Eakin (1949) in not using precipitation below 5,000 feet amsl for recharge. Katzer and Durbin deviated from this standard and thus obtained a much higher value for recharge to Ivanpah South (4,000 acre-feet/year verses the ENSR/ESI estimate of 1,200 acre-feet/year). This alone accounts for about 72% of the difference between the ENSR/ESI estimate of recharge to Ivanpah Valley and the Katzer/Durbin estimate. So, the discrepancy between the ENSR/ESI recharge and the Katzer/Durbin estimate of recharge to Ivanpah Valley revolves entirely around whether you allow precipitation below 5,000 feet amsl in Ivanpah South to recharge groundwater. ENSR/ESI do not agree with the Katzer/Durbin approach and until there are field data to suggest otherwise, we prefer to follow the USGS standard established by Maxey Eakin (1949) and not allow recharge below 5,000 feet amsl in desert basins.

II. VALUE OF A GROUNDWATER MODEL IN CONSTRAINING RECHARGE ESTIMATES

Estimates of recharge from mountain precipitation in desert basins have three components to the equation, all of which are either approximations or assumptions. The first is the precipitation verses elevation graph. Often, this graph is derived from stations that either are not in the basin being modeled, or only a few of the stations apply to the basin. The mountainous areas generally don’t have more than one or two stations on the graph, so the graph is an approximation, and when applied to a basin where the stations do not exist, it is an assumption that the graph is applicable. For Ivanpah Valley, only the precipitation verses elevation graph of Geomega (2000) is applicable, and even that graph is an approximation for the valley. Katzer/Durbin did not use this graph in their estimates of recharge. Secondly, the estimate of the area of each precipitation elevation zone is an approximation. Although modern GIS methods allow for accurate measurement of areas in each elevation zone (that is an area between two elevation contours), the assumption in the calculations is that precipitation is uniform across this area. That often is not the case in desert mountains. Thirdly and most importantly, is the “recharge efficiency factor”. This is a rough estimate, a “fudge factor” if you will allow this term, that balances the estimate of discharge from a valley with the precipitation so that precipitation recharge now equals the discharge. If the discharge can be measured for a valley, usually by measuring E/T from vegetation and assuming that this E/T is the bulk of outflow, then the recharge efficiency factor has validity, but only for that valley. Applying a recharge efficiency factor derived in one valley to another valley is quite a stretch and is an assumption. This is what must be done for Ivanpah Valley because we have no way of measuring discharge –there is no vegetation E/T for outflow. Thus, estimating recharge to a valley where you can not quantify discharge is very speculative.

There are three ways to put constraints on valley recharge from mountain precipitation: 1) provide actual field measurements of recharge from stream infiltration, etc., 2) quantify groundwater outflow, usually by vegetation E/T and use that as a constraint, and 3) develop a groundwater flow model that has sufficient water level and aquifer hydraulic property data to constrain the calibration. The groundwater flow model developed by ENSR/ESI constrains recharge in Ivanpah South because of the extensive database provided by Molycorp and TRC for the area around the Ivanpah ponds. Their reports, referenced in our report, provide aquifer hydraulic conductivities, water levels, transient water levels, pumping data, estimates of storage coefficients, and detailed geologic stratigraphy. Also, there are two groundwater models for Ivanpah South – the model developed for the area around the Molycorp ponds by TRC (2000) and the ENSR/ESI model for all of Ivanpah Valley. Both models found that recharge to Ivanpah South comparable to the estimate provided by Glancy (1968) provided the best calibration for both steady-state and transient conditions.

In summary, I would like to review two key points:

1. The main difference between the recharge estimate for Ivanpah Valley by Katzer/Durbin and ENSR/ESI lies in whether one uses the precipitation below the elevation of 5,000 feet amsl for calculating recharge to Ivanpah South. ENSR/ESI chose to follow the USGS standard and not allow recharge from precipitation below the 8-inch threshold at 5,000 feet amsl, as shown in our **Table 7-2**. Katzer/Durbin chose to use elevations below 5,000 feet amsl and applied their estimate of precipitation from a precipitation verses elevation graph from a mountain range in Las Vegas Valley.

2. A groundwater model calibrated using an extensive database of water level and aquifer property measurements, that is actual field data, provides a constraint on any recharge estimate. For Ivanpah Valley, and especially Ivanpah South, the groundwater model of ENSR/ESI and that of TRC (2000) both agree that the recharge to Ivanpah South should be in a range comparable to that estimated by Glancy (1968) and shown in our **Table 7-2**.

Therefore, I respectfully disagree with Katzer and Durbin that the ENSR/ESI report and groundwater flow model should be modified to incorporate their assumptions about recharge to Ivanpah Valley. Our groundwater flow model constrains estimates of recharge to Ivanpah Valley, especially Ivanpah South, and thus provides a better estimate of recharge to the valley.

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TABLES

Table 7-1 Maxey-Eakin method for estimating groundwater recharge Ivanpah Valley, California and Nevada

Ivanpah Valley
Nevada Portion

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Above 8,000	30	>20	1.8	54	20	10.8
7,000-8,000	780	15 to 20	1.5	1,170	15	175.5
6,000-7,000	3,100	12 to 15	1.1	3,410	7	238.7
5,000-6,000	10,840	8 to 12	0.8	8,672	3	260.16
Below 5,000	135,940	<8	0.5	67,970	0	0
Subtotal	**150,690**			**81,276**		**685**

Ivanpah Valley
California Portion

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Above 7,000	370	>15	1.5	555	15	83.25
6,000-7,000	1,830	12 to 15	1.1	2,013	7	140.91
5,000-6,000	25,410	8 to 12	0.8	20,328	3	609.84
Below 5,000	259,780	<8	0.5	129,890	0	0
Subtotal	**287,390**			**152,786**		**834**
Total Ivanpah Valley	**438,080**			**234,062**		**1,519**

Jean Lake Valley

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Above 6,000	460	>12	1.1	506	7	35.42
5,000-6,000	2,170	8 to 12	0.8	1,736	3	52.08
Below 5,000	60,140	<8	0.5	30,070	0	0
Total Jean Lake Valley	**62,770**			**32,312**		**88**

Hidden Valley

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Percent of Precipitation	Acre-Feet per Year
Below 5,000	21,700	<8	0.5	10,850	0	0
Total Hidden Valley	**21,700**			**10,850**		**0**

Source: Glancy (1968)

Table 7-2 Modified Maxey-Eakin Recharge
Ivanpah Valley California and Nevada

Ivanpah Valley
Nevada Portion

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Recharge Efficiency Factor	Acre-Feet per Year
Above 8,000	30	16 to 20	1.36	41	11.65%	4.8
7,000-8,000	780	14 to 16	1.27	991	9.65%	95.6
6,000-7,000	3,100	12 to 14	1.1	3,410	6.50%	221.6
5,000-6,000	10,840	10 to 12	0.94	10,190	4.22%	429.8
Below 5,000	135,940	<8	0.77	104,674	0	0
Subtotal	**150,690**			**119,305**		**752**

Ivanpah Valley
California Portion

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Recharge Efficiency Factor	Acre-Feet per Year
Above 7,000	370	14 to 16	1.27	470	9.65%	45.3
6,000-7,000	1,830	12 to 14	1.1	2,013	6.50%	130.8
5,000-6,000	25,410	10 to 12	0.94	23,885	4.22%	1,007.4
Below 5,000	259,780	<8	0.77	200,031	0	0.00
Subtotal	**287,390**			**226,399**		**1,184**
Total Ivanpah Valley	**438,080**			**345,704**		**1,935**

Jean Lake Valley

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Recharge Efficiency Factor	Acre-Feet per Year
Above 6,000	460	12 to 14	1.1	506	6.50%	32.9
5,000-6,000	2,170	10 to 12	0.94	2,040	4.22%	86.0
Below 5,000	60,140	<8	0.77	46,308	0	0
Total Jean Lake Valley	**62,770**			**48,854**		**119**

Hidden Valley

		Estimated Annual Precipitation			**Estimated Recharge**	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Recharge Efficiency Factor	Acre-Feet per Year
Below 5,000	21,700	<8	0.77	16,709	0	0
Total Hidden Valley	**21,700**			**10,850**		0

Note: (1) Precipitation based on equation of Geomega (2000); (2) Recharge efficiency factors from Katzer and Donovan (2003).

Sources(s): Glancy (1968); Geomega (2000); Katzer and Donovan (2003)

Table 7-3 Ivanpah Valley Springs

Spring Name	Map Ref	Elevation	State Plane Coord			T	R	S		Flow Rate	Date of	Source Info
	(Fig 7-1)	(amsl)	Northing	Easting						(gpm)	Meas.	
Burro	S1	4440	166,665	537,500		13N	14E	14P		dry	Dec-69	Calif. DWR 91-21
Butcher Knife	S2	5354	176,667	559,998		13N	15E	4P		0.56	Dec-69	Calif. DWR 91-21
Cottonwood	S3	5274	171,249	554,581		13N	15E	8E		0.28	Dec-69	Calif. DWR 91-21
Honwood	S4	5320	170,415	553,497		13N	15E	8E		0.47	Dec-69	Calif. DWR 91-21
Cabin	S5	5480	166,665	552,498		13N	15E	18B		0.06	Dec-69	Calif. DWR 91-21
Cut	S6	5160	192,498	508,333		14N	13E	23R		0.13	Dec-69	Calif. DWR 91-21
Garvanza	S7	4360	192,500	570,830		14N	15E	23K		0.19	Dec-69	Calif. DWR 91-21
Sacaton	S8	4200	190,832	556,831		14N	15E	29		0.06	Dec-69	Calif. DWR 91-21
Slaughterhouse	S9	4120	207,333	592,500		14N	16E	9D		0.38	Dec-69	Calif. DWR 91-21
Mineral	S10	4360	240,165	597,915		15N	14E	2		0.1	Dec-69	Calif. DWR 91-21
Wheaton	S11	4480	257,500	531,665		15N	16E	64B		0.56	Dec-69	Calif. DWR 91-21
Willow	S12	4540	217,916	610,416		15N	16E	36A		0.12	Dec-69	Calif. DWR 91-21
Dove	S13	5000	222,915	615,416		15N	17E	19N		0.94	Jan-70	Calif. DWR 91-21
Mescal	S14	4840	257,916	516,667		16N	13E	24L		1.95	Nov-69	Calif. DWR 91-21
BLM S15	S15	4080	257,250	515,416		16N	13E	24Q		0.08	Oct-69	Calif. DWR 91-21
Groaner	S16	4640	255,416	518,332		16N	13E	24		0.63	Nov-69	Calif. DWR 91-21
Unnamed S17	S17	4200	272,915	527,082		16N	14E	20E		0.04	Nov-69	Calif. DWR 91-21
BLM S18	S18	4640	285,833	512,083		17N	13E	26A		2.25	Nov-69	Calif. DWR 91-21
Ivanpah Spring	S19	4130	287,083	518,000		17N	13E	24				Taken from Topo
Whiskey Spring	S20	4100	293,332	515,000		17N	13E	13				Taken from Topo
Cave Spring	S21	5412	225,000	520,834		24S	58E	6				Taken from Topo
Mexican Spring	S22	5735	237,500	517,500		23S	58E	30				Taken from Topo
NinetyNine Spring	S23	6724	255,000	527,000		23S	58E	8				Taken from Topo
Bird Spring	S24	4428	226,670	563,300		24S	59E	4				Taken from Topo
McClanahan Spring	S25	4100	343,750	619,667		26S	61E	8				Taken from Topo
Unnamed Spring	S26	5248	325,000	618,336		26S	61E	32				Taken from Topo
McCullough Spring	S27	4150	326,250	635,832		26S	61E	26				Taken from Topo
Railroad Spring	S28	5412	311,252	616,667		27S	61E	18				Taken from Topo
Pine Spring	S29	5248	299,167	627,083		27S	61E	28				Taken from Topo
Juniper Spring	S30	4592	234,995	625,120		29S	61E	8				Taken from Topo
Indian Spring	S31	5051	227,500	630,830		29S	61E	34				Taken from Topo
Crescent Spring	S32	4264	265,832	621,665		28S	61E	29				Taken from Topo
Burro Spring	S33	5084	265,840	639,992		28S	61E	26				Taken from Topo

SOURCE: Calif DWR (Moyle 1972); Ivanpah and Mesquite 1:100,000 topo maps

TABLE 7-4 Summary of aquifer test data
Ivanpah Valley

WELL NAME	TOTAL DEPTH (feet)	DEPTH TO WATER (feet)	SCREEN INTERVAL (feet)	HYDRAULIC CONDUCTIVITY (cm/sec)	TYPE OF TEST
MOLYCORP NEW EVAPORATION PONDS					
Shallow Completions					
NIEP-1	95	59.65	70 to 95	8.24 - 9.87 E-4	Rising Head Slug Test
NIEP-2	96	54.26	70 to 95	3.64 - 4.06 E-5	Rising Head Slug Test
NIEP-3	95	54.5	70 to 95	1.74 - 2.08 E-4	Rising Head Slug Test
NIEP-4U	105	66.4	90 to 105	1.06 - 1.39 E-3	Rising Head Slug Test
NIEP-5	101	84.8	76 to 101	7.37 - 9.99 E-4	Rising Head Slug Test
NIEP-9U	96	47.41	75 to 95	1.06 - 1.35 E-4	Rising Head Slug Test
NIEP-10U	83	61.7	57 to 82	2.58 - 8.54 E-5	Rising Head Slug Test
NIEP-11	105	85.85	80 to 105	5.54 - 8.72 E-4	Rising Head Slug Test
MW-1	100	49.58	80 to 100	2.85 - 3.34 E-5	Rising Head Slug Test
MW-2	100	47.33	80 to 100	Greater than 1.0 E-3	Rising Head Slug Test
MW-3	100	49.95	80 to 100	Greater than 1.0 E-3	Rising Head Slug Test
MW-4	102	81.25	80 to 100	2.21 - 4.57 E-6	Rising Head Slug Test
Deep Completions					
NIEP-4L	184	78.1	159 to 184	1.64 - 2.07 E-6	Rising Head Slug Test
NIEP-6L	179	52.15	158 to 178	6.6 E-6	Rising Head Slug Test
NIEP-8L	179	84.6	140 to 179	2.55 E-6	Rising Head Slug Test
NIEP -8L (2)				2.39 E-2	Pumping Test (1) Storage Coefficient = 0.001.
NIEP-9L	190	86.2	169 to 189	1.98 E-9	Rising Head Slug Test
NIEP-10L	170	60.25	130 to 170	3.17 E-6	Rising Head Slug Test

Sources: (1) Molycorp (2000); (2) Calif DWR (1972); TRC (2000)

Notes: (1) Assumes 8-foot thick sand layer for calculations
(2) ME-8 used as pumping well. Recovery in NIEP-8L used for analysis.

TABLE 7-4 Summary of aquifer test data
Ivanpah Valley

WELL NAME	TOTAL DEPTH (feet)	DEPTH TO WATER (feet)	SCREEN INTERVAL (feet)	HYDRAULIC CONDUCTIVITY (cm/sec)	TYPE OF TEST
MOLYCORP OLD EVAPORATION PONDS TRC (2000)					
OIEP-1M				2.21-2.42 E-5	Rising Head Slug Test
OIEP-1U				2.61-3.38E-4	Rising Head Slug Test
OIEP-2				2.56-4.01 E-3	Rising Head Slug Test
OIEP-3				8.19 E-4 to 2.98 E-3	Rising Head Slug Test
OIEP-4				1.20-1.24 E-3	Rising Head Slug Test
OIEP-7M				6.36-8.74 E-4	Rising Head Slug Test
OIEP-8				5.61-9.25 E-5	Rising Head Slug Test
OIEP-9				3.32-8.75 E-4	Rising Head Slug Test
OIEP-10				6.36 E-5 to 1.09 E-4	Rising Head Slug Test
PRE-EXISTING WELLS TRC (2000)					
D-1				8.68 E-4	Pumping Test
D-2				3.88-E-4	Pumping Test
D-3				6.7 E-4	Pumping Test
D-4				8.68 E-4	Pumping Test
U-1				1.35 E-3	Pumping Test
IER-1				3.88-4.23 E-5	Slug Test
IEI-2U				3.46 E-4 to 1.88 E-3	Slug Test
IEI-2M				2.72 E-4 to 1.96 E-3	Slug Test
IEI-2L				1.06 E-5 to 1.41 E-3	Slug Test
IEI-5U				7.53 E-3	Slug Test
IEI-5M				8.43 E-4	Slug Test
IEI-5L				1.66 to 2.22 E-4	Slug Test

Sources: (1) Molycorp (2000); (2) Calif DWR (1972); TRC (2000)

Notes: (1) Assumes 8-foot thick sand layer for calculations
(2) ME-8 used as pumping well. Recovery in NIEP-8L used for analysis.

TABLE 7-5 Summary of specific capacity well test data
Ivanpah Valley

WELL NAME	DATE	WELL DEPTH (feet)	STATIC WATER LEVEL (feet)	PUMPING RATE (gpm)	DRAWDOWN (feet)	SPECIFIC CAPACITY (gpm/ft)	TRANSMISSIVITY (feet squared/day)
UNION PACIFIC RAILROAD							
15N/15E-13G01	1905	735	370	147	15	9.8	1,970
15N/15E-13G02	1923	735	367	200	20	10	2,010
15N/15E-13G03	1944	735	367	300	56	5.36	1,077
MOLYCORP							
15N/15E-56J01	1953	735	170	600	9	66.67	13,400
15N/15E-56J01	1970	735	186	400	67.1	5.96	1,198
15N/15E-56J02	1970	735	192.5	340	186.8	1.82	366
15N/15E-57G01	1970	735	90	100	50	2.00	402
RUOFF WELL							
16N/14E-01J02	1970	160	90	45	30.6	1.47	296
UNION PACIFIC RAILROAD							
16N/15E-12Q02	1923	609	270	80	9	8.89	1,787
16N/15E-12Q03	1943	609	325	305	21	14.52	2,919
16N/15E-12Q03	1944	609	367	300	56	5.36	1,077

Equation for Transmissivity: Transmissivity (feet squared/day) = 1500 x (specific capacity in gpm per foot) x (0.134) (Driscoll 1989)

Sources: (1) Glancy (1968); California DWR (1972).

Table 7-6 Aquifer properties bedrock units Molycorp Mountain Pass Mine area

Lithologic Unit	Measured Hydraulic Conductivity (meters/day)	Literature Values for Hydraulic Conductivity (meters/day)	Model Calibrated Parameters Kh (meters/day)	Kv (meters/day)	Sy	Ss
Highly Fractured Precambrian Rock	1.3 to 15.5 average = 3.47	0.3 to 78.0 average = 4.5	0.400	0.04	0.02	0.000001
Moderately Fractured Precambrian Rock	0.00396 to 3.63 average = 0.28	0.0001 to 4.5 average = 0.31	0.080	0.15	0.05	0.000005
Slightly Fractured Precambrian Rock	0.00396 to 3.63 average = 0.275	0.00396 to 3.63 average = 0.275	0.039	0.00043	0.005	0.0000002
Braided Stream Alluvium		0.017 to 16.0 average = 0.10	2.000	1.2	0.2	0.00001
Paleozoic and Mesozoic Sedimentary Rock		0.000043 to 1.96 average = 0.043	0.001	0.0001	0.01	0.0000005
Tertiary Volcanics		0.000001 to 0.041 average = 0.0001	0.001	0.00003	0.05	0.000003
Alluvial Fan Sediments	0.00108 to 0.93 average = 0.11	0.0086 to 0.86 average = 0.09	0.050	0.0016	0.05	0.000003

SOURCE: GEOMEGA (2000)

Table 7-7 Ivanpah Valley Molycorp new evaporation pond wells

Well ID	Map Ref	Elevation	Local Survey Coord.		State Plane Coord		T	R	S	Qtr	Formation Depth		Form. Elev.		Geologic	Screen	Depth	Water	Date of
	(Fig 7-1)	(amsl)	Northing	Easting	Northing	Easting					(feet)		(feet amsl)		Description	Depth	Water	Elev.	Meas.
																(feet)	(feet)	(feet amsl)	
NIEP-1	N-1	2607.8	28924.66	53598.633	284166	564000	16N	15E	9	NE	0	35	2607.8	2572.8	Bn silty CLAY	70-95	71	2536.8	1999
											35	45	2572.8	2562.8	Bn clayey SILT				
											45	95	2562.8	2512.8	Bn sillty CLAY				
NIEP-2	N-2	2608.153	32137.778	52064.415	287916	562500	16N	15E	4	NW	0	95	2608.153	2513.153	Bn silty CLAY	70-95	70	2538.153	1999
NIEP-3	N-3	2608.126	26409.419	50606.284	278000	560166	16N	15E	8	SE	0	95	2608.126	2513.126	Bn silty CLAY	70-95	70	2538.126	1999
NIEP-4U	N-4U	2608.4177	38510.04	45475.27	295250	555416	17N	15E	31	NE	0	70	2608.4177	2538.4177	Bn silty CLAY	90-105	91	2517.4177	1999
											70	75	2538.4177	2533.4177	SAND				
											75	90	2533.4177	2518.4177	Bn silty CLAY				
											90	98	2518.4177	2510.4177	SAND				
											98	100	2510.4177	2508.4177	Bn silty CLAY				
NIEP-4L	N-4L	2607.8861	38513.415	45500.25	295250	555416	17N	15E	31	NE	0	70	2607.8861	2537.8861	Bn silty CLAY	158-183	160	2447.8861	1999
											70	75	2537.8861	2532.8861	SAND				
											75	90	2532.8861	2517.8861	Bn silty CLAY				
											90	98	2517.8861	2509.8861	SAND				
											98	100	2509.8861	2507.8861	Bn silty CLAY				
											100	140	2507.8861	2467.8861	Bn silty CLAY				
											140	150	2467.8861	2457.8861	SAND				
											150	185	2457.8861	2422.8861	Bn silty CLAY				
NIEP-5	N-5	2608.144	32745.366	43654.77	288332	552916	16N	15E	6	cntr	0	25	2608.144	2583.144	Bn silty CLAY	76-100	77	2531.144	1999
											25	48	2583.144	2560.144	Bn clayey SILT				
											48	65	2560.144	2543.144	Bn silty CLAY				
											65	73	2543.144	2535.144	Bn SAND				
											73	85	2535.144	2523.144	Bn silty CLAY				
											85	98	2523.144	2510.144	Bn SAND				
											98	100	2510.144	2508.144	Bn silty CLAY				
NIEP-6L	N-6	2607.5111	29330.83	50547.018	284583	560833	16N	15E	5	SE/SE	0	35	2607.5111	2572.5111	Bn silty CLAY	158-178	160	2447.5111	
											35	50	2572.5111	2557.5111	Bn silty CLAY				
											50	70	2557.5111	2537.5111	Bn clayey SILT				
											70	88	2537.5111	2519.5111	Bn silty CLAY				
											88	152	2519.5111	2455.5111	Bn clayey SILT w/gyp				
											152	180	2455.5111	2427.5111	Bn CLAY				
NIEP-7	N-7	2608.5092	35718.814	50425.878	296667	562083	17N	15E	33	SW	0	73	2608.5092	2535.5092	Bn silty CLAY	73-100	74	2534.5092	1999
											73	88	2535.5092	2520.5092	Bn SAND				
											88	98	2520.5092	2510.5092	Bn silty CLAY				
											98	100	2510.5092	2508.5092	Bn SAND				
NIEP-8L	N-8L	2607.666	27706.663	46512.692	280833	555416	16N	15E	7	SE	0	65	2607.666	2542.666	Bn CLAY	139-179	140	2467.666	1999
											65	105	2542.666	2502.666	Bn SILT				
											105	180	2502.666	2427.666	Bn CLAY				
NIEP-9U	N-9U	2607.595	30319.524	48029.596	286670	557500	16N	15E	5	SW	0	8	2607.595	2599.595	Bn SILT	75-95	76	2531.595	1999
											8	12	2599.595	2595.595	Bn CLAY				
											12	14	2595.595	2593.595	Bn SILT				
											14	30	2593.595	2577.595	Bn CLAY				
											30	50	2577.595	2557.595	Bn SILT				
											50	70	2557.595	2537.595	Bn CLAY				
											70	90	2537.595	2517.595	Bn SAND				
											90	100	2517.595	2507.595	Bn CLAY				
NIEP-9L	N-9L	2607.219	30325.37	48010.74	286670	557500	16N	15E	5	SW	0	180	2607.219	2427.219	Bn CLAY -hard	169-189	170	2437.219	1999
NIEP-10U	N-10U	2608	34927.5	46328.8	290416	556833	16N	15E	5	NW	0	76	2608	2532	Bn silty CLAY	57-82	58	2550	1999
NIEP-10L	N-10L	2607.43	34908.84	46331.598	290416	556833	16N	15E	5	NW	0	240	2607.43	2367.43	Bn CLAY	130-168	64	2543.43	1999
NIEP-11	N-11	2616.5	32710.768	54009.627	288333	565000	16N	15E	4	NE	0	10	2616.5	2606.5	Bn SAND	80-105	81	2535.5	1999
											10	20	2606.5	2596.5	Bn SILT				
											20	30	2596.5	2586.5	Bn CLAY				
											30	72	2586.5	2544.5	Bn SILT				
											72	75	2544.5	2541.5	GRAVEL				
											75	105	2541.5	2511.5	Bn SAND w/silt & clay				

SOURCE: MOLYCORP (2000)

TABLE 7-8 Ivanpah Valley water wells and monitoring wells

Well ID	Map Ref	T	R	S	State Plane Coord		Owner	Top Casing	Depth of	Depth	Water	Date of	Lith Unit
	(Fig 7-1)				Northing	Easting			Well	Water	Elev.	Meas.	
								(feet amsl)	(feet)	(feet)	(feet amsl)		
Molycorp Evap Pond													
(Molycorp (2000))													
Pre-Pond Wells													
1	W-1	16N	15E	17	277,083	633,330					2531		alluvium
2	W-2	16N	14E	11	282,250	544,832					2544		alluvium
3	W-3	16N	14E	1	287,833	550,000					2526		alluvium
4	W-4	17N	14E	36	291,666	550,000	Same as GL-6				2526		alluvium
5	W-5	16N	15E	7	284,750	552,800					2526		alluvium
6	W-6	16N	14E	23	269,166	542,915					2560		alluvium
7	W-7	16N	15E	22	272,500	570,000					2530		alluvium
													alluvium
Molycorp Wells	W-8	15.5N	15E	20	256,250	558,500	Molycorp	2600	735	169	2516		alluvium
Murphy Well	W-9	15.5N	15E	23	255,416	570,083	Murphy	2695	125	98.2	2547		alluvium
USGS Test Well	W-10	15.5N	15E	35	248,400	574,300	USGS	2706	335	335	2371		alluvium
Wells From California													
DWR 91-21													
(Moyle 1972)													
1	DWR-1	13N	14E	11N1	170,832	536,665	Huff	4405	150	67	4338	Jan-70	alluvium
2	DWR-2	13N	14E	11N4	172,082	539,165	Huff	4435	360	56	4379	Jan-70	alluvium
3	DWR-3	13N	15E	04E	178,333	560,416	Huff	5130	160	39	5091	Jan-70	alluvium
4	DWR-4	14N	13E	01K	209,583	512,500	BLM	5045	100	46	4999	Dec-69	alluvium
Valley View Ranch 5	DWR-5	14N	13E	10D	206,667	498,332	Skinner	5110	91	59	5051	Dec-69	alluvium
6	DWR-6	14N	13E	13J	200,000	512,500	Statdler	4580	55	12	4568	Dec-69	alluvium
7	DWR-7	14N	13E	22R	193,332	505,833	Skinner	5120	24	6	5114	Dec-69	alluvium
8	DWR-8	14N	13E	25M	188,750	513,083	Bellview Mine	4960	9	7	4953	Dec-69	alluvium
9	DWR-9	14N	16E	03D	211,500	599,165	Heavy Metals	4270	425	150	4120	Jan-70	alluvium
10	DWR-10	14N	16E	03R	208,333	598,332	BLM	4400	59	58	4342	Jan-70	alluvium
11	DWR-11	15N	14E	22E	225,000	532,332		4420	115	107	4313	Nov-69	alluvium
12	DWR-12	15N	14E	28C	221,665	525,999	Morning Star	4600	67	66	4534	Nov-69	alluvium
13	DWR-13	15N	14E	33C	217,083	527,499	BLM	4540		56	4484	Nov-69	alluvium
14	DWR-14	15N	14E	57K	258,330	531,248	BLM	4150	60	5	4145	Oct-69	alluvium
Well 13G1-15	DWR-15	15N	15E	13G	231,666	576,667	UPRR	2927	735	371	2556	Jan-70	alluvium
Molycorp 16	DWR-16	15N	15E	56J	256,250	558,500	MolyCorp	2705	735	186	2519	Jan-70	alluvium
17	DWR-17	15N	16E	33R	213,332	592,332	Heavy Metals	3885	52	45	3840	Jan-70	alluvium
18	DWR-18	16N	13E	14J	263,332	510,416	Hwy Dept	4730	412	238	4492	Oct-69	alluvium
(2) 2544 19	DWR-19	16N	14E	11J	286,667	532,498	BLM	2750	300	206	2544	Oct-69	alluvium
20	DWR-20	16N	15E	06N	286,000	551,667	BLM	2608	120	90	2518	Nov-69	alluvium
Nipton Well 21	DWR-21	16N	16E	33M	261,666	593,832	Winnefield	3040	590	540	2500	Jan-70	alluvium
(4) 22	DWR-22	17N	14E	36L	291,250	550,000	BLM	2655	1600	131	2524	Oct-69	alluvium

Note: (1) Wells Tabulated from listed references.

TABLE 7-8 Ivanpah Valley water wells and monitoring wells

Well ID	Map Ref	T	R	S	State Plane Coord		Owner	Top Casing	Depth of	Depth	Water	Date of	
	(Fig 7-1)				Northing	Easting			Well	Water	Elev.	Meas.	
								(feet amsl)	(feet)	(feet)	(feet amsl)		
WELLS FROM													
GLANCY REPORT													
Glancy (1968)													
GL-1 (3)	GL-1	16N	14E	1H	288,749	550,000	Ruoff	2630	160	100	2530	1955	alluvium
GL-2 (6)	GL-2	16N	14E	23Q	2,645,166	542,915	Smith	3060	544	515	2545	1953	alluvium
GL-3	GL-3	16N	15E	6P	286,666	553,335	Yates	2615		88	2527	1967	alluvium
GL-4	GL-4	16N	15E	12Q	281,250	580,000	UPRR	2801	609	271	2530	1967	alluvium
GL-5 (21)	GL-5	16N	16E	33L	261,666	593,832	Nipton	3070	650	540	2530	1967	alluvium
GL-6 (9)	GL-6	17N	14E	36M	291,666	550,000	Smith	2665	800	132	2533	1967	alluvium
GL-7	GL-7	23S	61E	19D	432,083	612,500		2675	800	552	2123	1967	alluvium
GL-8	GL-8	24S	58E	26B	395,832	543,330	Goodsprings	3760		54	3706	1967	alluvium
GL-9 (Jean Well)	GL-9	25S	59E	13B	373,333	580,416	Jean	2840	945	365	2475	1958	alluvium
GL-10	GL-10	25S	59E	14B	374,166	575,000	Simon	2890	640	350	2540	1958	alluvium
GL-11	GL-11	25S	59E	14C	373,749	573,082	Hwy Dept	2850	450	354	2496	1967	alluvium
GL-12	GL-12	26S	59E	16C	342,499	562,500	Hwy Dept	2635		115	2520	1967	alluvium
GL-13	GL-13	27S	59E	8C	315,832	570,000	Primm	2602	600	83	2519	1967	alluvium
GL-15	GL-15	25S	60E	10D	379,583	597,082		2784	470	343	2441	1956	alluvium
GL-16	GL-16	24S	61E	20D	400,000	617,916	Wollenzen	3028	640	600	2428	1954	alluvium
GL-17	GL-17	24S	61E	28B	395,500	625,832	Smith	3030	1490	950	2080	1953	alluvium
GL-18	GL-18	25S	61E	5A	384,582	620,832	Wellington	3030	787	599	2431	1960	alluvium
California DWR													
Website Wells													
Mexican Well	DWR-23	16N	14E	31	261,666	520,832	Molycorp	4510		24	4486	1969	alluvium
13	DWR-24	16N	15E	22	272,499	570,000		2630		79	2551	1917	alluvium
14	DWR-25	16N	15E	33	260,000	561,249	Molycorp	2630		84	2546		alluvium
California DWR													
(Calif DWR (1956)													
	DWR-26	26S	59E	2	350,000	572,082	Borax	2722	687	199	2523		alluvium
	DWR-27	26S	59E	34	325,000	565,832	Morgan	2624		91	2533		alluvium
	DWR-28	27S	59E	9X			Calada Club	2650	637	116.7	2533.3	1957	alluvium
	DWR-29	16N	14E	30X			Div. Hwys	4300	140	84.8	4215.2	1954	alluvium
	DWR-30	16N	15E	13B			UPRR	2810	609	325	2485	1953	alluvium
	DWR-31	16N	15E	32K			Smith	2600	430	90	2510	1955	alluvium
Wells From USGS													
WRI 95-4168													
(Burbey 1995)													
Ivanpah Valley Wells	I-1	25S	59E	10	380,000	568,332		3034	939	840	2194		carbonate
near Jean, Nevada	I-2	25S	59E	11	376,667	574,950		2870	800	630	2240		alluvium
	I-3	25S	59E	14	375,000	575,000		2820	785	585	2235		alluvium
	I-4	25S	59E	13	373,330	576,670	Gold Strike	2025	1281	570	1455		alluvium
Las Vegas Valley Wells	L-12	22S	60E	34	454,998	598,749		2525	500	426	2099		carbonate
	L-13	23S	60E	10	443,332	596,665		2788	385				carbonate
	L-14	23S	61E	8	432,500	620,415		2624	755	345	2279		alluvium
	L-15	23S	61E	17	425,000	617,916		2952	670	520	2432		alluvium
WELLS FROM TRC													
TRC (2000)													
LO1S	TRC-8	15.5N	15E	57	254,166	559,166		2703	116.6	155.4	2547.6	1916	
McBride	TRC-2	16N	14E	36	259,168	548,748	McBride	3100	750	500	2600		
QO1S	TRC-15	16N	14E	23	270,000	544,165		3050		490	2560	1953	
Colosseum Well	TRC-24	16N	14E	2	287,500	541,248	Colosseum	2788		281	2507		
Bighorn Power	TRC-27	17N	14E	36	292,500	545,823	Bighorn Pwr	2689	205	155	2534		
Prim Golf Course	TRC-9	17N	14E	36	290,800	545,825	Primm GC	2689	705	168	2521		
Prim Golf Course	TRC-11	17N	14E	36	295,000	545,830	Primm GC	2689	470	151	2538		
	TRC-14	16N	14E	11	282,083	544,580		2754	300	210	2544		

Note: (1) Wells Tabulated from listed references.

TABLE 7-9 Transient calibration targets
Ivanpah Valley

WELL	TOWNSHIP	RANGE	SECTION	STATE PLANE COORDINATES NORTHING (feet)	EASTING (feet)	DATE	WATER LEVEL (feet amsl)
ME-4	16N	15E	16	274,584	565,000	1986	2628.4
						1999	2625
ME-3	16N	15E	21	254,166	562,500	1986	2527.3
						1999	2624.5
IER-3	16N	15E	32	265,000	560,000	1987	2521.3
						1991	2521
						1993	2520.6
						1994	2519.1
						1995	2520.3
						1997	2519.8
						1999	2520.9
IER-2	16N	15E	34	262,500	567,495	1987	2528
						1991	2527
						1993	2526.6
						1994	2525
						1995	2526.4
						1997	2526
						1999	2526.2
OIEP-5	16N	15E	33	261,250	561,665	1984	2529.1
						1991	2525.4
						1993	2524.6
						1994	2622.7
						1995	2524.1
						1997	2526.7
						1999	2521.3
OIEP-7	16N	15E	33	262,082	563,749	1984	2528.2
						1991	2526.5
						1993	2526.2
						1994	2524.4
						1995	2525.8
						1997	2525.5
						1999	2522.9
OIEP-9	16N	15E	33	259,667	562,332	1984	2527.7
						1991	2525.1
						1993	2525
						1994	2524.1
						1995	2523.2
						1997	2522.9
						1999	2521.5
OIEP-8	15.5 N	15E	21	250,000	560,250	1987	2512.5
						1991	2514.6
						1993	2514.4
						1994	2512.3
						1995	2513.6
						1997	2513.6
						1999	2516.6
OIEP-6	16N	15E	33	259,582	563,582	1984	2532.3
						1991	2627.7
						1993	2527.3
						1994	2525.5
						1995	2526.6
						1997	2526.4
						1999	2523

Source: TRC (2000)

TABLE 7-10 Groundwater withdrawal/recharge stresses
Ivanpah Valley

	PUMPING WELLS (ACRE-FEET/YEAR)							SEEPAGE RATES (ACRE-FEET/YEAR)		
YEAR	MOLYCORP WELLS	COLOSSEUM WELLS	PRIMM WELLS WHISKY PETE'S	PRIMM GOLF COURSE WELLS	CALNEVA WELLS	NIPTON WELL	DESERT WELL	NEW PONDS	OLD PONDS NORTH	OLD PONDS SOUTH
1953	484									
1954	484					16.13	24.2			
1955	484					16.13	24.2			
1956	484				1.06	16.13	24.2			
1957	484				1.06	16.13	24.2			
1958	484				1.06	16.13	24.2			
1959	484				1.06	16.13	24.2			
1960	484				1.06	16.13	24.2			
1961	484				1.06	16.13	24.2			
1962	662				1.06	16.13	24.2			
1963	662				1.06	16.13	24.2			
1964	662				1.06	16.13	24.2			
1965	662				1.06	16.13	24.2			
1966	662				1.06	16.13	24.2			
1967	662				1.06	16.13	24.2			
1968	726				1.06	16.13	24.2			
1969	646				1.06	16.13	24.2			
1970	620				1.06	16.13	24.2			
1971	642				1.06	16.13	24.2			
1972	645				1.06	16.13	24.2			
1973	849				1.06	16.13	24.2			
1974	930				1.06	16.13	24.2			
1975	948				1.06	16.13	24.2			
1976	1059				1.06	16.13	24.2			
1977	894				1.06	16.13	24.2			
1978	846				1.06	16.13	24.2			
1979	465				1.06	16.13	24.2			
1980	1174				1.06	16.13	45.17			34.28
1981	1171				1.06	16.13	45.17		6.72	137.12
1982	1188				1.06	16.13	45.17		80.66	137.12
1983	947				1.06	16.13	45.17		80.66	137.12
1984	1242				1.06	16.13	45.17		80.66	137.12
1985	823				1.06	33.6	45.17		80.66	137.12
1986	944				1.06	33.6	45.17		80.66	137.12
1987	768	256			1.06	33.6	45.17		80.66	137.12
1988	766	802			1.06	33.6	45.17	593.67		
1989	766	904			1.06	33.6	45.17	593.67		
1990	713	182			1.06	33.6	45.17	593.67		
1991	501	492			1.06	33.6	45.17	593.67		
1992	531	370	327		1.06	33.6	45.17	593.67		
1993	586	182	327		1.06	33.6	45.17	593.67		
1994	605		618		1.06	33.6	45.17	593.67		
1995	630		647	370	1.06	33.6	45.17	593.67		
1996	570		677	1372	1.06	33.6	45.17	593.67		
1997	503		783	1647	1.06	33.6	45.17	593.67		
1998	242	659	863	1248	1.06	33.6	45.17	178.1		
1999	4.5			1680	1.06	33.6	45.17			
2000										
2001										
2002				1784						
2003				1663						
2004				1615						
2005				1560						

Sources: (1) TRC (2000); (2) MWH (2006) for Primm Golf Course Wells (2002-2005)

Table 9-1. Water Budget (Acre-Feet per Year) for the Ivanpah Valley Groundwater Flow Model.

Pumping Rates

Stress Period	Basin Year	Ivanpah South Molycorp	Ivanpah South Colosseum Mine	Ivanpah South Whiskey Pete Well	Ivanpah South Golf Course	Ivanpah South Calneva	Ivanpah South Nipton	Ivanpah South Desert	Ivanpah North Goodsprings	Ivanpah North Jean	Ivanpah North Primm Municipal	Ivanpah North Mining Total	Ivanpah North Industrial Total	Ivanpah North Domestic Etc	Ivanpah North Jean Valley
1	Steadystate	660.0	0.0	0.0	0.0	1.1	16.1	24.2	10.0	58.0	0.0	0.0	0.0	0	0
2	1973-79	855.8	0.0	0.0	0.0	1.1	16.1	24.2	26.8	154.8	0.0	0.0	0.0	0	0
3	1980-87	1,032.2	0.0	0.0	0.0	1.1	20.7	45.2	58.3	336.3	100.0	50.0	50.0	10	10
4	1988-1991	628.2	595.3	0.0	0.0	1.1	33.6	45.2	83.5	481.5	150.0	100.0	70.0	20	15
5	1992-93	591.0	276.4	327.0	0.0	1.1	33.6	45.2	96.1	520.0	200.0	200.0	100.0	25	20
6	1994-97	577.0	0.0	681.6	847.4	1.1	33.6	45.2	105.0	554.1	400.0	250.0	120.0	30	30
7	1998	242.8	659.2	862.7	1,248.0	1.1	33.6	45.2	110.0	610.0	500.0	300.0	130.0	32	40
8	1999-current	4.5	659.2	862.7	1,660.0	1.1	33.6	45.2	120.0	690.0	610.0	397.0	150.0	36	50

Return Flows (30% for Primm Golf Course and 40% for Municipal and Mine Pumping

Stress Period	Basin Year	Ivanpah South Molycorp*	Ivanpah South Colosseum Mine	Ivanpah North Primm Casinos	Ivanpah South Golf Course	Ivanpah South Calneva	Ivanpah South Nipton	Ivanpah South Desert	Ivanpah North Goodsprings	Ivanpah North Jean	Ivanpah North Primm Municipal	Ivanpah North Mining Total	Ivanpah North Industrial Total	Ivanpah North Domestic Etc	Ivanpah North Jean Valley
1	Steadystate	0.0	0.0	0.0	0.0	0.4	6.5	9.7	4.0	23.2	0.0	0.0	0.0	0.0	0.0
2	1973-79	0.0	0.0	0.0	0.0	0.4	6.5	9.7	10.7	61.9	0.0	0.0	0.0	0.0	0.0
3	1980-87	0.0	0.0	0.0	0.0	0.4	8.3	18.1	23.3	134.5	40.0	20.0	20.0	4.0	4.0
4	1988-1991	0.0	238.1	0.0	0.0	0.4	13.4	18.1	33.4	192.6	60.0	40.0	28.0	8.0	6.0
5	1992-93	0.0	110.6	130.8	0.0	0.4	13.4	18.1	38.4	208.0	80.0	80.0	40.0	10.0	8.0
6	1994-97	0.0	0.0	272.6	254.2	0.4	13.4	18.1	42.0	221.6	160.0	100.0	48.0	12.0	12.0
7	1998	0.0	263.7	345.1	374.4	0.4	13.4	18.1	44.0	244.0	200.0	120.0	52.0	12.8	16.0
8	1999-current	0.0	263.7	345.1	498.0	0.4	13.4	18.1	48.0	276.0	244.0	158.8	60.0	14.4	20.0

* Molycorp returns listed under recharge below

Recharge

Stress Period	Basin Year	Ivanpah South NewPonds	Ivanpah South OldPondsN	Ivanpah South OldPondsS	Ivanpah North Ivanpah North	Ivanpah South Ivanpah South	Ivanpah North Jean Valley
1	Steadystate	0.0	0.0	0.0	752.0	1,184.0	119.0
2	1973-79	0.0	0.0	0.0	752.0	1,184.0	119.0
3	1980-87	0.0	80.7	137.1	752.0	1,184.0	119.0
4	1988-1991	593.7	0.0	0.0	752.0	1,184.0	119.0
5	1992-93	593.7	0.0	0.0	752.0	1,184.0	119.0
6	1994-97	593.7	0.0	0.0	752.0	1,184.0	119.0
7	1998	178.1	0.0	0.0	752.0	1,184.0	119.0
8	1999-current	0.0	0.0	0.0	752.0	1,184.0	119.0

TABLE 9-2: IVANPAH BASIN MASS BALANCE SUMMARY

Mass Balance Summary **IVANPAH BASIN -TOTAL** **Units: acre-feet/year**

Stress Period	Year	Pumping	Recharge	Returns	Surplus
1	Steady-State	769.4	2,055.00	43.8	1,329.40
2	1973-1979	1078.8	2,055.00	89.2	1,065.40
3	1980-1987	1713.7	2,272.80	272.6	831.70
4	1988-1991	2223.3	2,648.70	638.1	1,063.50
5	1992-1993	2435.3	2,648.70	737.7	951.10
6	1994-1997	3674.9	2,648.70	1154.4	128.20
7	1998	4814.5	2,233.10	1703.9	-877.50
8	1999-2005	5319.2	2,055.00	1959.9	-1,304.30

Mass Balance Summary **IVANPAH BASIN -SOUTH** **Units: acre-feet/year**

Stress Period	Year	Pumping	Recharge	Returns	Surplus
1	Steady-State	701.4	1,184.00	16.6	499.20
2	1973-1979	897.2	1,184.00	16.6	303.40
3	1980-1987	1,099.10	1,401.80	26.8	329.50
4	1988-1991	1,303.30	1,777.70	270.1	744.50
5	1992-1993	1,274.20	1,777.70	142.5	646.00
6	1994-1997	2,185.80	1,777.70	286.1	-122.00
7	1998	3,092.50	1,362.10	670	-1,060.40
8	1999-2005	3,266.20	1,184.00	793.6	-1,288.60

Mass Balance Summary **IVANPAH BASIN -NORTH** **Units: acre-feet/year**

Stress Period	Year	Pumping	Recharge	Returns	Surplus
1	Steady-State	68	871	27.2	830.20
2	1973-1979	181.6	871	72.6	762.00
3	1980-1987	614.6	871	245.8	502.20
4	1988-1991	920	871	368	319.00
5	1992-1993	1,161.10	871	595.2	305.10
6	1994-1997	1,489.10	871	868.30	250.20
7	1998	1,722.00	871	1,033.90	182.90
8	1999-2005	2,053.00	871	1,166.30	-15.70

Table 9-3. Water Level Targets for the Ivanpah Valley Groundwater Flow Model.

Name	Time	Easting	Northing	Layer	Observed	Computed	Residual
W-2	Steadystate	2,106,856	12,901,527	1	2,544.0	2,524.4	19.6
W-3	Steadystate	2,112,024	12,907,110	1	2,526.0	2,523.9	2.1
W-4	Steadystate	2,112,024	12,910,943	1	2,526.0	2,524.2	1.8
W-5	Steadystate	2,114,824	12,904,027	1	2,526.0	2,523.1	2.9
W-6	Steadystate	2,104,939	12,888,443	1	2,560.0	2,547.1	12.9
W-7	Steadystate	2,133,967	12,893,941	1	2,530.0	2,537.9	-7.9
W-8	Steadystate	2,119,302	12,881,522	2	2,516.0	2,489.2	26.8
W-9	Steadystate	2,135,352	12,877,127	1	2,547.0	2,553.2	-6.2
DWR-13	Steadystate	2,091,081	12,834,802	1	4,484.0	4,624.6	-140.6
DWR-15	Steadystate	2,138,696	12,850,377	2	2,556.0	2,595.2	-39.2
DWR-16	Steadystate	2,120,823	12,875,527	2	2,519.0	2,464.3	54.7
DWR-17	Steadystate	2,155,102	12,836,536	1	3,840.0	3,932.5	-92.5
DWR-19	Steadystate	2,094,343	12,907,472	1	2,544.0	2,552.0	-8.0
DWR-20	Steadystate	2,113,691	12,905,277	1	2,518.0	2,523.4	-5.4
DWR-21	Steadystate	2,156,895	12,881,952	1	2,500.0	2,574.1	-74.1
GL-1	Steadystate	2,112,024	12,908,026	1	2,530.0	2,524.0	6.0
GL-3	Steadystate	2,115,359	12,905,943	1	2,527.0	2,523.3	3.7
GL-4	Steadystate	2,143,855	12,901,823	2	2,530.0	2,538.7	-8.7
GL-5	Steadystate	2,155,856	12,880,943	1	2,530.0	2,573.5	-43.5
GL-6	Steadystate	2,112,024	12,910,943	2	2,533.0	2,523.3	9.7
GL-8	Steadystate	2,104,698	13,013,298	1	3,706.0	3,714.4	-8.4
GL-9	Steadystate	2,140,301	12,992,057	2	2,475.0	2,486.1	-11.1
GL-11	Steadystate	2,136,723	12,990,571	2	2,496.0	2,496.1	-0.1
GL-12	Steadystate	2,124,680	12,961,242	1	2,520.0	2,517.5	2.5
GL-13	Steadystate	2,121,278	12,935,402	2	2,519.0	2,520.6	-1.6
GL-15	Steadystate	2,159,106	12,998,860	2	2,441.0	2,447.0	-6.0
DWR-24	Steadystate	2,132,478	12,891,776	1	2,551.0	2,538.2	12.8
DWR-25	Steadystate	2,122,954	12,878,939	1	2,546.0	2,527.7	18.3
DWR-26	Steadystate	2,135,240	12,968,943	2	2,523.0	2,515.8	7.2
DWR-27	Steadystate	2,127,856	12,944,277	1	2,533.0	2,519.5	13.5
TRC-8	Steadystate	2,121,960	12,874,559	1	2,547.6	2,529.3	18.3
TRC-2	Steadystate	2,109,536	12,880,375	2	2,600.0	2,530.1	69.9
TRC-15	Steadystate	2,106,144	12,890,212	1	2,560.0	2,524.8	35.2
TRC-24	Steadystate	2,102,981	12,907,407	1	2,507.0	2,526.2	-19.2
TRC-27	Steadystate	2,109,794	12,910,732	1	2,534.0	2,524.6	9.4
TRC-9	Steadystate	2,107,604	12,909,191	2	2,521.0	2,524.8	-3.8
TRC-11	Steadystate	2,107,280	12,913,084	2	2,538.0	2,525.0	13.0
TRC-14	Steadystate	2,105,739	12,900,756	1	2,544.0	2,524.6	19.4
DWR-1a	Steadystate	2,103,461	12,794,536	1	4,338.0	4,211.5	126.5
ME-4	4927.5	2,127,228	12,894,151	1	2,527.4	2,536.7	-9.3
ME-4	9672.5	2,127,228	12,894,151	1	2,524.0	2,537.7	-13.7
ME-3	4927.5	2,124,128	12,889,315	1	2,530.7	2,535.3	-4.6
ME-3	9672.5	2,124,128	12,889,315	1	2,527.9	2,530.1	-2.2
IER-3	5292.5	2,121,565	12,881,838	1	2,529.0	2,543.6	-14.6
IER-3	6752.5	2,121,565	12,881,838	1	2,528.7	2,525.1	3.6
IER-3	7482.5	2,121,565	12,881,838	1	2,528.3	2,525.2	3.1
IER-3	7847.5	2,121,565	12,881,838	1	2,526.8	2,525.3	1.5
IER-3	8212.5	2,121,565	12,881,838	1	2,528.0	2,525.4	2.6
IER-3	8942.5	2,121,565	12,881,838	1	2,527.5	2,525.6	1.9
IER-3	9672.5	2,121,565	12,881,838	1	2,528.6	2,525.0	3.6
IER-2	5292.5	2,129,128	12,883,036	1	2,535.6	2,551.7	-16.2
IER-2	6752.5	2,129,128	12,883,036	1	2,534.6	2,540.4	-5.8
IER-2	7482.5	2,129,128	12,883,036	1	2,534.2	2,540.4	-6.3
IER-2	7847.5	2,129,128	12,883,036	1	2,532.6	2,540.5	-7.9
IER-2	8212.5	2,129,128	12,883,036	1	2,534.0	2,540.5	-6.6
IER-2	8942.5	2,129,128	12,883,036	1	2,533.6	2,540.7	-7.1

Name	Time	Easting	Northing	Layer	Observed	Computed	Residual
IER-2	9672.5	2,129,128	12,883,036	1	2,533.8	2,539.6	-5.8
OIEP-5	4197.5	2,123,107	12,880,391	1	2,534.0	2,563.3	-29.3
OIEP-5	6752.5	2,123,107	12,880,391	1	2,530.3	2,529.0	1.3
OIEP-5	7482.5	2,123,107	12,880,391	1	2,529.5	2,529.1	0.4
OIEP-5	7847.5	2,123,107	12,880,391	1	2,527.6	2,529.2	-1.6
OIEP-5	8212.5	2,123,107	12,880,391	1	2,529.0	2,529.3	-0.3
OIEP-5	8942.5	2,123,107	12,880,391	1	2,531.6	2,529.5	2.1
OIEP-5	9672.5	2,123,107	12,880,391	1	2,526.2	2,529.1	-2.9
OIEP-7	4197.5	2,126,683	12,881,398	1	2,534.4	2,562.7	-28.3
OIEP-7	6752.5	2,126,683	12,881,398	1	2,532.7	2,535.1	-2.5
OIEP-7	7482.5	2,126,683	12,881,398	1	2,532.4	2,535.2	-2.8
OIEP-7	7847.5	2,126,683	12,881,398	1	2,530.6	2,535.2	-4.7
OIEP-7	8212.5	2,126,683	12,881,398	1	2,532.0	2,535.3	-3.3
OIEP-7	8942.5	2,126,683	12,881,398	1	2,531.7	2,535.5	-3.8
OIEP-7	9672.5	2,126,683	12,881,398	1	2,529.1	2,534.8	-5.7
OIEP-9	4197.5	2,126,725	12,878,969	1	2,535.8	2,566.3	-30.5
OIEP-9	6752.5	2,126,725	12,878,969	1	2,533.2	2,535.3	-2.1
OIEP-9	7482.5	2,126,725	12,878,969	1	2,533.1	2,535.3	-2.2
OIEP-9	7847.5	2,126,725	12,878,969	1	2,532.2	2,535.3	-3.2
OIEP-9	8212.5	2,126,725	12,878,969	1	2,531.3	2,535.4	-4.2
OIEP-9	8942.5	2,126,725	12,878,969	1	2,531.0	2,535.6	-4.6
OIEP-9	9672.5	2,126,725	12,878,969	1	2,529.6	2,535.2	-5.6
OIEP-8	5292.5	2,122,549	12,877,291	2	2,480.5	2,439.3	41.2
OIEP-8	6752.5	2,122,549	12,877,291	2	2,482.6	2,451.2	31.4
OIEP-8	7482.5	2,122,549	12,877,291	2	2,482.4	2,454.6	27.8
OIEP-8	7847.5	2,122,549	12,877,291	2	2,480.3	2,456.0	24.3
OIEP-8	8212.5	2,122,549	12,877,291	2	2,481.6	2,457.2	24.4
OIEP-8	8942.5	2,122,549	12,877,291	2	2,481.6	2,459.0	22.6
OIEP-8	9672.5	2,122,549	12,877,291	2	2,484.6	2,470.5	14.1
Residual Mean							**-0.26**
Residual Standard Deviation							**29.83**
Absolute Residual Mean							**16.54**
Minimum Residual							**-140.59**
Maximum Residual							**126.53**
Range in Water Levels							**2043.00**
Residual Mean/Range							**-0.01%**
Standard Deviation/Range							**1.46%**
Absolute Residual Mean/Range							**0.81%**

Table 9-4. Summary of Model Mass Balance for Each Time Step (units are Acre-Ft/Year)

Time	Storage Inflow	Recharge Inflow	Total Inflow	Storage Outflow	Well Outflow	GHB Outflow	Total Outflow	Error
SteadyState	0	2,098	2,098	0	769	1,331	2,100	-2
99	297	2,144	2,441	35	1,079	1,331	2,445	-3
218	295	2,144	2,439	25	1,079	1,331	2,434	5
359	286	2,144	2,429	21	1,079	1,331	2,431	-2
529	281	2,144	2,424	17	1,079	1,331	2,427	-2
733	278	2,144	2,421	12	1,079	1,331	2,422	0
978	276	2,144	2,420	9	1,079	1,331	2,419	1
1,272	272	2,144	2,415	7	1,079	1,331	2,416	-1
1,625	271	2,144	2,414	5	1,079	1,331	2,415	0
2,048	269	2,144	2,413	4	1,079	1,331	2,414	-1
2,556	269	2,144	2,413	3	1,079	1,331	2,413	0
2,668	763	2,545	3,308	264	1,714	1,331	3,309	-1
2,803	701	2,545	3,246	204	1,714	1,331	3,249	-3
2,965	659	2,545	3,204	160	1,714	1,331	3,205	-1
3,160	627	2,545	3,172	127	1,714	1,331	3,172	0
3,393	601	2,545	3,146	103	1,714	1,331	3,148	-2
3,673	582	2,545	3,127	82	1,714	1,331	3,127	0
4,009	565	2,545	3,110	66	1,714	1,331	3,111	0
4,412	552	2,545	3,097	51	1,714	1,331	3,096	0
4,896	542	2,545	3,087	40	1,714	1,331	3,085	2
5,476	532	2,545	3,076	32	1,714	1,331	3,077	0
5,532	1,275	3,286	4,561	1,009	2,223	1,331	4,564	-3
5,600	1,191	3,286	4,477	929	2,223	1,331	4,483	-6
5,681	1,119	3,286	4,405	852	2,223	1,331	4,407	-2
5,778	1,056	3,286	4,342	786	2,223	1,331	4,341	1
5,895	1,000	3,286	4,287	735	2,223	1,331	4,290	-3
6,034	953	3,286	4,240	685	2,223	1,331	4,239	0
6,202	911	3,286	4,197	642	2,223	1,331	4,197	0
6,404	874	3,286	4,161	605	2,223	1,331	4,160	1
6,646	844	3,286	4,130	571	2,223	1,331	4,126	4
6,936	811	3,286	4,097	543	2,223	1,331	4,098	0
6,964	1,171	3,386	4,556	796	2,435	1,331	4,563	-6
6,998	1,100	3,386	4,486	731	2,435	1,331	4,498	-12
7,038	1,057	3,386	4,443	681	2,435	1,331	4,447	-4
7,087	1,026	3,386	4,412	642	2,435	1,331	4,409	3
7,145	995	3,386	4,380	620	2,435	1,331	4,387	-6
7,215	969	3,386	4,355	588	2,435	1,331	4,354	1
7,299	941	3,386	4,327	561	2,435	1,331	4,328	-1
7,400	913	3,386	4,298	531	2,435	1,331	4,298	1
7,521	888	3,386	4,274	500	2,435	1,332	4,267	7
7,666	854	3,386	4,240	474	2,435	1,332	4,241	-1
7,722	2,155	3,803	5,958	955	3,675	1,332	5,961	-3
7,790	2,038	3,803	5,840	840	3,675	1,332	5,846	-6
7,871	1,964	3,803	5,767	762	3,675	1,332	5,769	-2
7,968	1,907	3,803	5,710	702	3,675	1,332	5,709	1
8,085	1,845	3,803	5,648	645	3,675	1,332	5,651	-3
8,224	1,786	3,803	5,589	582	3,675	1,332	5,588	0
8,392	1,728	3,803	5,530	525	3,675	1,332	5,531	-1
8,594	1,669	3,803	5,472	465	3,675	1,332	5,472	0
8,836	1,613	3,803	5,416	406	3,675	1,332	5,413	3
9,126	1,556	3,803	5,358	352	3,675	1,332	5,359	-1
9,140	3,084	3,937	7,020	887	4,815	1,332	7,034	-13
9,157	3,048	3,937	6,984	864	4,815	1,332	7,010	-26
9,177	3,030	3,937	6,966	827	4,815	1,332	6,974	-7
9,201	3,005	3,937	6,941	790	4,815	1,332	6,937	5
9,231	2,971	3,937	6,907	772	4,815	1,332	6,918	-11
9,266	2,951	3,937	6,887	739	4,815	1,332	6,885	2
9,308	2,928	3,937	6,864	718	4,815	1,332	6,865	0
9,358	2,905	3,937	6,841	693	4,815	1,332	6,839	2
9,418	2,891	3,937	6,828	668	4,815	1,332	6,814	14
9,491	2,858	3,937	6,795	651	4,815	1,332	6,797	-2
9,603	3,625	4,014	7,640	995	5,315	1,332	7,641	-2
9,738	3,555	4,014	7,570	926	5,315	1,332	7,573	-3
9,900	3,504	4,014	7,518	873	5,315	1,332	7,519	-1
10,095	3,461	4,014	7,476	829	5,315	1,332	7,475	1
10,328	3,422	4,014	7,436	791	5,315	1,332	7,438	-2
10,608	3,386	4,014	7,400	753	5,315	1,332	7,400	0
10,944	3,348	4,014	7,363	716	5,315	1,332	7,363	0
11,347	3,311	4,014	7,325	678	5,315	1,332	7,325	0
11,831	3,273	4,014	7,288	639	5,315	1,332	7,286	2
12,411	3,232	4,014	7,247	600	5,315	1,332	7,247	0

TABLE 10-1

ESTIMATED GROUNDWATER RECHARGE
FROM
MOUNTAIN-FRONT RUNOFF
IVANPAH VALLEY
NEVADA AND CALIFORNIA

IVANPAH VALLEY
Nevada Portion

		Estimated Annual Precipitation			Geomega (2000) Est. Runoff	Moore (1968) Est. Runoff	Method of Savard (1998) Estimated Groundwater Recharge	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Average (acre-feet)	Average (acre-feet)	**Geomega (2000)** (acre-feet)	**Moore (1968)** (acre-feet)
Above 8,000	30	16 to 20	1.36	41	2.86	7	-5	-1
7,000-8,000	780	14 to 16	1.27	991	69.34	98	59	86
6,000-7,000	3,100	12 to 14	1.1	3,410	238.70	181	223	167
5,000-6,000	10,840	10 to 12	0.94	10,190	713.27	271	682	254
Below 5,000	135,940	<8	0.77	104,674	0.00	0	-8	-8
Subtotal	**150,690**			**119,305**	**1,024**	**556**	**951**	**498**

IVANPAH VALLEY
California Portion

		Estimated Annual Precipitation			Geomega (2000) Est. Runoff	Moore (1968) Est. Runoff	Method of Savard (1998) Estimated Groundwater Recharge	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Average (acre-feet)	Average (acre-feet)	**Geomega (2000)** (acre-feet)	**Moore (1968)** (acre-feet)
Above 7,000	370	14 to 16	1.27	470	32.89	46	24	37
6,000-7,000	1,830	12 to 14	1.1	2,013	140.91	107	128	95
5,000-6,000	25,410	10 to 12	0.94	23,885	1,671.98	635	1,610	607
Below 5,000	259,780	<8	0.77	200,031	0.00	0	-8	-8
Subtotal	**287,390**			**226,399**	**1,846**	**788**	**1,754**	**731**
TOTAL IVANPAH VALLEY	**438,080**			**345,704**	**2,870**	**1,345**	**2,705**	**1,229**

JEAN LAKE VALLEY

		Estimated Annual Precipitation			Geomega (2000) Est. Runoff	Moore (1968) Est. Runoff	Method of Savard (1998) Estimated Groundwater Recharge	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Average (acre-feet)	Average (acre-feet)	**Geomega (2000)** (acre-feet)	**Moore (1968)** (acre-feet)
Above 6,000	460	12 to 14	1.1	506	35.42	27	26	18
5,000-6,000	2,170	10 to 12	0.94	2,040	142.79	54	130	44
Below 5,000	60,140	<8	0.77	46,308	0.00	0	-8	-8
Total Jean Lake Valley	**62,770**			**48,854**	**178**	**81**	**148**	**54**

HIDDEN VALLEY

		Estimated Annual Precipitation			Geomega (2000) Est. Runoff	Moore (1968) Est. Runoff	Method of Savard (1998) Estimated Groundwater Recharge	
Elevation Zone (feet)	Areal Extent (acres)	Range (inches)	Average (feet)	Average (acre-feet)	Average (acre-feet)	Average (acre-feet)	**Geomega (2000)** (acre-feet)	**Moore (1968)** (acre-feet)
Below 5,000	21,700	<8	0.77	16,709	0.00	0	-8	-8
Total Hidden Valley	**21,700**			**10,850**	**0.00**	**0.00**	**-8.11**	**-8.11**

Note: (1) Precipitation based on equation of Geomega (2000); (2) Runoff set at 7% of total precipitation in each elevation zone (Geomega 2000)
(3) Runoff for Moore (1968) based on altitude/runoff table for region F in Nevada. (4) Following Moore (1968), no runoff below 5,000 feet elevation.
(5) Groundwater recharge from mountain-front runoff based on Savard (1998): Equation: Recharge = 0.968*Runoff - 10,000, where
units are in cubic meters. Based on Figure 8 in Savard (1998) for Fortymile Canyon. Calculations done in cubic meters and converted to acre-feet

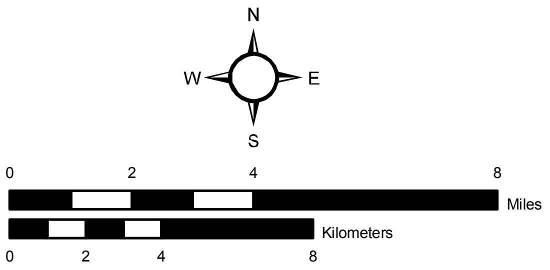
Source (s) : Glancy (1968); Geomega (2000); Moore (1968); Savard (1998)

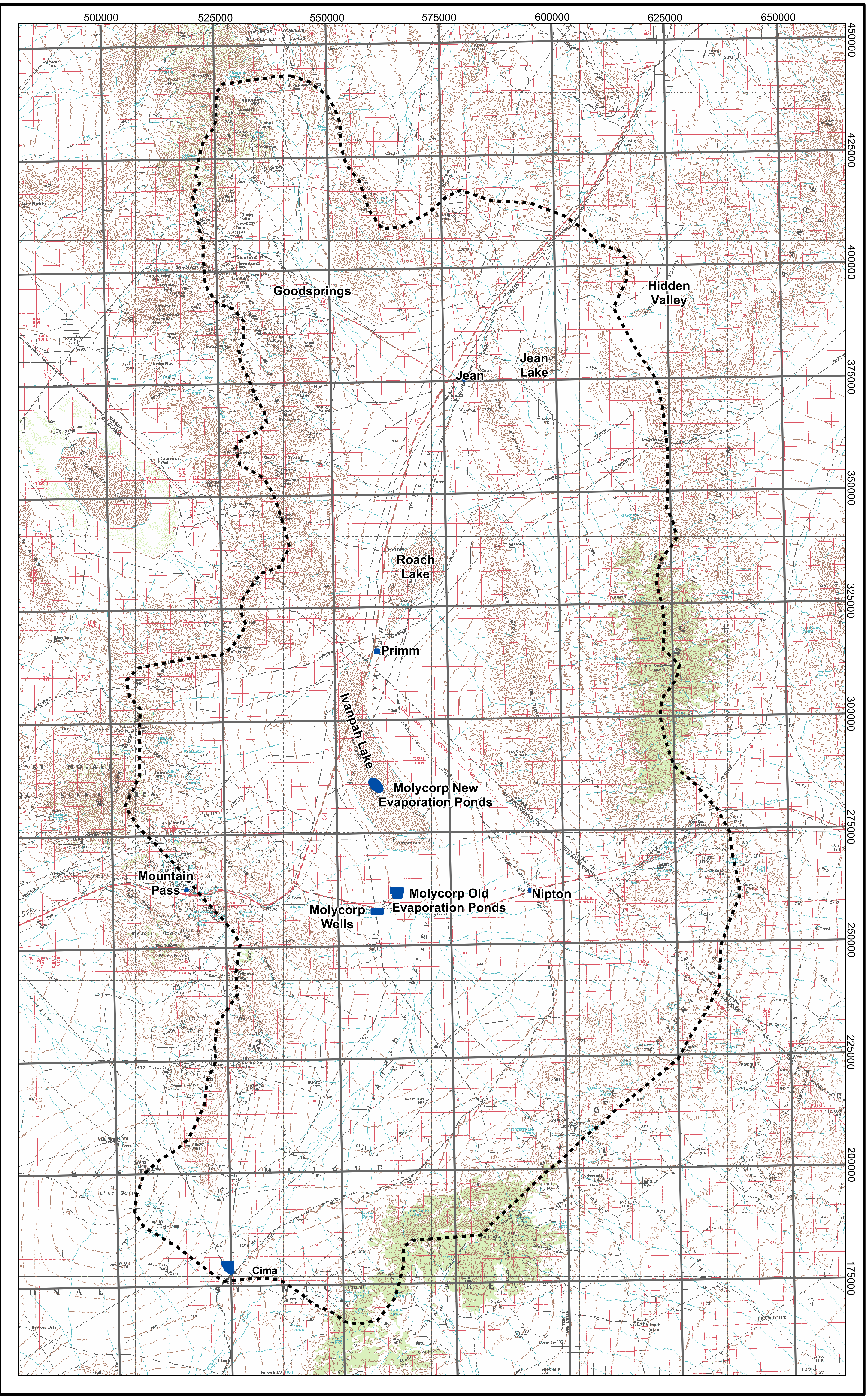
FIGURES

Legend

The grid is in Nevada State Plane Feet

▭ Groundwater Model Domain Boundary





MOLYCORP SUPPLEMENTAL ENVIRONMENTAL PROJECT
Numerical Groundwater Flow Model
Ivanpah Valley

Figure 6-1
Site Location Map

04/05/2006

Legend

The grid is in Nevada State Plane Feet

QUATERNARY

□ QAL: Valley alluvium and alluvial fans. Units range from coarse alluvial fans to fine-grained clays and silts near the center of the valley. Alluvial sediments are locally interbedded with basalt flows.

TERTIARY

■ TKQ: Teutonia Quartz Monzonite. Intrusive stock near south end of the valley.

■ TR: Rhyolite plug

■ TSF: Volcanic flows and breccias with intermixed volcaniclastic sediments.

PALEOZOIC/MESOZOIC

■ P/M: Intermixed Paleozoic and Mesozoic sedimentary rocks juxtaposed by thrust faulting and normal faults. Mesozoic units are the Chinle formation, the Moenkopi formation, the Aztec Sandstone, and both igneous and volcanic rocks.

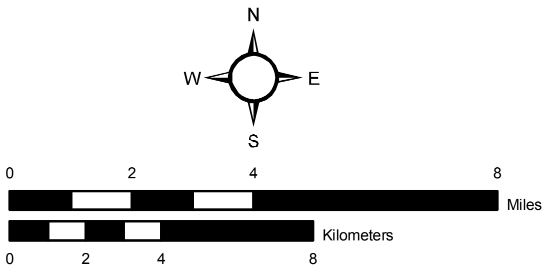
PALEOZOIC

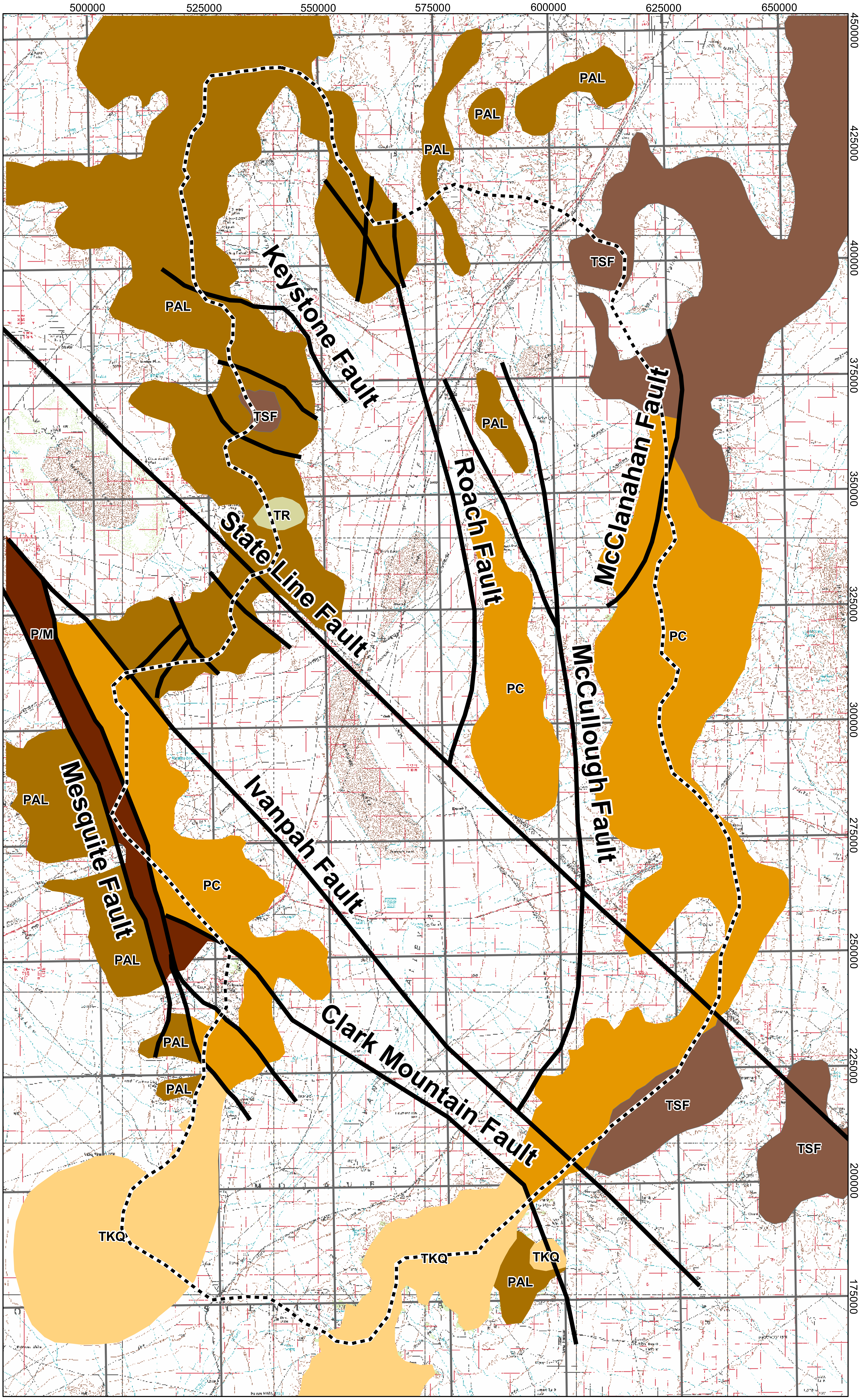
■ PAL: Paleozoic sedimentary rocks. Main units are the Cambrian Pioche Shale and Prospect Mountain Quartzite, Devonian Goodsprings Dolomite, and Missippian and Pennsylvanian Kaibab Limestone, Supai formation, Bird Spring formation, and Monte Cristo Limestone.

PRECAMBRIAN

PC: Precambrian gneisses and sedimentary rocks. Main sedimentary units are Kingston Peak formation, Beck Spring formation, and Crystal Spring formation.

⬚ Groundwater Model Domain Boundary

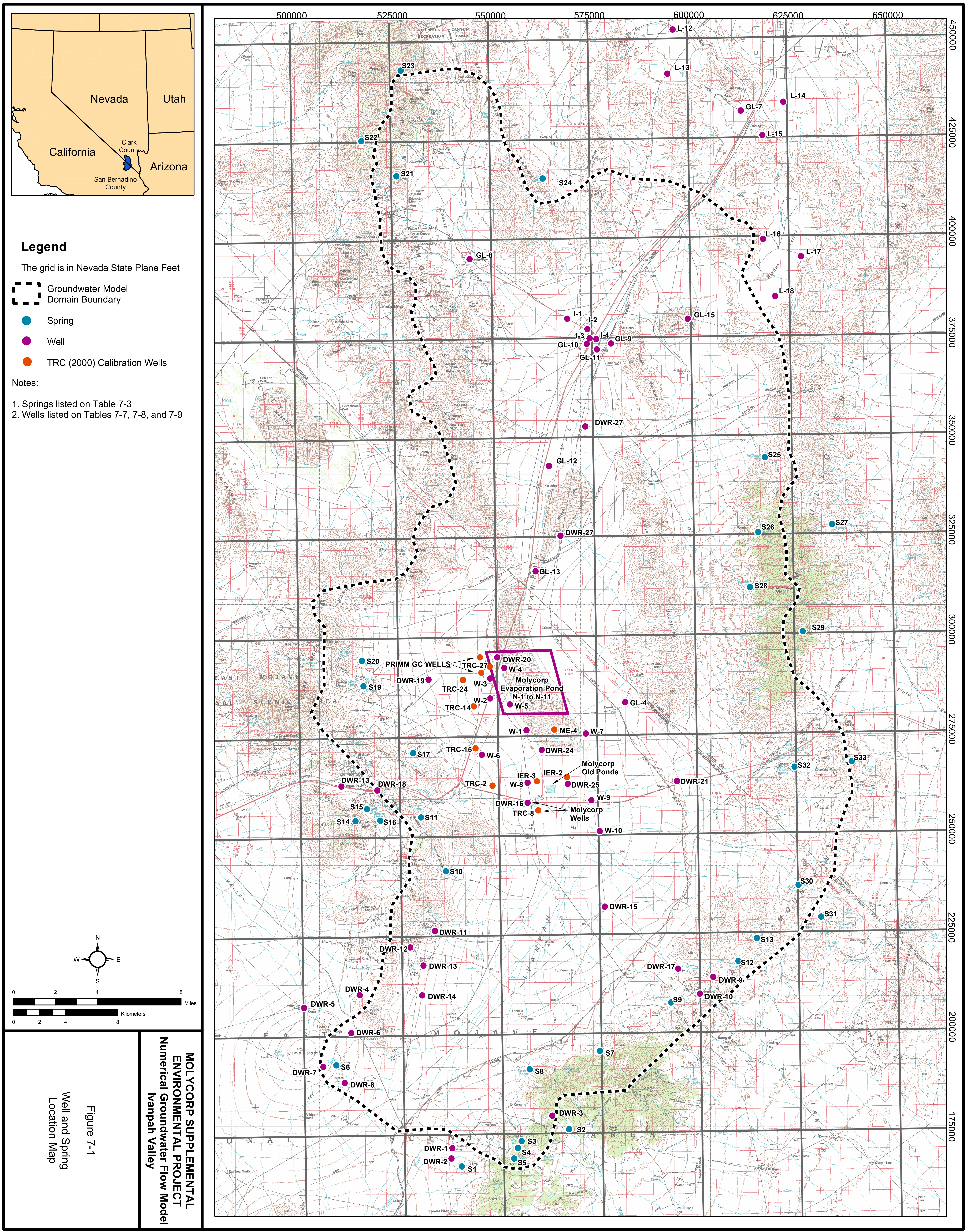




MOLYCORP SUPPLEMENTAL ENVIRONMENTAL PROJECT
Numerical Groundwater Flow Model
Ivanpah Valley

Figure 6-2
Geologic Map
Ivanpah Valley

04/05/2006



Legend

The grid is in Nevada State Plane Feet

▨ Groundwater Model Domain Boundary

● Spring

● Well

● TRC (2000) Calibration Wells

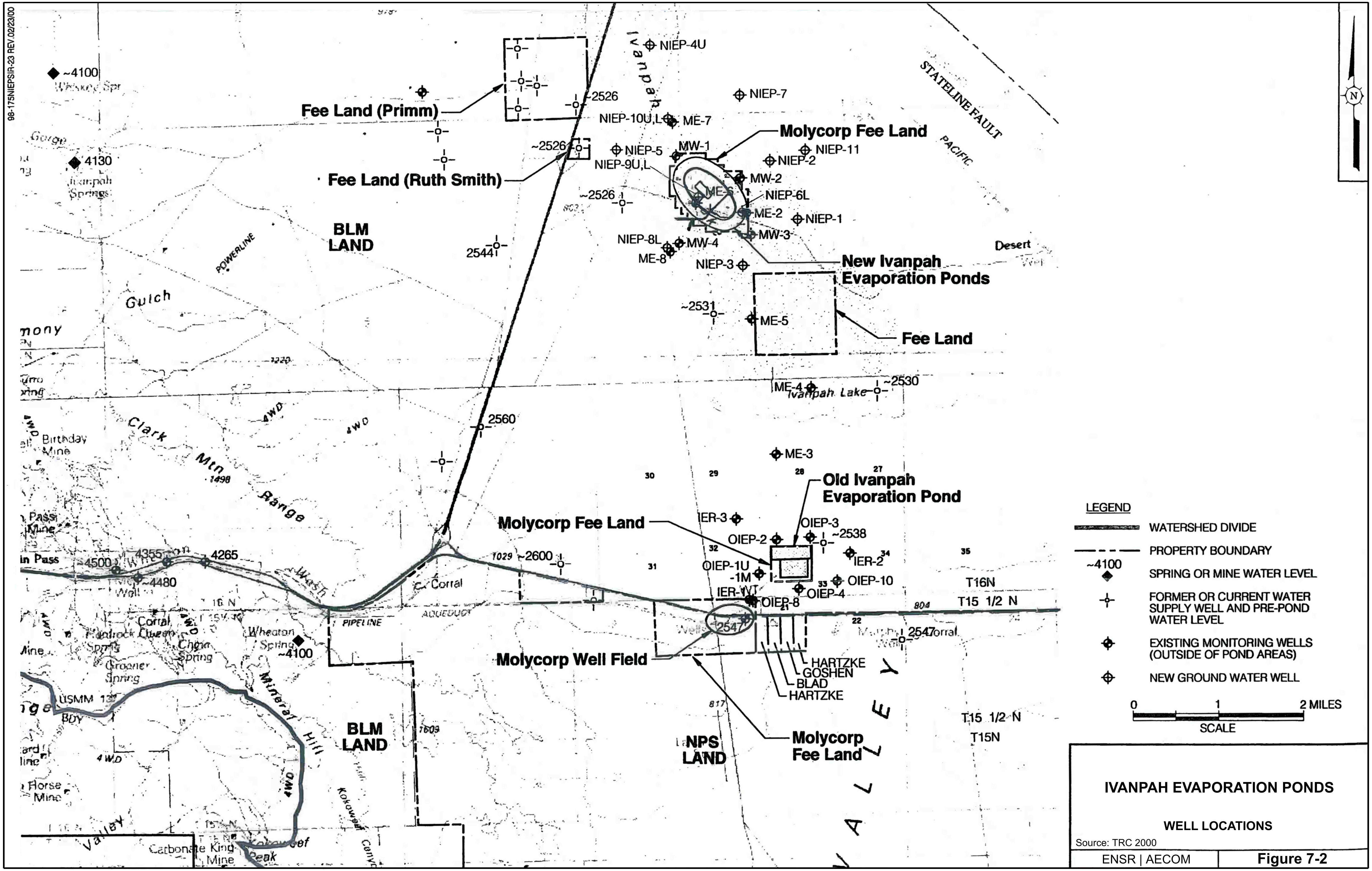
Notes:

1. Springs listed on Table 7-3
2. Wells listed on Tables 7-7, 7-8, and 7-9

MOLYCORP SUPPLEMENTAL ENVIRONMENTAL PROJECT
Numerical Groundwater Flow Model
Ivanpah Valley

Figure 7-1
Well and Spring
Location Map

04/09/2007



IVANPAH EVAPORATION PONDS

WELL LOCATIONS

Source: TRC 2000

ENSR | AECOM

Figure 7-2

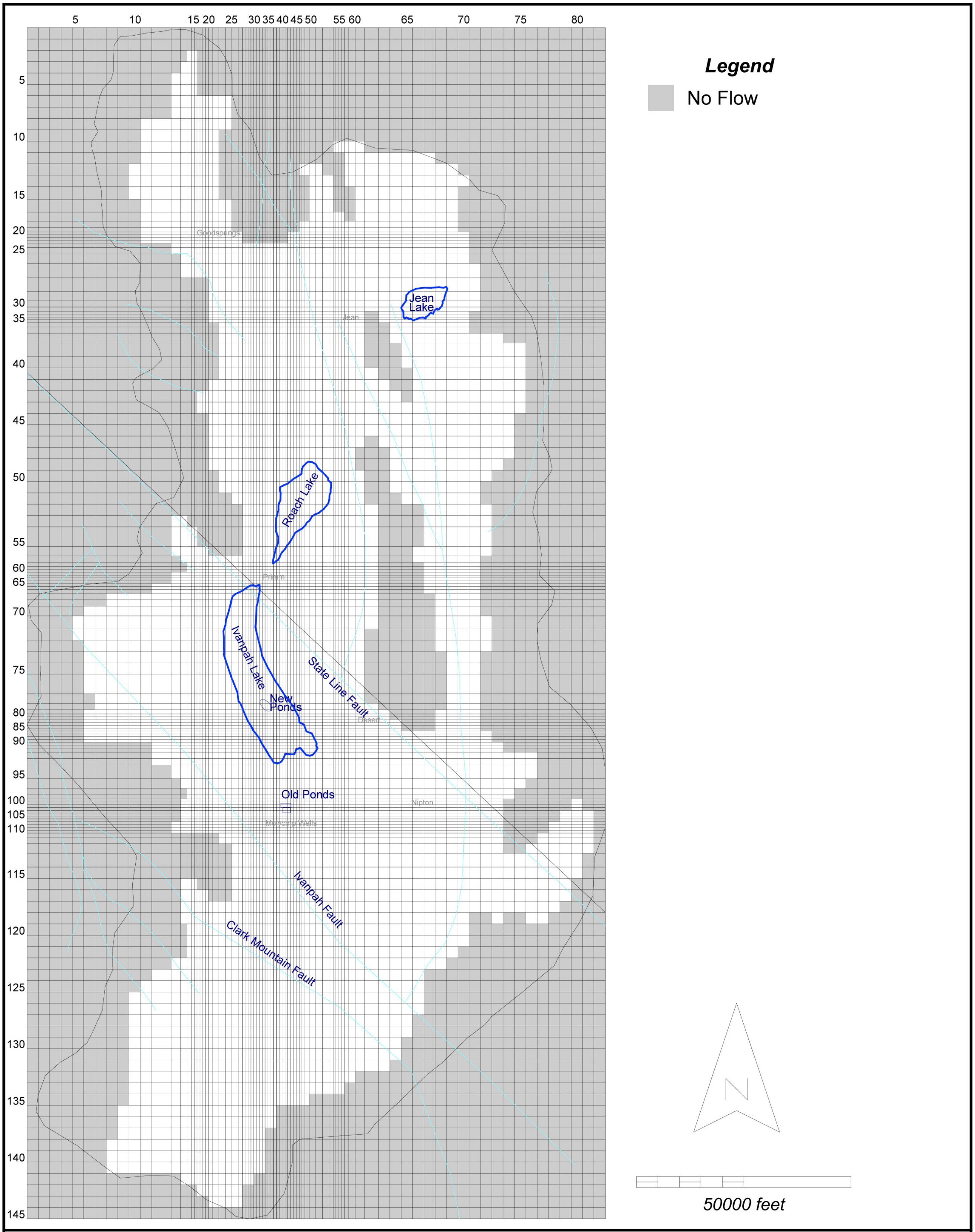


Figure 9-1. Finite-difference Grid for the Ivanpah Valley Model.

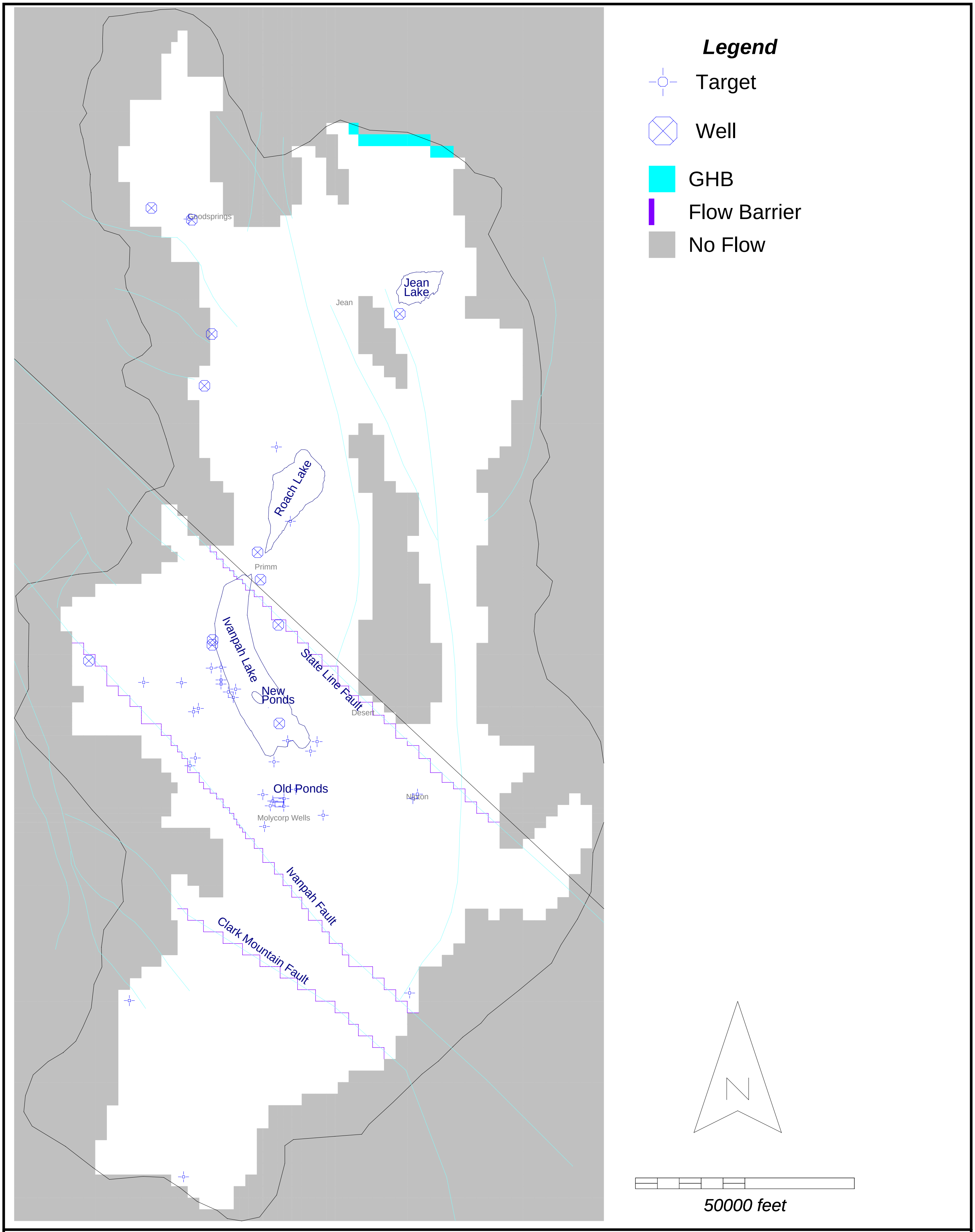


Figure 9-2. Boundary Conditions and Calibration Targets for the Ivanpah Valley Model in Layer 1.

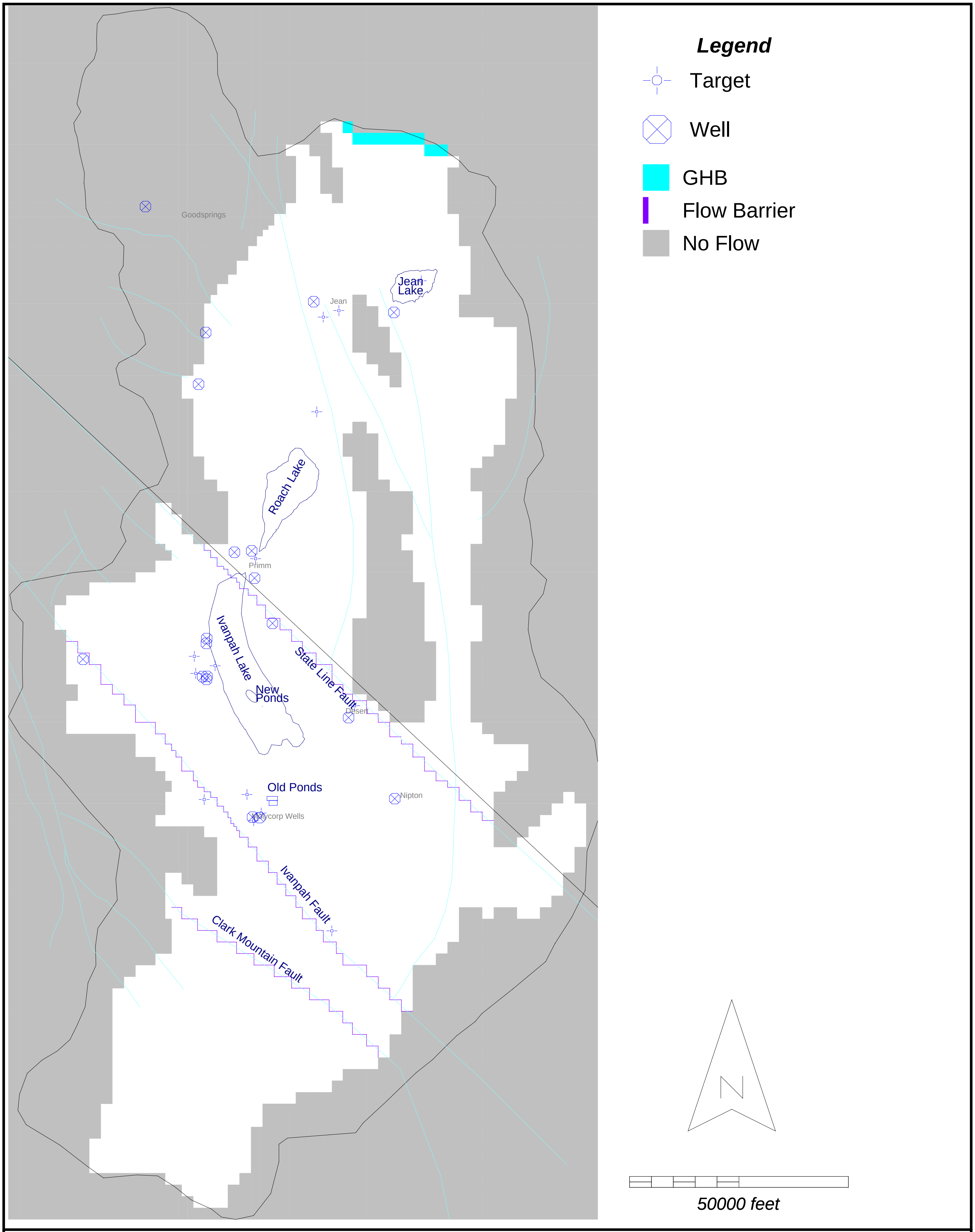
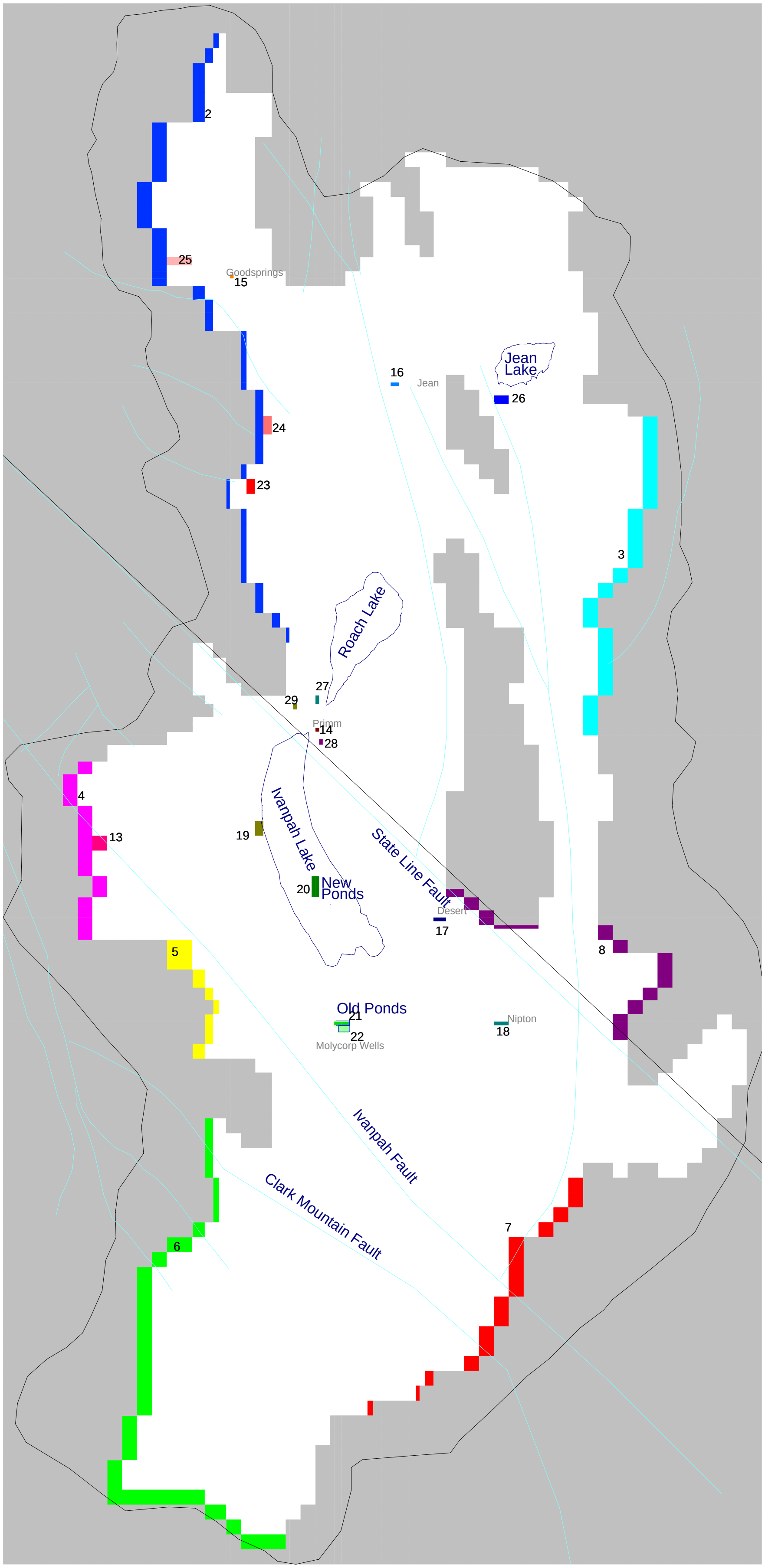
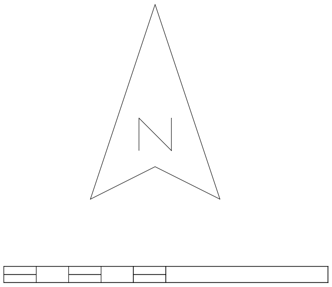


Figure 9-3. Boundary Conditions and Calibration Targets for the Ivanpah Valley Model in Layer 2.



Legend

Zone		Recharge Value (ft/d)	
1		0.000e+000	
2	🟦	4.901e-004	Ivanpah North
3	🟦	9.491e-005	Jean Valley
4	🟪	1.699e-004	Ivanpah South
5	🟨	3.795e-004	Ivanpah South
6	🟩	2.132e-004	Ivanpah South
7	🟥	1.863e-004	Ivanpah South
8	🟪	5.064e-004	Ivanpah South
13	🟥	0.000e+000	
14	🟫	0.000e+000	Whiskey Pete
15	🟧	1.100e-003	Goodsprings
16	🟦	2.825e-003	Jean
17	🟦	7.858e-004	Desert
18	🟩	4.419e-004	Nipton
19	🟫	0.000e+000	Primm Golf C.
20	🟩	0.000e+000	New Ponds
21	🟩	0.000e+000	Old Pond N
22	🟩	0.000e+000	Old Pond S
23	🟥	0.000e+000	Mine 1
24	🟥	0.000e+000	Mine 2
25	🟥	0.000e+000	Mine 3
26	🟦	0.000e+000	Jean Valley
27	🟩	0.000e+000	Industrial
28	🟪	0.000e+000	Municipal
29	🟫	0.000e+000	Domestic



50000 feet

Figure 9-4a. Steady-state Recharge Zones for the Ivanpah Valley Model.

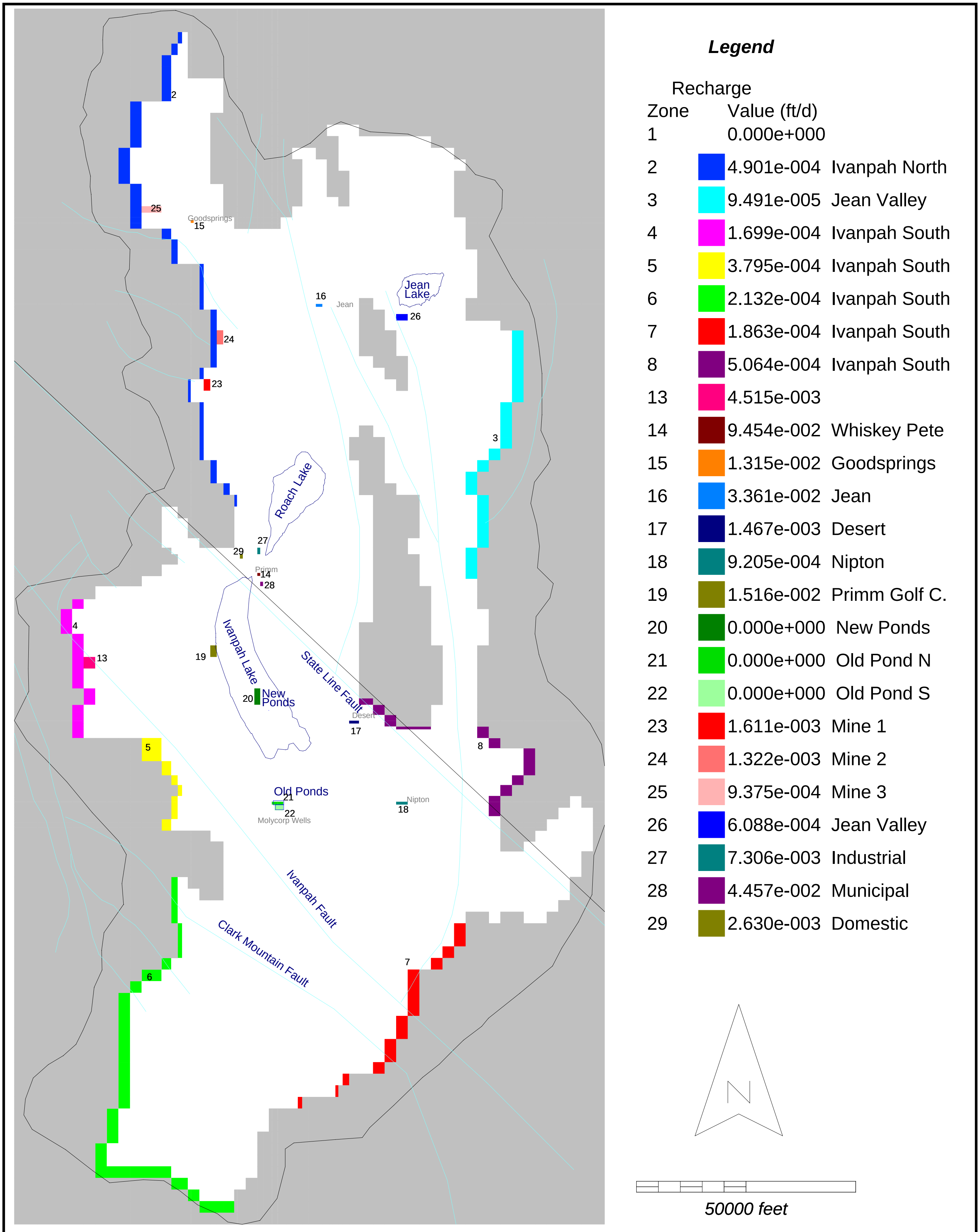


Figure 9-4b. Recharge Zones in Stress Period 8 for the Ivanpah Valley Model.

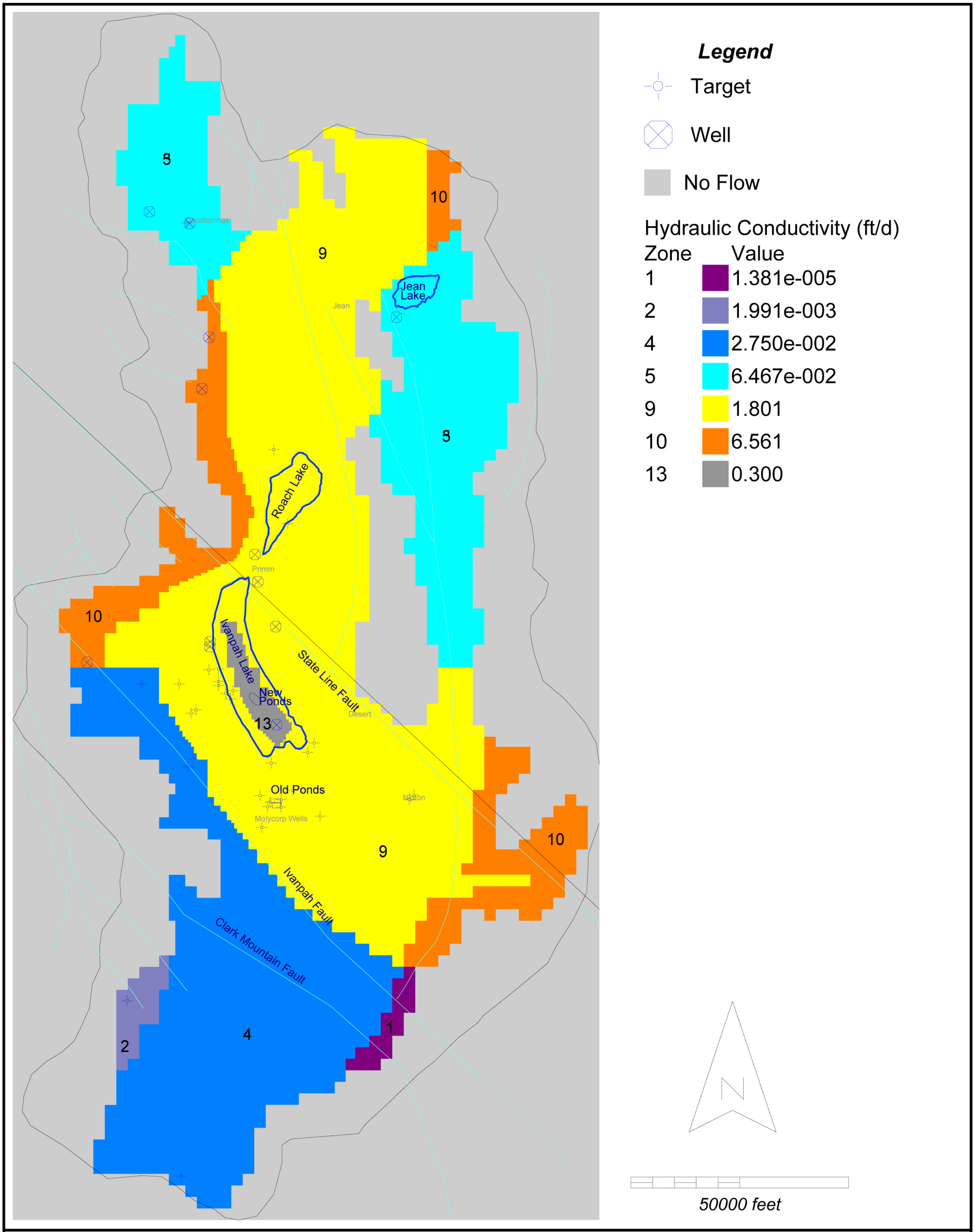


Figure 9-5. Hydraulic Conductivity Zones for the Ivanpah Valley Model in Layer 1.

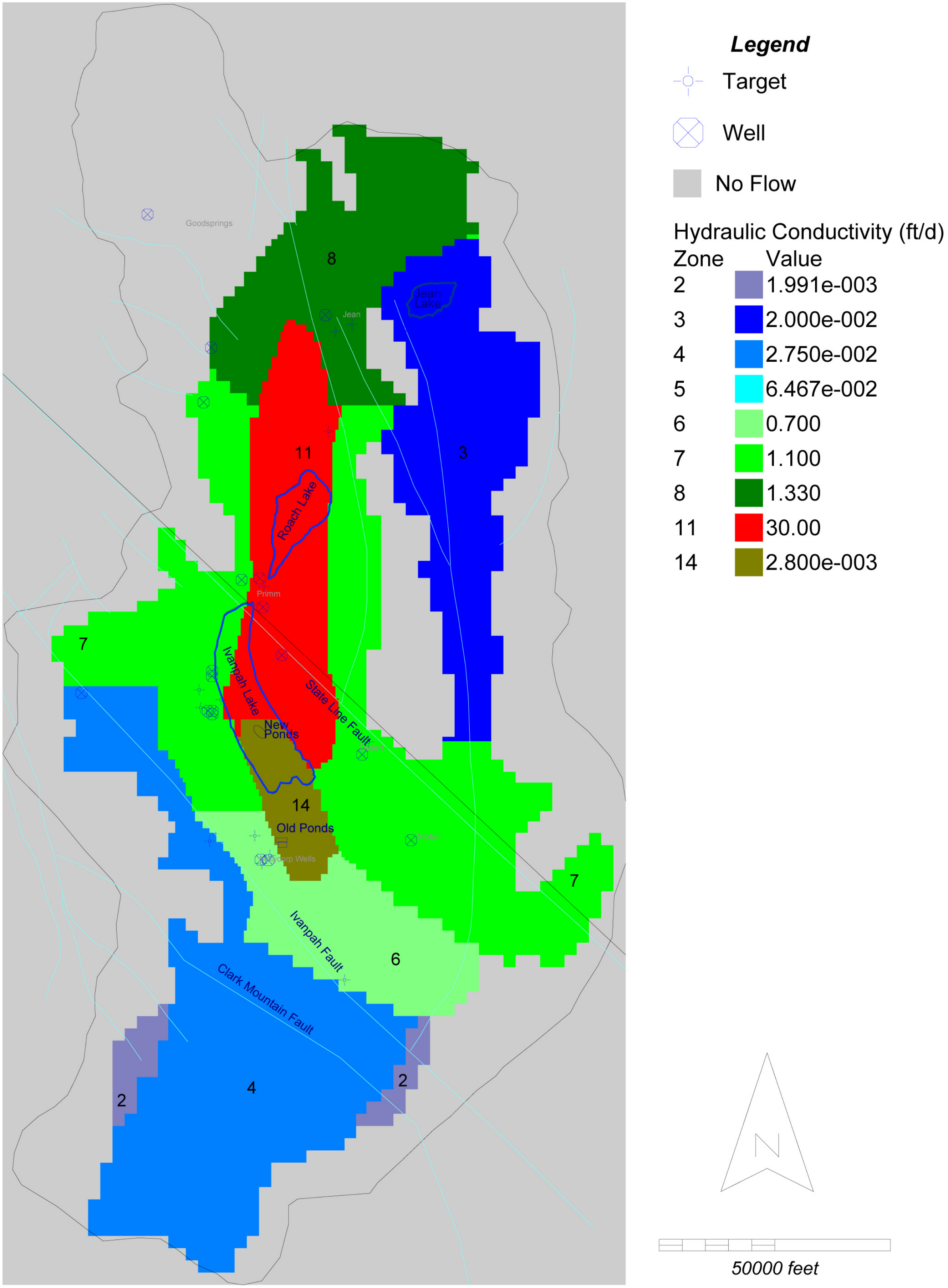
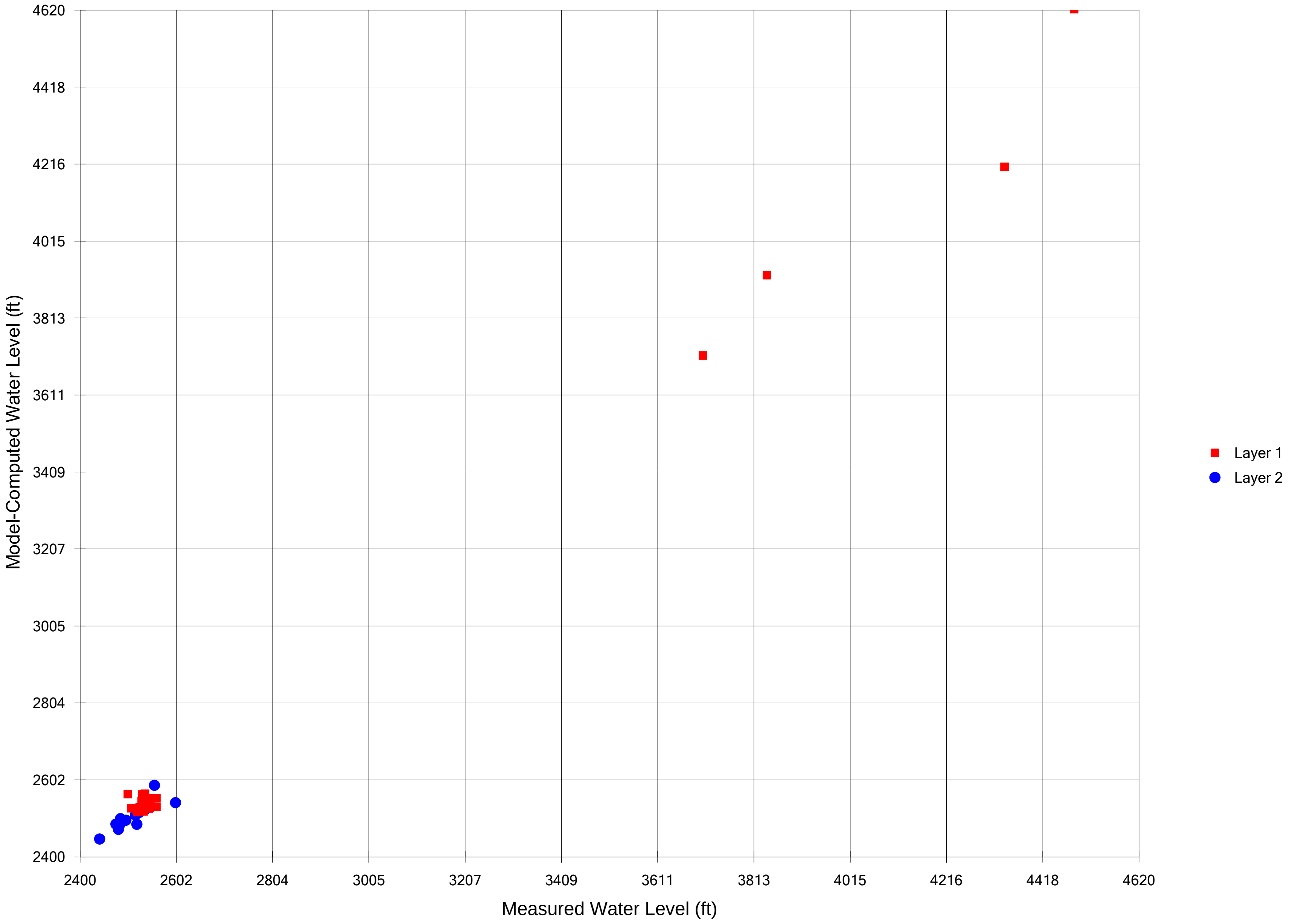
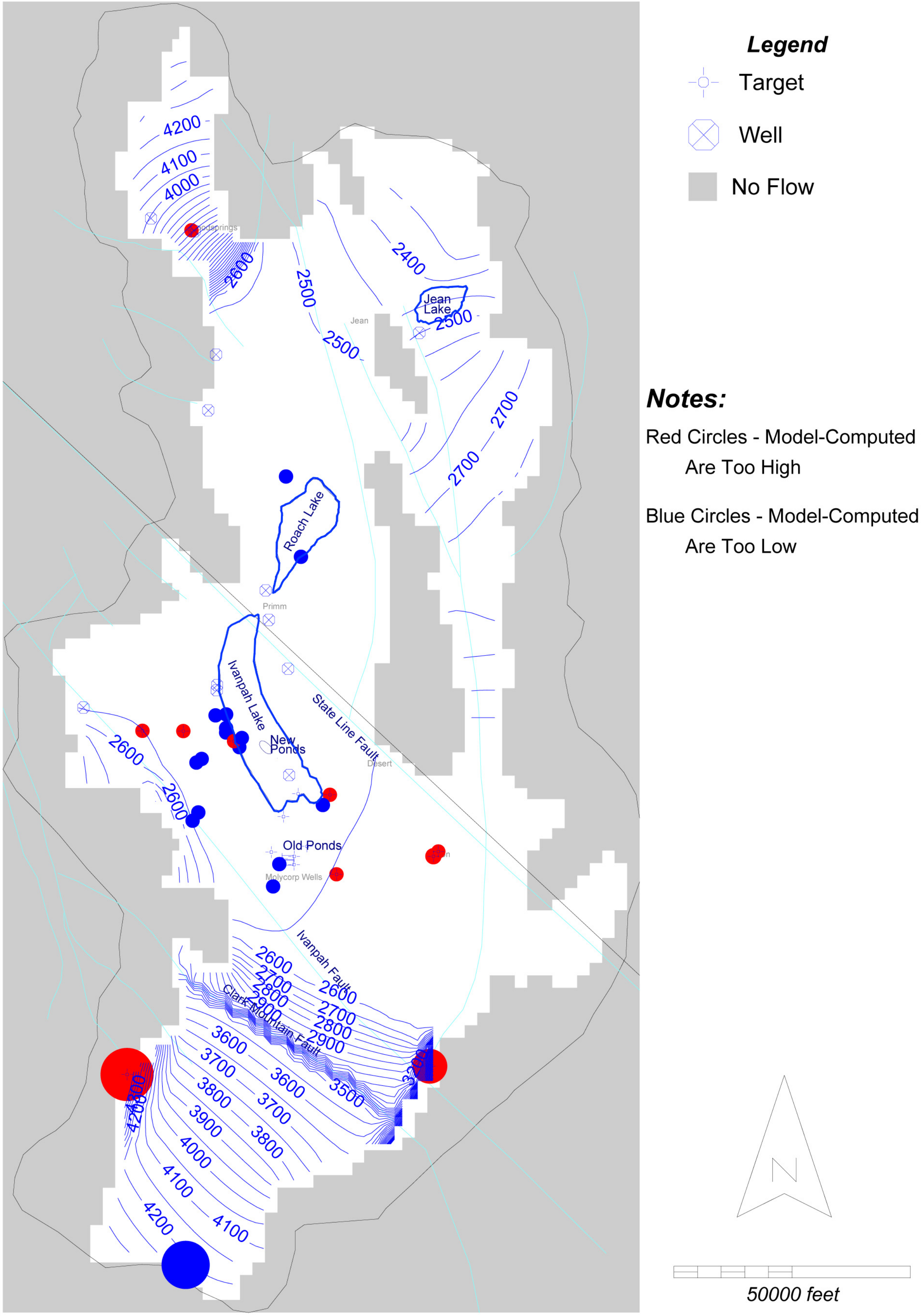


Figure 9-6. Hydraulic Conductivity Zones for the Ivanpah Valley Model in Layer 2.

Figure 9-7. Observed vs. Computed Water Levels in the Ivanpah Valley Model.





Notes:

Red Circles - Model-Computed Water Levels Are Too High

Blue Circles - Model-Computed Water Levels Are Too Low

Figure 9-8A. Steady-state Water Table for the Ivanpah Valley Model in Layer 1.

Figure 9-8B. Water Table Representing Current Conditions in Layer 1.

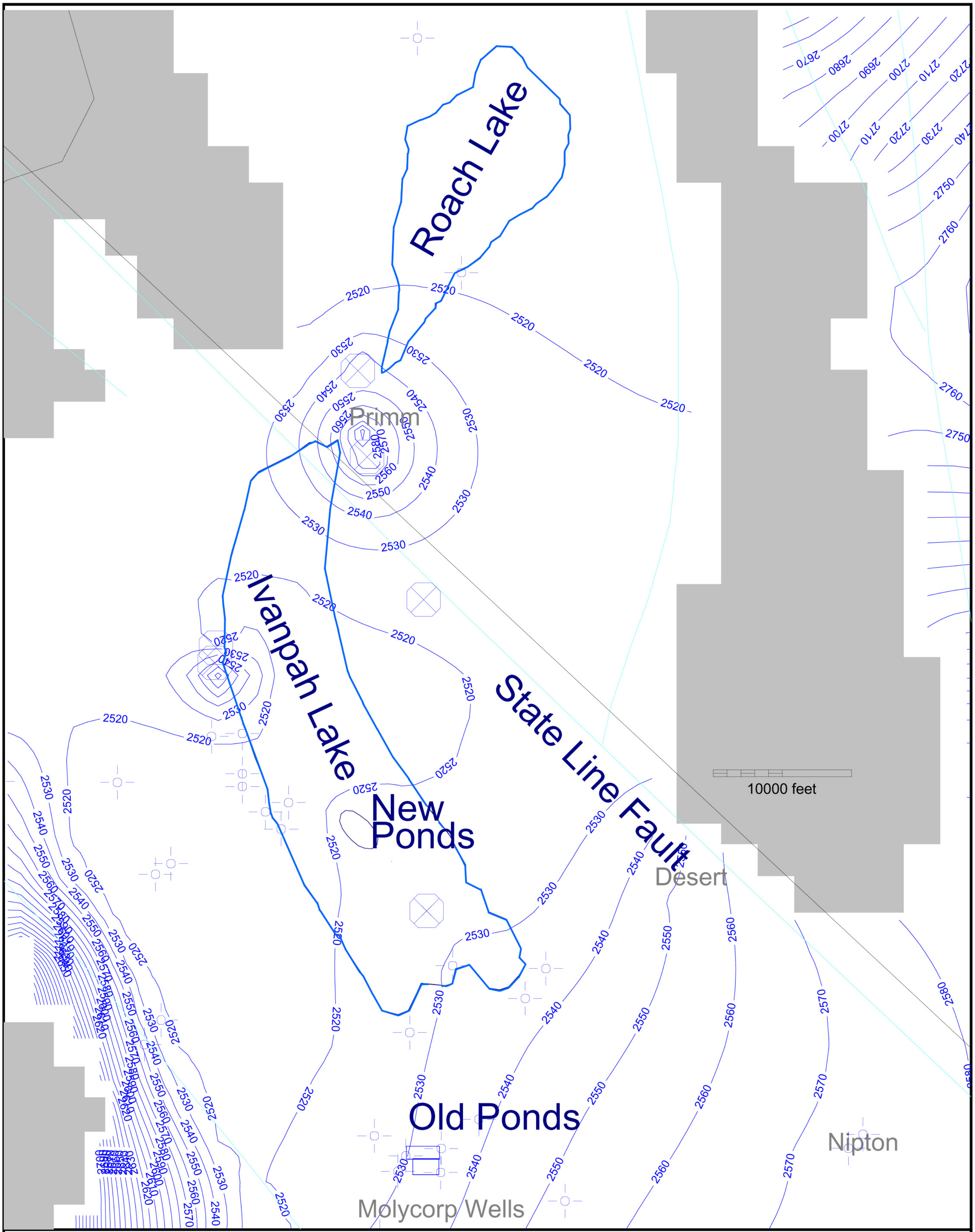


Figure 9-8C. Water Table for Current Conditions in Layer 1.

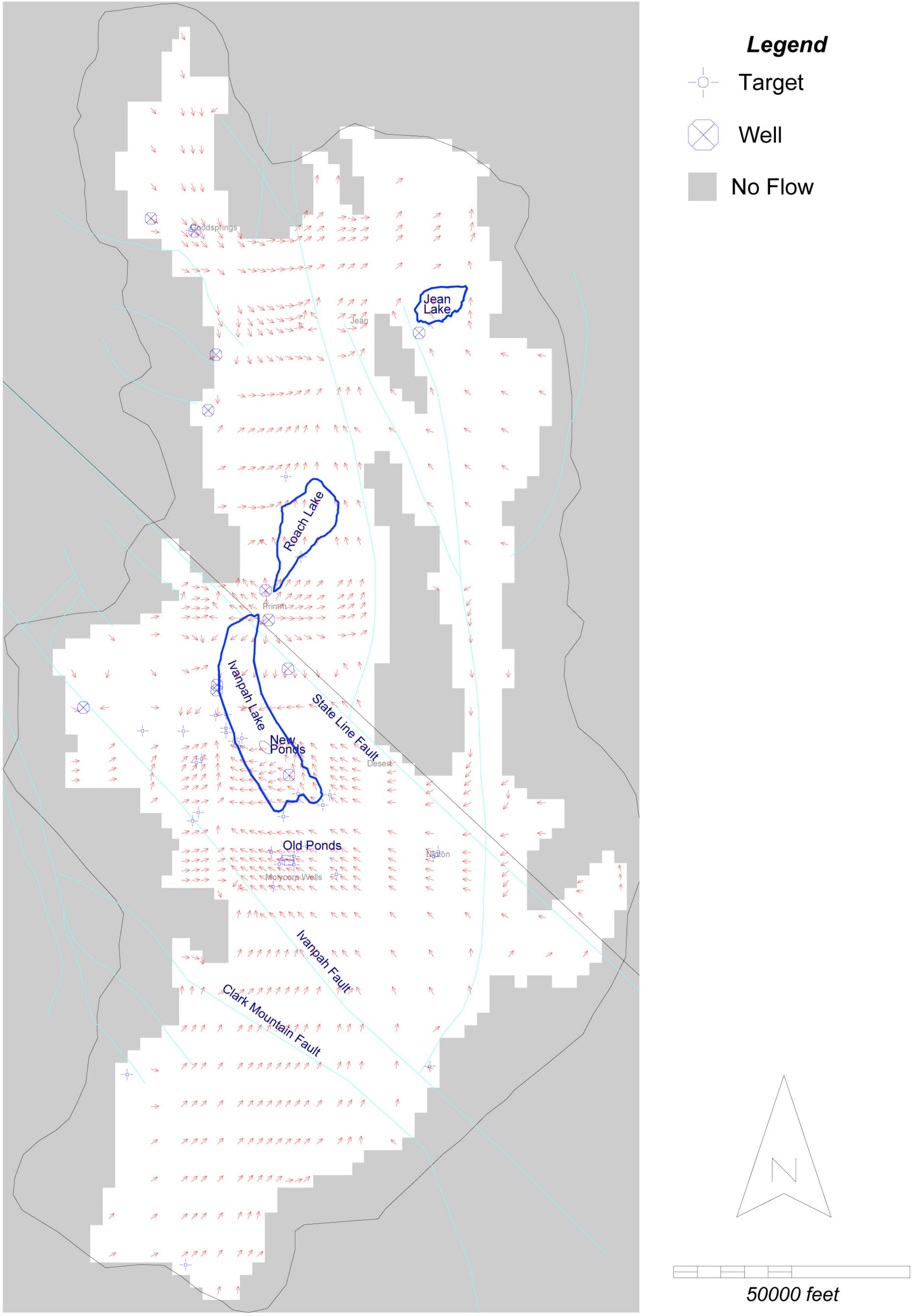
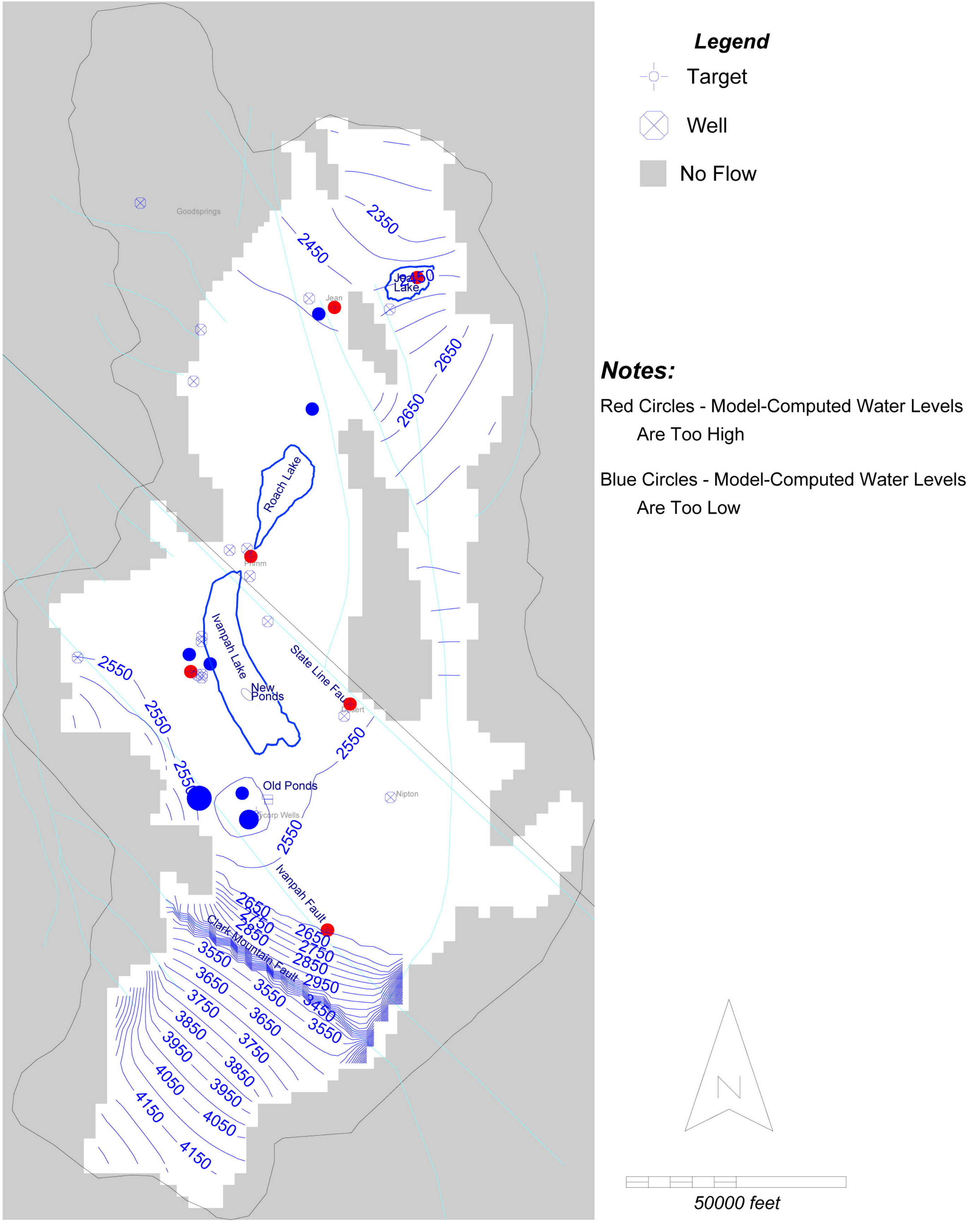


Figure 9-8D. Groundwater Flow Directions in Layer 1 Under Current Conditions.



Legend

- Target
- Well
- ▨ No Flow

Notes:

Red Circles - Model-Computed Water Levels
Are Too High

Blue Circles - Model-Computed Water Levels
Are Too Low

Figure 9-9A. Steady-state Potentiometric Surface for the Ivanpah Valley Model in Layer 2.

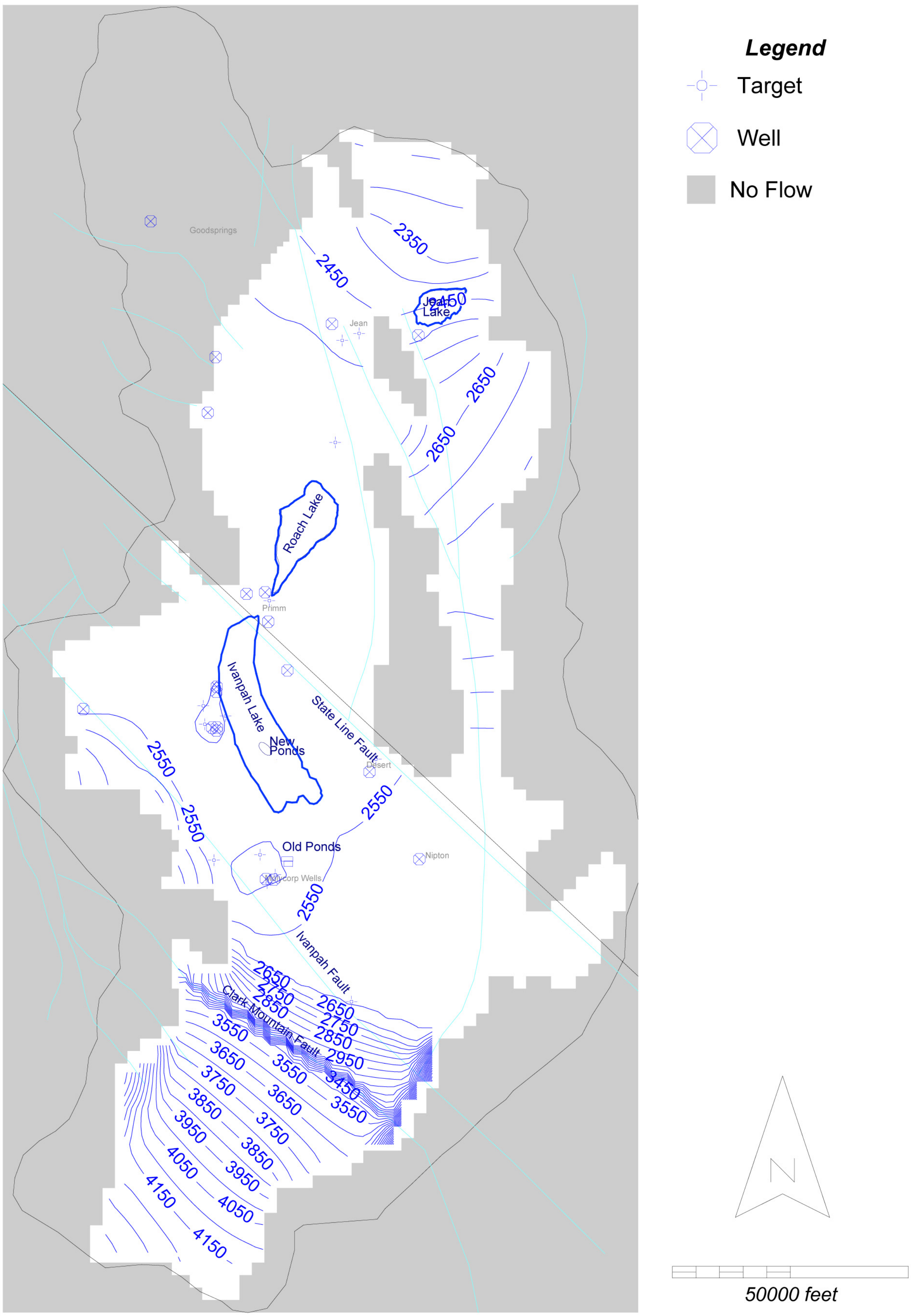


Figure 9-9B. Potentiometric Surface Representing Current Conditions in Layer 2.

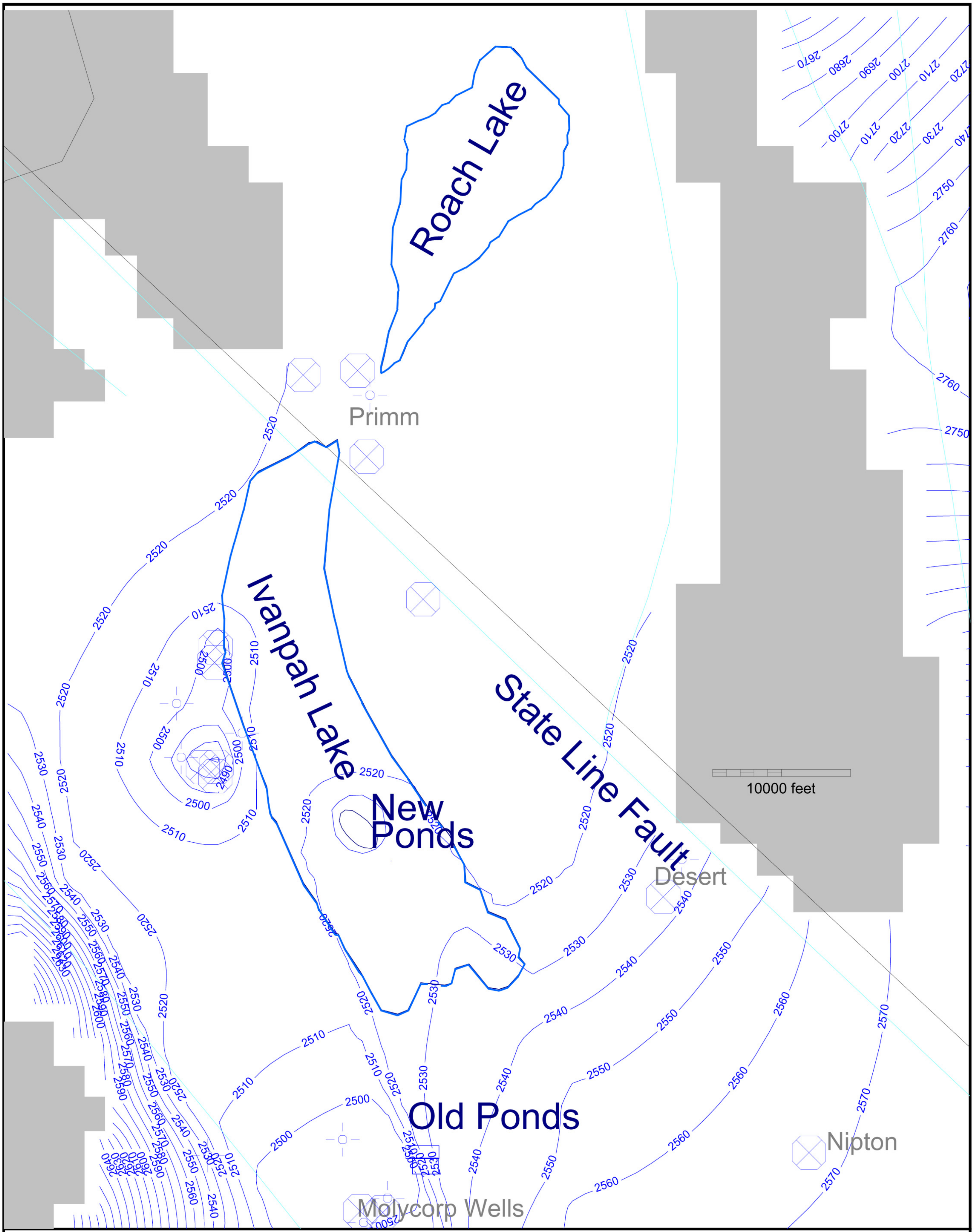
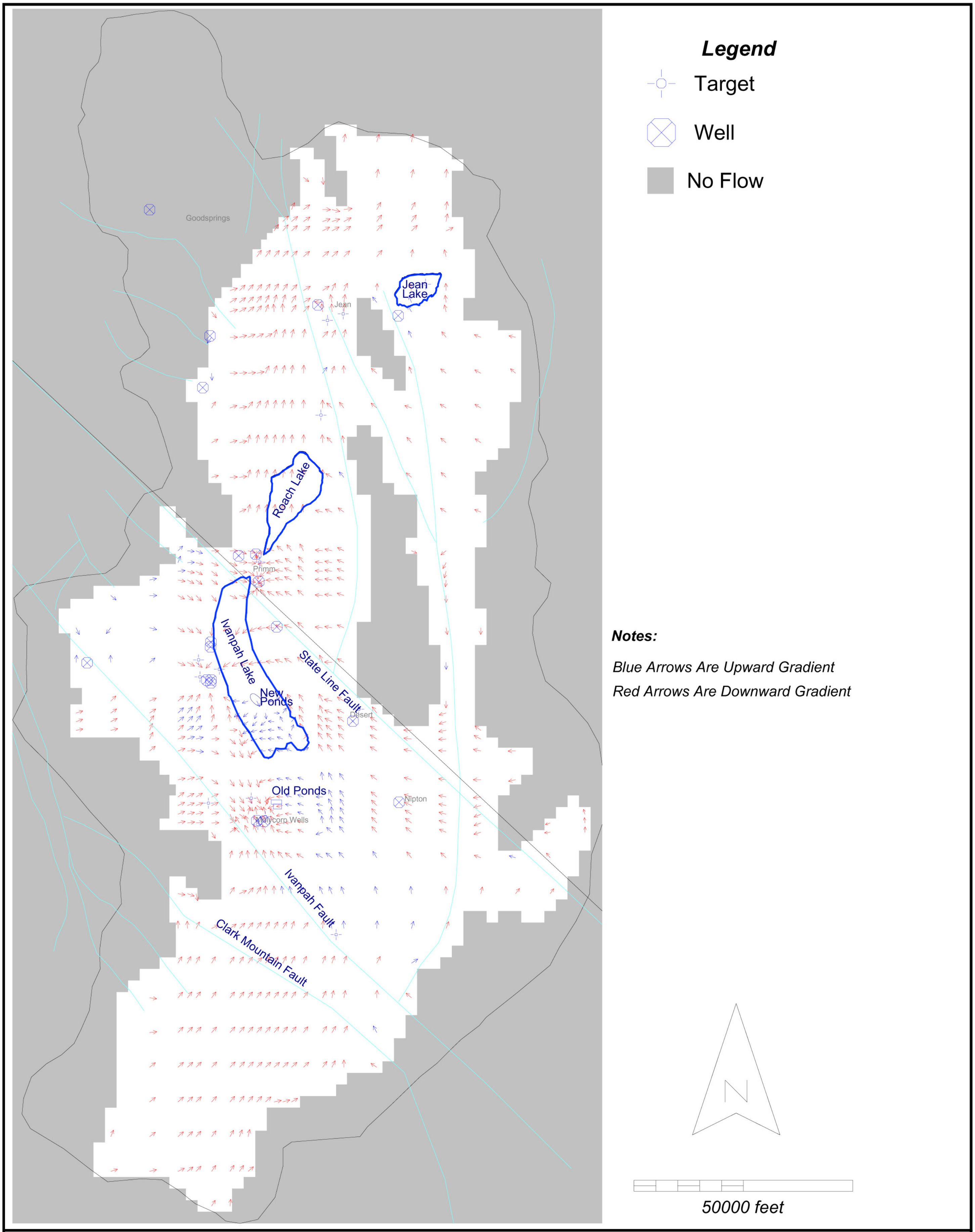


Figure 9-9C. Potentiometric Surface for Current Conditions in Layer 2.



Notes:

Blue Arrows Are Upward Gradient

Red Arrows Are Downward Gradient

Figure 9-9D. Groundwater Flow Directions in Layer 2 Under Current Conditions.

Figure 9-10 Hydrograph for Well ME-3.

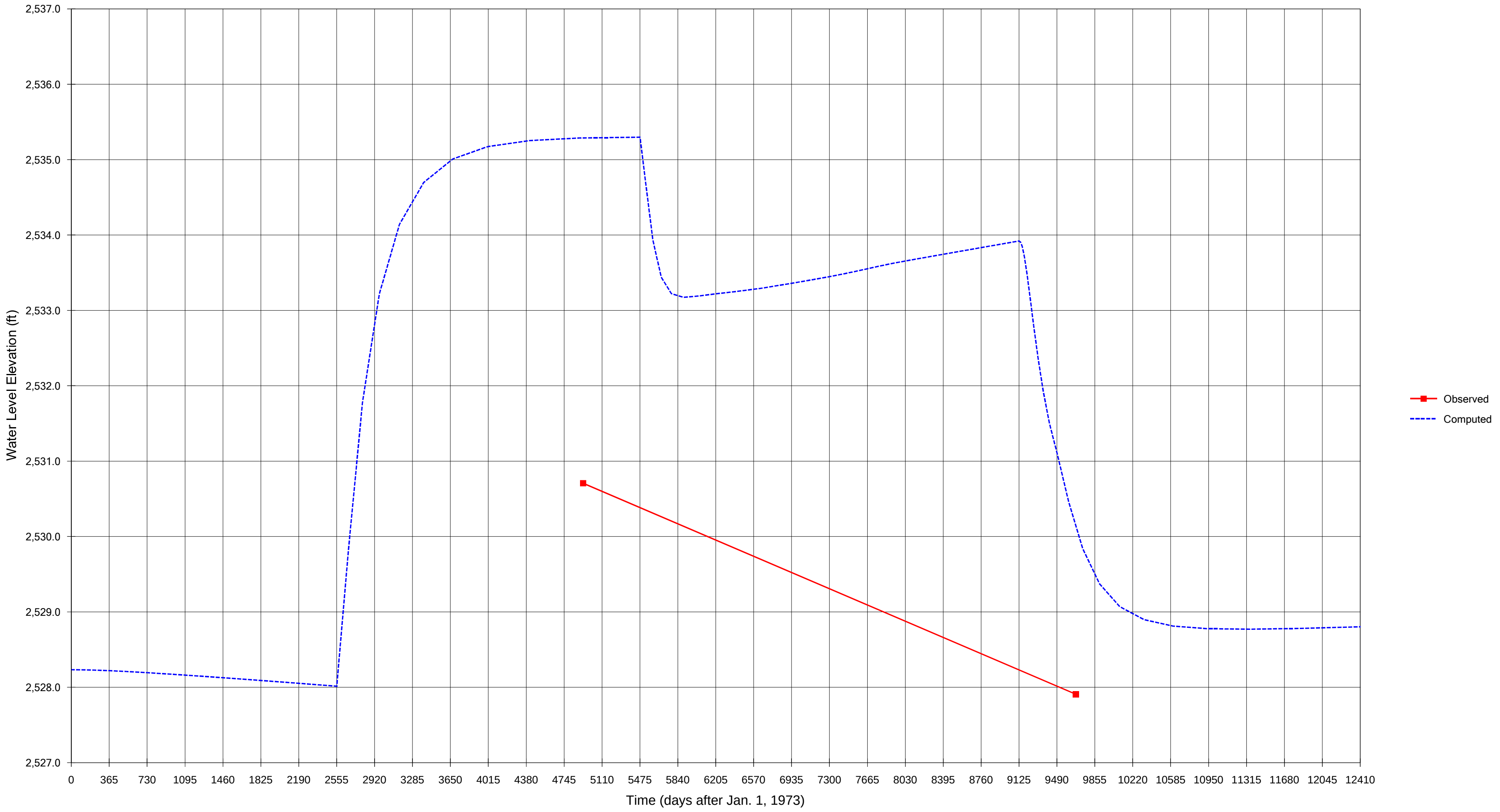


Figure 9-11 Hydrograph for Well ME-4.

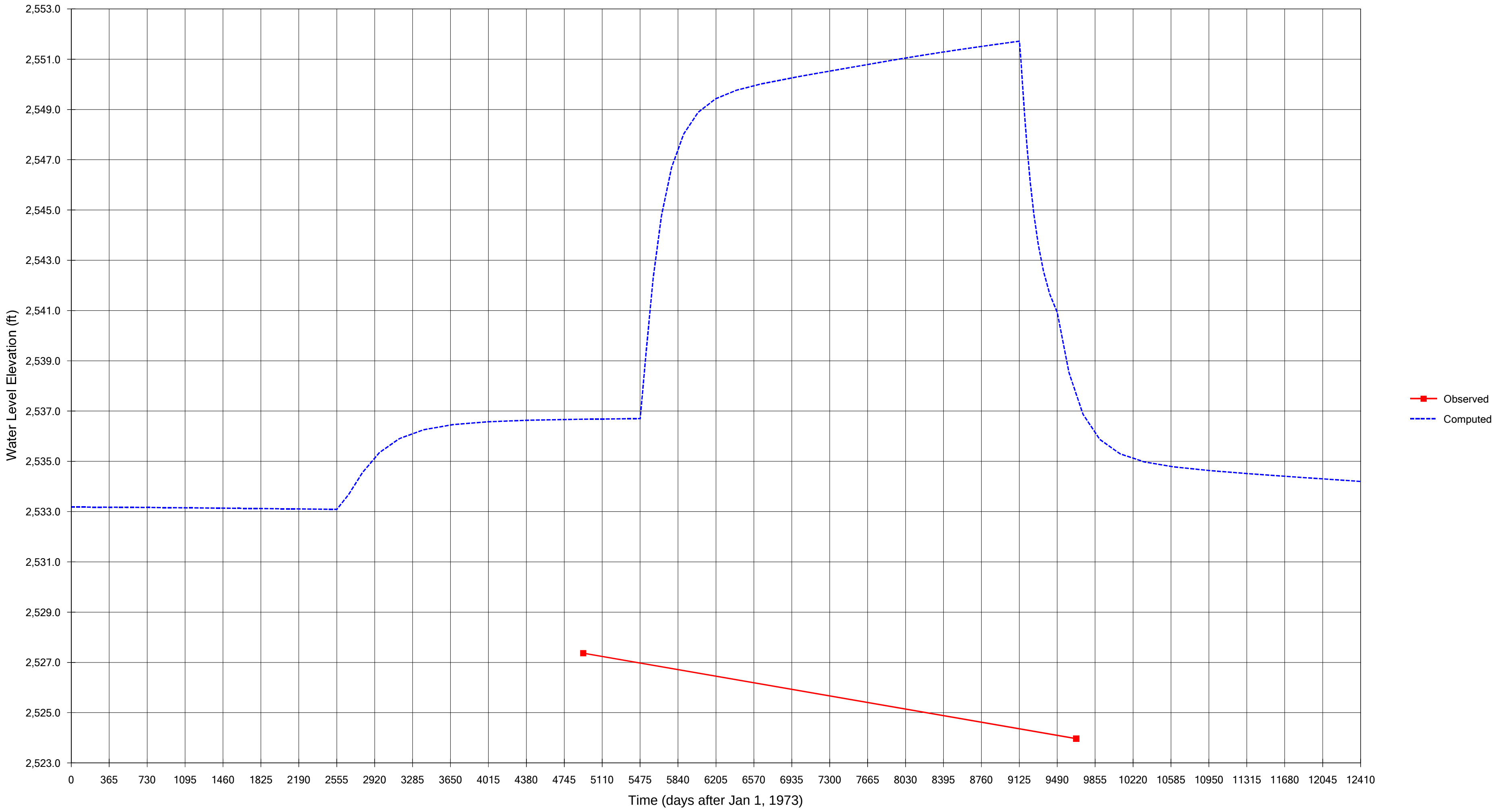


Figure 9-12 Hydrograph at Well IER-2.

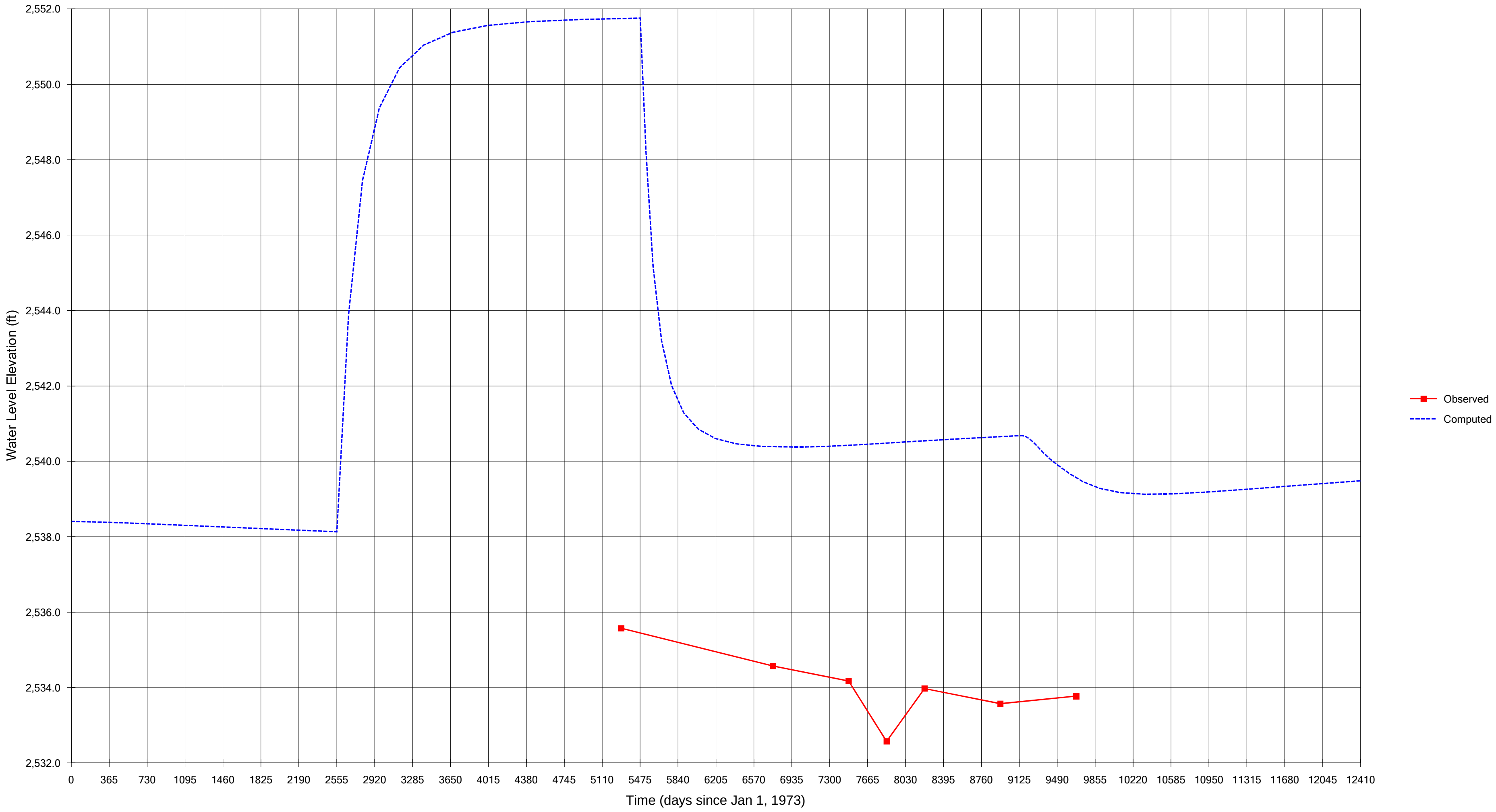


Figure 9-13 Hydrograph at Well IER-3.

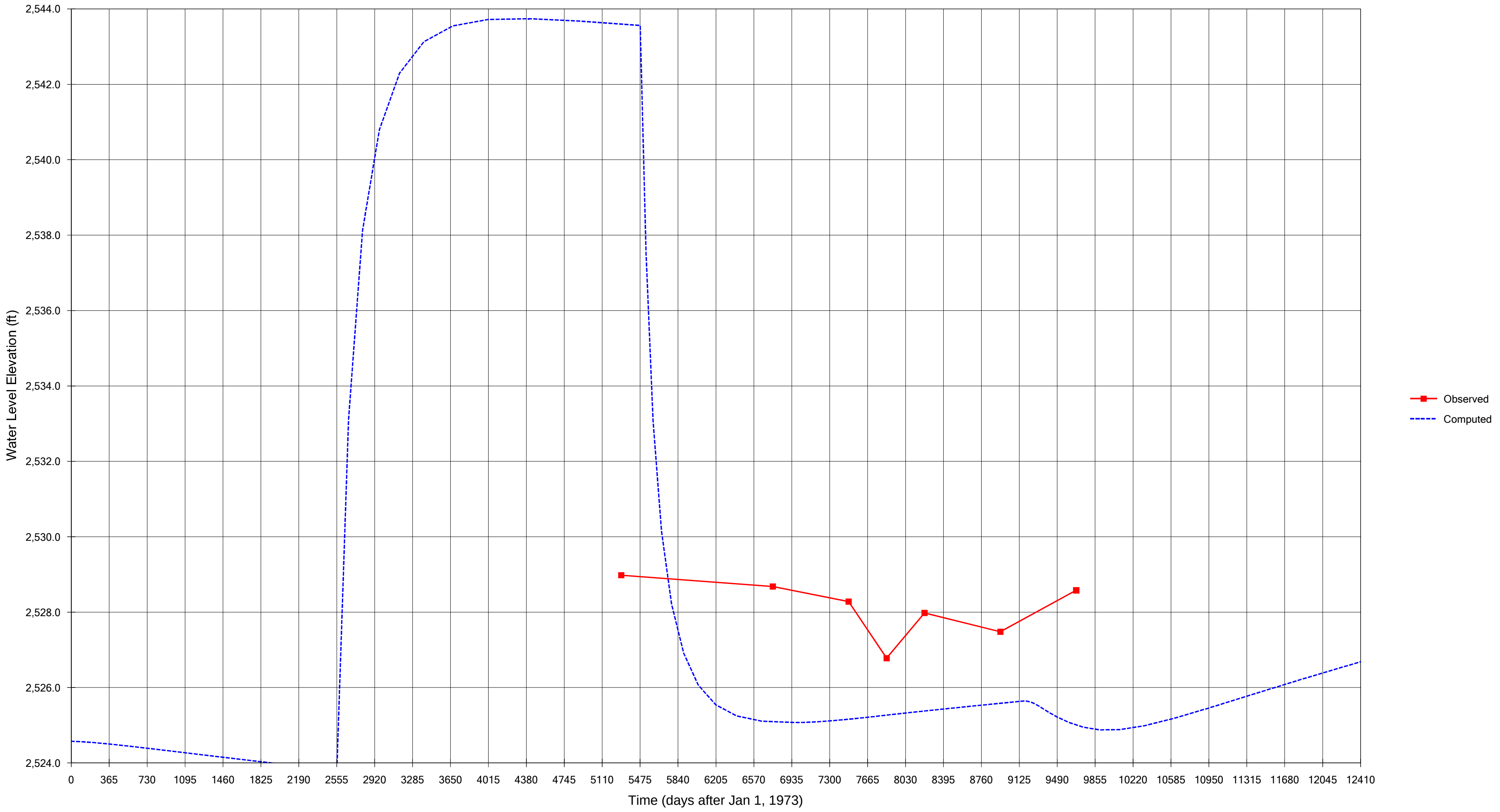


Figure 9-14 Hydrograph at Well OIEP-5.

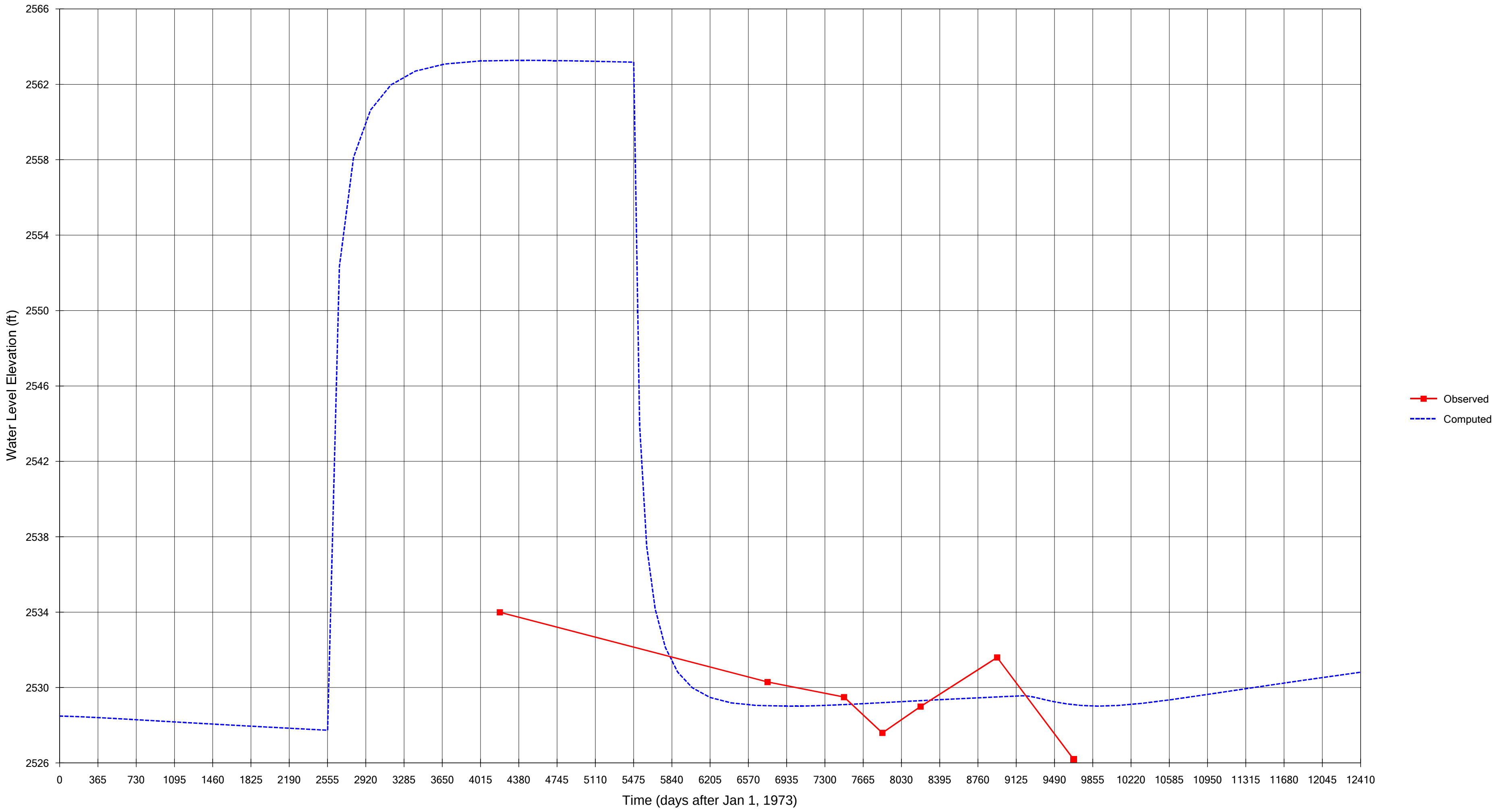


Figure 9-15 Hydrograph at Well OIEP-7.

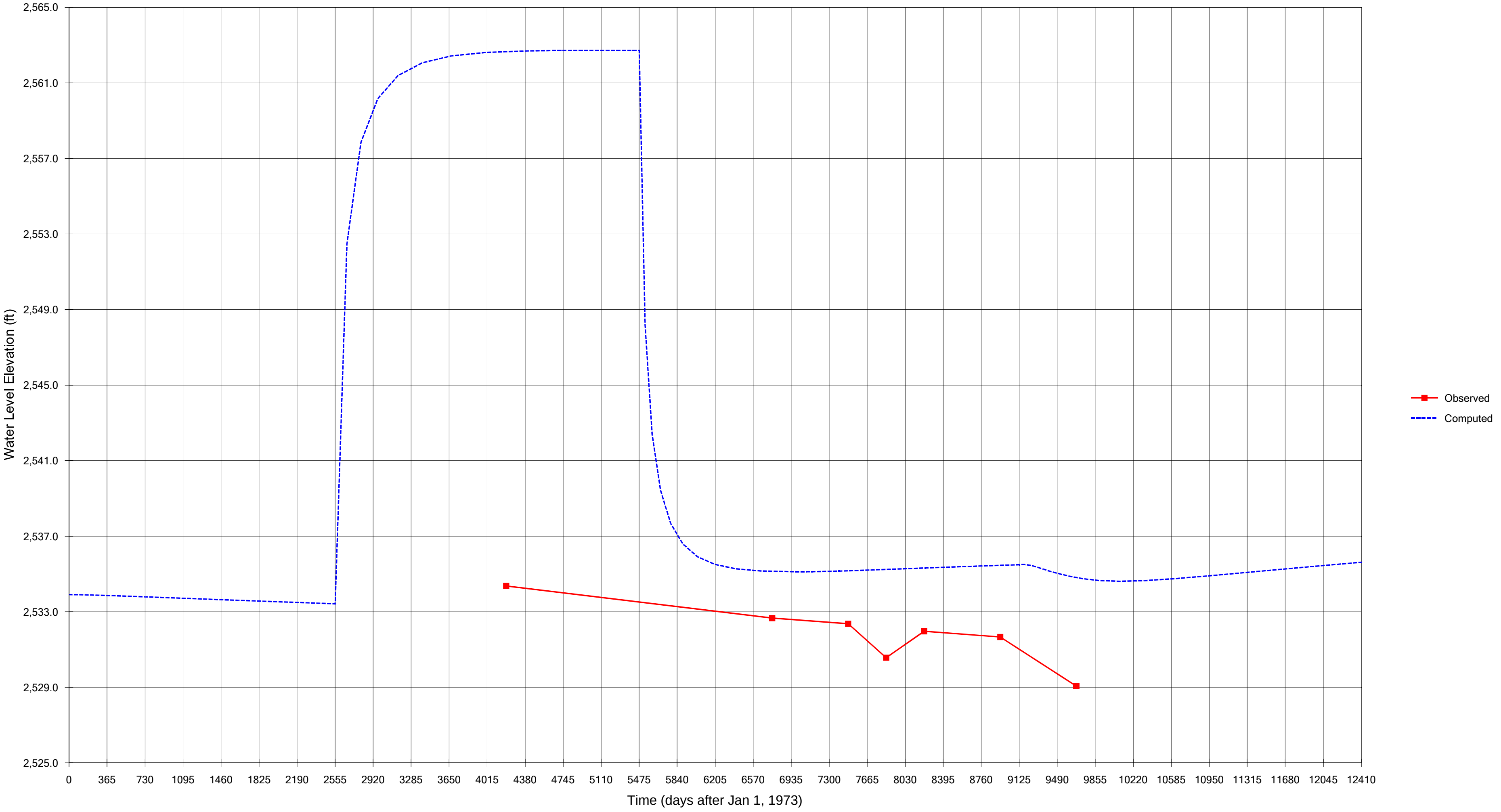


Figure 9-16 Hydrograph at Well OIEP-8.

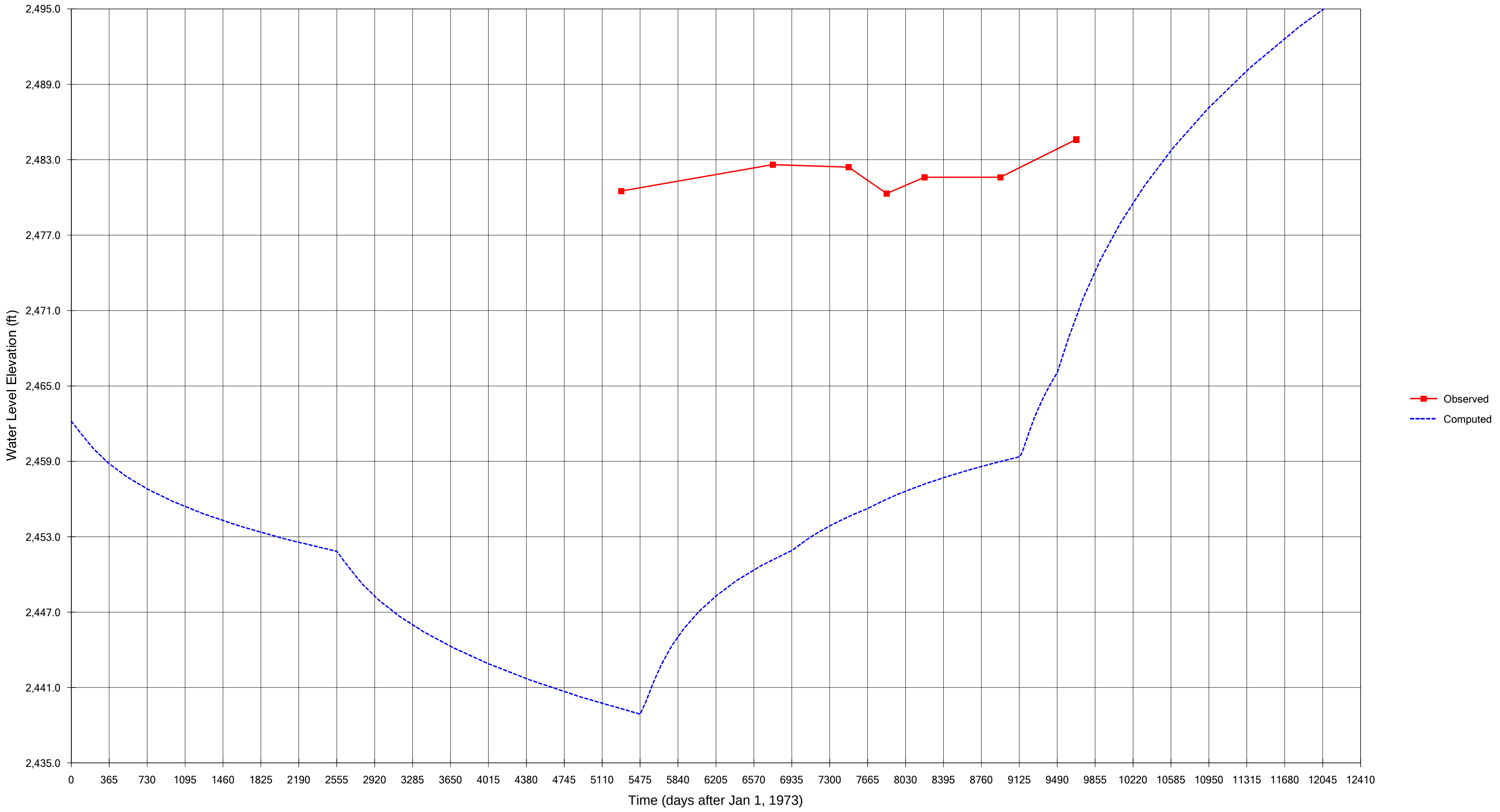


Figure 9-17 Hydrograph at Well OIEP-9.

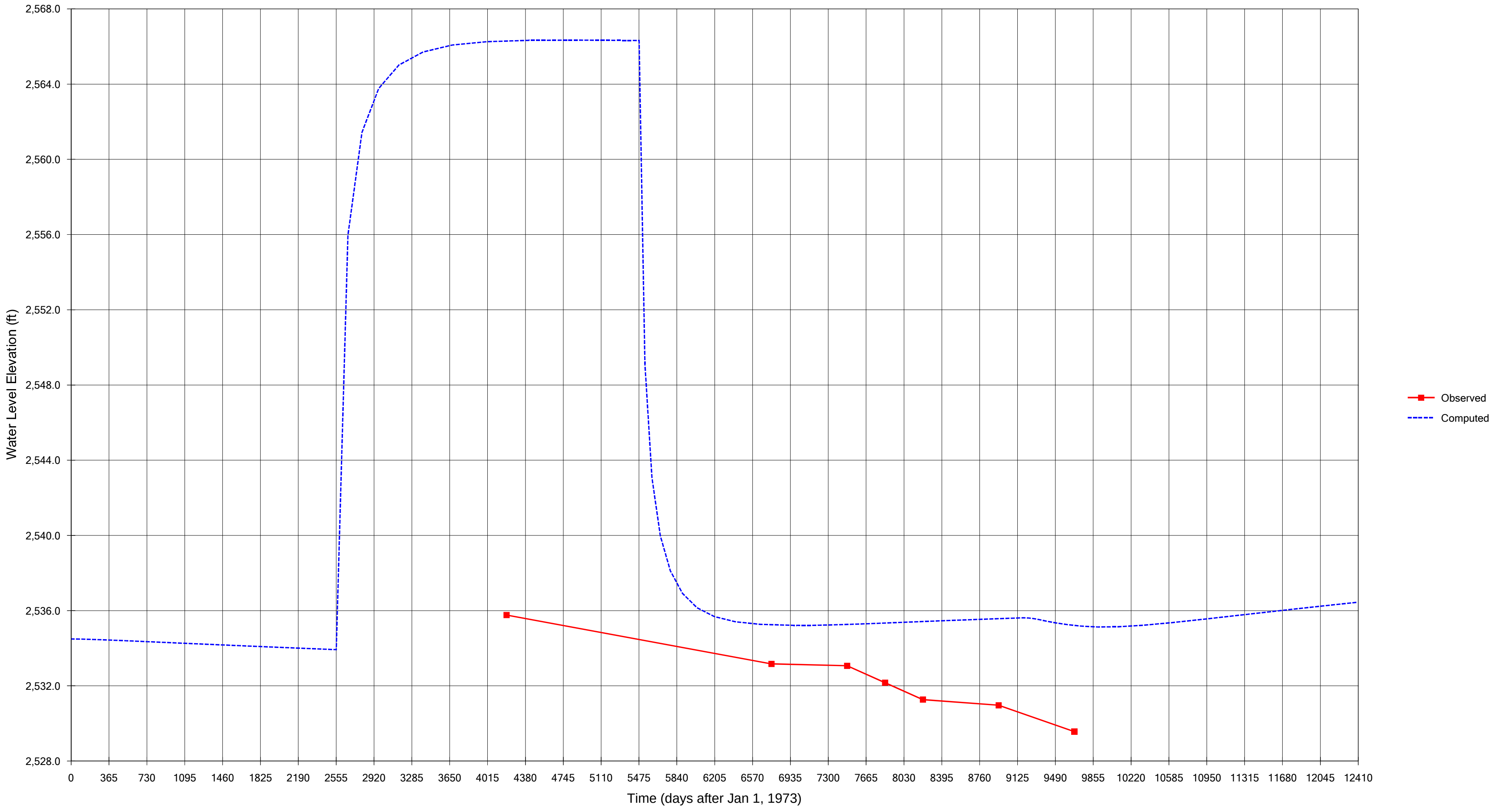
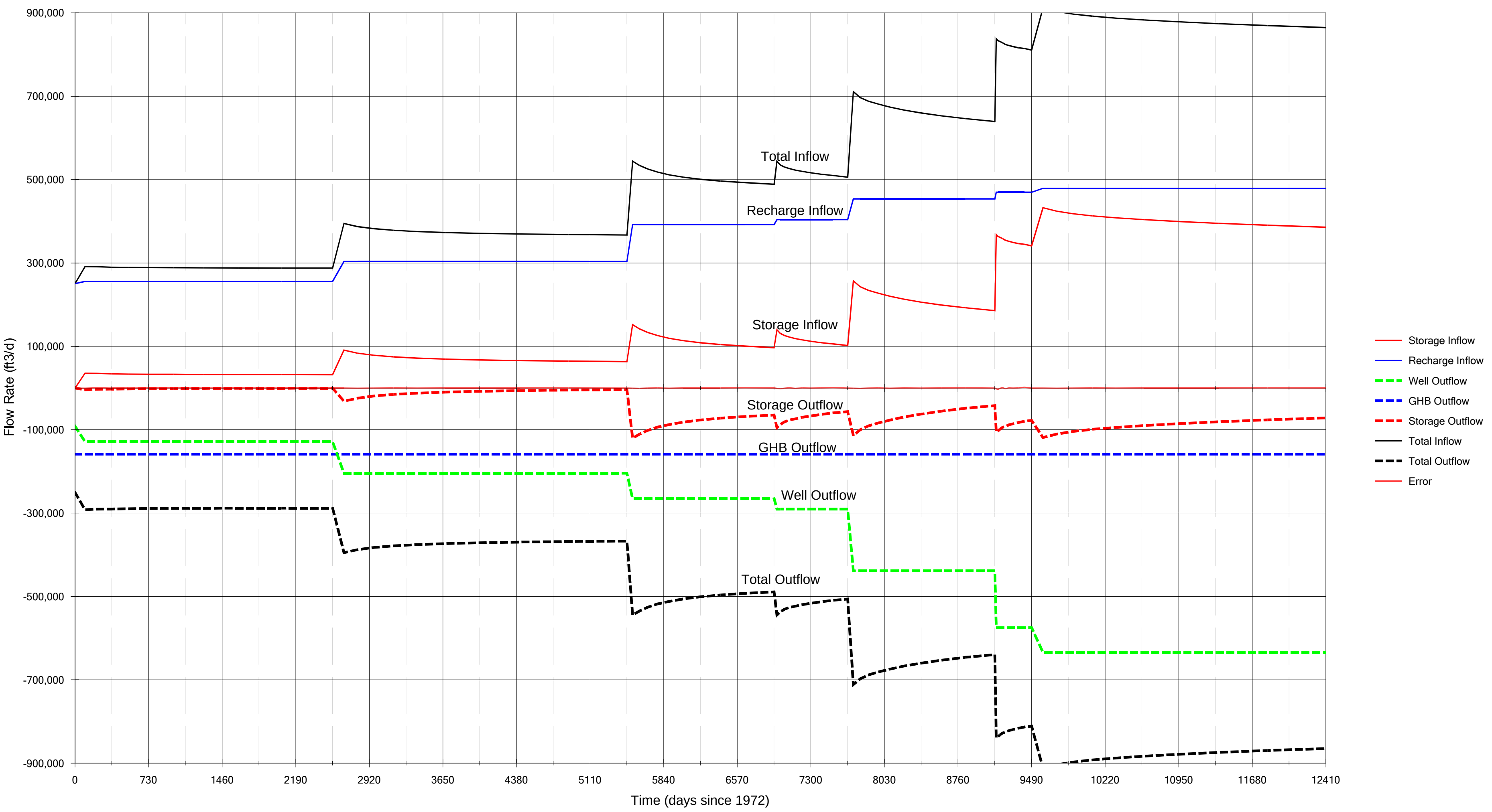
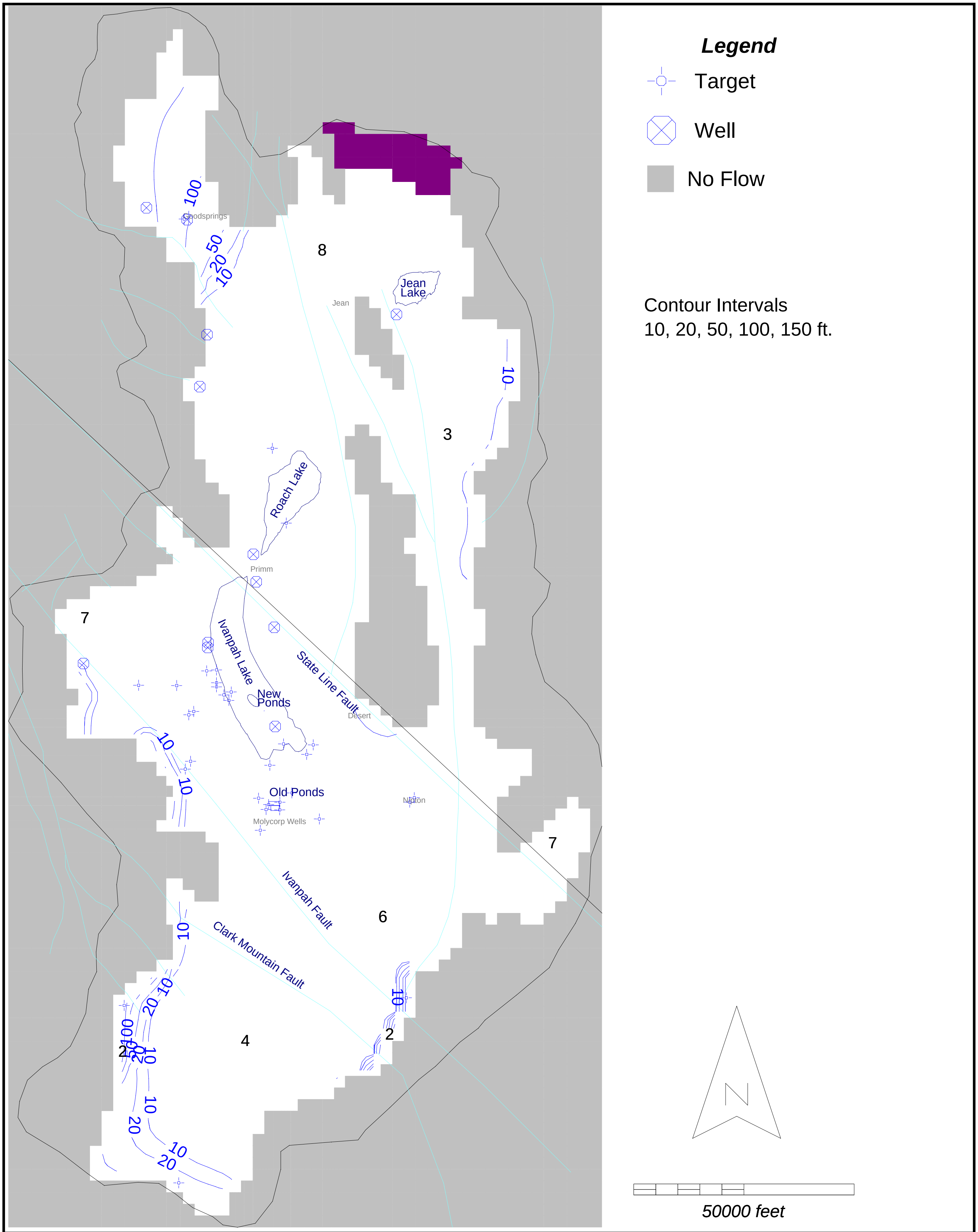


Figure 9-18. Mass Balance Summary for Ivanpah Valley Model





Figiure 9-19. Decrease in Water Table Elevation from a 5 Year Drought.

APPENDICES

Appendix A.

Calibration Sensitivity Analysis

A sensitivity analysis was conducted on the calibrated model to determine which parameters were most important in the model. Parameters tested included the 11 horizontal hydraulic conductivity zones, 11 vertical hydraulic conductivity zones, general head boundary (GHB) conductance at the north end of the basin, specific yield of layer 1, specific storage of layer 2, and the 17 recharge zones. For each parameter zone, the model was run twice for an increase of 50% and a decrease of 50% in the parameter value. **Table A1** summarizes the results using the RMS Error (residual standard deviation). The table lists the RMS Error for each run and an average percent change in the RMS Error for the two runs over the base calibration. The larger the percent error, the more sensitive was the parameter.

The ten most sensitive parameter zones are shown in bold in Table A1. These include horizontal hydraulic conductivity zones 2, 4, 5, 6, and 8, vertical hydraulic conductivity zones 1 and 2, and recharge zones 2, 6, and 7. The most sensitive parameter was recharge zone 6, which is in the southwest corner of Ivanpah South. These are probably the most sensitive because they are in an area of very steep gradients and thus cause large head fluctuations when they are modified. The most sensitive hydraulic conductivity zone (zone 2) is also in the southwest portion of Ivanpah South, in the same area as recharge zone 6. Again, since these areas have very steep gradients, small changes in parameter value translates into large changes in water levels in these areas. The same is true of the northwestern portion of Ivanpah North, near Goodsprings. Hydraulic conductivity zone 5 and recharge zone 2 are both in this area and are both very sensitive.

Table A-1. Results of the Calibration Sensitivity Analysis for the Ivanpah Basin Model.

Parameter	Zone	RMS Error (+50%)	RMS Error (- 50%)	Average Percent Change
Kx	1	26.7	27.2	0.063%
Kx	**2**	**26.3**	**106.8**	**147.049%**
Kx	3	27.0	27.0	0.249%
Kx	**4**	**14.4**	**27.3**	**-22.637%**
Kx	**5**	**35.7**	**66.4**	**89.379%**
Kx	**6**	**26.5**	**31.7**	**8.026%**
Kx	7	26.4	28.1	1.102%
Kx	**8**	**31.9**	**29.7**	**14.374%**
Kx	9	26.7	28.0	1.511%
Kx	10	26.9	26.9	-0.011%
Kx	11	27.0	26.8	-0.030%
Kz	**1**	**26.0**	**31.8**	**7.209%**
Kz	**2**	**24.3**	**48.7**	**35.441%**
Kz	3	27.0	27.0	0.044%
Kz	4	27.0	26.8	-0.197%
Kz	5	26.9	27.0	0.026%
Kz	6	26.9	27.1	0.193%
Kz	7	26.9	26.9	-0.030%
Kz	8	27.0	27.0	0.044%
Kz	9	26.9	27.2	0.416%
Kz	10	26.9	26.9	-0.030%
Kz	11	27.0	26.9	0.026%
Sy	1	26.9	26.9	-0.011%
Ss	2	26.9	27.0	0.044%
GHB Conductance	1	27.3	26.4	-0.364%
Recharge	**2**	**38.6**	**44.2**	**53.686%**
Recharge	3	26.8	27.3	0.471%
Recharge	4	26.6	27.5	0.379%
Recharge	5	26.2	28.3	1.102%
Recharge	**6**	**91.3**	**103.0**	**260.661%**
Recharge	**7**	**76.9**	**61.2**	**156.311%**
Recharge	8	27.2	28.2	2.884%
Recharge	13	26.9	26.9	0.007%
Recharge	14	26.9	26.9	0.007%
Recharge	15	27.0	26.9	0.007%
Recharge	16	26.8	27.1	0.044%
Recharge	17	26.9	27.0	0.026%
Recharge	18	27.0	27.0	0.063%
Recharge	19	26.9	26.9	0.007%
Recharge	20	26.9	27.0	0.044%
Recharge	21	26.7	27.2	0.082%
Recharge	22	27.4	26.6	0.193%

Appendix B. Well Coordinates

Well Name	X (ft)	Y (ft)	X (m)	Y (m)
Calibration Targets				
W-2	2,106,856	12,901,527	642,170	3,932,385
W-3	2,112,024	12,907,110	643,745	3,934,087
W-4	2,112,024	12,910,943	643,745	3,935,255
W-5	2,114,824	12,904,027	644,598	3,933,147
W-6	2,104,939	12,888,443	641,585	3,928,397
W-7	2,133,967	12,893,941	650,433	3,930,073
W-8	2,119,302	12,881,522	645,963	3,926,288
W-9	2,135,352	12,877,127	650,855	3,924,948
DWR-13	2,091,081	12,834,802	637,361	3,912,048
DWR-15	2,138,696	12,850,377	651,875	3,916,795
DWR-16	2,120,823	12,875,527	646,427	3,924,461
DWR-17	2,155,102	12,836,536	656,875	3,912,576
DWR-19	2,094,343	12,907,472	638,356	3,934,197
DWR-20	2,113,691	12,905,277	644,253	3,933,528
DWR-21	2,156,895	12,881,952	657,422	3,926,419
GL-1	2,112,024	12,908,026	643,745	3,934,366
GL-3	2,115,359	12,905,943	644,761	3,933,731
GL-4	2,143,855	12,901,823	653,447	3,932,476
GL-5	2,155,856	12,880,943	657,105	3,926,111
GL-6	2,112,024	12,910,943	643,745	3,935,255
GL-8	2,104,698	13,013,298	641,512	3,966,453
GL-9	2,140,301	12,992,057	652,364	3,959,979
GL-11	2,136,723	12,990,571	651,273	3,959,526
GL-12	2,124,680	12,961,242	647,602	3,950,586
GL-13	2,121,278	12,935,402	646,566	3,942,711
GL-15	2,159,106	12,998,860	658,096	3,962,053
DWR-24	2,132,478	12,891,776	649,979	3,929,413
DWR-25	2,123,273	12,879,277	647,174	3,925,604
DWR-26	2,135,240	12,968,943	650,821	3,952,934
DWR-27	2,127,856	12,944,277	648,571	3,945,416
TRC-8	2,121,960	12,874,559	646,773	3,924,166
TRC-2	2,109,536	12,880,375	642,987	3,925,938
TRC-15	2,106,144	12,890,212	641,953	3,928,937
TRC-24	2,102,981	12,907,407	640,989	3,934,178
TRC-27	2,109,794	12,910,732	643,065	3,935,191
TRC-9	2,107,604	12,909,191	642,398	3,934,721
TRC-11	2,107,280	12,913,084	642,299	3,935,908
TRC-14	2,105,739	12,900,756	641,829	3,932,150
DWR-1a	2,103,461	12,794,536	641,135	3,899,774
ME-4	2,127,228	12,894,151	648,379	3,930,137
ME-3	2,124,128	12,889,315	647,434	3,928,663
IER-3	2,121,565	12,881,838	646,653	3,926,384
IER-2	2,129,128	12,883,036	648,958	3,926,749
OIEP-5	2,123,839	12,880,391	647,346	3,925,943
OIEP-7	2,126,401	12,880,929	648,127	3,926,107
OIEP-9	2,126,359	12,879,194	648,114	3,925,578
OIEP-8	2,122,549	12,877,291	646,953	3,924,998

Pumping Wells	**X (ft)**	**Y (ft)**	**X (m)**	**Y (m)**
Molycorp2	2,122,203	12,876,247	646,847	3,924,680
Molycorp1	2,120,573	12,876,342	646,351	3,924,709
Desert	2,142,504	12,899,093	653,035	3,931,643
Nipton	2,153,055	12,880,582	656,251	3,926,001
Goodsprings	2,105,356	13,013,144	641,712	3,966,406
Jean	2,134,543	12,994,104	650,609	3,960,603
Colloseum	2,081,845	12,912,409	634,546	3,935,702
WhiskeyPete1	2,110,112	12,917,148	643,162	3,937,147
WhiskeyPete2	2,110,028	12,916,047	643,137	3,936,811
GolfCourse1	2,110,161	12,908,504	643,177	3,934,512
GolfCourse2	2,109,170	12,908,470	642,875	3,934,502
GolfCourse3	2,110,070	12,907,821	643,149	3,934,304
Calneva	2,125,123	12,920,623	647,738	3,938,206
obs1	2,125,639	12,880,190	647,895	3,925,882
Mine1	2,108,242	12,975,236	642,592	3,954,852
Mine2	2,109,882	12,987,047	643,092	3,958,452
Mine3	2,096,124	13,015,834	638,899	3,967,226
Jean_Valley	2,152,861	12,991,640	656,192	3,959,852
Industrial	2,120,381	12,937,179	646,292	3,943,252
Primm_Municipal	2,121,037	12,930,945	646,492	3,941,352
Domestic	2,116,444	12,936,851	645,092	3,943,152