ANL/EVS-14/7

Groundwater Modeling to Assess Water Resource Impacts at the Dry Lake Solar Energy Zone

Final Report

Environmental Science Division

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Groundwater Modeling to Assess Water Resource Impacts at the Dry Lake Solar Energy Zone

Final Report

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prepared for
The Bureau of Land Management
National Renewable Energy Coordination Office
U.S. Department of Interior
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The following is a list of acronyms, initials, symbols, and abbreviations (including units of measure) used in this document.

Acronyms, Initials, Symbols and Abbreviations

BLM	Bureau of Land Management
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
GIS	geographic information system
GMS	Groundwater Modeling System
GUI	graphical user interface
HA	Hydrologic Area
HUF	Hydrogeologic Unit Flow
MSL	mean sea level
NDWR	Nevada Department of Water Resources
PEIS	Programmatic Environmental Impact Statement
PV	photovoltaic
SNWA	Southern Nevada Water Authority
SEZ	solar energy zone
USGS	U.S. Geological Survey

Units of Measure

ac	acre
ac-ft	acre-feet
d	day
ft	feet
in.	inch
km	kilometer
m	meter
m^2	square meter
m^3	cubic meter
mi	mile
mi^2	square mile
yr	year

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A GROUNDWATER MODEL TO ASSESS WATER RESOURCE IMPACTS AT THE DRY LAKE SOLAR ENERGY ZONE

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1 INTRODUCTION

The purpose of this study is to develop a groundwater flow model to examine the influence of potential groundwater withdrawal to support utility-scale solar energy development at the Dry Lake Solar Energy Zone (SEZ) as a part of the Bureau of Land Management's (BLM's) Solar Energy Program.

A highly detailed three-dimensional numerical groundwater flow model was recently created for a region including the SEZ. In this report, this model is referred to as the Department of Interior (DOI) numerical model or DOI model, because it was a study funded by the National Park Service, U.S. Fish and Wildlife Service, and BLM (Tetra Tech 2012a,b).

This report describes the DOI model and its application for assessing the drawdown associated with SEZ groundwater pumping rates for a 20-year duration considering three categories of water demand (high, medium, and low) based on technology-specific considerations. This report also makes recommendations for the further development of the groundwater model as information becomes available from individual project investigations associated with the siting, construction, and operation of a utility-scale solar energy facility.

1.1 The Bureau of Land Management's Solar Energy Program

In 2012, BLM officially established its Solar Energy Program, which facilitates permitting of utility-scale solar energy development on BLM lands in six southwestern states (Arizona, California, Colorado, Nevada, New Mexico, and Utah) in an environmentally responsible manner (BLM 2012b). As a part of the Solar Energy Program, the BLM established SEZs, which are areas that are well-suited for utility-scale production of solar energy where BLM will prioritize solar development. The BLM, together with the Department of Energy (DOE), analyzed the potential environmental impacts of the Solar Energy Program in the *Final Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States* (Solar PEIS), including impacts on water resources (BLM and DOE 2012). Groundwater is the primary water resource available for solar energy development in most of the SEZs, and impacts of groundwater withdrawals were investigated qualitatively and semi-quantitatively in the Solar PEIS to assess the range of potential effects. Impacts of reduced groundwater flow magnitude and timing of groundwater flows to streams, springs, seeps, and wetlands would depend upon the connectivity of surface water and groundwater in the region. These impacts include decreased water supply for downstream users; loss of wetland vegetation species; loss of habitat and forage for wildlife, wild horses, and livestock; and others.

As a part of the Solar PEIS analysis, water requirements for cooling and/or washing uses at solar energy facilities were examined for different technologies and varying levels of development and compared with basin-scale water budgets. In addition, one-dimensional groundwater modeling was performed to examine potential radial drawdown for different solar development scenarios. As a follow-on to the work done for the Solar PEIS, BLM identified a subset of SEZs, including the Dry Lake SEZ, for which three-dimensional groundwater models would be identified and applied (if there was a pre-existing model), or newly developed. The models are being used to examine potential groundwater impacts associated with proposed solar development of the SEZs, with a particular focus on examining groundwater drawdown and potential loss of connectivity to surface-water features, springs, and vegetation. In addition to these analyses, the developed numerical groundwater models are being made available through the Solar PEIS Web site (http://blmsolar.anl.gov) so that they can be used for project-scale review and for the development of long-term monitoring programs.

1.2 The Dry Lake Solar Energy Zone

The Dry Lake SEZ covers approximately 5,700 acres (23 km^2), and is located in Clark County in Southern Nevada (Figure 1). The Dry Lake SEZ is within the Garnet Valley groundwater basin, an arid alluvial basin-fill aquifer covering approximately 342,400 ac (1,386 km^2) and bounded by bedrock mountains, characteristic of the Basin and Range physiographic province. The SEZ has surface elevations ranging between 2,000 and 2,560 ft above mean sea level (MSL) (between 600 and 780 m above MSL).

In a management context, the Nevada Department of Water Resources (NDWR) considers the Garnet Valley to be Hydrologic Area (HA) 216. The NDWR decides on the allocation of the groundwater that is allowed to be withdrawn from the basin. The Garnet Valley groundwater basin is a designated groundwater basin, and preferred uses of groundwater include municipal, quasi-municipal, industrial, commercial, mining, stock water, and wildlife purposes, set up to specifically exclude irrigation. The perennial yield for Garnet Valley is set at 400 ac-ft/yr (490,000 m^3/yr), and the basin is currently overappropriated, with approximately 3,400 ac-ft/yr (4.2 million m^3/yr) committed for beneficial uses. Garnet Valley is also referred to as Dry Lake Valley, although it is distinct from another Dry Lake Valley (HA 181) that contains the Dry Lake Valley North SEZ, which is approximately 80 mi (130 km) to the north of Garnet Valley.

Topographically, Garnet Valley is a closed depression. The basin is bounded by The Arrow Canyon Range on the west and north, which partially separates it from nearby, topographically higher Hidden Valley (HA 217). On the south, Garnet Valley is bordered by the Las Vegas Range. On the east, the Dry Lake Range and alluvial fan deposits separate Garnet Valley from California Wash (HA 218), a topographically lower basin. There are no perennial surface-water features in the SEZ, but Garnet Valley contains Dry Lake and some associated ephemeral channels that drain to the dry lake.

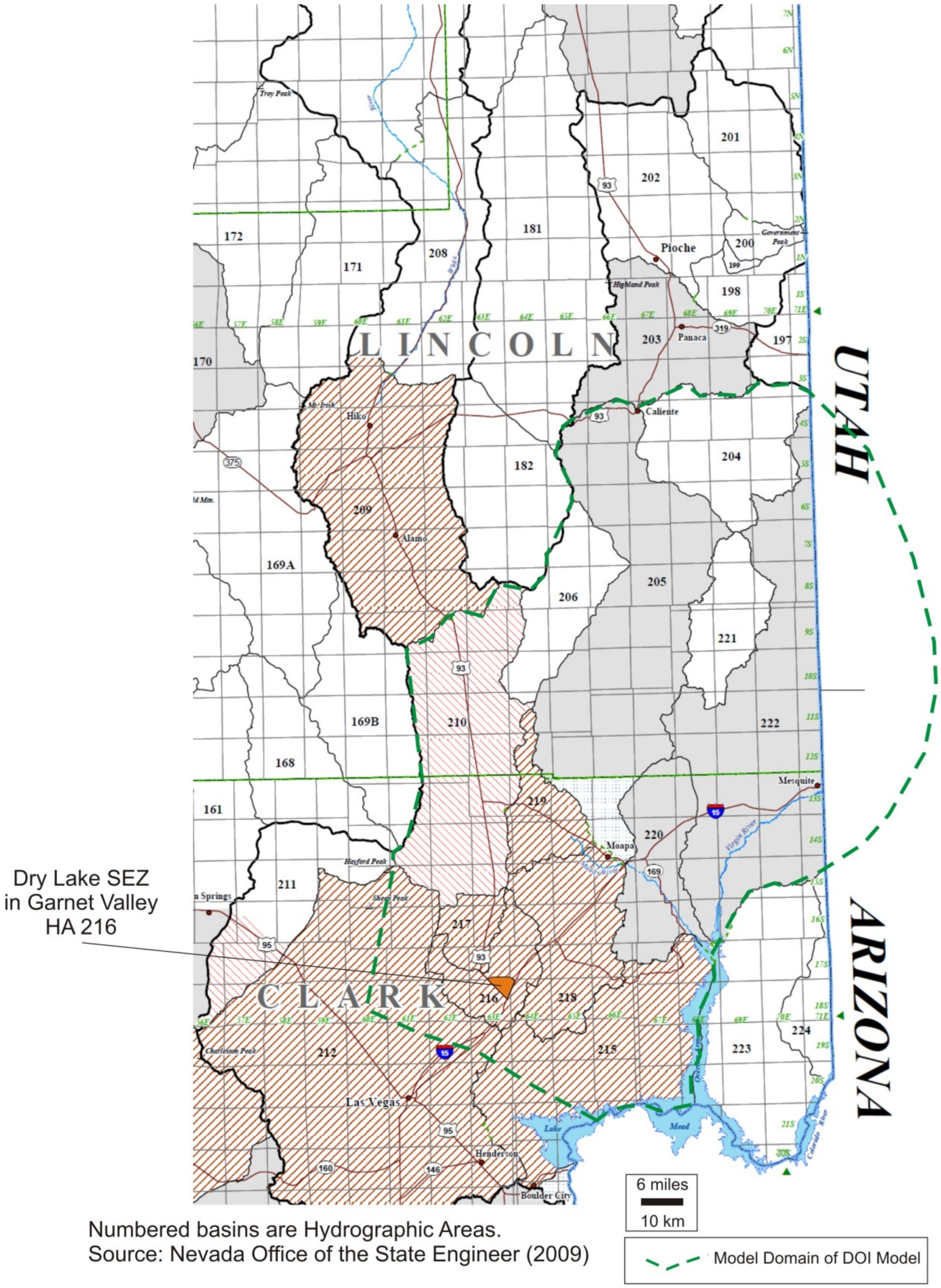

Figure 1 Location of Dry Lake SEZ and the DOI Model Domain

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2 HYDROGEOLOGIC SETTING AND MODEL INPUT PARAMETERS

2.1 Geology and Hydrogeology

The overall geologic framework in the vicinity of Garnet Valley is thick alluvial sediment underlain by sequences of carbonate bedrock. The surrounding region is a hydrogeologic setting referred to as the Colorado Regional Groundwater Flow System (Tetra Tech 2012a) or the Central Carbonate Rock Province (SNWA 2009a,b).

Page et al. (2011) produced a series of geologic cross-sections of a region in southeast Nevada, including the vicinity of Dry Lake Valley (Garnet Valley) (Figure 2). Here, sequences of Paleozoic sedimentary rock formations are present, with an overall thickness on the order of 23,000 ft (7,000 m). High-angle faults and thrust faults complicate the subsurface relationships among the rock units. Generally, in the local area, the bedrock ranges (Las Vegas Range, Arrow Canyon Range, Dry Lake Range) are comprised of Lower Permian to Upper Mississippian carbonate rocks, including the Bird Spring and Indian Spring Formations (PMu in Figure 2). Collectively, these units have a thickness of 1,500 to 8,200 ft (460 to 2,500 m). Below these are Upper Mississippian to Middle Devonian units, including the Monte Cristo Group, Crystal Pass Limestone, and Guilmette Formation (MDu in Figure 2) with a combined thickness of about 980 to 5,900 ft (300 to 1,800 m). Below these units are Middle Devonian to Silurian rocks, including the Simonson Dolomite, the Sevy Dolomite, and the Laketown Dolomite (DSu on Figure 2) with a combined thickness of 660 to 2,600 ft (200 to 780 m). Below these are Upper Ordovician to Upper Cambrian units, including the Ely Springs Dolomite, the Eureka Quartzite, and the Pogonip Group (O€u in Figure 2) with a combined thickness of about 1,800 to 3,900 (550 to 1,200 m). Due to regional thrust faulting, much of the deeper Paleozoic stratigraphy is a repetition of the above sequence.

Basin fill between mountain ranges is predominantly comprised of alluvium along with playa deposits and colluvium (QTKu in Figure 2). Burbey (1997) estimates the thickness of valley fill sediments to be up to 4,500 ft (1,400 m) in Garnet Valley. In terms of available measurements, a log from a U.S. Geological Survey (USGS) boring located in the Dry Lake basin itself is 1,500 ft (460 m) deep and only encountered alluvial materials (Rush 1968).

An environmental impact statement was prepared for a project of groundwater extraction from east-central Nevada and construction of a pipeline system to convey the water to Las Vegas (BLM 2012a). As part of this project, a series of reports were generated by the Southern Nevada Water Authority (SNWA), including reports on geology, hydrogeology, and groundwater modeling. SNWA (2008b) describes the Mississippian-Ordovician carbonate sequence as being highly permeable. The Cambrian carbonate sequence is also highly permeable. Deeper units are generally impermeable except where fractured.

Faulting associated with Paleozoic Sevier orogeny may have created some groundwater flow barriers in the study area (SNWA 2008b). Extensional tectonics in the basin and range province during Miocene to Holocene time created north–south faults that may be preferential pathways for groundwater flow. Fracturing of brittle rocks in the region enhanced the permeability of local

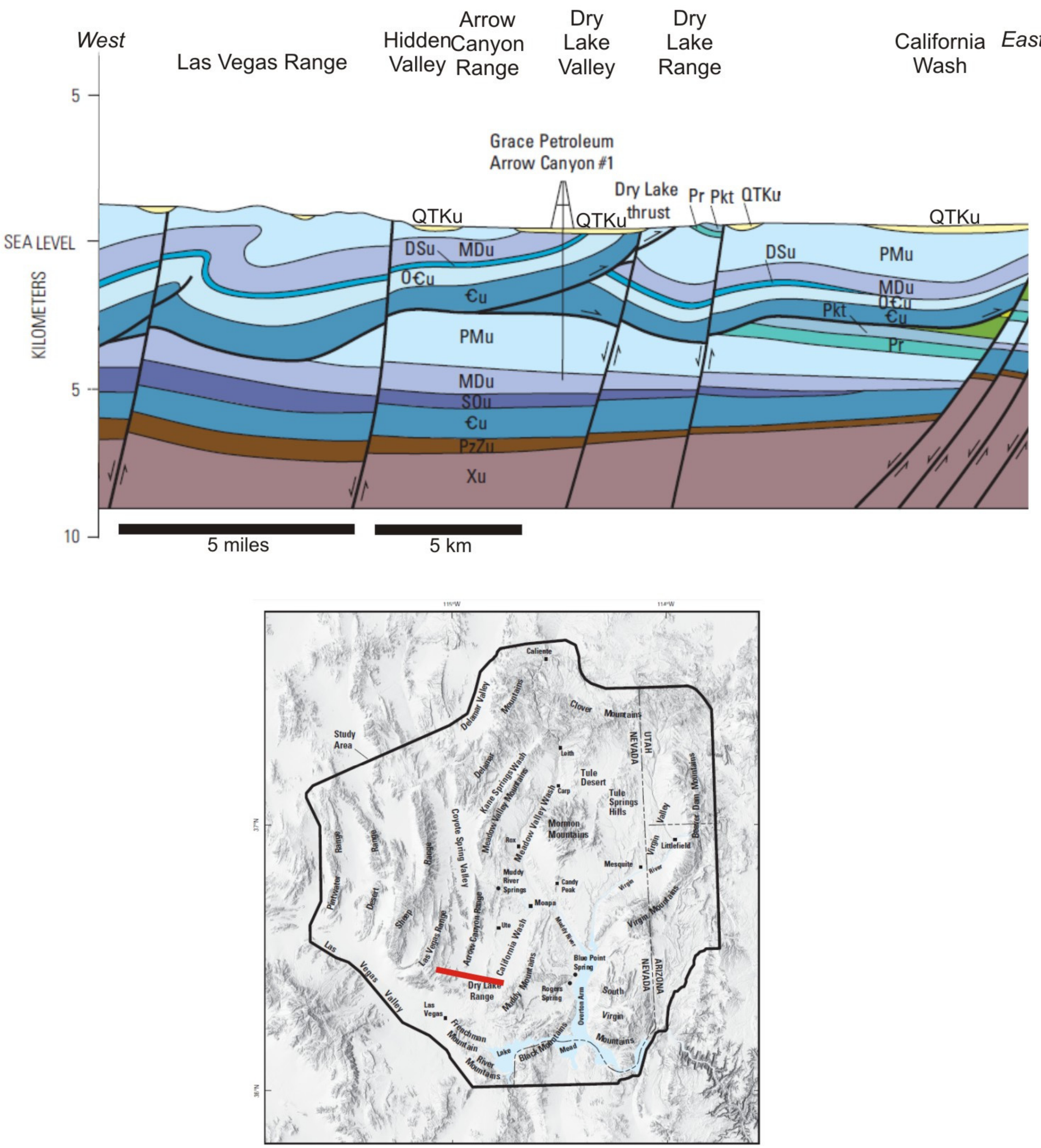

Figure 2 West-East Hydrogeological Cross-section through Dry Lake Study Area and Cross-section Location Map (Source: modified from Page et al. 2011)

and regional aquifers, and solution enlargement of fractures is expected (Rush 1968). This includes the carbonate aquifer, and post-fracturing dissolution of the carbonate resulted in greater interconnection of conduit flowpaths (SNWA 2008b).

The alluvial basin fill has a wide range of textures, from fine-grained clay and silt to coarse-grained sand and gravel, and therefore has a wide range of permeabilities (SNWA 2008b). The arrangement of these units varies over short distances. Overall, the unit has a moderate permeability.

2.1.1 Stratigraphic Data

The State of Nevada has made drilling logs accessible online (NDWR 2012b). All available drilling logs for HA 216 (Garnet Valley) were downloaded from the database. These handwritten logs were then interpreted to assess the geologic materials encountered, and this information was compiled as input to the Groundwater Modeling System (GMS) tool for inspection and visualization of the stratigraphic framework of the study area. Static water levels and screened intervals were also obtained. Location information for these logs was provided at the resolution of quarter of quarter of sections. In addition, Rush (1968) contains a compilation of logs, including four additional logs from Garnet Valley.

The logs from Rush (1968), including two additional logs for the adjacent California Wash (HA 218), and 48 logs from the State were compiled in a three-dimensional scientific visualization tool (Groundwater Modeling System version 8.3) to examine the local topography, the available stratigraphic data, static water levels from well logs, and depths of screened intervals within the wells.

The interactive analysis demonstrated the basin's level of complexity in alluvial lithologies, the irregular surface between alluvium and bedrock, and the variety of bedrock descriptions provided on drilling logs. Notably, well screens in Garnet Valley were generally in the same elevation interval (950 to 1,800 ft, or 290 to 5,500 m, above MSL) whether the wells were completed in deep basin fill in Garnet Valley or in bedrock near the fringes of the basin.

2.2 Groundwater Flow

According to Burbey (1997), water levels are about 200 to 300 ft (60 to 90 m) below ground surface in Garnet Valley. Groundwater flow in Garnet Valley is easterly (Figure 3). In Hidden Valley to the west, which is about 700 ft (210 m) higher in elevation, water levels are about 800 to 900 ft (240 to 270 m) below ground surface.

Water level data show that regional flow in the carbonate aquifer is to the east-southeast in the Garnet and Hidden valley vicinity. Although no data points are present in nearby Hidden Valley, water levels are generally 1,820 ft (555 m) above MSL in southern Garnet Valley and 1,814 ft (553 m) above MSL in northern Garnet Valley (Figure 3).

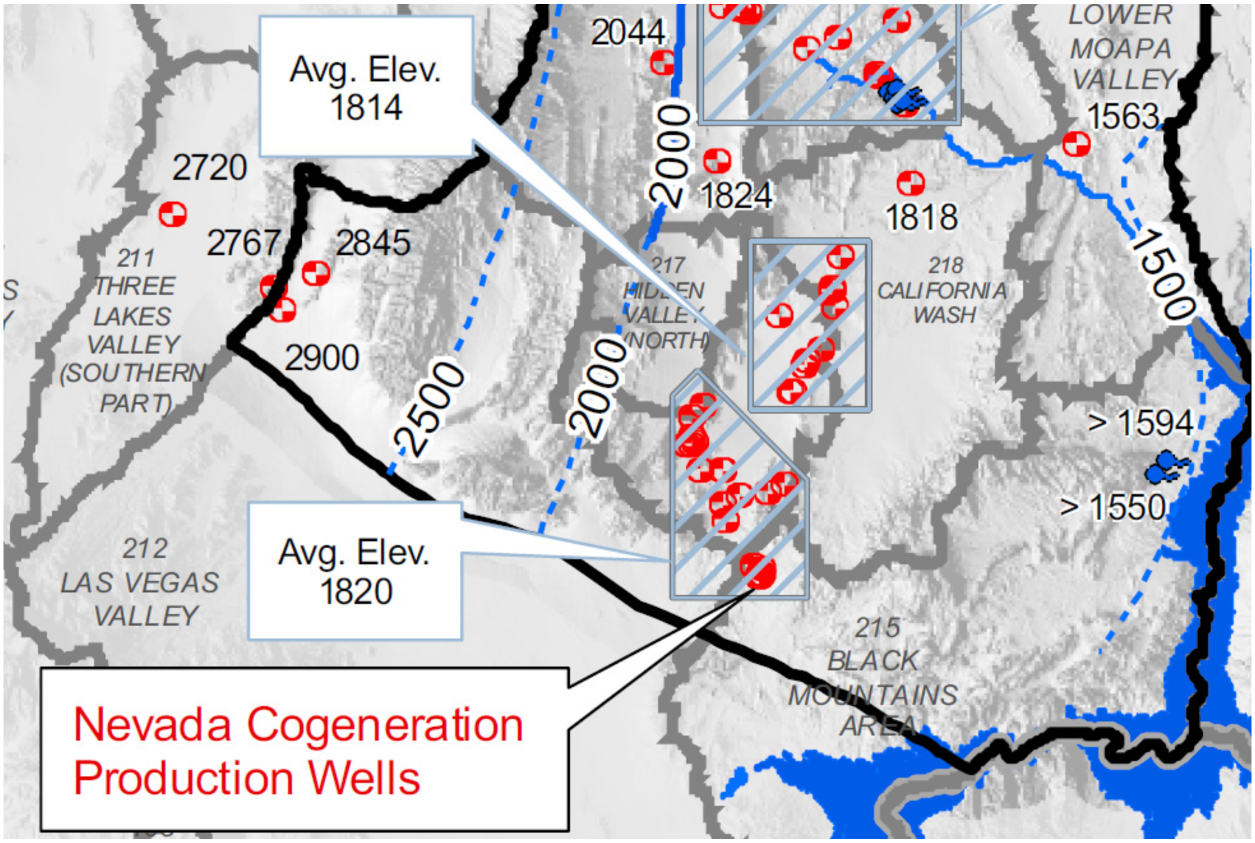

Figure 3 Water Level Elevations in the Carbonate Aquifer in Garnet Valley in Feet above MSL (Cross-hatched areas represent groupings of wells with similar water levels.) (Source: modified from SNWA 2008a)

SNWA (2009b) assembled the results of numerous prior studies of groundwater flow assessments in the region and acknowledged that different interpretations of groundwater exchange between basins are possible due to sparse data.

Conceptually, the bulk of the groundwater flow is expected to take place in permeable units within the basin fill and within the underlying carbonate aquifer, with interaction between the aquifer types as determined by local permeability relationships. The arrangement of permeable and impermeable material within basin fill is complex, as is the interconnectedness of permeable fill units and conduit flowpaths in the bedrock. Groundwater flow in the region is more active at shallower depths (Harrill and Prudic 1998). Deeper groundwater may be too uneconomical to pump (Eakin 1963) or of poor quality.

Basin fill has stratigraphic complexity, and zonation of different types of alluvial materials aerially or vertically in the study area would be difficult to support because of the inherent depositional variability and the lack of details in drilling logs (i.e., “alluvium” does not give strong indication of permeable vs. impermeable sediments). Rush (1968) generalized that the deeper alluvial deposits have a range of permeability values based on sediment texture and cementation. Much of the deep alluvium is Muddy Creek Formation, which is a poor aquifer

(Rush 1968). Younger alluvium, where thick and saturated, may be the best aquifer in the study area (Rush 1968). The playa deposits are assumed to have very low permeability (Rush 1968).

Groundwater throughout the Dry Lake SEZ study area is too deep to be affected by evapotranspiration (Burbey 1997).

2.3 Aquifer Properties

SNWA (2009a) identified basin fill in Garnet Valley to be "upper valley fill." Upper valley fill hydraulic conductivity, based on 132 constant-rate tests in the region, has a mean of 12 ft/d (3.7 m/d), with a range of 2×10^{-4} to 3,600 ft/d (6×10^{-5} to 1,100 m/d), and a 95% confidence interval range of 0.066 to 2,089 ft/d (0.020 to 636.7 m/d). For the upper valley fill, specific yield in the region (17 data points) ranges from 0.0004 to 0.2870, with a mean of 0.0424. Specific storage (36 data points) ranges from 1.72×10^{-7} to 3.38×10^{-3} ft^{-1} (5.24×10^{-7} to 1.03×10^{-3} m^{-1}) with a mean of 1.21×10^{-4} ft^{-1} (3.69×10^{-5} m^{-1}).

SNWA (2009a) presents hydraulic conductivity values for the carbonate aquifer of Garnet Valley. Five measurements range from >0.025 to >250 ft/d (>7.6×10^{-3} to >76 m/d). For the overall eastern Nevada region, based on 89 constant-rate tests, SNWA gives a mean of 5.37 ft/d (1.64 m/d) for the carbonate aquifer, with a range of 0.027 to 3,200 ft/d (8.2×10^{-3} to 980 m/d), and a 95% confidence interval range of 0.020 to 1,440 ft/d (6.1×10^{-3} to 439 m/d). For the carbonate aquifer, specific yield (2 data points) in the region ranges from 0.0012 to 0.0309, with a mean of 0.0160. Specific storage (3 data points) ranges from to 4.67×10^{-7} to 1.24×10^{-5} ft^{-1} (1.42×10^{-7} to 3.78×10^{-6} m^{-1}), with a mean of 8.26×10^{-6} ft^{-1} (2.52×10^{-6} m^{-1}).

2.4 Recharge

In the DOI model, recharge was estimated using a modified Maxey-Eakin method to relate spatially varying estimated precipitation to estimated recharge (Tetra Tech 2012a). The results include a recharge estimate of zero at the SEZ location, in most of Garnet Valley, and in a least half of the modeling domain. Recharge is greatest at high elevations, with values of over 2.1 in./yr (5.3 cm/yr) in some areas in the northern portion of the model. Other estimates of recharge have been made for Garnet Valley. SNWA (2009a) relied on groundwater balance methods to estimate the recharge to basins throughout east-central Nevada. This approach relied on data on precipitation bands combined with recharge efficiencies. A recharge value of 101 ac-ft/yr (125,000 m^3/yr) was determined for Garnet Valley. With an area of 342,400 ac (1,386 km^2), this equates to a direct recharge rate of 3.5×10^{-3} in./yr (8.9×10^{-3} cm/yr). SNWA (2009a) summarized several other studies, which estimated a range of recharge values determined by various methods of 0 to 1,000 ac-ft/yr (0 to 1,000,000 m^3/yr) for Garnet Valley, or 0 to 3.5×10^{-2} in./yr (0 to 8.9×10^{-2} cm/yr) of direct recharge. LVVWD (2001) estimated 393 ac-ft/yr (485,000 m^3/yr) for Garnet Valley, or 8.9×10^{-2} in./yr (0.23 cm/yr). The zero recharge determined by Tetra Tech (2012a) is similar to these other negligible rates of direct recharge for the Garnet Valley.

2.5 Basin Yield and Water Users

NDWR (undated) assumes that the perennial yield for Garnet Valley is 400 ac-ft/yr (490,000 m^3/yr), and the basin is currently overappropriated, with approximately 3,400 ac-ft/yr (4.2 million m^3/yr) committed for beneficial uses. These include 14 ac-ft/yr (17,000 m^3/yr) commercial, 3 ac-ft/yr (3,700 m^3/yr) domestic, 612 ac-ft/yr (755,000 m^3/yr) industrial, 284 ac-ft/yr (350,000 m^3/yr) mining and milling, 2,275 ac-ft/yr (2.806×10^6 m^3/yr) municipal, and 178 ac-ft/yr (220,000 m^3/yr) quasi-municipal, for a total of 3,365 ac-ft/yr (4.151×10^6 m^3/yr). State pumpage inventories for 2001 through 2010 (NDWR 2012a) for all categories except domestic averaged 1,352 ac-ft/yr (1.668×10^6 m^3/yr), which is far below the appropriated level but well above the perennial yield.

In 2001, the Nevada State Engineer held a hearing on applications in Coyote Spring Valley. Testimony and evidence presented in the hearing resulted in uncertainty regarding water availability in the area and identified that the hydrology and geology, particularly the carbonate-rock aquifer, were generally not well known. Based on the findings in the hearing, the State Engineer issued Order 1169 in March 2002, covering six basins including Garnet Valley, where the Dry Lake SEZ is located. Order 1169 held all pending and new water rights applications in abeyance until further studies could be conducted to provide information by stressing the aquifer through use of existing, permitted water rights in the carbonate-rock aquifer system. The studies concluded in December 2012, and all participants were asked to submit reports analyzing the data. The State Engineer issued rulings for each of the six basins in January 2014. In ruling 6256, the State Engineer concluded that there is no additional groundwater available for appropriation in Garnet Valley. Additionally, the State Engineer concluded that approval of the pending applications within Garnet Valley would prove detrimental to the public interest based on impacts to the Muddy River Springs Area and denied all of the pending applications. Although no order has been issued closing Garnet Valley to water rights applications, the ruling does suggest that future water rights applications for large quantities of water would be denied. Lawsuits have been filed against the State Engineer in regards to the Order 1169 rulings. Currently these rulings are in full force and effect.

In general, the development of groundwater resources is expected to remove water from storage, with a slow rate of replenishment if pumping ceased (Burbey 1997).

3 METHODOLOGY

The assessment of groundwater flow and well drawdown can be approached with a variety of computational tools. The USGS model MODFLOW (Harbaugh et al. 2000) is a finite-difference numerical model capable of incorporating spatially and temporally varying inputs to calculate head throughout a modeling domain. Multiple model layers may be delineated in three-dimensional MODFLOW models. Examples of the types of input include spatially varying aquifer properties (hydraulic conductivity, storativity, and unit geometry), spatially varying recharge, and temporally varying pumping rates. A numerical analysis must also incorporate proper model boundary conditions, ideally far from the main area of interest.

Numerical modeling of groundwater flow systems in southeast Nevada involves the complexities of the alluvial aquifer/aquitard framework, the irregular contact between alluvium and bedrock, spatially varying bedrock properties, spatial and temporal aspects of recharge, detailed information on well pumping in the modeling area, and satisfactory modeling of boundary conditions. Because of the effort involved in such a process, a modeling project may require multiple investigators over a long period of time. For this reason, existing numerical models were sought after for use in these SEZ assessments. As described in Section 1, a multiyear MODFLOW-based modeling project (the DOI model) has been completed in the region including the SEZ area. This model was utilized in assessing Dry Lake SEZ–produced drawdown from projected SEZ groundwater requirements.

The permeability of the carbonate aquifer may be affected locally or regionally by fracturing, solution enlargement, and fault plane barriers or preferential flowpaths. Because of the scale of the DOI numerical model and the lack of detailed information, the carbonate aquifer is assumed to function as a porous media in the model.

The operational water requirements for an SEZ will depend on the degree of buildout on the SEZ and on the solar energy technology used (BLM and DOE 2012). Some technologies require a cooling system, while some technologies require water for cleaning panels or mirrors. For the Dry Lake SEZ, the considered low-, medium-, and high-demand groundwater pumping scenarios represent full buildout of the SEZ assuming photovoltaic (PV) panel, dry-cooled parabolic trough, and wet-cooled parabolic trough facilities, respectively (BLM and DOE 2012). Dry- and wet-cooled power tower facilities would have comparable water requirements to those of dry- and wet-cooled parabolic trough facilities, respectively. The assumed water requirements are summarized in Table 1.

Table 1 Low, Medium, and High SEZ Groundwater Pumping Requirements Assumed for Dry Lake SEZ

Description	Pumping Scenario	Assumed Pumping Requirements		
		ac-ft/yr	m3/d	ft3/d
Full buildout of PV	Low	26	88	3,101
Full buildout of dry-cooled parabolic trough	Medium	653	2,206	77,890
Full buildout of wet-cooled parabolic trough	High	4,586	15,492	547,018

3.1 Application of the DOI Model

The DOI model (Tetra Tech 2012a,b) is a highly detailed, 18-layer numerical model created using MODFLOW-2000 (Harbaugh et al. 2000). It incorporates information from various sources regarding evapotranspiration rates, pumping rates, groundwater levels, well construction, streamflow, and spring discharge. The model relies on recent geologic analysis regarding the structure and extent of the region's formations (Page et al. 2011). Faults in the region were considered in the flow model, and their effects were modeled using the Horizontal Flow Barrier package. The main focus of the model is the Muddy River Springs vicinity, located about 20 mi (32 km) northeast of the Dry Lake SEZ near Moapa, Nevada (Figure 1). Grid cells near the springs are 820 ft × 820 ft (250 m × 250 m); away from this area, model cells gradually increase to a maximum of 4,921 ft × 4,921 ft (1,500 m × 1,500 m). Model layers increased progressively in thickness from 100 ft (30 m) thick for surficial layer 1 to 3,100 ft (940 m) thick for the deepest layer, layer 18. In this manner, the design of the model allows for greater resolution closer to the surface.

The DOI model relied on a customized version of MODFLOW-2000 to account for a modified approach to using the Hydrogeologic Unit Flow (HUF) package for the modeling of the hydrogeologic framework. In this approach, the HUF input file, which allows for decreasing hydraulic conductivity with depth, was modified to allow specification of a minimum hydraulic conductivity value. Other custom changes were made to an HUF supporting file. Because of these changes, the DOI input files cannot fully be used as input to a standard MODFLOW graphical user interface (GUI). Therefore, for this study, the well pumping input file was modified manually to account for SEZ pumping in the center of the SEZ, and the modified MODFLOW executable was run independent of the GMS software package GUI. Model output could then be manipulated to be input to GMS and displayed on the model grid, which was an input file compatible with GMS.

Tetra Tech (2012b) considered several pumping scenarios in predictive model runs. Scenario 2 is based on the pumping of all existing groundwater rights in the modeled area, including currently unpumped rights. This amounts to 60,255 ac-ft/yr (7.432×10^7 m^3/yr) from the entire modeling domain, of which 3,328 ac-ft/yr (4.105×10^6 m^3/yr) is local to Garnet Valley. In the modeling domain, Scenario 2 assumes approximately three times the current pumping rate. Other scenarios considered by Tetra Tech (2012b) included the additional pumping that would be associated with pending applications if the facilities were built, which amounted to several times the overall pumping rate of Scenario 2. Although other pumping scenarios given in Tetra Tech (2012b) could also serve as the base case for SEZ impact analysis, what is key for the current model analysis is the difference created by 20 years of SEZ pumping compared to the non-SEZ pumping in the study area. Scenario 2 was selected as the base case for examining potential SEZ impacts.

In the vicinity of Dry Lake (Garnet Valley), the DOI model accounts for several hydrogeologic units: alluvial basin fill, Paleozoic carbonate, a clastic sequence, and crystalline basement (Tetra Tech 2012a). The basin fill in the vicinity of the SEZ was determined to have a calibrated hydraulic conductivity of 66 ft/d (20 m/d) and a calibrated specific yield of 0.2. The underlying Paleozoic carbonate aquifer's thickness was estimated using interpolation methods; based on coarsely binned thicknesses illustrated in the report, it is roughly 12,000 ft (3,700 m) thick. In the SEZ vicinity, the Paleozoic carbonate aquifer was determined to have a calibrated hydraulic conductivity of 1,500 ft/d (457 m/d) and a calibrated specific yield of 0.02. Most of the model layers are basin fill or Paleozoic carbonate in the SEZ vicinity; the layer geometry and unit type vary spatially. Only the deeper units contain the clastics and basement rock; these are far below the zone of active pumping in the basin.

The DOI modeling process included an initial calibration to pre-development water levels. Following that, transient modeling was performed by DOI to mimic long-term pumping in the study area and achieve water levels consistent with year 2011 observations. These water levels then served as initial conditions for various DOI predictive model scenarios.

The approach taken to assess the impact of the additional drawdown that could be produced by SEZ pumping involved running the customized transient model of Scenario 2 pumping rates without SEZ pumping and then with the high-, medium-, and low-demand SEZ pumping. Pumping at the SEZ is modeled with a single well, although practically, multiple pumping wells may be installed at the SEZ, with the pumping rates of Table 1 distributed among them. The location of the new well(s) is assumed to be within the SEZ with a well screened in the alluvial aquifer at an elevation interval consistent with other wells in Garnet Valley (see Section 2.1). Hydraulic heads after 20 years of pumping were determined for each case, then the additional drawdown attributed to the SEZ pumping well was determined by comparing the heads resulting from the combined Scenario 2 and SEZ pumping with the heads resulting from Scenario 2 pumping alone.

In the area local to the SEZ, the DOI model includes 13 Scenario 2 pumping wells in Garnet Valley with a total withdrawal rate of 3,328 ac-ft/yr (4.105×10^6 m^3/yr) (Table 2). For Scenario 2, this combined pumping rate is less than the SEZ high-demand pumping rate (Table 1).

Table 2 Pumping Rates of Garnet Valley Wells in the DOI Model's Scenario 2

Developer	Well Name	Pumping Rate (ac-ft/yr)	Pumping Rate (m^3/d)	Pumping Rate (ft^3/d)
SNWA	Duke WS-1	325	1,098	24,090
SNWA	Duke WS-2	1,120	3,784	24,090
SNWA	Mirant 1	165	558	24,090
SNWA	PW-WS1	545	1,842	24,090
SNWA	RW-1	45	152	24,090
Georgia Pacific Corp	EBA-1	144	487	24,090
Chemical Lime Company of AZ	US LIME-1	0	0	24,090
Chemical Lime Company of AZ	4(none)	158	534	24,090
Chemical Lime Company of AZ	US LIME-2	126	426	24,090
Dry Lake Water LLC	DRY LAKE GV-2	157	531	24,090
Republic Environmental Technologies	#1	0	0	24,090
Republic Environmental Technologies	#2	202	683	24,090
Republic Environmental Technologies	#5	133	449	24,090
Republic Environmental Technologies	#6	133	449	24,090
Nevada Power Company	RW-1	75	253	24,090
Totals		3,328	11,245	361,350

Source: Tetra Tech (2012b)

4 RESULTS AND DISCUSSION

4.1 Summary of Numerical Model Results

The SEZ pumping rate under assumed high-, medium-, and low-demand situations was combined with the Scenario 2 pumping rates (Tetra Tech 2012b) as input to MODFLOW. Each simulation required about 9 hours of run time on an Intel Core2 Quad 3.00GHz 64-bit personal computer, as the DOI Scenario 2 prediction model is designed for a 1,000-year analysis. Results were brought into the GMS model, which included the model grid, and were contoured. The water levels resulting from 20 years of pumping under Scenario 2, without any SEZ pumping, are shown in Figure 4. Although localized cones of depression exist, they are generally less than 2 ft (0.6 m) deep in Garnet Valley at the 20-year point.

The additional pumping by the SEZ well would result in significant drawdown at the SEZ location if the high rate of 4,586 ac-ft/yr (5.657×10^6 m^3/yr) is assumed to be achievable (despite being greater than the current overall basin pumping rate) and is modeled. In this situation, the additional drawdown in the model cell containing the SEZ well is 37.5 ft (11.4 m) at the 20-year point (Figure 5). Drawdown of 1 ft (0.3 m) extends 6 to 14 mi (10 to 23 km). This relatively large amount of additional drawdown is due to the proposed high-demand pumping rate being larger than the combined pumping of the 13 wells local to Garnet Valley (Table 2).

In the medium SEZ pumping situation, 653 ac-ft/yr (805,000 m^3/yr) is withdrawn, and the additional drawdown in the model cell containing the SEZ well is 5.3 ft (1.6 m) (Figure 6). In the minimum SEZ pumping situation, 26 ac-ft/yr (32,000 m^3/yr) is withdrawn, and the modeled additional drawdown at the SEZ is less than 0.2 ft 0.06 m); these results are not illustrated.

4.2 Comparison of Numerical Model with Solar PEIS Analytical Model

In the Solar PEIS (BLM and DOE 2012), an initial assessment of drawdown associated with the low-, medium-, and high-demand SEZ scenarios was explored using a one-dimensional analytical model adapted from the Theis and Jacob methods for long-duration analyses. In the Solar PEIS, the analytical model assumed an unconfined alluvial aquifer with a thickness of 1,640 ft (500 m), K of 1 ft/d (0.3 m/d), and a specific yield of 0.1.

The results for the high-, medium-, and low-demand cases are shown in Figure 7. For comparison, the approximate additional drawdown from the numerical model for the high-demand SEZ case is shown in Figure 7 at several distances from the pumping location. The analytical model produced greater drawdown than the numerical model. At very small distances from the well, this is due to the analytical model's ability to calculate a large amount of drawdown in the vicinity of the well; this is averaged out over the dimensions of the well-containing cell in the numerical model. At larger distances, the differences between the models are attributed to different input values. For the numerical model, the hydraulic conductivity was 66 ft/d (20 m/d) and the specific yield was 0.2 in model layers representing the alluvial aquifer in the Garnet Valley area. If these values were used in the analytical model, along with an aquifer

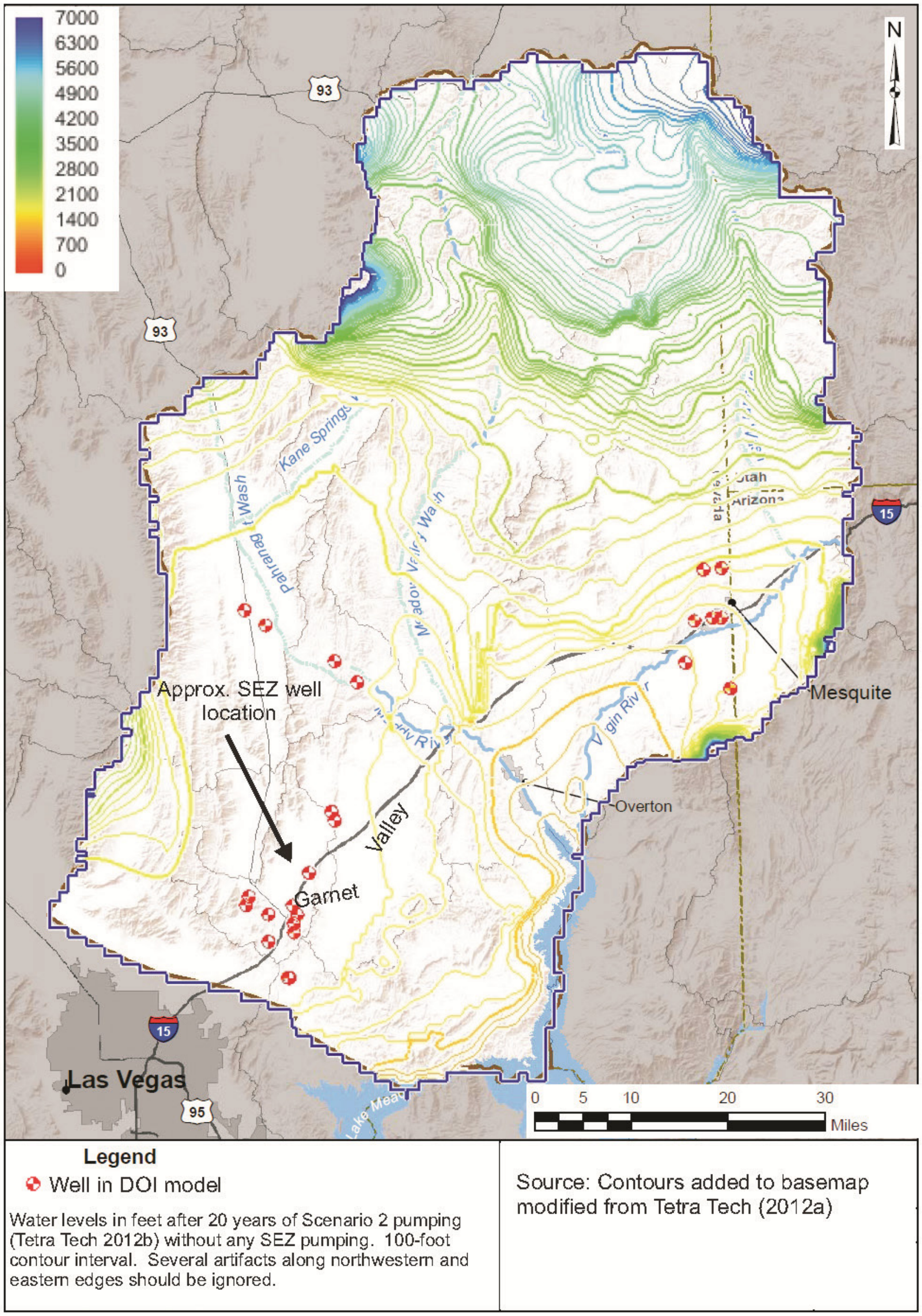

Figure 4 Predicted Water Levels after 20 years of DOI Scenario 2 Pumping without any SEZ Pumping

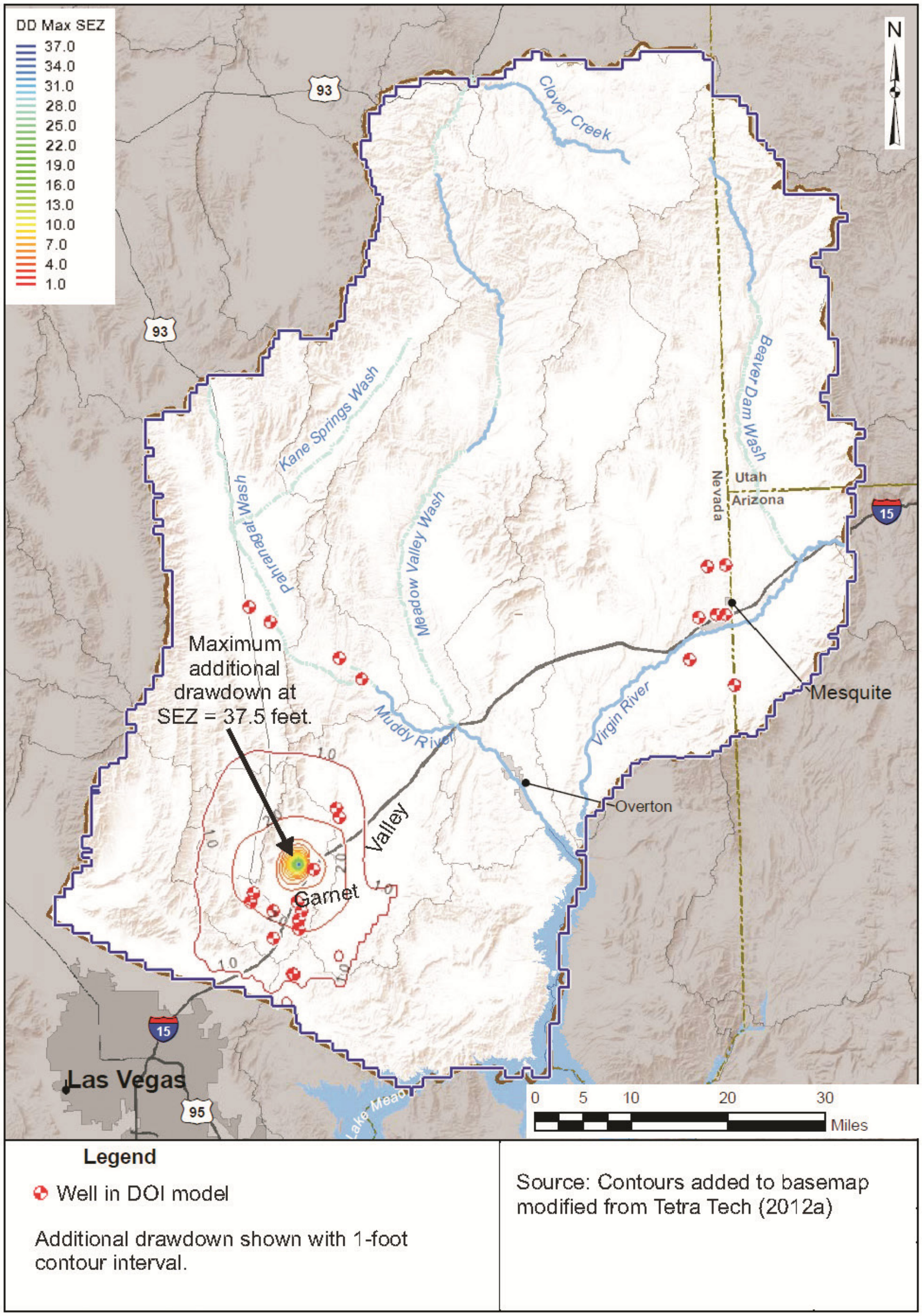

Figure 5 Additional Drawdown after 20 years Due to High SEZ Pumping Rate (full buildout of wet-cooled solar power production)

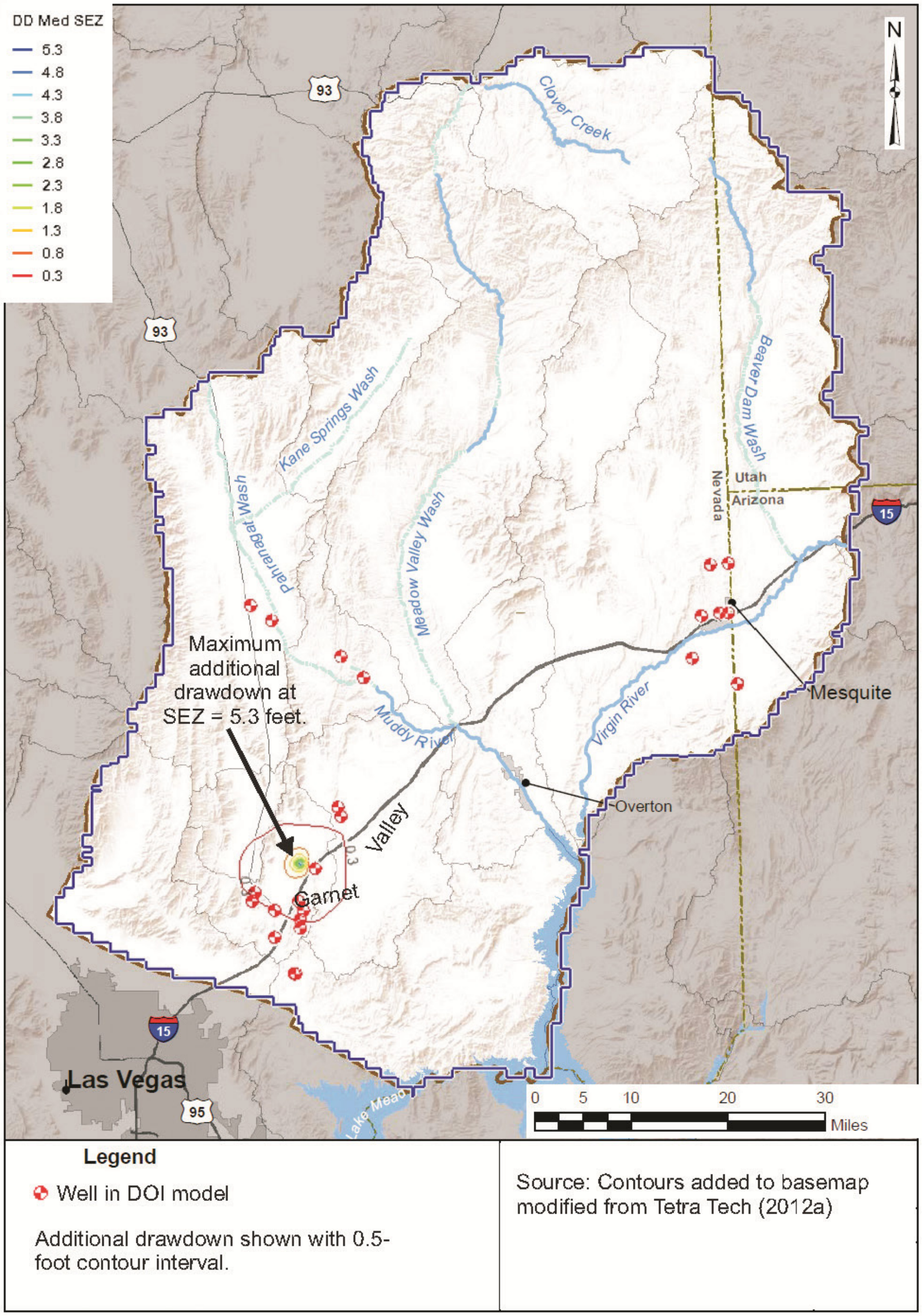

Figure 6 Additional Drawdown Due to Medium SEZ Pumping after 20 years

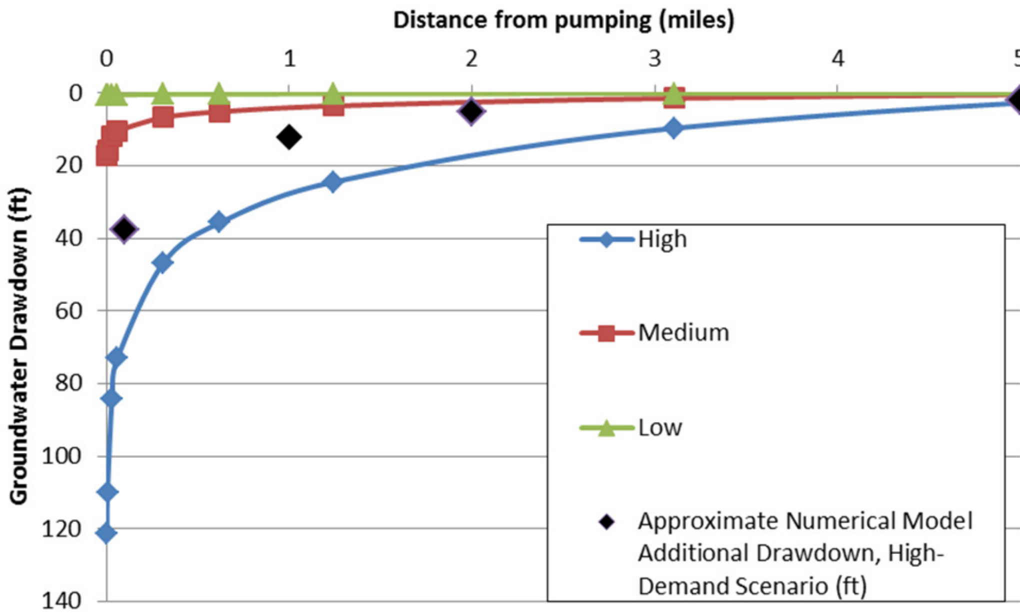

Figure 7 Analytical Model Drawdown Results for the High-, Medium-, and Low-Demand Dry Lake SEZ Cases after 20 years, and Numerical Model Additional Drawdown Results for the High-Demand Case

thickness consistent with the thickness penetrated by most well screens, the results of the analytical model and numerical model match very closely despite differences in methods and assumptions.

4.3 Implications for Future Model Development

Improvements in the current models could be made with the discovery or collection of new data regarding the hydrogeological framework and aquifer parameter values. A model such as the DOI model could be refined if high-quality, site-specific information were generated for the SEZ; the one-dimensional modeling could also be refined. Drilling for production or monitoring wells, for example, could generate high-quality drill logs that could refine the hydrogeologic framework and aquifer parameter values in the local vicinity of the SEZ. New wells could also provide water level data for improved model calibration, and aquifer tests could provide aquifer parameter refinements. The nature of the alluvium is that it is highly variable spatially. Site-specific data would improve the design and accuracy where such improvements are most needed for assessing drawdown impacts.

This model may be used by regulators in the planning and assessment of future water resources needs in Garnet Valley on the basis of permit applications. It may also be used by developers to evaluate the potential impacts on groundwater levels from SEZ pumping. Model runs could assess the cumulative effect on groundwater levels from changes in water usage by others in

Garnet Valley. It should be noted that although the Garnet Valley may have the ability to supply the water necessary for the Dry Lake SEZ's water use over a 20-year window, water use even at current levels is not sustainable over the longer term, because it far exceeds basin yield. Even if pumping were to cease, the replenishment of groundwater removed from storage would be expected to occur at a slow rate (Burbey 1997).

4.4 Summary of Model Files and Future Use

Original DOI files may be obtained from the DOI. Modeling for this study was performed using the customized DOI MODFLOW executable through a batch file. Model outputs were brought into GMS version 9.1.4 (64-bit) with a build date of May 7, 2013. The files are packaged in a single zip file. When unzipped, they may be viewable by older or newer versions of GMS or by other commercial graphical user interfaces; however, functionality cannot be guaranteed.

The zip file set includes the following:

- **Implementing the custom DOI files for display in GMS.txt—**Instructions on using the custom DOI MODFLOW executable and input files and displaying head output in GMS version 9.

- **Prediction081413.gpr and folder Prediction081413_MODFLOW—**This is a GMS file of the DOI model's Scenario 2 model with SEZ pumping included. Items in the GMS Project Explorer's 2D-Grid Data module include DD Max SEZ, DD Med SEZ, and DD Min SEZ, which are the calculated drawdown differences between the Scenario 2 results at 20 years and the Scenario 2 results at 20 years including the SEZ pumping. Note that this GMS file set is not intended to run properly within GMS because of custom modifications in the DOI executable and input files.

4.5 Disclaimer for Use of the Dry Lake SEZ Model

Groundwater modeling studies were performed by Argonne National Laboratory for BLM/DOE to analyze the potential impacts of groundwater pumping associated with utility-scale solar energy development. The models used for these analyses have relied on established hydrogeologic principles and established groundwater modeling software. The approach taken for the SEZs includes the evaluation and modification of models already created by various agencies. While efforts were made to develop modeling tools for proper assessment of impacts from groundwater pumping to support solar energy, the models are not intended to be exact predictors of groundwater impacts that could be present over time in the study areas. Hydrogeologic information that is obtained as individual solar projects are developed should be used to refine, modify, and update the models and analyses used for this study. This report makes recommendations for the further development of the groundwater models as information becomes available.

MODFLOW-based modeling was performed for this study using a customized version of MODFLOW developed by a DOI contractor. Output from this model was managed and viewed using a particular version of GMS. Because of customization of DOI model input files, the files are not fully incorporated in GMS. The model files associated with the groundwater modeling studies may be useable by older or newer versions of GMS or by other commercial graphical user interfaces; however, functionality cannot be guaranteed.

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