

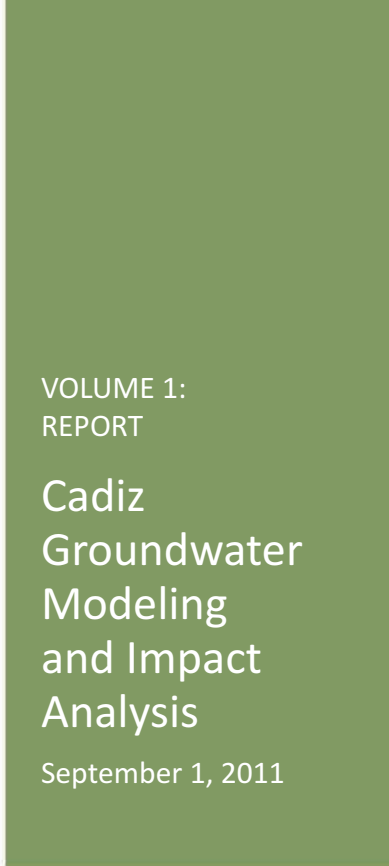
# Appendix H1

## Cadiz Groundwater Modeling and Impact Analysis





# VOLUME 1



VOLUME 1:  
REPORT

## Cadiz Groundwater Modeling and Impact Analysis

September 1, 2011



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## ABBREVIATIONS AND DEFINITIONS

<b>acre-ft/yr</b>	acre-feet per year.
<b>Alluvial</b>	A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water.
<b>amsl</b>	above mean sea level
<b>Antiform</b>	Arch-shaped rock structure which, by definition, closes (i.e. arches) upward. Antiforms are usually accompanied by synforms, which are oppositely shaped.
<b>Aquifer</b>	A geologic formation or group of formations which store, transmit, and yield significant quantities of water to wells and springs.
<b>Archean</b>	An eon of geologic time extending from about 3.9 billion years ago to 2.5 billion years ago.
<b>bgs</b>	below ground surface
<b>Carbonate</b>	A rock consisting primarily of a carbonate mineral such as calcite or dolomite, the chief minerals in limestone and dolostone, respectively.
<b>CDMG</b>	California Division of Mines and Geology
<b>CRA</b>	Colorado River Aqueduct
<b>DEM</b>	Digital Elevation Model
<b>Detachment Fault</b>	A nearly horizontal fault at the base of a fault system associated with large-scale extensional tectonics.
<b>Dispersivity</b>	A geometric property of a porous medium which determines the dispersion characteristics of the medium by relating the components of pore velocity to the dispersion coefficient.
<b>Drawdown</b>	The change in hydraulic head or water level relative to a background condition.
<b>DWR</b>	California Department of Water Resources

<b>Effective Porosity</b>	A fraction of the void spaces which forms part of the interconnected flow paths through the medium, per unit volume of porous medium (excluding void space in isolated or dead-end pores). Also known as "specific yield."
<b>Evapotranspiration</b>	The combined loss of water from a given area by evaporation from the land and transpiration from plants.
<b>Fanglomerate</b>	A sedimentary rock of heterogeneous materials that were originally deposited in an alluvial fan and have since become cemented into rock.
<b>Fault</b>	A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other.
<b>Formation</b>	A geologic term that designates a body of rock or rock/sediment strata of similar lithologic type or combination of types.
<b>ft</b>	feet, foot
<b>ft/day</b>	feet per day
<b>gpm</b>	gallons per minute
<b>Groundwater</b>	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
<b>Hangingwall</b>	Of the two sides of a fault, the side above the fault plane. It is called the hanging wall because where inactive faults have been "filled in" with mineral deposits and then mined, this is the side on which miners can hang their lanterns.
<b>Head</b>	Energy, produced by elevation, pressure, or velocity, contained in a water mass.
<b>Holocene</b>	An epoch of the Quaternary period extending from the end of the Pleistocene, approximately 11,000 years ago, to the present time.
<b>Hydraulic Conductivity</b>	The measure of the ability of the soil to transmit water, dependent upon both the properties of the soil and those of the fluid.
<b>ID</b>	inside diameter
<b>in.</b>	inch
<b>Inselberg</b>	An isolated residual knob or hill rising abruptly from a lowland erosion surface.



<b>Jurassic</b>	The second period of the Mesozoic era extending from approximately 200 to 145 million years ago.
<b>Land Subsidence</b>	The lowering of the natural land surface due to extraction of fluids and/or gas from the subsurface.
<b>Leakage</b>	The vertical movement (either downward or upward) of ground water from one aquifer to another.
<b>Listric Fault</b>	Listric faults can be defined as curved normal faults in which the fault surface is concave upwards; its dip decreases with depth. These faults also occur in extension zones where there is a main detachment fracture following a curved path rather than a planar path. Hanging wall blocks may either rotate and slide along the fault plane (eg slumps), or they may pull away from the main fault, slipping instead only along the low dipping part of the fault. Roll-over anticlines will often form between bedding planes and the main fault plane as a result of the flexing between the two.
<b>Mesozoic</b>	An era of geologic time extending from approximately 250 to 65 million years ago.
<b>Metamorphic</b>	A rock changed from its original form and/or composition by heat, pressure, or chemically active fluids.
<b>mg/l</b>	milligrams per liter
<b>Miocene</b>	An epoch of the early Tertiary period extending from approximately 23 to 5.3 million years ago.
<b>MODFLOW-2000</b>	A modular finite-difference flow model developed by the United States Geological Survey (USGS) to solve the groundwater flow equation.
<b>MT3DMS</b>	A modular three-dimensional solute transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems.
<b>Normal Fault</b>	A fault characterized by predominantly vertical displacement in which the hanging wall is moved downward with respect to the footwall of the fault. Generally, this kind of fault is a sign of tectonic extension.
<b>OD</b>	outside diameter
<b>Paleozoic</b>	An era of geologic time extending from approximately 542 to 250 million years ago.

<b>Permeability</b>	The capability of soil or other geologic formations to transmit water. The term is used to separate the effects of the medium from those of the fluid on the hydraulic conductivity.
<b>PEST</b>	Parameter ESTimation software
<b>Pleistocene</b>	An epoch of the Tertiary period extending from approximately 2.6 million years ago to 11,000 years ago.
<b>Preconsolidation Stress</b>	The maximum stress to which a deposit has been subjected, and which it can withstand without undergoing additional permanent deformation.
<b>Proterozoic</b>	An eon of geologic time extending from approximately 2.5 billion years ago to 542 million years ago.
<b>Quaternary</b>	The second period of the Cenozoic era extending from approximately 2.6 million years ago to 5,000 years ago.
<b>Saline Water</b>	Water characterized by a total dissolved solids concentration in excess of 1,000 milligrams per liter.
<b>SEAWAT-2000</b>	Developed by the USGS to simulate three-dimensional, variable density, groundwater flow and solute transport in porous media. The source code for SEAWAT Version 4 was developed by combining MODFLOW and MT3DMS into a single program that solves the coupled flow and solute transport equations
<b>Specific Yield</b>	See “Effective Porosity”
<b>Storativity</b>	The volume of water that an aquifer releases or takes into storage per unit change in hydraulic head.
<b>Synform</b>	A structure formed by the downward bending of rock strata onto earlier and steeper folds of smaller size. Synforms are usually accompanied by antiforms, which are oppositely shaped.
<b>TDS</b>	total dissolved solids
<b>Tertiary</b>	The second period of the Cenozoic era extending from approximately 65 to 2.6 million years ago.
<b>USGS</b>	United States Geological Survey
<b>Volcanic</b>	Pertaining to the activities, structures, or rock types of a volcano.
<b>yr(s)</b>	year or years

## CADIZ GROUNDWATER MODELING AND IMPACT ANALYSIS

### 1.0 EXECUTIVE SUMMARY

The Cadiz Groundwater Conservation and Storage Project (Project) is a water conservation supply and conjunctive use storage project that would allow for management of the groundwater basin within the Fenner Watershed and the Orange Blossom Wash in the Eastern Mojave Desert. The Project will develop a new water supply and storage facility for the Santa Margarita Water District (SMWD) and other participating water agencies. The first phase of the Project, the Conservation Component, would extract and convey an average of approximately 50,000 acre-ft/yr from a wellfield in Fenner Gap via a pipeline to the Colorado River Aqueduct (CRA). The second phase of the Project, the Storage Project, would involve managing the groundwater basin as a conjunctive use project. Water belonging to water agencies would be conveyed to the Fenner Watershed (Fenner Gap area) from the CRA through the pipeline constructed under the Conservation Component of the Project. This water would be recharged into the aquifer system via spreading basins.

The purpose of this study was to evaluate the impacts of the proposed conservation project. Groundwater modeling was conducted to assess the impacts of the conservation project on existing groundwater levels, on the existing freshwater/saline water interface and groundwater quality, and on subsurface sediments - specifically the potential for the occurrence of subsidence. The following is a brief summary of the analysis.

The Project area is located in the eastern Mojave Desert of San Bernardino County, California approximately 200 miles east of Los Angeles, 60 miles southwest of Needles, and 40 miles northeast of Twentynine Palms. The conservation project is located in Fenner Gap which is located between the Marble and Ship Mountains east of Cadiz. Fenner Gap lies within a topographically closed drainage system that includes three main watersheds and associated groundwater basins: Bristol, Cadiz, and Fenner.

One of the first investigations of the area is a United States Geological Survey (USGS) publication on "The Mojave Desert Region" by Thompson (1929). This pioneering investigation includes numerous geohydrologic data in the area. A 1967 investigation by the California Department of Water Resources (DWR) (Moyle, 1967) presents useful water well data and geologic map. A report prepared by Shafer (1964) also includes valuable hydrogeologic data.

In 1998 and 1999, Metropolitan Water District of Southern California (MWD), in conjunction with the Cadiz, Inc. evaluated the feasibility of operating a groundwater storage and transfer project near Cadiz. Comprehensive field testing was conducted in and around the Fenner Gap to characterize the geologic and hydrologic properties. The field testing program included installation of a deep 16-inch-diameter production well and a total of ten groundwater monitoring wells, drilled and installed in the Fenner Gap area prior to construction of the pilot spreading basin, followed by an 8-month large-scale artificial recharge test (GEOSCIENCE, 1999). In addition, a groundwater flow and solute transport model was developed to assess the potential impacts on groundwater levels and water quality due to the project.

Several geohydrologic investigations were conducted from between late 2009 and 2011 to provide supplemental geohydrologic properties for the Project. CH2M Hill (2010) provides an updated assessment of potential recoverable water that could be conserved over the long-term and groundwater in storage in the Fenner Valley and northern Bristol Valley area. This updated assessment included collection of additional field data, development of a watershed soil-moisture budget model based on the USGS INFIL3.0 model, and development of a three-dimensional groundwater flow model of the Fenner Gap area (see Appendix A). This report was prepared in July 2010 and updated in August 2011 to include additional field data that were collected and analyzed since the original report was published. Dr. Miles Kenney (2011) provided a geologic map and eight cross-sections in the Fenner Gap area (see Appendix B). The geologic map and cross-sections were constructed utilizing data obtained from field mapping bedrock exposures within hills and mountain ranges, Google Earth imagery, evaluation of well cores and samples, interpretation of a seismic reflection line, geologic structural principles, and well documented structural characteristics associated with extensional tectonics and igneous intrusions. GEOSCIENCE (2011) provides an updated evaluation of the geohydrology in the Fenner Gap area considering recent exploratory drilling and testing performed in late 2009 and early 2010. In conjunction with this task, independent analyses of pumping test data were made and aquifer parameters evaluated (see Appendix C).

The Cadiz groundwater model is a six-layer flow and solute transport model constructed to simulate the aquifer systems within Fenner Valley and Fenner Gap and the aquifer system that underlies a portion of the Bristol and Cadiz Dry Lakes. Recent geologic mapping, interpretive geologic cross-sections and lithologic logs from exploratory borings and water wells were used to develop the six model layers. The model layers consist of the following:

- Layer 1 - Upper Alluvium
- Layer 2 - Alluvium beneath the Upper Alluvium to a depth of approximately 1,200 ft



- Layer 3 - Alluvium beneath a depth of 1,200 ft
- Layer 4 - Conglomerate, carbonate, lower Paleozoic sequence and weathered granitic rocks
- Layer 5 - Carbonate, lower Paleozoic sequence and weathered granitic rocks
- Layer 6 - A Detachment Fault Zone (approximately 200 ft thick) in the Fenner Gap area, and weathered granitic rocks

Groundwater flow is assumed to occur horizontally within each of the model layers while the layers maintain hydraulic connection to each other through vertical leakage. Bedrock beneath model layer 6 was considered as non-water bearing. The sources of recharge in the Cadiz groundwater model include natural recharge and artificial recharge during the pilot infiltration test conducted in 1999 (GEOSCIENCE, 1999). The discharge terms include evapotranspiration from the Bristol and Cadiz dry lakes, and Cadiz agricultural pumping.

Model calibration is performed to compare model-simulated groundwater levels to field-measured values. The method of calibration used by the Cadiz groundwater model was the industry standard “history matching” technique, including steady state and a transient calibration. For the steady state calibration, the model was calibrated against water levels measured in 1964. The transient model calibration covers the period from 1986 through 1990 with an annual stress period and from January 1991 through December 2009 with a monthly stress period. To assist in the trial-and-error adjustment of parameters for “history matching”, the software PEST (Parameter ESTimation) (Doherty, 2004) was used to aid in the calibration of the groundwater flow model during the steady state model calibration. After the initial calibration, regularization, in combination with pilot points (Doherty, 2004), was used to improve the model calibration. Regularization provides smoothing of parameter estimates, so that each model cell is not considered to have a unique independent value and there is a “smooth transition” across the model cells from high to low values. Three versions of the model were developed, representing a range of recharge (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr and 5,000 acre-ft/yr).

The relative error of the water residuals (i.e., standard deviation of the residuals divided by the observed head range) was calculated to quantitatively evaluate the model calibration. Common modeling practice is to consider a good fit between historical and model predicted data if the relative error is below 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999). The relative error for steady state model calibration was 0.15% for each calibration run, well below the recommended relative error of 10%. For the transient calibration runs (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr), the model-calculated water levels match very

well with observed data. The relative error of the water level residuals is 1.7% for each transient calibration run, well below the recommended error of 10%.

After the model was calibrated, three model runs were simulated for a period of 100 years with an annual stress period. The predictive model runs include one Project scenario and two sensitivity scenarios. The purpose of the sensitivity scenarios was to evaluate the potential ranges of worst case impacts by: (1) reducing the amount of available natural recharge, and (2) increasing the distances between the wells within the proposed Project wellfield. Two wellfield configurations were used for the sensitivity analysis. Wellfield Configuration A consists of wells clustered around Fenner Gap and Wellfield Configuration B consists of wells spread out southwest from Fenner Gap. Wellfield Configuration B, coupled with lower natural recharge volumes, presents a worst-case scenario in terms of the potential impact to Bristol Dry Lake from Project pumping. Additionally, Wellfield Configuration B presents a worst-case scenario for impacts related to migration of saline water from Bristol Dry Lake as the wells are located closer to the saline water/freshwater interface. The model scenarios and the assumptions used for each are provided in the following table:

Model Scenario	Assumptions			
	Natural Recharge	Wellfield Configuration	Average Annual Groundwater Pumping from Years 1 to 50	Average Annual Groundwater Pumping from Years 51 to 100
	[acre-ft/yr]		[acre-ft/yr]	[acre-ft/yr]
Project Scenario	32,000	Clustered around Fenner Gap (Configuration A)	50,000	0
Sensitivity Scenario 1	16,000	Spread Out from Fenner Gap (Configuration B)	50,000	0
Sensitivity Scenario 2	5,000	Spread Out from Fenner Gap (Configuration B)	50,000	0

The following findings and recommendations are based on the results of the groundwater model and impact analyses:

### ***Groundwater Elevations***

- Model-calculated groundwater elevations at the end of 50 years (i.e., end of Project pumping) under Project Scenario and Sensitivity Scenario conditions indicate that the lowest water levels (i.e., greatest potential impact) would occur at the center of the wellfield in the vicinity of Fenner Gap.
- Under Project pumping conditions, groundwater would flow toward the proposed wellfield from Fenner, Bristol and Cadiz valleys.
- At the end of 100 years (i.e., 50 years following cessation of Project pumping), water levels in the wellfield recover and groundwater flow directions would be similar to current conditions (i.e., groundwater flow within the Bristol watershed flows toward, and terminates in, Bristol Dry Lake; groundwater flow within the Cadiz watershed flows toward, and terminates in, Cadiz Dry Lake; groundwater flow within the Fenner watershed flows from Fenner Valley through Fenner Gap and terminates at Bristol and Cadiz Dry Lakes).

### ***Groundwater Level Drawdown***

- Predicted regional drawdown at the end of 50 years (i.e., end of Project pumping) under Project Scenario and Sensitivity Scenario conditions indicate that a maximum groundwater level drawdown (i.e., greatest potential impact) of 260 to 270 ft (under natural recharge conditions of 5,000 acre-ft/yr) would occur at the center of the wellfield in the vicinity of Fenner Gap.
- Groundwater levels in the Bristol and Cadiz Dry Lakes would decline as a result of interception of natural recharge by the Project, consequently reducing or eliminating groundwater currently lost to evaporation from the surface of the dry lakes.
- Drawdown within the wellfield, including the center of the wellfield and the area of the existing Cadiz wells, corresponds to hydrologic conditions and amount of natural recharge.
- The maximum single year drawdown would be 22.1 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2) and dry year conditions (i.e., pumping of

75,000 acre-ft/yr). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), there would be very little change in drawdown during single dry, wet and average years.

- Maximum drawdown within the wellfield during multiple dry year conditions (i.e., pumping of 75,000 acre-ft/yr; hydrologic years 1988 to 1992) would be 65.9 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.3 ft.
- Maximum drawdown within the wellfield during multiple wet year conditions (i.e., pumping of 25,000 acre-ft/yr; hydrologic years 1980 to 1984) would be -39.4 ft (groundwater level rise) under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.9 ft.
- Maximum drawdown within the wellfield during multiple average year conditions (i.e., pumping of 50,000 acre-ft/yr; hydrologic years 1964 to 1968) would be 25.1 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.8 ft.

### *Depth to Groundwater*

- Depth to groundwater at the end of 50 years (end of Project pumping under Project Scenario conditions) would range from 197 to 435 ft bgs in the vicinity of the wellfield, 50 to 68 ft bgs at Bristol Dry Lake, and 21 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 50 years (end of Project pumping under Sensitivity Scenario 1 conditions) would range from 241 to 486 ft bgs in the vicinity of the wellfield, 63 to 95 ft bgs at Bristol Dry Lake, and 59 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 50 years (end of Project pumping under Sensitivity Scenario 2 conditions) would range from 315 to 627 ft bgs in the vicinity of the wellfield, 54 to 118 ft bgs at Bristol Dry Lake, and 72 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Project Scenario conditions) would range from 154 to 351 ft bgs in the vicinity of the wellfield, 33 to 42 ft bgs at Bristol Dry Lake, and 10 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Sensitivity Scenario 1 conditions) would range from 181 to 371 ft bgs in the vicinity of the wellfield, 62 to 74 ft bgs at Bristol Dry Lake, and 17 ft bgs at Cadiz Dry Lake.

- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Sensitivity Scenario 2 conditions) would range from 219 to 412 ft bgs in the vicinity of the wellfield, 79 to 108 ft bgs at Bristol Dry Lake, and 68 ft bgs at Cadiz Dry Lake.

### ***Saline Water/Freshwater Interface***

- The location of the current saline water/freshwater interface for this Project is defined by the location of the 1,000 mg/L TDS concentration contour.
- Results of the modeling indicate the saline water/freshwater interface in the Bristol Dry Lake area would move a maximum distance of approximately 10,400 ft northeast during Project pumping (years 1 to 50) under Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). The saline water/freshwater interface would move a maximum of approximately 9,700 ft and 6,300 ft to the northeast during the same period of time under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr) and Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr), respectively.
- Following Project pumping for all scenarios, the saline water/freshwater interface in the Bristol Dry Lake area continues to move towards the northeast to reach a distance of 11,500 ft, 11,100 ft, and 9,200 ft for the Project Scenario conditions (under natural recharge conditions of 32,000 acre-ft/yr), Sensitivity Scenario 1 (under natural recharge conditions of 16,000 acre-ft/yr), and Sensitivity Scenario 2 (under natural recharge conditions of 5,000 acre-ft/yr), respectively.

### ***Groundwater in Storage***

- The cumulative annual change in groundwater storage would reach a maximum of -1,090,000 acre-ft (a negative sign represents a decline in groundwater storage) in year 50 under the Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). This decline in groundwater storage is approximately 3% to 6% of the total groundwater in storage.
- The groundwater in storage would begin to recover following the cessation of Project pumping in year 50. The cumulative annual change in groundwater storage would be approximately -220,000 acre-ft in year 100 under Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the

groundwater storage would fully recover in year 117 (i.e., 67 years after Project pumping stopped).

- The cumulative annual change in groundwater storage would reach a maximum of -1,680,000 acre-ft in year 50 under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr). This decline in groundwater storage is approximately 5 to 10% of the total groundwater in storage.
- The cumulative annual change in groundwater storage would be approximately -870,000 acre-ft in year 100 under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 153 (i.e., 103 years after Project pumping stopped).
- The cumulative annual change in groundwater storage would reach a maximum of -2,160,000 acre-ft in year 50 under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr). This decline in groundwater storage is approximately 6 to 13% of the total groundwater in storage.
- The cumulative annual change in groundwater storage would be approximately -1,870,000 acre-ft in year 100 under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 440 (i.e., 390 years after Project pumping stopped).

### ***Potential Land Subsidence***

- In general, the amount of land subsidence corresponds to the magnitude of water level decline and the thickness of the clay layers.
- The maximum model-predicted land subsidence is 2.7 ft at the center of Bristol Dry Lake at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).
- The maximum model-predicted land subsidence ranges from 0.7 to 1.5 ft in the vicinity of the Cadiz wellfield at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).

- The maximum model-predicted land subsidence is 0.6 ft at the edge of Cadiz Dry Lake at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).
- Predicted subsidence would occur gradually over time and be dispersed laterally over a large area from Fenner Gap to the Bristol and Cadiz Dry Lakes.

Consideration of the Cadiz Groundwater Modeling and Impact Analysis report will be incorporated into the Groundwater Management Plan.

## 2.0 INTRODUCTION

### 2.1. Purpose and Scope

The Cadiz Groundwater Conservation and Storage Project (Project) is a water conservation supply and conjunctive use storage project that would allow for management of the groundwater basin within the Fenner Watershed and the Orange Blossom Wash in the Eastern Mojave Desert (see Figure 1). The Project will develop a new water supply and storage facility for the Santa Margarita Water District (SMWD) and other participating water agencies. The first phase of the Project, the Conservation Component, would extract and convey an average of approximately 50,000 acre-ft/yr from a wellfield in Fenner Gap via a pipeline to the Colorado River Aqueduct (CRA). The long-term average annual natural recharge of the Bristol, Cadiz and Fenner Watersheds has been calculated to be approximately 32,000 acre-ft/yr (CH2M Hill, 2010; see Appendix A). In addition to this amount, the Project would extract 18,000 acre-ft/yr to create and maintain a groundwater trough that would ensure that groundwater flowing from Fenner Valley would be drawn to the wellfield in order to capture the long-term sustainable yield. The second phase of the Project, the Storage Project, would involve managing the groundwater basin as a conjunctive use project. The trough created by extracting more than the annual natural recharge amount of 32,000 acre-ft will create supplemental storage space within the basin, optimizing the conservation and conjunctive use of water. Water belonging to water agencies would be conveyed to the Fenner Watershed (Fenner Gap area) from the CRA through the pipeline constructed under the Conservation Component of the Project. This water would be recharged into the aquifer system via spreading basins. Under terms that would protect the beneficial uses of the groundwater basin, participating water agencies could extract previously recharged water from the basin when needed. Under the Storage Component of the Project, up to 1 million acre-ft of dewatered capacity would be managed and made available for groundwater banking.

The purpose of this study was to evaluate the impacts of the proposed conservation project. Groundwater modeling was conducted to assess the impacts of the conservation project on existing groundwater levels, on the existing freshwater/saline water interface and groundwater quality, and on subsurface sediments - specifically the potential for the occurrence of subsidence. This report summarizes the groundwater modeling results of the Phase I Conservation Scenarios of the Project.

### 2.2. Description of Study Area

The Project area is located in the eastern Mojave Desert of San Bernardino County, California approximately 200 miles east of Los Angeles, 60 miles southwest of Needles, and 40 miles northeast of



Twentynine Palms (see Figure 1). The conservation project is located in Fenner Gap which is located between the Marble and Ship Mountains east of Cadiz (see Figure 1). Fenner Gap lies within a topographically closed drainage system that includes three main watersheds and associated groundwater basins: Bristol, Cadiz, and Fenner. These watersheds are considered to be one drainage system because all surface and groundwater drains to a central lowland area at Bristol and Cadiz Dry Lakes. The Bristol, Cadiz, and Fenner watersheds are separated from the surrounding watersheds by topographic divides (generally mountain ranges).

The total area of the Bristol, Cadiz and Fenner watersheds is approximately 2,710 square miles. The Bristol Watershed is 1,170 square miles, the Cadiz Watershed is 540 square miles, and the Fenner Watershed is 1,000 square miles. Groundwater flow within the Bristol watershed flows toward, and terminates in, Bristol Dry Lake. Groundwater flow within the Cadiz watershed flows toward, and terminates in, Cadiz Dry Lake. Groundwater flow within the Fenner watershed flows from Fenner Valley through Fenner Gap and terminates at Bristol and Cadiz Dry Lakes (see Figure 2).

### 2.3. Previous Investigations

One of the first investigations is a United States Geological Survey (USGS) publication on “The Mojave Desert Region” by Thompson (1929). This pioneering investigation includes numerous geohydrologic data in the area. A 1967 investigation by the California Department of Water Resources (DWR) (Moyle, 1967) presents useful water well data and geologic map. A report prepared by Shafer (1964) also includes valuable hydrogeologic data.

In 1998 and 1999, Metropolitan Water District of Southern California (MWD), in conjunction with the Cadiz, Inc. evaluated the feasibility of operating a groundwater storage and transfer project near Cadiz. Comprehensive field testing was conducted in and around the Fenner Gap to characterize the geologic and hydrologic properties. The field testing program included installation of a deep 16-inch-diameter production well and a total of ten groundwater monitoring wells, drilled and installed in the Fenner Gap area prior to construction of the pilot spreading basin, followed by an 8-month large-scale artificial recharge test (GEOSCIENCE, 1999). As part of the study, all available published and unpublished geologic and hydrologic reports, maps, and data relative to the project area were collected, compiled, and reviewed. In addition, a groundwater flow and solute transport model was developed to assess the potential impacts on groundwater levels and water quality due to the project.

## 2.4. Recent Supplemental Geohydrologic Investigations

Several geohydrologic investigations were conducted from between late 2009 and 2011 to provide supplemental geohydrologic properties for the Project. These investigations include:

- Cadiz Groundwater Conservation and Storage Project. Prepared by CH2M Hill. (see Appendix A),
- Geologic Structural Evaluation of the Fenner Gap region located between the southern Marble Mountains and Ship Mountains, San Bernardino County, California. Prepared by Dr. Miles Kenney (see Appendix B), and
- Geohydrologic Assessment of the Fenner Gap Area. Prepared by GEOSCIENCE Support Services, Inc. (see Appendix C).

CH2M Hill's study provides an updated assessment of potential recoverable water that could be conserved over the long-term and groundwater in storage in the Fenner Valley and northern Bristol Valley area. This updated assessment included collection of additional field data, development of a watershed soil-moisture budget model based on the USGS INFIL3.0 model, and development of a three-dimensional groundwater flow model of the Fenner Gap area (see Appendix A). This report was prepared in July 2010 (see Appendix A). Appendix A of this report has been updated in August 2011 to include additional field data that were collected and analyzed since the original report was published. Note that geology and hydrology have not been updated to reflect the additional geologic assessments provided by Dr. Miles Kenny (see Appendix B).

Kenney's study provides a geologic map and eight cross-sections in the Fenner Gap area (see Appendix B). The geologic map and cross-sections were constructed utilizing data obtained from field mapping bedrock exposures within hills and mountain ranges, Google Earth imagery, evaluation of well cores and samples, interpretation of a seismic reflection line, geologic structural principles, and well documented structural characteristics associated with extensional tectonics and igneous intrusions.

GEOSCIENCE's study provides an updated evaluation of the geohydrology in the Fenner Gap area considering the recent exploratory drilling and testing performed in late 2009 and early 2010. In conjunction with this task, independent analyses of pumping test data were made and aquifer parameters evaluated (see Appendix C). This report was prepared in April 2010 and updated in August 2011 to include additional field data that were collected and analyzed since the original report was published, and additional geologic assessments provided by Dr. Miles Kenny (see Appendix B).

## 2.5. Sources of Data

Data used for this study were obtained from multiple sources. The primary sources include the documents discussed in the Section 2.3 (i.e., Previous Investigations) and Section 2.4 (i.e., Recent Supplemental Geohydrologic Investigations) of this report. A complete list of references is provided in Section 11.0 of this report.

## 3.0 GEOLOGY

### 3.1. Geologic Setting

The study area is located in the Basin and Range Geomorphic Province, characterized by a series of structural and topographic basins bounded by relatively linear mountain ranges. The Basin and Range Geomorphic Province is present throughout Nevada, eastern and southeastern California, and western to southern Arizona. The alternating mountains and valley topography primarily resulted from extensional (pulling apart) tectonics that occurred during the Miocene (Wernicke, 1992). Most valleys within the Basin and Range Geomorphic Province are enclosed basins. That is to say, flow within basin drainages remain within the basins, creating dry lakes where surface flows gather and evaporate. Sediments eroding from the local mountain ranges deposit relatively locally within the immediate valley (basin). Groundwater flow within closed basins moves from the mountain front into the valley where it evaporates through the surface of the playa lake. The project area is located within portions of the Bristol, Cadiz, and Fenner Valley watersheds in the Eastern Mojave Desert of California. Together the Bristol and Cadiz watersheds form a broad valley-like depression that has been referred to in literature as the Bristol Trough (Thompson, 1929; Bassett et al., 1964; Jachens et al., 1992). All surface and groundwater flow terminate at the Bristol and Cadiz dry lakes, which are the low points of the regional watershed, (Bassett et al., 1959; Handford, 1982; Rosen, 1989). As such, it is considered to be a hydraulically closed system. The depression that forms Bristol Dry Lake is thought to be 6-10 million years old (Rosen, 1989)--having formed as a result of movement on a system of regional faults. This movement resulted in the relative raising of the mountain ranges and lowering of the basin floor.

Until recently, geologic mapping conducted by the California Division of Mines and Geology (CDMG, 1964) has served as the basis for understanding local geologic conditions in Fenner Gap. Prior to this investigation, detailed geologic mapping of the project area had not been conducted. Recent geologic mapping of the southeastern portion of the Marble Mountains, Fenner Gap, and the northwestern portion of the Ship Mountains was conducted for this investigation by Dr. Miles Kenney. This detailed mapping was conducted to allow interpretation of the geologic structure in Fenner Gap in order to determine potential groundwater flow paths and rates. Dr. Kenney's report entitled "Draft Geologic Structural Evaluation of the Fenner Gap region located between the southern Marble Mountains and Ship Mountains, San Bernardino County, California" is presented as Appendix B of this report and formed the basis for construction of the groundwater flow model described in this report.

The age of the rocks in the study area, range from Archean<sup>1</sup> (1.4 Billion years old), to currently depositing alluvial sediments of Quaternary age. Thus the geologic history of the site covers approximately 1.4 billion years (see Plate 2 Kenney, 2011 [Appendix B] for the areal distribution of geologic units within the study area. Using detailed geologic mapping, coupled with evaluation of the subsurface data collected from borings, geologic cross-sections were constructed to interpret the geologic structure across and through the axis of Fenner Gap. The geologic cross-sections are presented on Plate 3 and Plate 4 of Appendix B.

### 3.2. Geologic Units

Geologic formations found in the Bristol, Cadiz, and Fenner watersheds can be grouped into four broad categories:

1. Archean to Jurassic granitic and metamorphic rock of the mountain ranges and watershed margins;
2. Tertiary volcanic and conglomerate units;
3. Pleistocene to Holocene alluvial sediments weathering from the flanks of the surrounding hills and mountains; and
4. Fine-grained (i.e., silt and clay) sediments and evaporite (i.e., salt and gypsum) deposits underlying Bristol and Cadiz dry lakes (see Figure 2 of Appendix C).

A brief description of the geologic units present in the study area is presented below. See Appendix B for a complete description of the geologic units present within the study area.

#### 3.2.1. Alluvium

Sediments eroding from the bedrock are deposited as alluvium on the flanks of the hills and mountains, and over time, have largely filled the valleys between the mountain ranges. Geophysical evidence indicates that the depth of alluvium locally exceeds 3,500 ft below ground surface (bgs) in the area between Bristol Dry Lake and Fenner Gap in the vicinity of the irrigation wellfield (Maas, 1994). Based on recent drilling, the depth of alluvial sediments in Fenner Gap is known to reach 1,500 ft. It is

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<sup>1</sup> The Archean is an eon of geologic time extending from approximately 3.9 billion years ago to 2.5 billion years ago. Recent mapping has found that rocks within the study area are actually younger, and part of the Proterozoic. However, in the interest of consistency with previous mapping/literature, the Archean terminology is retained.

believed that most of the groundwater in the Bristol, Cadiz, and Fenner watershed area is stored within these alluvial sediments. However, permeable bedrock lying beneath the alluvium may contain an appreciable amount of groundwater within secondary porosity features.

Alluvial sediments are primarily composed of layers of gravel, sand, silt, and clay in varying proportions (Koehler, 1983; Freiwald, 1984). The grain size of the alluvium is generally coarse on the upper parts of the alluvial slopes with more fine-grained deposits down slope (Dibblee, 1980b; Koehler, 1983; Freiwald 1984). However, significant layers of coarse-grained material (including cobbles and boulders) have been noted in Fenner Gap and as far down slope as Bristol Dry Lake (Rosen, 1989). Most of the exposed alluvial sediments were deposited from 10,000 years ago to the present. However, deposits older than 10,000 years have been noted in some areas (Dibblee, 1980, Kenney, 2011).

### 3.2.2. Tertiary Volcanics and Fanglomerates

Volcanic rocks are found primarily on the northeast side of the Marble Mountains, the north side of the Ship Mountains, and in the Clipper Mountains.



**Volcanic Terrain in the Foreground and the Northern Ship Mountains in the Background**

Fanglomerates are exposed in the northeastern Ship Mountains (see Plate 2 of Appendix B for locations). The Fanglomerate unit may be at least 1,000 feet thick and consists of sediments deposited into the basins prior to and during local Miocene extension. The basal members of the fanglomerate contain exotic and well-rounded clasts (conglomerates), very well sorted sedimentary members, and few volcanic deposits or clasts. According to Kenney (2011) there is an “...increase in proximal clasts, interbedded volcanic members, increase in grain size, grain angularity (conglomerate to breccia) and progressively shallower dips...” higher in the section which are the result of ongoing geologic structural

changes. The Fanglomerate unit was penetrated by a number of the borings within Fenner Valley, during this investigation, and was found to consist of consolidated sediments of sand, gravel, and cobbles (see Plates 2, 3, and 4 of Appendix B).

### **3.2.3. Archaen and Jurassic Granitic and Metamorphic Bedrock**

The bedrock exposed in the mountain ranges surrounding these regional watersheds consists of Archaen (up to 1.4 billion years old; Silver et al., 1963), and in some areas, Mesozoic (167 to 151 million years old) granitic and metamorphic rocks. Paleozoic (570 to 240 million years old) meta-sedimentary rocks consisting of quartzite, shale, limestone, and dolomite are present in the Marble Mountains and on the northwestern and northern flanks of the Ship Mountains. The general distribution of the bedrock units are shown on Figure 2 of Appendix C. The detailed distribution, of these units is shown on Plate 2 of Appendix B.

## **3.3. Geologic Structure**

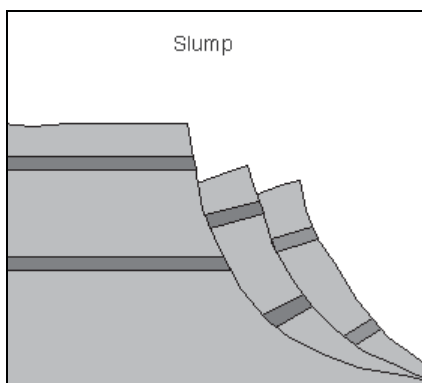
### **3.3.1. Overview of Geologic History and Structure**

The brief overview of the geologic structure in the study area is presented below. For a complete description of the geologic history and structure in the study area, please refer to Appendix B of this report.

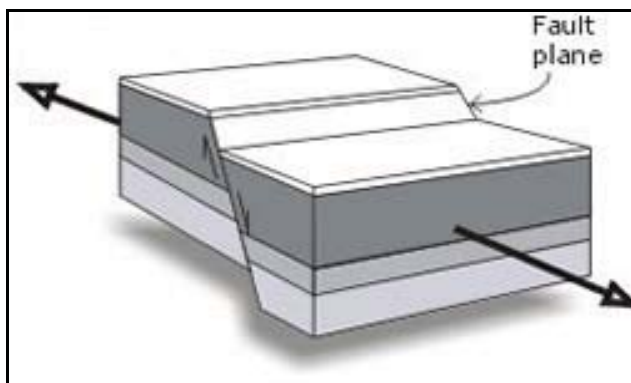
The geologic structure in the study area, as well as the Basin and Range Geomorphic Province in general, is the result of two main geologic events. Initially, Paleozoic sediments were deposited on Archaen cratonal crust during a relatively quiet geologic time period. During the Jurassic, intrusive rocks were emplaced at depth resulting in folding and metamorphism of some of the older rocks into which they intruded. As an example within the study area, Paleozoic Rocks in the Marble Mountains are unmetamorphosed but are moderately folded and faulted—recent geologic mapping indicates that only a few granitic sills are present in the southern Marble Mountains area. The Paleozoic sedimentary units exhibit an average northward strike and dip approximately 30 degrees to the east. In contrast, most of the Ship Mountains are dominated by intrusions from the Jurassic Igneous and Metamorphic Suite. In this area, the Paleozoic rocks are uplifted, metamorphosed, eroded away, and folded by the Jurassic igneous intrusions.

The second and most dominating event was the occurrence of the Miocene extension which formed the arrangement of mountains and valleys making up the Basin and Range Geomorphic Province. During

the Miocene crustal extension, detachment faults developed as a basal slip surface to accommodate the movement of the upper portions of the crust with respect to the lower portions. An imbricated series of listric faults (i.e. Faults 1-9 shown on Plate 2 of Appendix B) developed above the detachment faults as the area was pulled apart. Highland and adjacent lowland areas (i.e., horsts and grabens) formed from movement of the listric faults.



**Example of Listric Fault**



**Example of Normal Fault**

The development of high angle normal faults occurs subsequent to extension and can extend through and offset the detachment faulting (i.e., Cross Faults CF-A through CF-L, shown on Plate 4 of Appendix B). The result of these processes in the study area, are highly faulted, tilted, and rotated blocks of Paleozoic sediments and Mesozoic granitic rocks (see Plates 3 and 4 of Appendix B). Movement along faults created highland areas (mountains) from which sediments were eroded, and basins (valleys) into which sediments were deposited, forming the fanglomerate units described previously. Volcanic rocks which are typically associated with the Miocene extensional period were deposited following the deposition of the fanglomerate units (see Plate 2 of Appendix B for the distribution of volcanic units exposed within the study area). From the Miocene period of extension and continuing to the present, the basin areas were filled with sediments which continued to erode from the adjacent highland areas creating thick sequences of basin fill. The geologic structure and depth of alluvium through Fenner Gap, as based on subsurface boring data and geologic mapping, is shown on Plates 3 and 4 of Appendix B.

### **3.3.2. Geologic Structure in Fenner Gap**

In general, the geologic structure in Fenner Gap is characterized by highly faulted and folded bedrock overlain by Tertiary fanglomerates and Pleistocene to Holocene alluvial units. Plates 3 and 4 of Appendix B show the dominance of normal faults and the Jurassic intrusives in development of the



geologic structure in the Fenner Gap area. In general, the southern portion of Fenner Gap is underlain primarily by faulted Archaen and Jurassic intrusive rock on the western side of the Gap and by faulted Paleozoic limestones on the eastern side of the Gap. Due to faulting an increase in Paleozoic limestone units are interpreted to occur beneath Fenner Gap further up the valley. Paleozoic units (i.e., limestones and quartzites) are faulted, tilted, and folded. An antiform and synform is shown to be present near the center of Fenner Gap as a means to explain the distribution and bedding dip angles of the Paleozoic units. Both the normal faults and the detachment fault are shown to have a zone of fractures on the hanging wall of the fault (above the fault plane) which are approximately 150 to 400 feet thick. The existence and zone of faulting is based on geologic exposures of some of these faults in the study area. With respect to the movement of groundwater through Fenner Gap, the existence of extensive faulting, tilting, and folding of both Paleozoic and Jurassic bedrock units, along with accompanying joint and fracture systems, provide extensive secondary groundwater flow paths within the bedrock.

## 4.0 HYDROLOGY

The hydrology of the Project area is summarized in the following sections. A more detailed description of the hydrology is provided in the Appendices A and C.

### 4.1. Precipitation

Most of the precipitation in the Eastern Mojave Desert accumulates during the late Fall and Winter months from November through March. Early summer and late fall are typically periods of little rainfall. The amount of precipitation in the Bristol, Cadiz, and Fenner basins vary with differences in altitude. Average annual precipitation ranges from approximately 3 inches on the Cadiz and Bristol dry lakes (elevations of 545 to 595 ft above mean sea level [amsl]) to over 12 inches in the Providence and New York mountains (elevations over 7,000 ft amsl). However, most of the study area receives, on the average, 4 to 6 inches of rain annually. A more detailed discussion of precipitation patterns in the study area can be found in Section 2.2 of CH2M Hill, 2010.

### 4.2. Groundwater Occurrence and Movement

The primary sources of replenishment to the groundwater system in the Project area include direct infiltration of precipitation (both rainfall and snowfall) into fractured bedrock exposed in mountainous terrain and infiltration of ephemeral stream flow in sand-bottomed washes, particularly in the higher elevations of the watershed (see Appendix A). The source of most of the groundwater recharge within the regional watershed occurs in the higher elevations since the higher elevations receive the higher volumes of precipitation (see Appendix A).

A conceptualization of groundwater occurrence and movement is provided in Figure 2-13 of Appendix A. A schematic cross-section showing groundwater in fractured bedrock in the mountain ranges that is recharged by precipitation is shown in Figure 2-14 of Appendix A. As shown, precipitation flows down the mountain slopes by infiltrating into rock fractures or overland if the volume of flow is sufficient to overcome infiltration. In some cases in the higher elevations, the infiltrating water may be diverted to the land surface or groundwater may intersect the land surface creating a spring, but only at the higher elevations of the mountain slopes. Ultimately, this infiltrating water moves vertically downward into the alluvial materials and fractured bedrock of the regional groundwater system, tens of feet below the ground surface. Groundwater continues to flow downgradient through the principal aquifer systems.

In Bristol and Cadiz watersheds, groundwater flows toward the dry lakes from Fenner Gap and the surrounding hills and mountains (see Figure 2). In Orange Blossom Wash, groundwater flows southeasterly from the Granite Mountains through the wash, and then southwestward into Bristol dry lake. In the Fenner Watershed, groundwater generally flows southwestward and southward from the New York and Providence Mountains into the main part of Fenner Valley, and then south-southwesterly through Fenner Gap. Some of the groundwater flowing through Fenner Gap flows toward Bristol dry lake and some of the groundwater flows toward Cadiz dry lake.

### 4.3. Aquifer Systems

Based on available geologic and geophysical data, the principle geologic deposits in the Project area that can store and transmit groundwater (i.e., aquifers) can be divided into three units: an upper alluvial aquifer, a lower alluvial aquifer, and a bedrock aquifer consisting of Tertiary fanglomerate, Paleozoic carbonates and fractured and faulted granitic rock. In general, these three units are in hydraulic continuity with each other and the separation is primarily due to stratigraphic differences.

The upper alluvial aquifer consists mainly of Quaternary alluvial sediments consisting of stream-deposited sand and gravel with lesser amounts of silt (Moyle, 1967). The thickness of this aquifer varies from approximately 200 to 800 feet. To the west of Fenner Gap, the upper aquifer is separated from the lower aquifer system by discontinuous layers of silt and clay. The average thickness of the upper aquifer in Fenner Gap is approximately 500 feet. The upper aquifer is very permeable in places and can yield 3,000 gallons per minute (gpm) or more to wells with less than 20 feet of drawdown.

The lower alluvial aquifer consists of older sediments, including interbedded sand, gravel, silt, and clay of late Tertiary to early Quaternary age (Moyle, 1967; Bassett and Kupfer, 1964). The maximum thickness of the lower aquifer is unknown but may reach over 6,000 feet in the vicinity of Bristol dry lake (Maas, 1994). Where these materials extend below the water table, they yield water freely to wells but are generally less permeable than the upper aquifer sediments (Moyle, 1967). The Cadiz agricultural wells are screened primarily in the lower alluvial aquifer and typically yield 1,000 to 2,000 gpm.

Based on findings from recent drilling in the Fenner Gap area, Tertiary fanglomerate, fractured and faulted granitic rock, and Paleozoic carbonates, located beneath the lower alluvial aquifer, contain groundwater and are considered a third aquifer unit. Groundwater movement and storage within the carbonate bedrock aquifer primarily occurs within secondary porosity features (i.e., fracture zones associated with faulting and cracks, and cavities developed within the rocks over time).

#### 4.4. Groundwater Storage

The volume of groundwater in storage was estimated to be about 17 million to 34 million acre-feet in the alluvium of the Fenner Valley, Orange Blossom Wash, and northern Bristol Valley area (see Appendix A). It is this geographic area that the Project would utilize for the conservation and storage Project. It is important to note that this storage estimate does not include water contained within the carbonate and fractured portion of the bedrock beneath the alluvial units. Recent drilling has revealed that these units also store groundwater. As such, the estimated volume of groundwater in storage is a conservative underestimate; the actual volume of groundwater in storage is larger by some unknown amount.

#### 4.5. Groundwater Quality

The quality of the groundwater in the Fenner Gap and Fenner Valley area is relatively good, with total dissolved solids (TDS) concentrations typically in the range of 300 to 400 milligrams per liter (mg/L). At Bristol and Cadiz dry lakes, surface water and shallow groundwater evaporation concentrates dissolved salts in the water, resulting in TDS concentrations as high as 298,000 mg/L in these areas (Shafer, 1964). In general, as groundwater moves toward the dry lakes from Fenner Gap and the surrounding mountains, it becomes more saline and mineralized in the immediate vicinity of the dry lakes as the “fresh” groundwater mixes with the more saline lake water. The freshwater/saline water interface, as defined by TDS concentrations greater than 1,000 mg/L, is located near the margins of the dry lakes as shown on Figure 3. For more detailed groundwater quality information, see GEOSCIENCE, 1999.

## 5.0 MODEL DEVELOPMENT AND CONSTRUCTION

### 5.1. Conceptual Model

The Cadiz groundwater model is a six-layer flow and solute transport model constructed to simulate the aquifer systems within Fenner Valley and Fenner Gap and the aquifer system that underlies a portion of the Bristol and Cadiz Dry Lakes. Recent geologic mapping (see Appendix B), interpretive geologic cross-sections and lithologic logs from exploratory borings and water wells were used to develop the six model layers. The model layers consist of the following:

- Layer 1 - Upper Alluvium
- Layer 2 - Alluvium beneath the Upper Alluvium to a depth of approximately 1,200 ft<sup>2</sup>
- Layer 3 - Alluvium beneath a depth of 1,200 ft
- Layer 4 - Conglomerate, carbonate, lower Paleozoic sequence and weathered granitic rocks
- Layer 5 - Carbonate, lower Paleozoic sequence and weathered granitic rocks
- Layer 6 - A Detachment Fault Zone (approximately 200 ft thick) in the Fenner Gap area, and weathered granitic rocks

Groundwater flow is assumed to occur horizontally within each of the model layers while the layers maintain hydraulic connection to each other through vertical leakage. Bedrock beneath model layer 6 was considered as non-water bearing. The sources of recharge in the Cadiz groundwater model include natural recharge and artificial recharge during the pilot infiltration test conducted in 1999 (GEOSCIENCE, 1999). The discharge terms include evapotranspiration from the Bristol and Cadiz dry lakes, and Cadiz agricultural pumping.

### 5.2. Computer Code

The computer codes used in the Cadiz groundwater model include MODFLOW-2000 and SEAWAT-2000 Version 4. MODFLOW is a modular finite-difference flow model developed by the United States Geological Survey (USGS) to solve the groundwater flow equation (Harbaugh, et. al., 2000). SEAWAT-2000 was developed by the USGS (Langevin, et. al., 2008) to simulate three-dimensional, variable density, groundwater flow and solute transport in porous media. The source code for SEAWAT Version

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<sup>2</sup> 1,200 feet is the assumed base of the primary groundwater production zone based on screen intervals of existing wells (GEOSCIENCE, 1999).

4 was developed by combining MODFLOW and MT3DMS<sup>3</sup> into a single program that solves the coupled flow and solute transport equations. MODFLOW was used for the steady state and transient model calibration runs. SEAWAT-2000 Version 4 was used in the Cadiz groundwater model predictive model runs in order to evaluate the potential movement of saline water present beneath Bristol and Cadiz Dry Lakes due to Project pumping.

In addition, In order to simulate subsidence potential, the Cadiz groundwater model was augmented by incorporating the Subsidence and Aquifer-System Compaction (SUB) Package (Hoffmann, et. al, 2003). The SUB package is used in conjunction with SEAWAT-2000 to simulate the elastic (recoverable) compaction and expansion and inelastic (permanent) compaction of compressible fine-grained beds (interbeds) within the aquifers. The deformation of interbeds is caused by changes in effective stress as a result of water level changes. If the stress is less than the preconsolidation<sup>4</sup> stress of the sediments, the deformation is elastic (i.e., recoverable). If the stress is greater than the preconsolidation stress, the deformation is inelastic (i.e., permanent).

### 5.3. Model Domain, Grid and Time Discretization

The Cadiz groundwater model covers approximately 3,000 square miles (see Figure 4) and consists of 674 nodes (model cells) in the north-to-south direction (i-direction) and 492 nodes in the west-to-east direction (j-direction), for a total of 1,989,648 nodes for all six model layers (see Figure 5). Each model cell represents an area of approximately 500 ft x 500 ft (5.7acres).

The transient model calibration run covers the period from 1986 through 2009. A total of 233 stress periods<sup>5</sup> were used including an annual stress period for the period from 1986 through 1990 and a monthly stress period for the period from January 1991 through December 2009. All the predictive model runs were simulated for a 100 year period with an annual stress period.

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<sup>3</sup> MT3DMS is a modular three-dimensional solute transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems (Zheng and Wang, 1999).

<sup>4</sup> Preconsolidation stress is the maximum stress to which a deposit has been subjected, and which it can withstand without undergoing additional permanent deformation.

<sup>5</sup> Stress period is the time length used to change model parameters such as pumping and natural recharge.

## 5.4. Boundary Conditions

A boundary condition is any external influence or effect that either acts as a source or sink, adding or removing water from the groundwater flow system. The boundary conditions used in the Cadiz groundwater model are no-flow (inactive), wells, evapotranspiration, and natural recharge (see Figure 6). In general, the groundwater flow model boundary conditions can be grouped into three main types: 1) constant head (this type was not used in the Cadiz groundwater model), 2) specified flux (i.e., wells, recharge, and no-flow), and 3) head-dependant with a limiting conductance or rate term (i.e., evapotranspiration).

For the Cadiz groundwater model, the no-flow cells include bedrock in the mountainous areas (i.e., Hackberry, Clipper, Marble, Ship, and Bristol mountains) and unsaturated alluvium in the Fenner Valley. Natural recharge was distributed along the contact of model inactive and active cells as well as portion of the valley floor. Evapotranspiration was simulated at the Bristol and Cadiz dry lakes using the Evapotranspiration Package by specifying the maximum evapotranspiration rate, evapotranspiration surface and extinction depth<sup>6</sup>.

## 5.5. Aquifer Parameters

### 5.5.1. Lithologic Model in the Fenner Gap Area

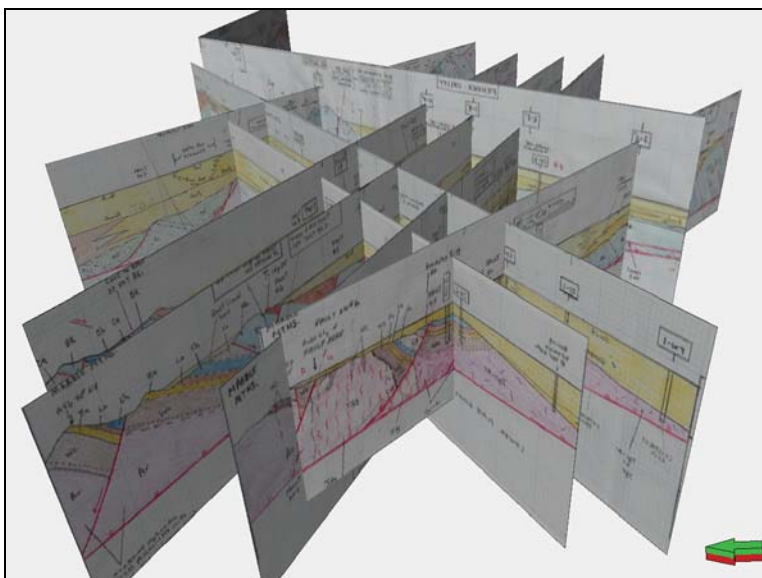
A 3-dimensional lithologic model was constructed for the Fenner Gap area by Numeric Solutions, LLC., to identify the physical extents, thickness, and continuity of the lithologic and geologic units encountered (see Figure 7 for the lithologic model boundary). The model was generated utilizing the Schlumberger Petrel 3-Dimensional Geo-Modeling software. Results from lithologic model were used to determine the extent of the model layers and the distribution of hydraulic conductivity. Construction of the 3-dimensional lithologic model included the following steps:

1. Place eight geologic cross-sections constructed by Dr. Miles Kenney (see Appendix B) within 3-dimensional space inside the geo-modeling software (see example below).
2. Digitize the base of model layer 3 for the Fenner Gap area along the nine cross-sections, separating the geology into conceptual model layers. Model layers 1 through 3 include the alluvium.

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<sup>6</sup> The maximum rate is used when the water level is at the land surface. No evapotranspiration occurs when the water level is below the extinction depth. In between these two extremes, the evapotranspiration rate is assumed to be linear.

3. Digitize the base of model layer 4. The base of model layer 4 was delineated by incorporating the bottom of the fanglomerate and lower Paleozoic Sequence (see Figures 8a and 8b). Model layer 4 includes fanglomerate, carbonate, the lower Paleozoic Sequence, and weathered and fractured granitic rock.
4. Digitize the base of model layer 5. The base of model layer 5 was delineated as the top of the detachment fault separating the water bearing geology from non-water bearing geology. Model layer 5 consists of carbonate and, weathered, fractured and faulted granitic rocks (see Figures 8a and 8b).
5. Digitize the base of model layer 6 assuming a 200 ft thick layer that simulates the groundwater flow through the detachment fault zone.
6. Interpolate 3-dimensional surfaces for each of the model layers and connect the cross-section layers into 3-dimensional surfaces.
- 7.



**Example of Geologic Cross-Sections in 3-Dimensional Space**

The faults separating the geologic units were digitized into the lithologic model in order to determine the percent carbonate distribution. From these fault elements and the knowledge of their type, expected displacement and hierarchy, a 3D fault framework was developed. Once the faults and lithologic framework was constructed, a Cartesian 3D block model was developed. The lithologic model was separated (digitized) into carbonate (i.e., high hydraulic conductivity) and non-carbonate (i.e., low hydraulic conductivity) units. The digitized carbonate units honoring the lithologic model were used to distribute the carbonate, and inversely the non-carbonate, over the 3D grid cell within the 3D block



model. The percent carbonate distribution is estimated by vertically averaging the carbonate and non-carbonate of the 3D block model into groundwater model layers 4 and 5. Results are shown as zones of percent carbonate (see Figures 9 and 10 for model layers 4 and 5, respectively), and were used to assign the hydraulic conductivity values for Cadiz ground water model layers 4 and 5.

### 5.5.2. Layer Elevations

The Cadiz groundwater model is a six-layer groundwater model, where the land surface elevation (top of model layer 1) was determined from a 10-meter Digital Elevation Model (DEM). The base of alluvium (i.e., base of model layer 3) was delineated based on geophysical studies by Maas (1994), USGS (2006), and NORCAL (1997), drillers lithologic logs in the Fenner Gap area (GEOSCIENCE, 1999), and recent geologic mapping by Kenney (see Appendix B). The total alluvial thickness was further separated into the three uppermost model layers (i.e. model layers 1 through 3). The base of model layer 1 (upper alluvial aquifer) is separated from the model layer 2 by a discontinuous clay-rich sequence. Wells utilized to delineate the boundary of model layers 1 and 2 are shown in the following table:

Well	Elevation [ft amsl]	Elevation Base of Model Layer 1 [ft amsl]	Depth to Base of Model Layer 1
5N/14E-13	898 ft	350 ft	548 ft
22	754 ft	430 ft	324 ft
21N	789 ft	450 ft	339 ft
Chambless Trailer Park	683 ft	360 ft	323 ft
California Salt Company	756 ft	400 ft	356 ft

The base elevation of model layer 2 was arbitrarily limited to 1,200 ft, which is the assumed base of the primary groundwater production zone based on screen intervals of existing wells (GEOSCIENCE, 1999). For areas with alluvial thickness less than 1,200 ft, model layer 3 was assigned a thickness of 10 ft.

The base of model layers 4, 5 and 6 in the Fenner Gap area were delineated based on the results of the 3-dimensional lithologic model discussed in the previous section. For the area outside of Fenner Gap, a 10 ft thickness was assumed for each of the model layers. See Figure 11 for the base elevations and Figure 12 for the thickness of each model layer.

### 5.5.3. Effective Porosity and Storativity

The unconfined storage coefficient (i.e., effective porosity or specific yield) and confined storage coefficient were estimated initially based on the character of aquifer materials and adjusted during the transient model calibration. An unconfined storage coefficient of 0.15 and a confined storage coefficient of 0.00001 were used for the Cadiz groundwater model based on the results from transient model calibration for the natural recharge of 32,000 acre-ft/yr. The coefficients remain the same for the transient calibration runs with natural recharge of 16,000 acre-ft/yr and 5,000 acre-ft/yr.

### 5.5.4. Hydraulic Conductivity

Initial hydraulic conductivity values, prior to calibration, were assigned based on hydraulic conductivity values estimated from pumping test data. The initial hydraulic conductivity values for the alluvium in the area of the existing Cadiz wells were estimated to be 3 ft/day to 270 ft/day (see Table 14 in GEOSCIENCE, 1999). Based on the pumping tests conducted for wells TW-1 and TW-2, the hydraulic conductivity values in the Fenner Gap area were estimated by CH2M Hill to be 9 ft/day to 794 ft/day for the alluvium, and 1,139 ft/day to 1,168 ft/day for the carbonates (see Table 2 of Appendix A of Appendix A of this report). Using the same pumping test data, the hydraulic conductivity values in the Fenner Gap area were estimated by GEOSCIENCE to be 37 ft/day to 780 ft/day for the alluvium and 602 ft/day to 1,023 ft/day for the carbonates (see Table 1 of Appendix C). The hydraulic conductivity values for the fractured rock aquifers were estimated to range from 3.9 to 4.2 ft/day by CH2M Hill (see Table 2 of Appendix A of Appendix A) and from 5 ft/day to greater than 40 ft/day by GEOSCIENCE (see Appendix C). The hydraulic conductivity values were then modified within pre-established upper and lower bounds during model calibration in order to match the observed groundwater levels in the model area. The calibrated hydraulic conductivity values for each transient calibration run (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr and 5,000 acre-ft/yr, respectively) are shown in

Figures 13, 14 and 15. The following table summarizes the calibrated hydraulic conductivity used for the Cadiz groundwater model.

Model Layer	Lithology/Location	Hydraulic Conductivity [ft/day]		
		Natural Recharge of 32,000 acre-ft/yr	Natural Recharge of 16,000 acre-ft/yr	Natural Recharge of 5,000 acre-ft/yr
1	Alluvium	0.2 – 543	0.1 – 267	0.02 - 84
2	Alluvium	0.2 – 543	0.1 – 267	0.02 - 84
3	Alluvium	0.7 – 406	0.1 - 200	0.02 - 128
4	Carbonate	500 – 1,500	500 – 1,500	150 – 450
	Fanglomerate, Lower Paleozoic Sequence and Weathered Granitic Rocks in the Fenner Gap Area	60	25	9
	Fanglomerate, Lower Paleozoic Sequence and Weathered Granitic Rocks Outside of Fenner Gap Area	2	1	0.3
5	Carbonate	500 – 1,500	500 – 1,500	150 – 450
	Fanglomerate, Lower Paleozoic Sequence and Weathered Granitic Rocks in the Fenner Gap Area	60	25	9
	Fanglomerate, Lower Paleozoic Sequence and Weathered Granitic Rocks Outside of Fenner Gap Area	2	1	0.3
6	Weathered Granitic Rocks in the Detachment Fault Zone in the Fenner Gap Area	75	50	15
	Weathered Granitic Rocks Outside of Fenner Gap Area	2	1	0.3

As shown in the above table and Figures 13 through 15, in general, the variations of the hydraulic conductivity values used for the same lithology in the model are approximately proportional to the amount of natural recharge. For example, the hydraulic conductivity values in the Fenner Gap are 400 ft/day and 200 ft/day in model layer 1 for natural recharge of 32,000 acre-ft/yr and 16,000 acre-ft/yr, respectively (see Figures 13 and 14)—an approximate ratio of 2 to 1 for both hydraulic conductivity and the amount of natural recharge. The reduction of hydraulic conductivity values with reduced natural recharge is necessary in order to calibrate against the observed water levels. In general, the calibrated hydraulic conductivity values are considered reasonable as compared to the values from the pumping tests and published documents.

#### **5.5.5. Vertical Leakance**

Vertical leakance values between model layers were determined based on model calibration. The final calibrated vertical leakance values range from  $0.00001 \text{ day}^{-1}$  for the alluvium in the existing Cadiz agricultural well area to  $1 \text{ day}^{-1}$  for the Carbonate in the Fenner Gap area (see Figure 16)

#### **5.5.6. Initial Groundwater Elevations**

Initial groundwater level elevations for the steady state model calibration used an arbitrary elevation of 4,000 ft amsl initially and adjusted based on the results from the preliminary steady state model calibration. Groundwater elevations from each final steady state model calibration run (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr and 5,000 acre-ft/yr) were used for initial water levels of the transient model calibration runs (see Figures 17, 18, and 19).

#### **5.5.7. Dispersivity**

A longitudinal dispersivity of 200 ft was used for all the predictive model scenarios. The horizontal transverse dispersivity was assumed to be 20 ft, while the vertical transverse dispersivity was assumed to be 2 ft.

#### **5.5.8. Elastic and Inelastic Storage Coefficients**

In the Cadiz groundwater model, it was assumed that compaction occurs only in model layers 1 and 2. It was assumed there is little potential for compaction of sediments in layers 3 through 6 as they have been subjected to very large overburden stress due to their greater depth.

The elastic storage coefficient (i.e., elastic compressibility) used in the Cadiz groundwater model was assumed to be 0.00001 based on the lithology. The inelastic storage coefficient (i.e., virgin compressibility) was calculated as the product of the specific inelastic storage coefficient and thickness of the clay in model layers 1 and 2. A specific inelastic storage coefficient of  $0.00012 \text{ ft}^{-1}$  was assigned based on the value previously used for subsidence evaluation in the Cadiz area (GEOSCIENCE, 1999). Clay layers and their thickness were identified based on the geophysical borehole logs. For the model layer 1, the clay thickness ranges from 3 ft in most of the area to 150 ft beneath Bristol dry lake (see Figure 20). For the model layer 2, the clay thickness ranges from 20 ft in most of the area to 350 ft beneath Bristol dry lake (see Figure 20). The resultant inelastic storage coefficients range from 0.00036 to 0.018 for model layer 1 and 0.0024 to 0.042 for model layer 2 (see Figure 20).

#### 5.5.9. Preconsolidation Stress

In the model, a normally consolidated condition was assumed for the preconsolidation stress. Normally consolidated materials have been only subjected to the cumulative weight of the overburden. Over-consolidated sediments have been either subjected to additional overburden weights (which may have been eroded away), subsequent wetting and drying (i.e., desiccation) of clayey materials, or extreme drawdowns in the past (increasing effective stresses and resulting compactions). By assuming normally consolidated conditions, the worst case was considered.

### 5.6. Recharge and Discharge

#### 5.6.1. Natural Recharge and Artificial Recharge

Natural recharge and artificial recharge were simulated using the Recharge Package. A long-term average natural recharge of approximately 32,000 acre-ft/yr from the Fenner Watershed and Orange Blossom Wash was used for the Cadiz groundwater model based on results from the watershed model conducted by CH2M Hill using INFIL 3.0 (see Appendix A). Appendix D contains a chronology of estimated natural recharge to the Cadiz project area. Figure 21 shows the areal distribution of the recharge rates. These average long-term rates remain the same through the entire transient model calibration period from 1986 to 2009. This is justified because regional groundwater levels show a fairly steady trend outside of the Cadiz agricultural pumping area. The steady trend in water levels reflects that recharge variation effects are largely dampened as water is transmitted through the bedrock outcrop areas. A test run was made using a varying transient recharge condition. Results show that there is little to no variation in the Fenner Gap and Bristol Valley area.

In order to assess the effects of the amount of natural recharge on the model results, the model was also calibrated to a natural recharge of 16,000 acre-ft/yr and 5,000 acre-ft/yr, respectively. This was done by multiplying the recharge rates used for the 32,000 acre-ft/y by a factor of 0.5 for the natural recharge of 16,000 acre-ft/yr calibration (i.e., 16,000 divided by 32,000). A factor of 0.1563 was used for the natural recharge of 5,000 acre-ft/yr calibration run (i.e., 5,000 divided by 32,000). However, due to the reduction of natural recharge, in order to calibrate against the observed water levels, hydraulic conductivity values and maximum evapotranspiration rates were reduced.

A volume of 1,118 acre-ft was recharged during the pilot infiltration testing conducted during the period from March to September 1999 (GEOSCIENCE, 1999) was also simulated using the Recharge Package.

### 5.6.2. Groundwater Pumping

Groundwater pumping was simulated using the Well Package in the Cadiz groundwater mode. Cadiz, Inc., currently owns and operates seven full-scale irrigation wells in the Cadiz Valley including Wells 21 South, 21 North, 22, 27 South, 27 North, 28 and 33. Groundwater production data has been compiled for the Cadiz production wells. Where wells are screened in multiple aquifers, a proportion of the total production for the well was apportioned to each aquifer according to the screened interval of the well and the hydraulic conductivity of each aquifer within the screened interval. During the period from 1986 to 2009, the annual total amount of groundwater pumped by Cadiz, Inc. ranged from approximately 1,882 acre-ft in 2009 to 6,689 acre-ft in 1990 with an annual average of 4,602 acre-ft/yr (see Figure 22). In addition, a total of 1,118 acre-ft of groundwater was pumped from Well PW-1 to provide a source of water for the pilot infiltration test conducted during the period between March and September 1999 (GEOSCIENCE, 1999).

Table 1 summarizes the groundwater pumping for each well for each stress period of transient model calibration (i.e., annual pumping for the period 1986 to 1990 and monthly pumping for the period January 1991 through December 2009).

### 5.6.3. Evapotranspiration

The Evapotranspiration Package was used to simulate the effects of plant transpiration and direct evaporation in removing water from the saturated groundwater regime in the Bristol and Cadiz dry lakes. Data on maximum evapotranspiration rate, evapotranspiration surface, and extinction depth are required for the model. The evapotranspiration surface was determined based on surface elevations for the USGS 15 minute topographic quadrangles (Cadiz, Danby, Bristol Lake and Cadiz Lake). Extinction

depth was assumed to be 15 ft. The maximum evapotranspiration rates for the dry lakes were determined based on the model calibration results. The following table summarizes the evapotranspiration rates used in the model.

Location	Maximum Evapotranspiration Rate [in/year]		
	Natural Recharge of 32,000 acre-ft/yr	Natural Recharge of 16,000 acre-ft/yr	Natural Recharge of 5,000 acre-ft/yr
Bristol Dry Lake	240	120	18
Cadiz Dry Lake	613	307	44

It is important to note that the maximum evapotranspiration rates used were based on model calibration results in order to obtain a more reasonable evapotranspiration from the dry lakes and a better match between the model-calculated and observed water levels. It may exceed the pan evaporation rate of 158 in/yr at the Amboy weather station (US Ecology, 1989). For example, a maximum evapotranspiration rate of 240 in/yr was used for the Bristol dry lake for the calibration run with natural recharge of 32,000 acre-ft/yr. This is due to the fact that groundwater levels were not simulated to the accuracy required to calculate the evapotranspiration across the entire dry lake surface. Results show an average of 19 in/yr over those cells where evapotranspiration is occurring in this run, which is reasonable as an average. For the Cadiz dry lake, the maximum evapotranspiration rate was adjusted by a factor of approximately 2.5 from the maximum evapotranspiration rate of the Bristol dry lake due to the fact that most of the Cadiz Dry Lake area is outside of the model boundary.

## 6.0 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

### 6.1. Model Calibration Approach

Model calibration is performed to compare model-simulated groundwater levels to field-measured values. The method of calibration used by the Cadiz groundwater model was the industry standard “history matching” technique, including steady state and a transient calibration. For the steady state calibration, the model was calibrated against water levels measured in 1964. The transient model calibration covers the period from 1986 through 1990 with an annual stress period<sup>7</sup> and from January 1991 through December 2009 with a monthly stress period.

To assist in the trial-and-error adjustment of parameters for “history matching”, the software PEST (Parameter ESTimation) (Doherty, 2004) was used to aid in the calibration of the groundwater flow model during the steady state model calibration. PEST is an inverse modeling technique used to estimate groundwater model parameter values, such as hydraulic conductivity, where measurements of groundwater levels and stresses (such as pumping or recharge) are known (i.e., PEST calculates values of hydraulic conductivity that make the groundwater model “calibrate” to the measured values). PEST makes many (often thousands) model simulation runs to find the best set of parameter values that minimizes the residuals (differences) in simulated and observed measurements (e.g., groundwater levels).

In the steady state model calibration process, initial hydraulic conductivity values were input to PEST in the form of ranges of acceptable values for each hydraulic conductivity zone established based on estimated hydraulic conductivity values from pumping tests and aquifer lithology. Through a nonlinear estimation technique, PEST adjusted the values assigned to each of the hydraulic conductivity zones to best fit the model-calculated water levels to the observed heads (reduce residual error) at wells across the model area.

After the initial calibration, regularization, in combination with pilot points (Doherty, 2004), was used to improve the model calibration. Regularization provides smoothing of parameter estimates, so that each model cell is not considered to have a unique independent value and there is a “smooth transition” across the model cells from high to low values. In addition, prior information is used to “tell PEST” the preferred values for each parameter and a range over which PEST may vary parameter values in order to match target values (i.e., measured groundwater levels). Parameter values are estimated by

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<sup>7</sup> Stress period is the time length used to change model parameters such as pumping and natural recharge.



PEST at pilot points; then, kriging techniques are employed to spatially interpolate parameter values to all cells in the Cadiz groundwater model. Regularization is used to estimate hydraulic conductivity values of the alluvial aquifer units in the Fenner Gap, Bristol and Cadiz valleys (model layers 1 and 2), and the Fenner valley (model layers 1, 2 and 3), and evapotranspiration rates for Bristol and Cadiz dry lakes. Hydraulic conductivity of underlying aquifer units, including carbonates, fractured bedrock, and detachment fault zone, is held constant during PEST simulations at values determined from the initial model calibration.

Figure 23 shows the distribution of pilot points. A total of 66 pilot points were used in the Cadiz groundwater model. In general, pilot points were spaced relatively uniformly, subject to aquifer geometry, approximately 15,000 to 20,000 feet apart. In the Fenner Gap area, pilot points were spaced more densely, approximately 3,000 to 5,000 feet apart.

Three versions of the model were developed, representing a range of recharge (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr and 5,000 acre-ft/yr<sup>8</sup>). The majority of the PEST regularization runs were carried out using the natural recharge of 16,000 acre-ft/yr. For this run, a maximum hydraulic conductivity of 10 ft/day was imposed in the Bristol dry lake area based on lithology and well pumping rates in the area. A maximum hydraulic conductivity of 25 ft/day was assigned in the vicinity of existing Cadiz agricultural wells based on transient calibration results. In the remaining model domain, the maximum hydraulic conductivity was set to 200 ft/day based on aquifer testing of alluvium. For the steady state calibration runs with natural recharge of 32,000 acre-ft/yr and 5,000 acre-ft/yr, adjustments were made manually (i.e., without PEST) to the hydraulic conductivity until the model calibrated. All the transient model calibration runs also use manual trial-and-error adjustments.

## 6.2. Steady State Model Calibration

Steady-state calibration was performed using groundwater level measurements collected in 1964 to generate the initial water levels for the transient model calibration. A total of 31 water level measurements from wells (i.e., target wells) were used for the steady state model (see Figure 24). Fifteen of these 31 water level targets were based on the data collected in 1964 (Shafer 1964 and Moyle 1967). Twelve water level targets located in the Fenner Gap area were carried over from the Fenner Gap model (see Appendix A); however, a water level of five feet was added to each water level

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<sup>8</sup> Natural recharge of 32,000 acre-ft/yr is based on the results from the INFIL3.0 model (see Appendix A). Natural recharge of 16,000 acre-ft/yr is to account for a 50% variability in the estimate. Natural recharge of 5,000 acre-ft/yr is to represent the Cadiz historical production.

measurement based on transient water level data suggesting an approximately 5 ft decline in heads in the Fenner Gap from predevelopment conditions. Three water level targets in the northern Fenner Valley were developed based on historical water level data outside the model boundary. Additionally, one target located in the north of the Clipper Mountains was estimated based land surface elevation in order to avoid simulated water levels from being above the land surface. The historical water level data were evaluated and anomalous and redundant data were not used.

The model-calculated water levels match very well with observed data for all the calibration runs (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr). The following table summarizes the water level residual (i.e., measured water level minus model-calculated water levels) statistics.

Parameter	Natural Recharge of 32,000 acre-ft/yr	Natural Recharge of 16,000 acre-ft/yr	Natural Recharge of 5,000 acre-ft/yr
Mean Residual	1.4 ft	1.7 ft	0.8 ft
Standard Deviation of Residuals	3.7 ft	3.6 ft	3.6 ft
Relative Error	0.15%	0.15%	0.15%

Relative Error = standard deviation of the residuals divided by the observed head range

The relative error of the water level residuals (i.e., standard deviation of the residuals divided by the observed head range) was calculated to quantitatively evaluate the model calibration. Common modeling practice is to consider a good fit between historical and model predicted data if the relative error is below 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999). As seen in the table above, the relative error is 0.15% for each calibration run, well below the recommended relative error of 10%.

A graphical comparison between measured and model-calculated water levels for the steady state calibration is shown on Figure 25, 26 and 27 for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively. In these figures, the closer the water levels fall on the straight line,

the better the match. As shown, there is a very good match between the model-calculated and measured water levels.

Figures 28, 29, and 30 show the spatial distribution of the water level residuals in the 31 wells for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively. As shown, the water level residuals in the Fenner Gap area are very small, indicating a good calibration in the Gap area. The average water level residuals are -0.7 ft (model overestimation), 0.6 ft (model underestimation) and 0.5 ft (model underestimation) for the natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively.

### 6.3. Transient Model Calibration

The results of the initial steady-state calibration provided initial aquifer parameter estimates and groundwater elevations for the transient flow model calibration. A total of 1,700 groundwater elevation data points, measured in 29 wells during the period from 1986 to 2009 were utilized for the transient calibration. Figure 31 shows the location of these 29 wells (i.e., target wells). Adjustments to horizontal hydraulic conductivity, vertical leakance, and storativity / specific yield were made iteratively until an acceptable match between measured and model-generated groundwater elevations was achieved.

In order to evaluate the accuracy of the model calibration, water levels from each of the three calibration runs are shown as hydrographs at selected target wells (see Figures 32, 33, and 34 for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively). Hydrographs for all 29 target wells are shown in Appendices E, F, and G. In general, the pattern of the model-generated and measured hydrographs is similar in that the model appears to capture the long- and short-term temporal trends for groundwater levels in the model area.

Plots of measured water levels versus model-calculated water levels within orthogonal axes for the 29 target wells were also prepared to show the performance of the match and the ranges of variations (see Figures 35, 36, and 37 for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively). As shown, all of the water levels are clustered around the diagonal line indicating a good match between the observed and model-calculated water levels.

Residual water levels for the 29 target wells during the period from 1986 to 2009 were also plotted as histograms for each calibration run (see Figures 38, 39, and 40 for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively). Water level residuals are calculated by subtracting the model-calculated water levels from the measured water levels. Consequently, a

negative residual represents an overestimation by the model and a positive residual indicates an underestimation by the model. The histograms show a bell shape with most of the water level residuals in the range of  $\pm 10$  ft, indicating a good model calibration. As shown, water level residuals between an overestimated 10 ft and an underestimated 10 ft account for 70%, 77% and 79% of the 1,700 water level measurements for natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively.

In order to examine the spatial distribution of water level residuals over time, water level residuals for the target wells in selected years 1994, 1999, 2004, and 2009 were plotted (see Figures 41, 42, and 43 for calibration run with natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively). In general, water level residual distribution is random with most of residuals in the range of  $\pm 10$  ft. These figures show that there are slightly higher residuals in the vicinity of the existing Cadiz agricultural wells. The reason for the higher residuals is likely due to a combination of model resolution (i.e., cell size) and quality of water level data. It is most likely that many of the larger residuals are due to the reported groundwater levels not being true static levels (i.e., not fully recovered from pumping). Additionally, the model-predicted value is averaged over the 500 ft x 500 ft area, whereas the actual water level measurement taken at the well is for a small point within the model cell

In addition, water level residuals over the time period from 1986 to 2009 for all 29 target wells were plotted in Figures 44, 45, and 46 for each calibration run with natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr, respectively. The cumulative departure from mean annual precipitation at Mitchell Caverns was also included on these figures to show climatic cycles during the same period of time. As shown in these figures, the water level residual is randomly distributed over the calibration period and is not particularly correlated with wet or dry periods.

Overall, the model-calculated water levels match very well with observed data for all the transient calibration runs (i.e., natural recharge of 32,000 acre-ft/yr, 16,000 acre-ft/yr, and 5,000 acre-ft/yr). The relative error of the water level residuals is 1.7% for each transient calibration run, which is well below the recommended error of 10%. The following table summarizes the water level residual (i.e., measured water levels minus model-calculated water levels) statistics.

Parameter	Natural Recharge of 32,000 acre-ft/yr	Natural Recharge of 16,000 acre-ft/yr	Natural Recharge of 5,000 acre-ft/yr
Mean Residual	-3.6 ft	-1.5 ft	-0.7 ft
Standard Deviation of Residuals	9.2 ft	9.0 ft	8.9 ft
Relative Error	1.7%	1.7%	1.7%

#### 6.4. Sensitivity Analysis

Model sensitivity to hydraulic conductivity and maximum evapotranspiration rate was partly accomplished by reducing the estimated natural recharge of 32,000 acre-ft/yr to 16,000 acre-ft/yr and 5,000 acre-ft/yr. Each calibration run produces a set of best-estimated hydraulic conductivity values and maximum evapotranspiration rates. In general, a greater amount of natural recharge requires a higher hydraulic conductivity value and maximum evapotranspiration rate.

Additional sensitivity analysis was performed on the transient calibration run with natural recharge of 32,000 acre-ft/yr to assess the parameters that affect the model results. The parameters of specific yield/storativity and vertical leakance were varied by the amounts of plus or minus 50% to assess the relative change in model error. The sensitivity analysis indicates that the model is not sensitive to changes in specific yield/storativity or vertical leakance. A plot of the normalized sensitivities for the selected parameters is summarized on Figure 47.

## 7.0 MODEL PREDICTIVE SCENARIOS

### 7.1. Description of Model Scenarios

After the model was calibrated, three model runs were simulated for a period of 100 years with an annual stress period. The predictive model runs include one Project scenario and two sensitivity scenarios. The purpose of the sensitivity scenarios was to evaluate the potential ranges of worst case impacts by: (1) reducing the amount of available natural recharge, and (2) increasing the distances between the wells within the proposed Project wellfield. Two wellfield configurations were used for the sensitivity analysis. Wellfield Configuration A consists of wells clustered around Fenner Gap as shown on Figure 48. Wellfield Configuration B consists of wells spread out southwest from Fenner Gap as shown on Figure 49. Wellfield Configuration B, coupled with lower natural recharge volumes (i.e., natural recharge of 16,000 and 5,000 acre-ft/yr), presents a worst-case scenario in terms of the potential impact to Bristol Dry Lake from Project pumping. Situating the wellfield closer to the Bristol and Cadiz Dry Lakes will result in greater groundwater level drawdown and, as such, will present the greatest risk for potential land subsidence. Additionally, Wellfield Configuration B presents a worst-case scenario for impacts related to migration of saline water from Bristol Dry Lake as the wells are located closer to the saline water/freshwater interface. The model scenarios and the assumptions used for each are provided in the following table. Detailed discussions of each assumption are provided in the following sections.

Model Scenario	Assumptions			
	Natural Recharge	Wellfield Configuration	Average Annual Groundwater Pumping from Years 1 to 50	Average Annual Groundwater Pumping from Years 51 to 100
	[acre-ft/yr]		[acre-ft/yr]	[acre-ft/yr]
Project Scenario	32,000	Clustered around Fenner Gap (Configuration A)	50,000	0
Sensitivity Scenario 1	16,000	Spread Out from Fenner Gap	50,000	0

		(Configuration B)		
Sensitivity Scenario 2	5,000	Spread Out from Fenner Gap (Configuration B)	50,000	0

## 7.2. Project Pumping

The Project pumping was assumed to be 50,000 acre-ft/yr for a period of 50 years. The projected annual pumping for the 50-year period was determined based on projected annual State Water Project deliveries (referred to as Table A deliveries) water for hydrologic years from 1954 to 2003 (MWD, 2009). This period was considered as a representative hydrologic base period because it covers dry, average and wet year cycles and the average Table A delivery is approximately the long-term average delivery. Hydrologic years 1988 to 1992 represents a dry year cycle. During this period, four of five years have a 75% exceedance probability of Table A deliveries. On the other hand, hydrologic years 1980 to 1984 represent a wet year cycle, when four of five years have a 25% exceedance probability of Table A deliveries.

For years with 75% exceedance probability of Table A deliveries (i.e., dry year cycles), the annual pumping is assumed to be 75,000 acre-ft. For years with 25% exceedance probability of Table A deliveries, the annual pumping is assumed to be 25,000 acre-ft. The annual pumping for the remaining years is 50,000 acre-ft. Figure 50 shows the annual pumping for the Project Scenario. The same annual pumping was used for Sensitivity Scenarios 1 and 2. Project pumping in excess of the natural annual recharge of 32,000 acre-ft is for the purpose of creating and maintaining a groundwater trough in the Project area to ensure that groundwater flowing from Fenner Valley is captured by the wellfield, thus maximizing long-term sustainable yield. Additionally, supplemental storage space is created within the basin allowing for optimization of the conservation and conjunctive use of water.

## 7.3. Natural Recharge

A natural recharge value of approximately 32,000 acre-ft/yr was generated by CH2M Hill using INFIL 3.0 as the estimated annual recoverable water quantity for the model period 1958-2007 (see Appendix A). In order to assess the effects of natural recharge on the model results, two sensitivity model runs were performed with reduced natural recharge. In the model run for Sensitivity Scenario 1, the natural recharge was reduced to 16,000 acre-ft/yr to account for a 50% variability in the estimate. For

Sensitivity Scenario 2, the natural recharge was reduced to 5,000 acre-ft/yr. This is the approximate historical production by Cadiz.

## 7.4. Project Extraction Wells

### 7.4.1. Wellfield Configuration

Two wellfield configurations were used for the model scenarios. Wellfield Configuration A (see Figure 48) includes two new high capacity wells (15,000 acre-ft/yr [13,250 gpm] and 70% operational), 15 new wells (2,250 acre-ft/yr [2,000 gpm] and 70% operational) and five existing Cadiz agricultural wells (also pumping 2,250 acre-ft/yr [2,000 gpm] and 70 % operational). The 15 new wells are clustered closely with the two new high capacity wells in the Fenner Gap area. Wellfield Configuration B (see Figure 49) includes 29 new wells (2,206 acre-ft/yr [2,000 gpm], 68% operational) and five existing Cadiz agricultural wells (also pumping 2,206 acre-ft/yr [2,000 gpm], 68% operational). The 29 new wells are spread out from the Fenner Gap area towards the existing Cadiz agricultural wells. Wellfield Configuration B, located closer to Bristol and Cadiz Dry Lakes, represents a worst case scenario regarding Project impacts on land subsidence in the Bristol Dry Lake and saline water intrusion from the Bristol Dry Lake.

The following table summarizes the assumptions used for the two wellfield configurations:

Wellfield		Wellfield Configuration A	Wellfield Configuration B
Number of Wells	Existing Cadiz Wells	5	5
	Proposed New High Capacity Wells	2	0
	Proposed New Wells	15	29
	Total	22	34
Depth of Production	Existing Cadiz and Proposed New Wells	350 ft – 1,200 ft	200 ft – 1,200 ft
	Proposed New High Capacity Wells	450 ft – 2,100 ft	NA
Total Depth of Well	Existing Cadiz and	700 ft – 1,200 ft	680 ft – 1,200 ft
	Proposed New High Capacity Wells	1,800 ft - 2,100 ft	NA
Wells Penetrate Carbonate Rock		Yes	Yes
Well Capacity	Existing Cadiz and Proposed New Wells	2,000 gpm	2,000 gpm
	Proposed New High Capacity Wells	13,250 gpm	NA
Operation Time to Yield 75,000 acre-ft/yr		8.4 months (70% annually)	8.2 months (68% annually)



### 7.4.2. Conceptual Drill Site Layout and Wellfield Manifold System

The conceptual drill site layout is shown on Figure 51. The footprint required for drilling operations is an area measuring 15,000 to 20,000 square feet. Several pieces of equipment, taking up approximately 6,000 square feet of space, would be required for drilling a new Project well. Figure 51 also shows the approximate equipment dimensions. However, actual equipment sizes and arrangement may vary depending on the site location and contractor's equipment within the overall footprint shown on Figure 51.

The wells in the Project wellfield will be connected through a wellfield manifold system. A schematic of the wellfield manifold system shown on Figure 52 assumes that all wells will be connected together to a single pumping station positioned to pump water to the Colorado River Aqueduct (CRA). The schematic of the wellfield manifold system shown on Figure 52 will likely be refined based on productivity of the extractions wells as they are installed.

### 7.4.3. Well Cross-Section

Figure 53 shows a proposed conceptual well cross-section for new Project wells, including the following technical details:

- **Borehole:** 32 in. borehole (50-150 ft) and 28 in. borehole (150-940 ft)
- **Casing:** 36 in. OD x 3/8 in. wall, mild steel conductor casing (+0.5-50 ft), 18 in. ID x 5/16 in. wall copper-bearing steel well casing (+1-400, 900-920 ft)
- **Screen:** 18 in. ID x 5/16 in. wall copper-bearing steel Ful-Flo louvered well screen with 3/32 in. (0.094 in.) openings (400-900 ft)
- **Gravel feed tubes:** two (2), 3 in. sch. 40 mild steel gravel feed tubes (+1-140 ft)
- **Sounding tube:** 2 in. sch. 40 mild steel sounding tube (+1-398 ft)
- **Seal and filter pack:** sand-cement seal (0-130 ft), fine sand layer (130-133 ft), and ¼ in. x 16 custom blend filter pack (133-940 ft)

The actual depths and dimensions of the well casing and screen, and the well materials and filter pack gradation will be identified during the design phase based on the results of borehole lithology, geophysical logs, and anticipated production rate.

## 7.5. Initial conditions

The model-calculated water levels at the end of transient model calibration (i.e., December 2009, see Figure 54) with natural recharge of 32,000 acre-ft/yr were used as the initial water levels of the Project Scenario. Similarly, model-calculated water levels at the end of transient model calibration runs (i.e., December 2009, see Figures 55 and 56) with natural recharge of 16,000 acre-ft/yr and 5,000 acre-ft/yr were used as the initial water levels of the Sensitivity Scenario 1 and Sensitivity Scenario 2, respectively. The initial TDS concentrations developed based on the historical data (Shafer, 1964; Table 3 of GEOSCIENCE, 1999; and Table 3 of Appendix A of Appendix A of this report) were used as the initial TDS concentrations for all the predictive model scenarios (see Figure 57).

## 8.0 IMPACT ANALYSIS

### 8.1. Groundwater Elevations

The model-calculated groundwater elevations at the end of 50 years (i.e., end of Project pumping) and 100 years (i.e., end of model simulation) for each model layer under Project Scenario conditions are shown on Figures 58 and 59, respectively. The model-calculated groundwater levels for Sensitivity Scenario 1 are shown on Figures 60 and 61, and on Figures 62 and 63 for Sensitivity Scenario 2. In general, the lowest water levels (i.e., greatest impact) would occur at the center of the wellfield in the vicinity of Fenner Gap at the end of 50 years as a result of the Project pumping (see Figures 58, 60 and 62). Under Project pumping conditions, groundwater would flow toward the proposed wellfield from Fenner, Bristol and Cadiz valleys. At the end of 100 years, water levels in the wellfield recover and groundwater flow directions would be similar to current conditions (see Figures 59, 61 and 63). Groundwater flow within the Bristol watershed flows toward, and terminates in, Bristol Dry Lake. Groundwater flow within the Cadiz watershed flows toward, and terminates in, Cadiz Dry Lake. Groundwater flow within the Fenner watershed flows from Fenner Valley through Fenner Gap and terminates at Bristol and Cadiz Dry Lakes.

### 8.2. Drawdown Analysis

#### 8.2.1. Regional Drawdown

When Project pumping begins, water levels within the wells begin to decline and water levels fall below the level in the surrounding aquifer. As a result, groundwater is induced to move from the aquifer to the wells. The movement of water from an aquifer into the wellfield results in the formation of a local cone of depression. The cone of depression would expand outward from the wellfield and can affect areas in the regional scale. The affected areas can be evaluated using the areal decline in water levels (i.e., regional drawdowns). The predicted regional drawdowns at the end of 50 years (i.e., end of Project pumping) and 100 years (i.e., end of model simulation) for each model layer under Project Scenario conditions are shown on Figures 64 and 65, respectively. The regional drawdowns for Sensitivity Scenario 1 are shown on Figures 66 and 67, and on Figures 68 and 69 for Sensitivity Scenario 2. In general, the maximum drawdown would occur at the center of the wellfield in the vicinity of Fenner Gap. As anticipated, the water level in the Bristol and Cadiz Dry Lakes would decline as a result of interception of natural recharge by the Project, consequently reducing or eliminating

groundwater currently lost to evaporation from the surface of the dry lakes. The table on the following page summarizes the predicted drawdown at the wellfield and at Bristol Dry Lake.

Model Scenario	End of 50 Years (End of Project Pumping)		End of 100 Years (End of Model Simulation)	
	Drawdown at Wellfield [ft]	Drawdown at Bristol Dry Lake [ft]	Drawdown at Wellfield [ft]	Drawdown at Bristol Dry Lake [ft]
Project Scenario	70 – 80	10 – 30	0 – 10	10 – 20
Sensitivity Scenario 1	120 – 130	10 – 60	10 – 20	30 – 40
Sensitivity Scenario 2	260 – 270	0 – 80	50 – 60	10 – 70

### 8.2.2. Drawdown during Dry Year, Wet Year and Average Year Conditions

Drawdowns during a single (1) and multiple (5) dry, wet and average years were analyzed at selected locations. Figure 70 shows the predicted drawdown during the 100 year model simulation period at selected locations, including the center of the wellfield, the existing Cadiz wells, the edge of Bristol Dry Lake, the center of Bristol Dry Lake, and the edge of Cadiz Dry Lake. Average annual drawdown in a single dry year (i.e., pumping 75,000 acre-ft/yr), wet year (i.e., pumping 25,000 acre-ft/yr) and average year (i.e., pumping 50,000 acre-ft/yr) was calculated at these locations. The following table summarizes the results:

Location	Hydrology	Annual Drawdown [ft]		
		Project	Sensitivity	Sensitivity
Center of Wellfield	Single Dry Year	11.1	13.9	22.1
	Single Wet Year	-9.4	-9.1	-13.1
	Single Average Year	2.5	2.9	6.2
Existing Cadiz Wells	Single Dry Year	4.2	4.3	9.4
	Single Wet Year	-2.1	-0.9	-3.4
	Single Average Year	0.7	1.7	3.2
Edge of Bristol Dry Lake	Single Dry Year	0.8	1.2	1.6
	Single Wet Year	0.4	1.0	1.7
	Single Average Year	0.8	1.3	1.8
Center of Bristol Dry Lake	Single Dry Year	0.6	0.8	0.7
	Single Wet Year	0.6	0.9	0.8
	Single Average Year	0.6	0.9	0.7
Edge of Cadiz Dry Lake	Single Dry Year	0.4	1.0	1.2
	Single Wet Year	0.0	0.8	1.3
	Single Average Year	0.3	1.1	1.5

Note: A negative sign represents a rise of water level.

As shown in the above table, drawdowns in the wellfield, including the center of the wellfield and the area of the existing Cadiz wells, correspond to the hydrologic conditions and amount of natural recharge. The maximum single year drawdown would be 22.1 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2) and dry year conditions (i.e., pumping of 75,000 acre-ft/yr). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), there is very little change in drawdown during the dry, wet and average years.

Drawdown in multiple dry years (hydrologic years 1988 to 1992), multiple wet years (hydrologic years 1980 to 1984) and multiple average years (hydrologic years 1964 to 1968) was also calculated at these locations. The following table summarizes the results:

Location	Hydrology	Drawdown [ft]		
		Project Scenario	Sensitivity Scenario 1	Sensitivity Scenario 2
Center of Wellfield	Multiple Dry Years	24.5	38.0	65.9
	Multiple Wet Years	-17.2	-20.0	-39.4
	Multiple Average	3.8	8.1	25.1
Existing Cadiz Wells	Multiple Dry Years	13.7	17.1	32.4
	Multiple Wet Years	-6.2	-3.2	-7.0
	Multiple Average	4.0	8.2	15.6
Edge of Bristol Dry Lake	Multiple Dry Years	4.3	6.6	8.3
	Multiple Wet Years	0.6	4.3	8.9
	Multiple Average	4.4	6.8	8.8
Center of Bristol Dry Lake	Multiple Dry Years	2.3	4.1	4.8
	Multiple Wet Years	2.6	4.7	4.5
	Multiple Average	4.0	4.7	2.3
Edge of Cadiz Dry Lake	Multiple Dry Years	3.7	7.5	7.7
	Multiple Wet Years	-1.0	3.4	7.5
	Multiple Average	0.6	4.8	5.3

Note: A negative sign represents a rise of water level.

### 8.3. Depth to Groundwater

Figure 71 shows the predicted depth to groundwater during the 100 year model simulation period at selected locations, including the center of the wellfield, the existing Cadiz wells, at the edge of Bristol Dry Lake, at the center of Bristol Dry Lake, and at the edge of Cadiz Dry Lake. Depth to groundwater at

the end of 50 years (end of Project pumping) and at the end of 100 years (end of model simulation) was calculated at these locations. The following table summarizes the results:

Location	Time	Depth to Groundwater [ft]			
		Existing	Project Scenario	Sensitivity Scenario 1	Sensitivity Scenario 2
Center of Wellfield	End of 50 Years	354	435	486	627
	End of 100 Years		351	371	412
Existing Cadiz Wells	End of 50 Years	156	197	241	315
	End of 100 Years		154	181	219
Edge of Bristol Dry Lake	End of 50 Years	33	68	95	118
	End of 100 Years		42	74	108
Center of Bristol Dry	End of 50 Years	18	50	63	54
	End of 100 Years		33	62	79
Edge of Cadiz Dry Lake	End of 50 Years	7	21	59	72
	End of 100 Years		10	17	68

#### 8.4. Saline Water/Freshwater Interface

The SEAWAT-2000 variable density groundwater flow and solute transport model was used to predict the movement of the saline water/freshwater interface in the vicinity of Bristol and Cadiz Dry Lakes resulting from Project pumping. The location of the current saline water/freshwater interface for this Project is defined by the location of the 1,000 mg/L total dissolved solids (TDS)<sup>9</sup> concentration contour based on recent groundwater quality data from the Cadiz agricultural wells, monitoring wells, and from historical data from other wells in the area (see Figure 72). The locations of the model-predicted saline water/freshwater interface at the end of 50 years and 100 years is shown on Figures 72, 73, and 74 for the Project Scenario, Sensitivity Scenario 1 and Sensitivity Scenario 2, respectively. Results of the modeling indicate the saline water/freshwater interface in the Bristol Dry Lake area would move a maximum distance of approximately 10,400 ft northeast during Project pumping (years 1 to 50) under Project Scenario conditions. The saline water and freshwater interface would move a maximum of approximately 9,700 ft and 6,300 ft during the same period of time under Sensitivity Scenarios 1 and 2, respectively. After Project pumping for all scenarios, the saline water/freshwater interface in the Bristol Dry Lake area continues to move towards the northeast to reach a distance of 11,500 ft, 11,100 ft, and

<sup>9</sup> Saline groundwater is a general term referring to any groundwater containing more than 1,000 mg/L TDS (Todd, 1980).

9,200 ft for the Project Scenario, Sensitivity Scenario 1, and Sensitivity Scenario 2, respectively. The following table summarizes the maximum migration distance of the saline water/freshwater interface:

Model Scenario	Maximum Migration of Saline Water/Freshwater Interface at the End of 50 Years	Maximum Migration of Saline Water/Freshwater Interface at the End of 100 Years
Project Scenario	10,400 ft Northeast	11,500 ft Northeast
Sensitivity Scenario 1	9,700 ft Northeast	11,100 ft Northeast
Sensitivity Scenario 2	6,300 ft Northeast	9,200 ft Northeast

Model-predicted TDS concentrations over time at three selected locations (Locations A, B, and C) along the southern and southwestern boundaries of Cadiz owned land are shown on Figure 75.

## 8.5. Groundwater in Storage

The overall water budgets for each of the model runs were compiled (see Tables 2, 3 and 4 for the Project Scenario, Sensitivity Scenario 1, and Sensitivity Scenario 2, respectively). The inflow term for the model includes natural recharge and release of water from storage within the interbeds<sup>10</sup>, while the outflow terms consist of groundwater pumping, uptake of water into storage within the interbeds, and evapotranspiration. The difference between the total inflow and total outflow is the change in groundwater storage. Figure 76 shows cumulative annual changes in groundwater storage during the 100 year model simulation period for each model scenario. As shown, the cumulative annual change in groundwater storage would reach a maximum of -1,090,000 acre-ft (a negative sign represents a decline in groundwater storage) in year 50 under the Project Scenario conditions. This decline in groundwater storage is approximately 3% to 6% of the total groundwater in storage. The total groundwater in storage was estimated to be 17 to 34 million acre-ft (see Appendix A). The groundwater in storage would begin to recover after the Project pumping stops in year 50. The cumulative annual change in groundwater storage would be approximately -220,000 acre-ft in year 100 under the Project Scenario. According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 117 (i.e., 67 years after Project pumping stopped).

<sup>10</sup> Interbeds represent a poorly permeable bed within a relatively permeable aquifer and consist of highly compressible clay and silt deposits.

The following table summarizes the cumulative annual changes in groundwater storage at the end of 50 years (end of Project pumping) and 100 years (end of model simulation) for each model scenario as volume in units of acre-ft and percent of the total groundwater in storage. The amount of time it will take groundwater storage to recover is also included.

Model Scenario	Cumulative Annual Changes in Groundwater Storage at the End of 50 Years		Cumulative Annual Changes in Groundwater Storage at the End of 100 Years		Time for Groundwater Storage to Recover after Project Pumping Stopped in Year 50
	Volume	% of Total Groundwater Storage	Volume	% of Total Groundwater Storage	
	[acre-ft]	[%]	[acre-ft]	[%]	Years
Project Scenario	-1,090,000	3 to 6	-220,000	1	67 (in Year 117)
Sensitivity Scenario 1	-1,680,000	5 to 10	-870,000	3 to 5	103 (in Year 153)
Sensitivity Scenario 2	-2,160,000	6 to 13	-1,870,000	6 to 11	390 (in Year 440)

Note: A negative sign represents a decline in groundwater storage.

## 8.6. Potential Land Subsidence

Model-predicted potential land subsidence at the end of 50 years and 100 years is shown on Figures 77, 78, and 79 for the Project Scenario, Sensitivity Scenario 1, and Sensitivity Scenario 2, respectively. In general, the amount of land subsidence corresponds to the magnitude of water level decline and the thickness of the clay layers. A sharp increase in land subsidence from zone “0.75 to 1.0 ft” to zone “2.5 to 3.13 ft” in the Bristol Dry Lake area (see Figure 79 year 100) reflects changes in zone clay thickness from 120 ft to 350 ft (see Figure 20). Model-predicted land subsidence over time at selected locations (including the center of the wellfield, the existing Cadiz wells, at the edge of Bristol Dry Lake, at the center of Bristol Dry Lake, and at the edge of Cadiz Dry Lake) for each model run is shown on Figure 80. As shown, any predicted subsidence would occur gradually over time and be dispersed laterally over a large area from the Fenner Gap to the Bristol and Cadiz Dry Lakes.



The following table summarizes the maximum potential land subsidence at these locations for each model scenario.

Location	Time	Maximum Potential Land Subsidence [ft]		
		Project Scenario	Sensitivity Scenario 1	Sensitivity Scenario 2
Center of Wellfield	End of 50 Years	0.2	0.4	0.7
	End of 100 Years	0.2	0.4	0.7
Existing Cadiz Wells	End of 50 Years	0.6	1.0	1.5
	End of 100 Years	0.6	1.0	1.5
Edge of Bristol Dry Lake	End of 50 Years	0.5	1.0	1.4
	End of 100 Years	0.5	1.0	1.7
Center of Bristol Dry Lake	End of 50 Years	0.9	1.7	1.2
	End of 100 Years	0.9	2.1	2.7
Edge of Cadiz Dry Lake	End of 50 Years	0.1	0.4	0.5
	End of 100 Years	0.1	0.4	0.6

## 9.0 FINDINGS

The following findings and recommendations are based on the results of the groundwater model and impact analyses:

### *Groundwater Elevations*

- Model-calculated groundwater elevations at the end of 50 years (i.e., end of Project pumping) under Project Scenario and Sensitivity Scenario conditions indicate that the lowest water levels (i.e., greatest potential impact) would occur at the center of the wellfield in the vicinity of Fenner Gap.
- Under Project pumping conditions, groundwater would flow toward the proposed wellfield from Fenner, Bristol and Cadiz valleys.
- At the end of 100 years (i.e., 50 years following cessation of Project pumping), water levels in the wellfield recover and groundwater flow directions would be similar to current conditions (i.e., groundwater flow within the Bristol watershed flows toward, and terminates in, Bristol Dry Lake; groundwater flow within the Cadiz watershed flows toward, and terminates in, Cadiz Dry Lake; groundwater flow within the Fenner watershed flows from Fenner Valley through Fenner Gap and terminates at Bristol and Cadiz Dry Lakes).

### *Groundwater Level Drawdown*

- Predicted regional drawdown at the end of 50 years (i.e., end of Project pumping) under Project Scenario and Sensitivity Scenario conditions indicate that a maximum groundwater level drawdown (i.e., greatest potential impact) of 260 to 270 ft (under natural recharge conditions of 5,000 acre-ft/yr) would occur at the center of the wellfield in the vicinity of Fenner Gap.
- Groundwater levels in the Bristol and Cadiz Dry Lakes would decline as a result of interception of natural recharge by the Project, consequently reducing or eliminating groundwater currently lost to evaporation from the surface of the dry lakes.
- Drawdown within the wellfield, including the center of the wellfield and the area of the existing Cadiz wells, corresponds to hydrologic conditions and amount of natural recharge.

- The maximum single year drawdown would be 22.1 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2) and dry year conditions (i.e., pumping of 75,000 acre-ft/yr). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), there would be very little change in drawdown during single dry, wet and average years.
- Maximum drawdown within the wellfield during multiple dry year conditions (i.e., pumping of 75,000 acre-ft/yr; hydrologic years 1988 to 1992) would be 65.9 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.3 ft.
- Maximum drawdown within the wellfield during multiple wet year conditions (i.e., pumping of 25,000 acre-ft/yr; hydrologic years 1980 to 1984) would be -39.4 ft (groundwater level rise) under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.9 ft.
- Maximum drawdown within the wellfield during multiple average year conditions (i.e., pumping of 50,000 acre-ft/yr; hydrologic years 1964 to 1968) would be 25.1 ft under a natural recharge of 5,000 acre-ft/yr (i.e., Sensitivity Scenario 2). Away from the wellfield (i.e., the Bristol and Cadiz Dry Lakes), the maximum drawdown would be 8.8 ft.

### ***Depth to Groundwater***

- Depth to groundwater at the end of 50 years (end of Project pumping under Project Scenario conditions) would range from 197 to 435 ft bgs in the vicinity of the wellfield, 50 to 68 ft bgs at Bristol Dry Lake, and 21 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 50 years (end of Project pumping under Sensitivity Scenario 1 conditions) would range from 241 to 486 ft bgs in the vicinity of the wellfield, 63 to 95 ft bgs at Bristol Dry Lake, and 59 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 50 years (end of Project pumping under Sensitivity Scenario 2 conditions) would range from 315 to 627 ft bgs in the vicinity of the wellfield, 54 to 118 ft bgs at Bristol Dry Lake, and 72 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Project Scenario conditions) would range from 154 to 351 ft bgs in the vicinity of the wellfield, 33 to 42 ft bgs at Bristol Dry Lake, and 10 ft bgs at Cadiz Dry Lake.

- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Sensitivity Scenario 1 conditions) would range from 181 to 371 ft bgs in the vicinity of the wellfield, 62 to 74 ft bgs at Bristol Dry Lake, and 17 ft bgs at Cadiz Dry Lake.
- Depth to groundwater at the end of 100 years (50 years following cessation of Project pumping under Sensitivity Scenario 2 conditions) would range from 219 to 412 ft bgs in the vicinity of the wellfield, 79 to 108 ft bgs at Bristol Dry Lake, and 68 ft bgs at Cadiz Dry Lake.

### ***Saline Water/Freshwater Interface***

- The location of the current saline water/freshwater interface for this Project is defined by the location of the 1,000 mg/L TDS concentration contour.
- Results of the modeling indicate the saline water/freshwater interface in the Bristol Dry Lake area would move a maximum distance of approximately 10,400 ft northeast during Project pumping (years 1 to 50) under Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). The saline water/freshwater interface would move a maximum of approximately 9,700 ft and 6,300 ft to the northeast during the same period of time under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr) and Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr), respectively.
- Following Project pumping for all scenarios, the saline water/freshwater interface in the Bristol Dry Lake area continues to move towards the northeast to reach a distance of 11,500 ft, 11,100 ft, and 9,200 ft for the Project Scenario conditions (under natural recharge conditions of 32,000 acre-ft/yr), Sensitivity Scenario 1 (under natural recharge conditions of 16,000 acre-ft/yr), and Sensitivity Scenario 2 (under natural recharge conditions of 5,000 acre-ft/yr), respectively.

### ***Groundwater in Storage***

- The cumulative annual change in groundwater storage would reach a maximum of -1,090,000 acre-ft (a negative sign represents a decline in groundwater storage) in year 50 under the Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). This decline in groundwater storage is approximately 3% to 6% of the total groundwater in storage.
- The groundwater in storage would begin to recover following the cessation of Project pumping in year 50. The cumulative annual change in groundwater storage would be

approximately -220,000 acre-ft in year 100 under Project Scenario conditions (i.e., natural recharge of 32,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 117 (i.e., 67 years after Project pumping stopped).

- The cumulative annual change in groundwater storage would reach a maximum of -1,680,000 acre-ft in year 50 under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr). This decline in groundwater storage is approximately 5 to 10% of the total groundwater in storage.
- The cumulative annual change in groundwater storage would be approximately -870,000 acre-ft in year 100 under Sensitivity Scenario 1 conditions (i.e., natural recharge of 16,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 153 (i.e., 103 years after Project pumping stopped).
- The cumulative annual change in groundwater storage would reach a maximum of -2,160,000 acre-ft in year 50 under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr). This decline in groundwater storage is approximately 6 to 13% of the total groundwater in storage.
- The cumulative annual change in groundwater storage would be approximately -1,870,000 acre-ft in year 100 under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr). According to the rate of recovery from years 51 to 100, the groundwater storage would fully recover in year 440 (i.e., 390 years after Project pumping stopped).

### ***Potential Land Subsidence***

- In general, the amount of land subsidence corresponds to the magnitude of water level decline and the thickness of the clay layers.
- The maximum model-predicted land subsidence is 2.7 ft at the center of Bristol Dry Lake at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).
- The maximum model-predicted land subsidence ranges from 0.7 to 1.5 ft in the vicinity of the Cadiz wellfield at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).

- The maximum model-predicted land subsidence is 0.6 ft at the edge of Cadiz Dry Lake at the end of 100 years (i.e., 50 years following cessation of Project pumping) under Sensitivity Scenario 2 conditions (i.e., natural recharge of 5,000 acre-ft/yr).
- Predicted subsidence would occur gradually over time and be dispersed laterally over a large area from Fenner Gap to the Bristol and Cadiz Dry Lakes.

Consideration of the Cadiz Groundwater Modeling and Impact Analysis report will be incorporated into the Groundwater Management Plan.

## 10.0 MODEL LIMITATIONS AND UNCERTAINTY

The Cadiz groundwater model is a useful tool for evaluating water levels, water quality and potential land subsidence of the aquifer systems, as the model calibration exceeds industry standards. In addition, the confidence in using the predictive model runs is increased through the reasonable results from the Project Scenario and Sensitivity Scenarios. However, it should be noted that the model is a simplified approximation of a complex geohydrologic system. The accuracy of model predictions is dependent on the simplifying assumptions used due to limited hydrogeologic data. As an example, the potential land subsidence was based on an assumed specific inelastic storage coefficient from another groundwater basin due to there being no available site-specific data. Installation of extensometers to monitor the aquifer systems responding to the water level changes can significantly enhance the capability to predict land subsidence. It is anticipated that the Cadiz groundwater model will be updated when additional hydrogeologic data become available.

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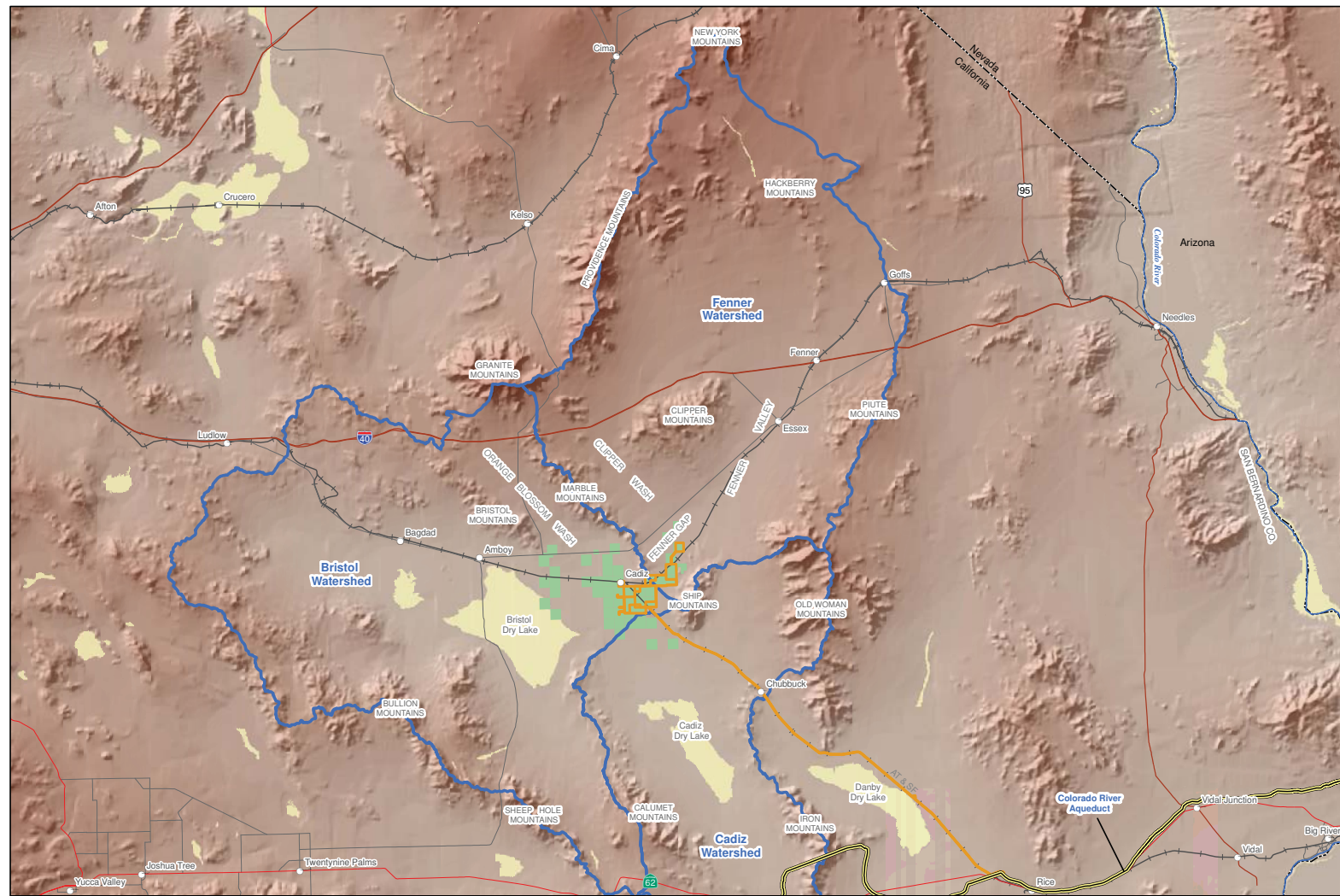
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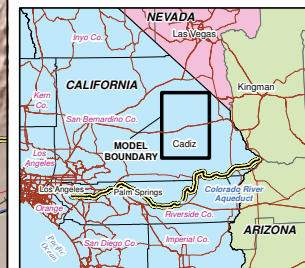
## FIGURES



# GENERAL PROJECT LOCATION

## EXPLANATION

- Selected Watershed Boundaries
- Wellfield Development Areas and Pipelines
- Cadiz Owned Land
- Railroad
- State Boundary
- Colorado River Aqueduct

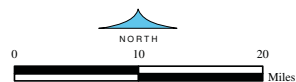


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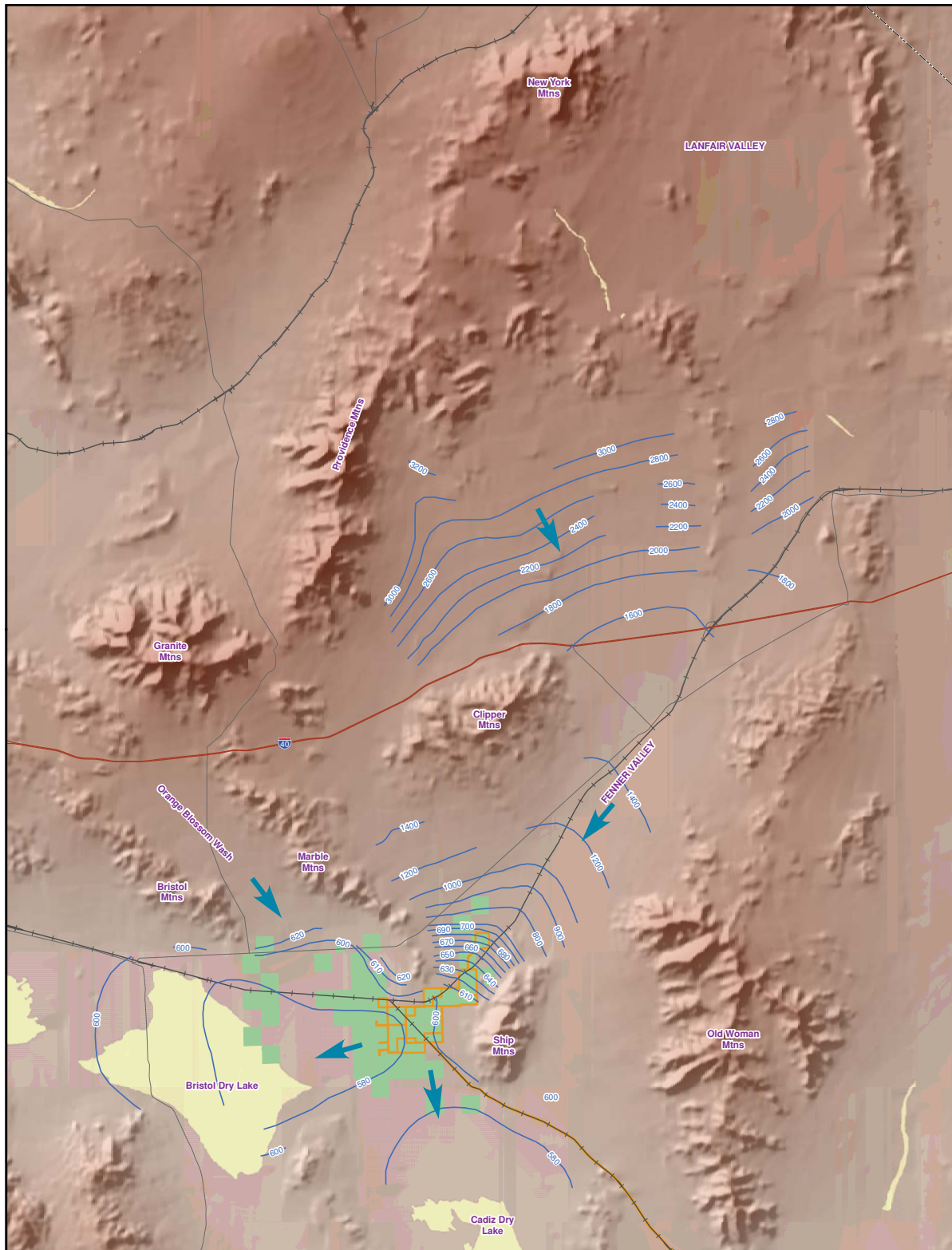
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**Figure 1**



Wellfield Development Areas  
and Pipelines

Cadiz Owned Land

— 580 — 2009 Groundwater Elevations  
(ft amsl)  
(Source: CH2M-Hill, 2010)

Groundwater Flow  
Direction

**2009 GROUNDWATER  
ELEVATIONS**

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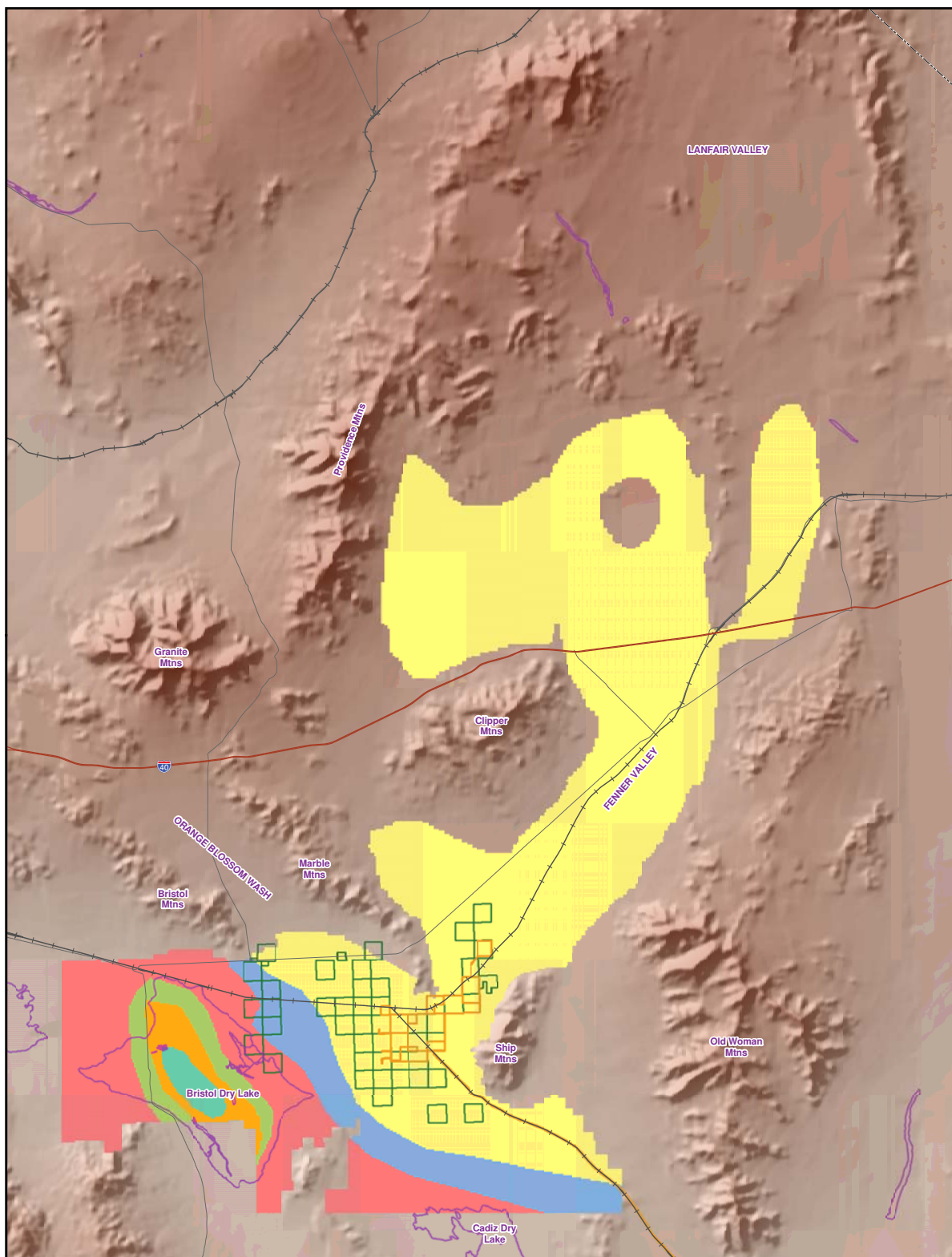


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**Figure 2**





Wellfield Development Areas  
and Pipelines

Cadiz Owned Land

TDS Concentration (mg/L)

<500

500 to 10,000

10,000 to 50,000

50,000 to 100,000

100,000 to 150,000

150,000 to 200,000

**TOTAL  
DISSOLVED SOLIDS  
CONCENTRATIONS**

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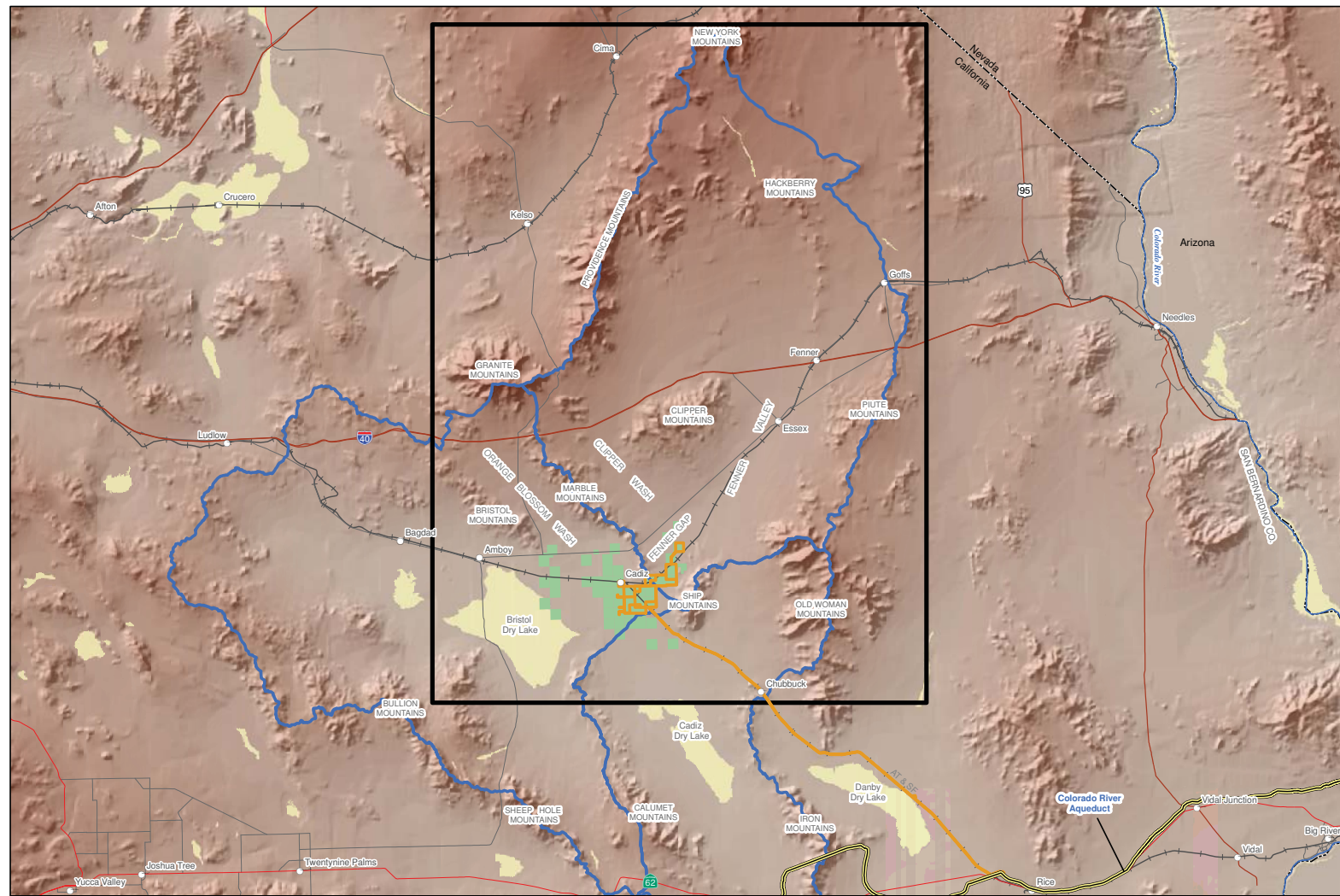
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**Figure 3**



**CADIZ GROUNDWATER MODEL BOUNDARY**

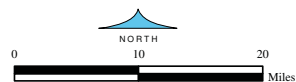
EXPLANATION

- Groundwater Model Boundary  
Cell Size is 500ft x 500ft
- Selected Watershed Boundaries
- Wellfield Development Areas and Pipelines
- Cadiz Owned Land
- Railroad
- State Boundary

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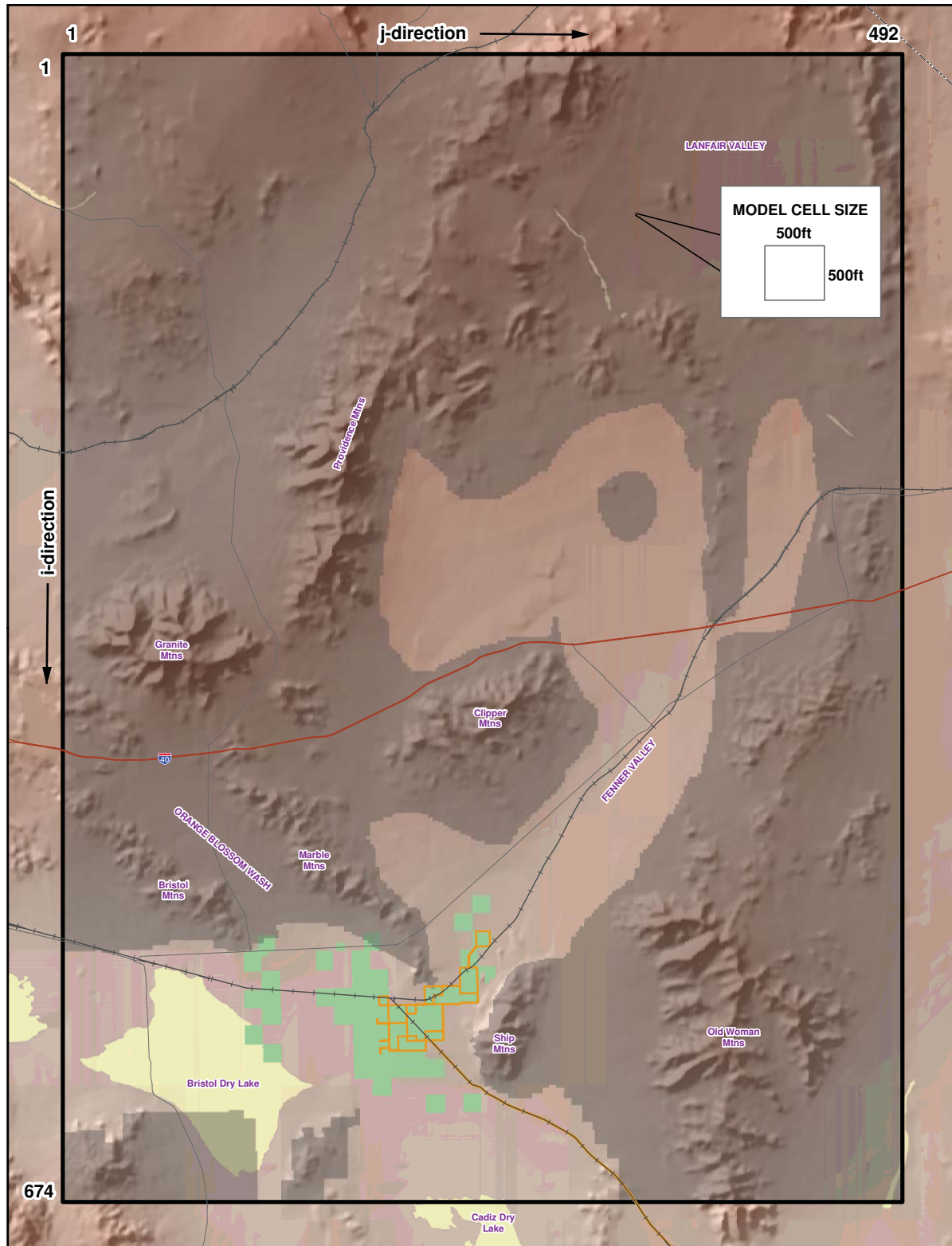
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**Figure 4**



-  Groundwater Model Boundary  
Cell Size = 500 ft x 500 ft
-  Wellfield Development Areas and Pipelines
-  No Flow Model Cell
-  Cadiz Owned Land

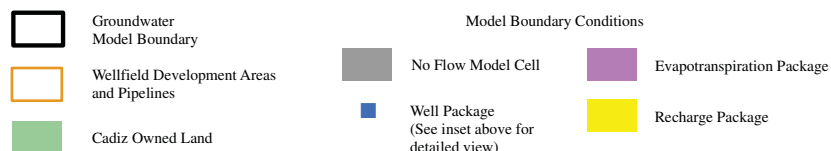
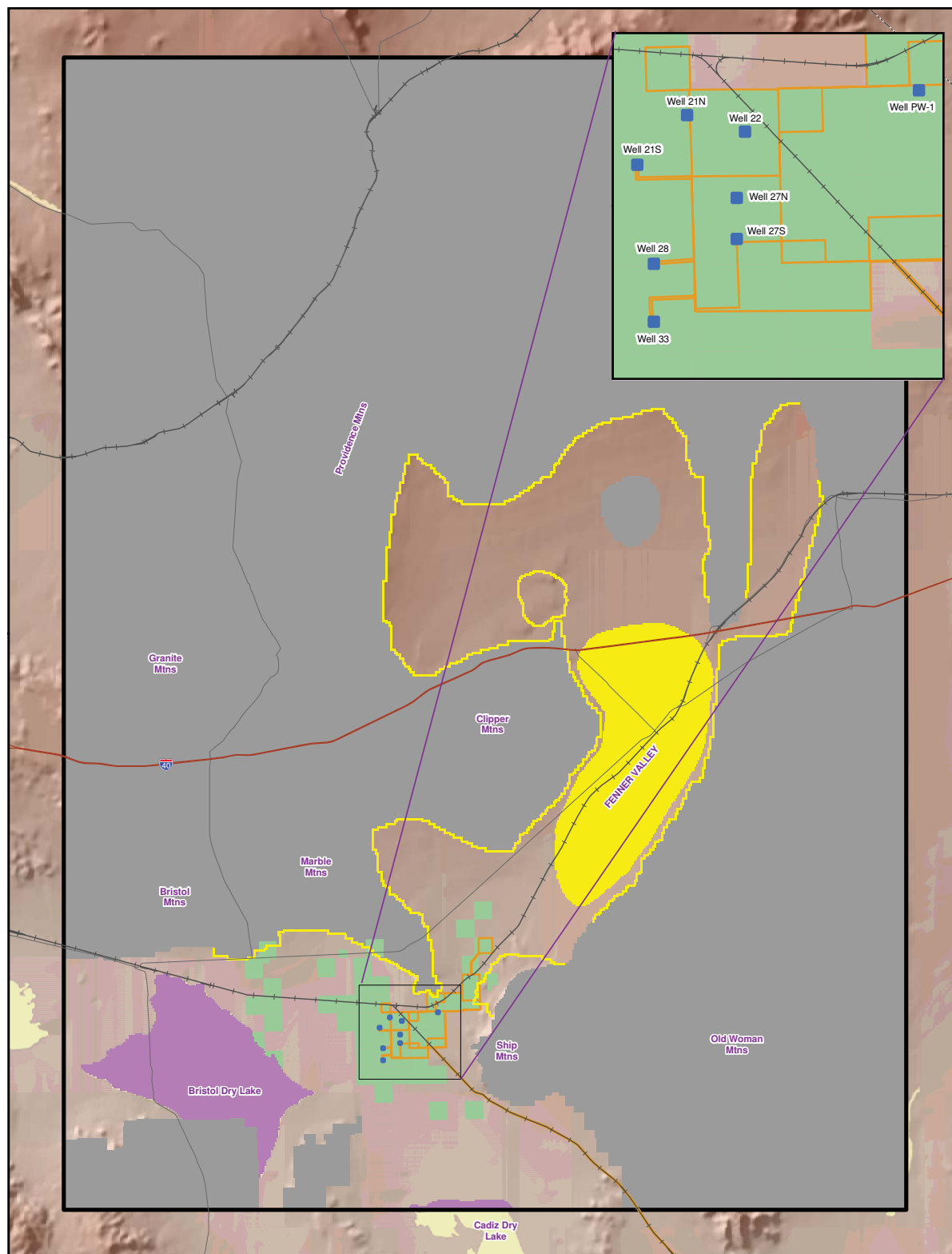
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**Figure 5**



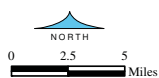


**BOUNDARY CONDITIONS  
OF THE CADIZ  
GROUNDWATER MODEL**

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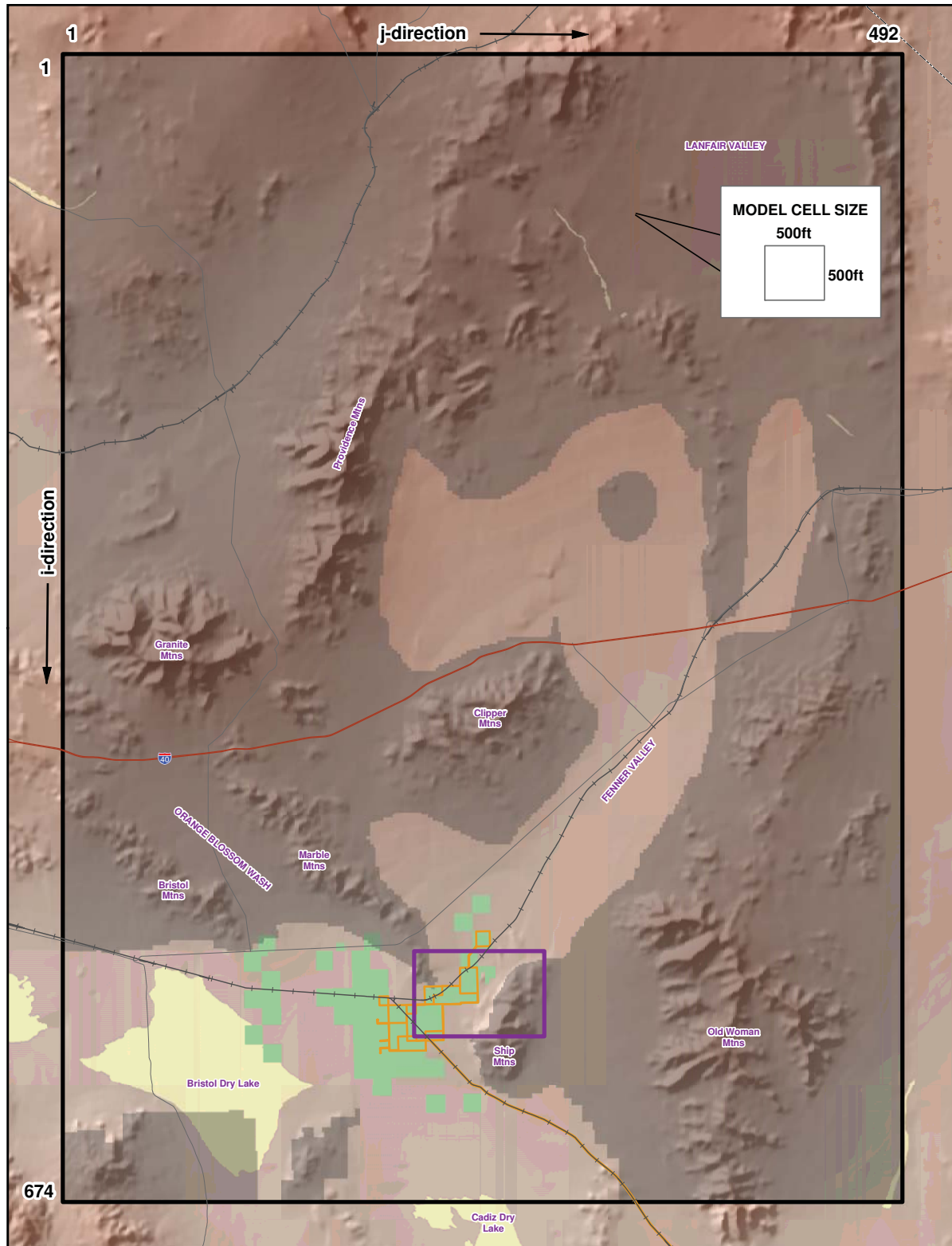
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**Figure 6**



**FENNER GAP  
LITHOLOGIC  
MODEL BOUNDARY**

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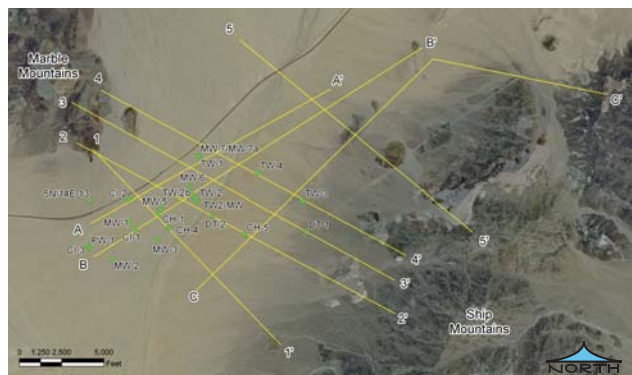
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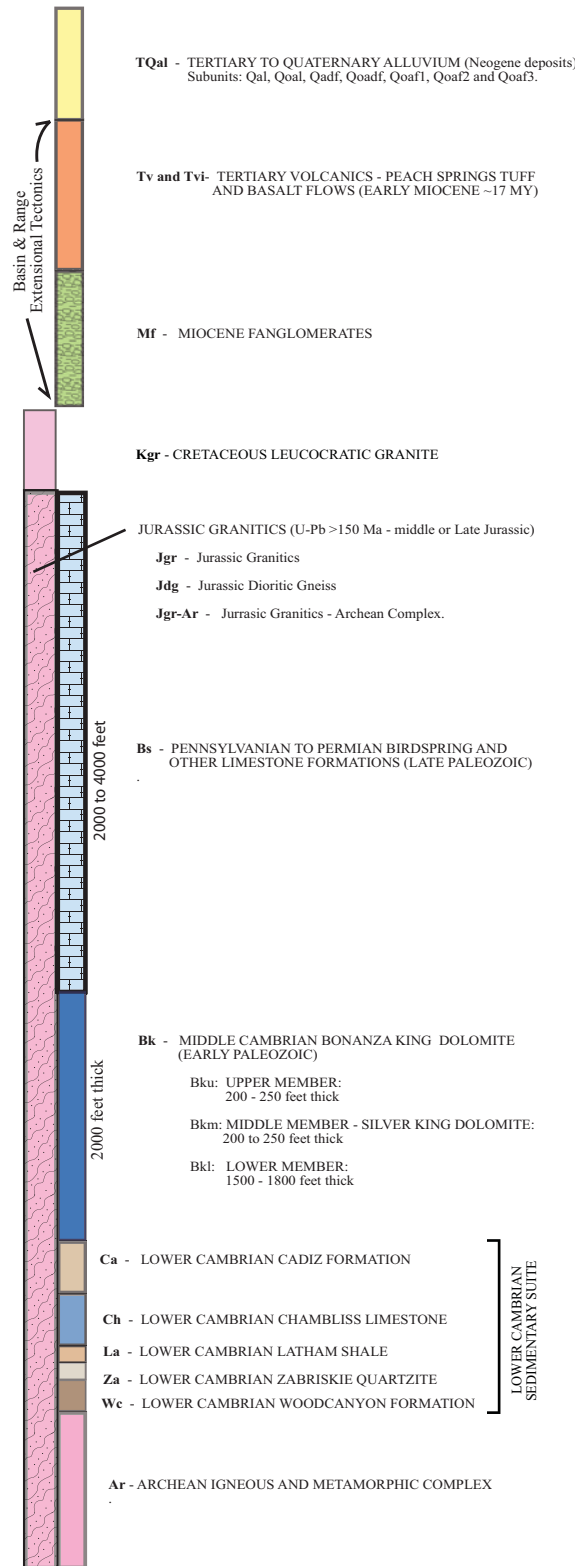
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**Figure 7**



See Figure 8b for Stratigraphic Legend

# STRATIGRAPHIC SECTION



See Figure 8a for Lithologic Cross Section

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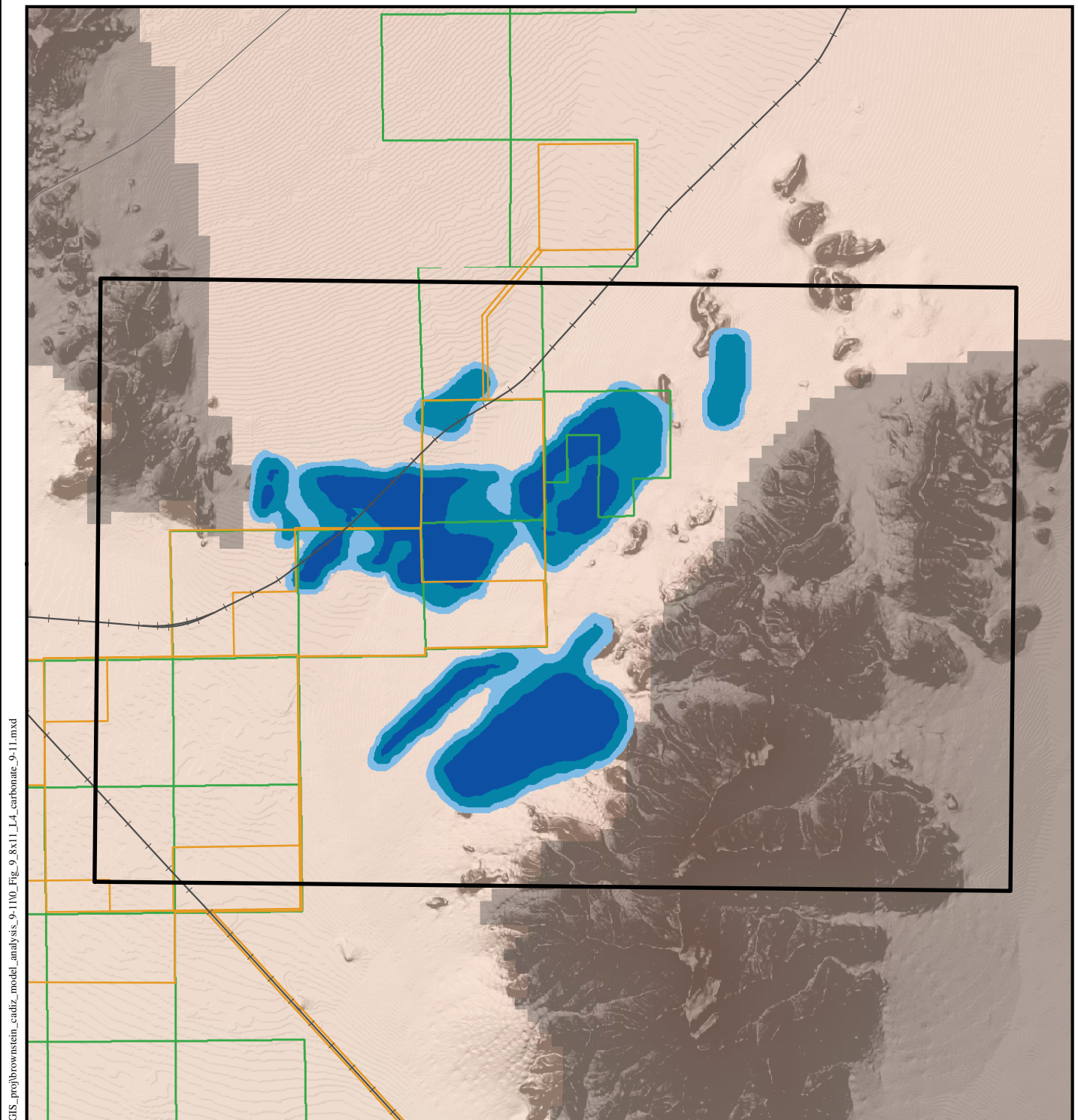
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LITHOLOGIC MODEL RESULTS  
CROSS SECTION 3-3' LEGEND

Figure  
8b





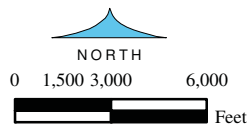
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- Lithologic Model Boundary
- No Flow Groundwater Model Cell
- Cadiz Owned Land
- Wellfield Development Areas and Pipelines

## Percent Carbonate Distribution

- <10%
- 10 to 30%
- 30 to 70%
- 70 to 100%

**ZONES OF PERCENT  
CARBONATE  
DISTRIBUTION FOR  
CADIZ GROUNDWATER  
MODEL LAYER 4**



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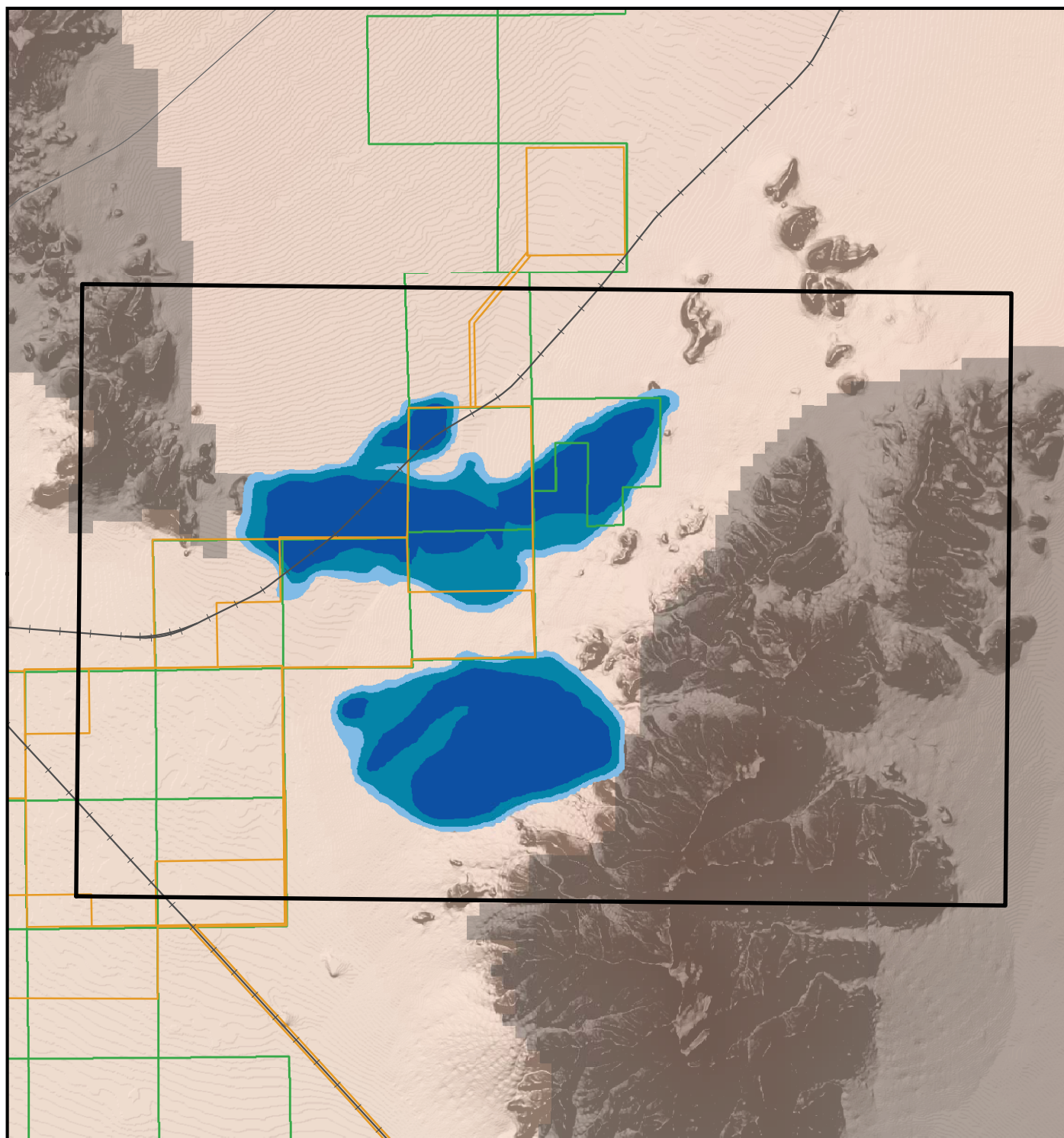
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**Figure 9**

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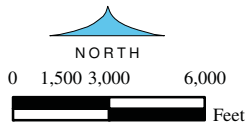


- Lithologic Model Boundary
- No Flow Groundwater Model Cell
- Cadiz Owned Land
- Wellfield Development Areas and Pipelines

## Percent Carbonate Distribution

- <10%
- 10 to 30%
- 30 to 70%
- 70 to 100%

**ZONES OF PERCENT  
CARBONATE  
DISTRIBUTION FOR  
CADIZ GROUNDWATER  
MODEL LAYER 5**



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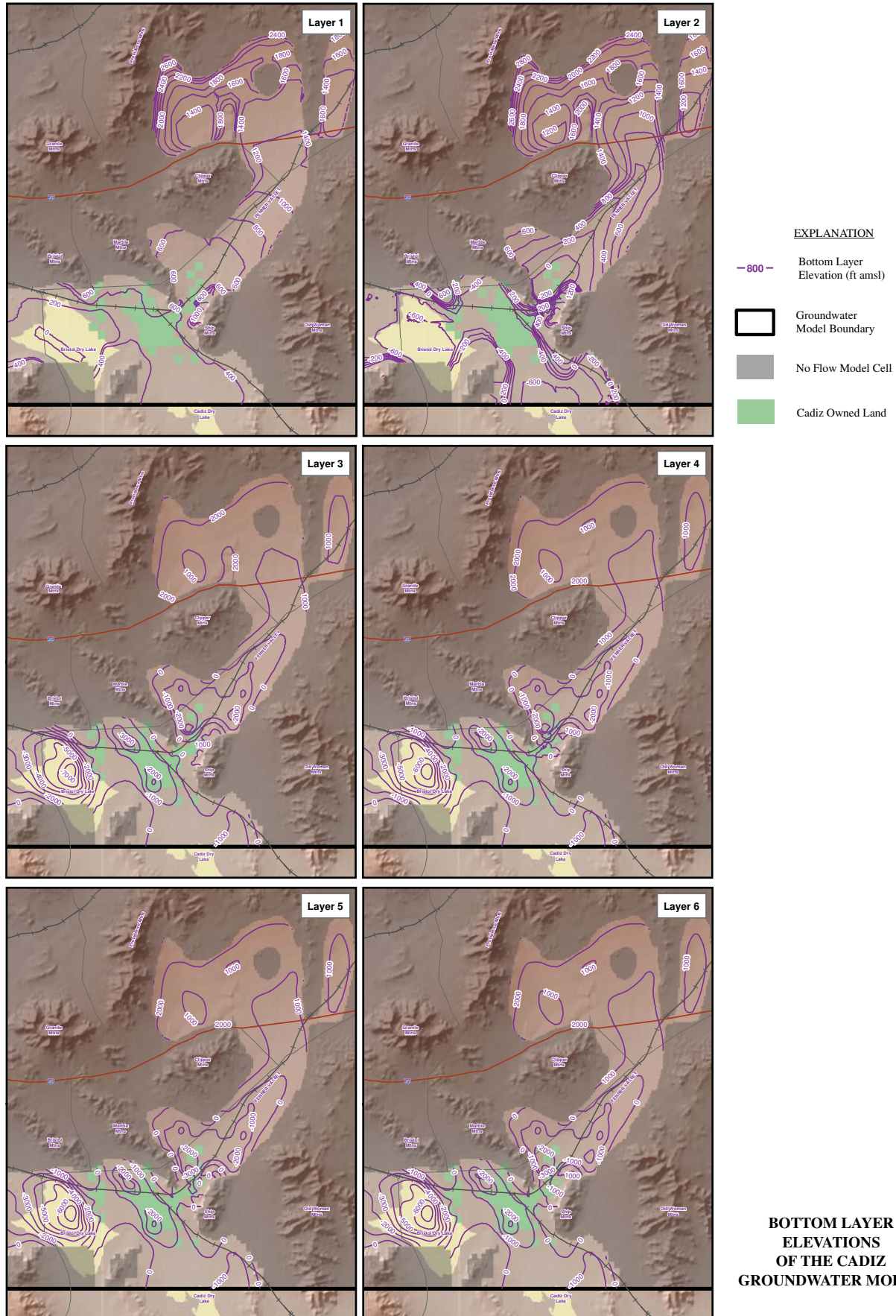
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**Figure 10**





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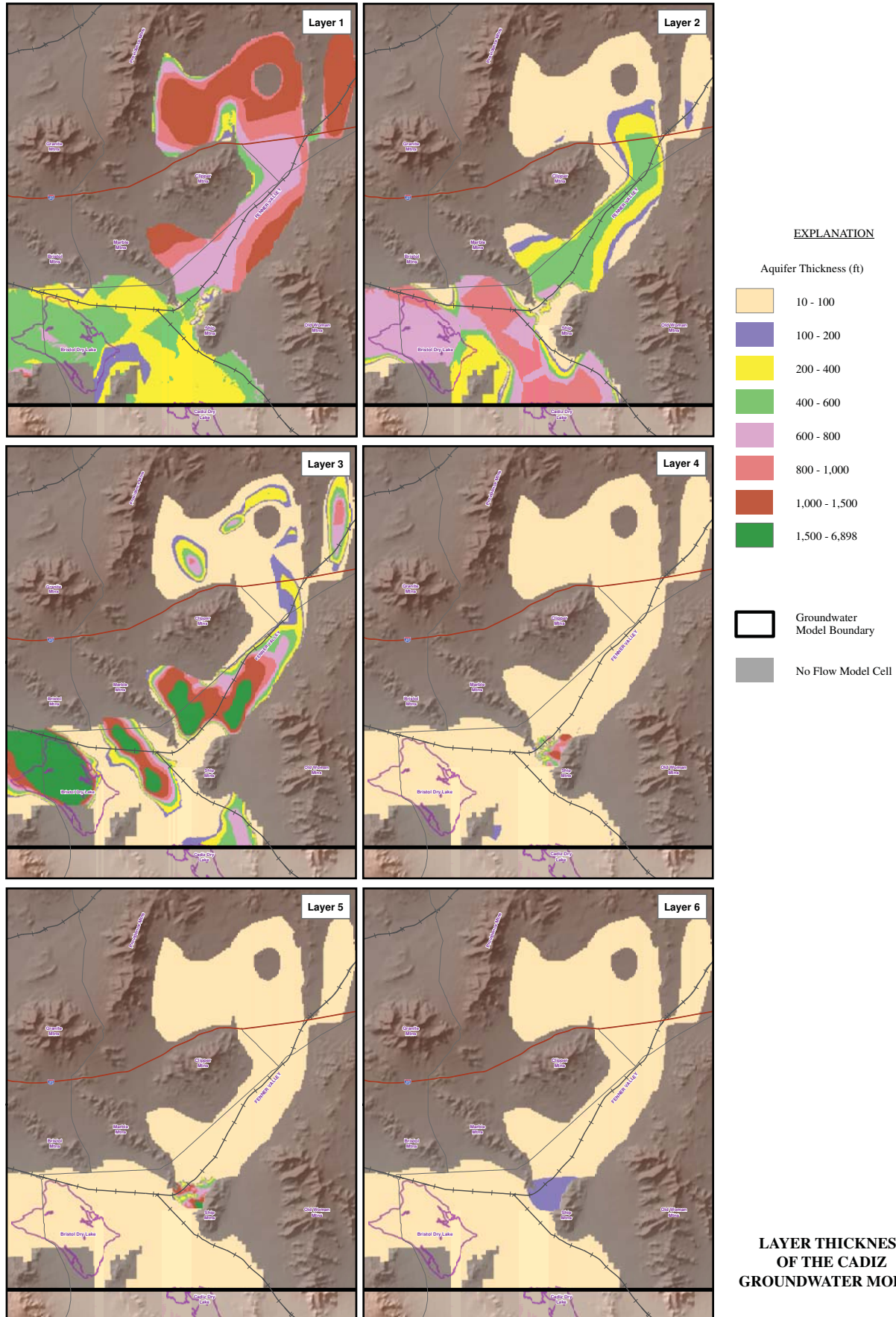
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**Figure 11**



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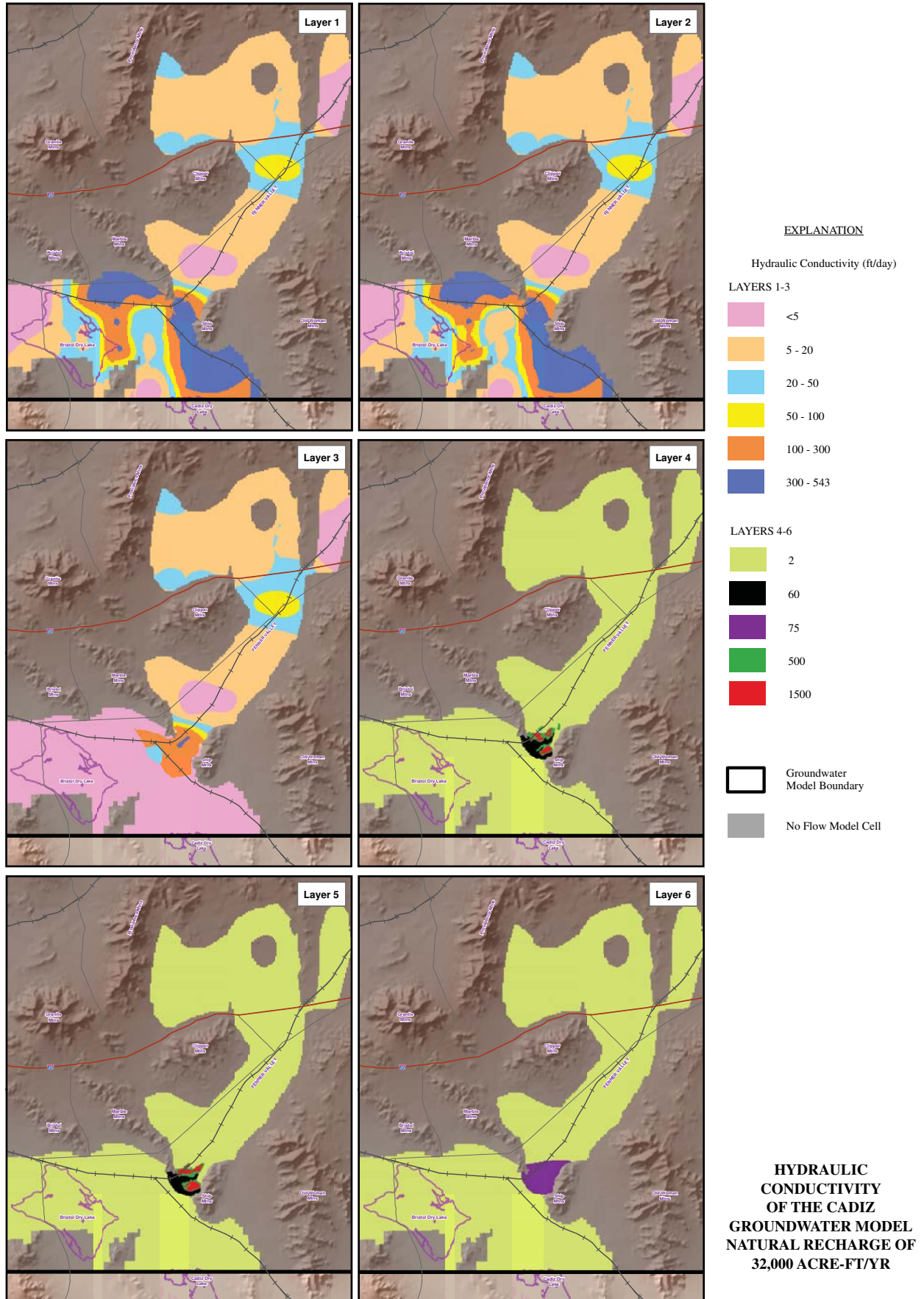


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Figure 12





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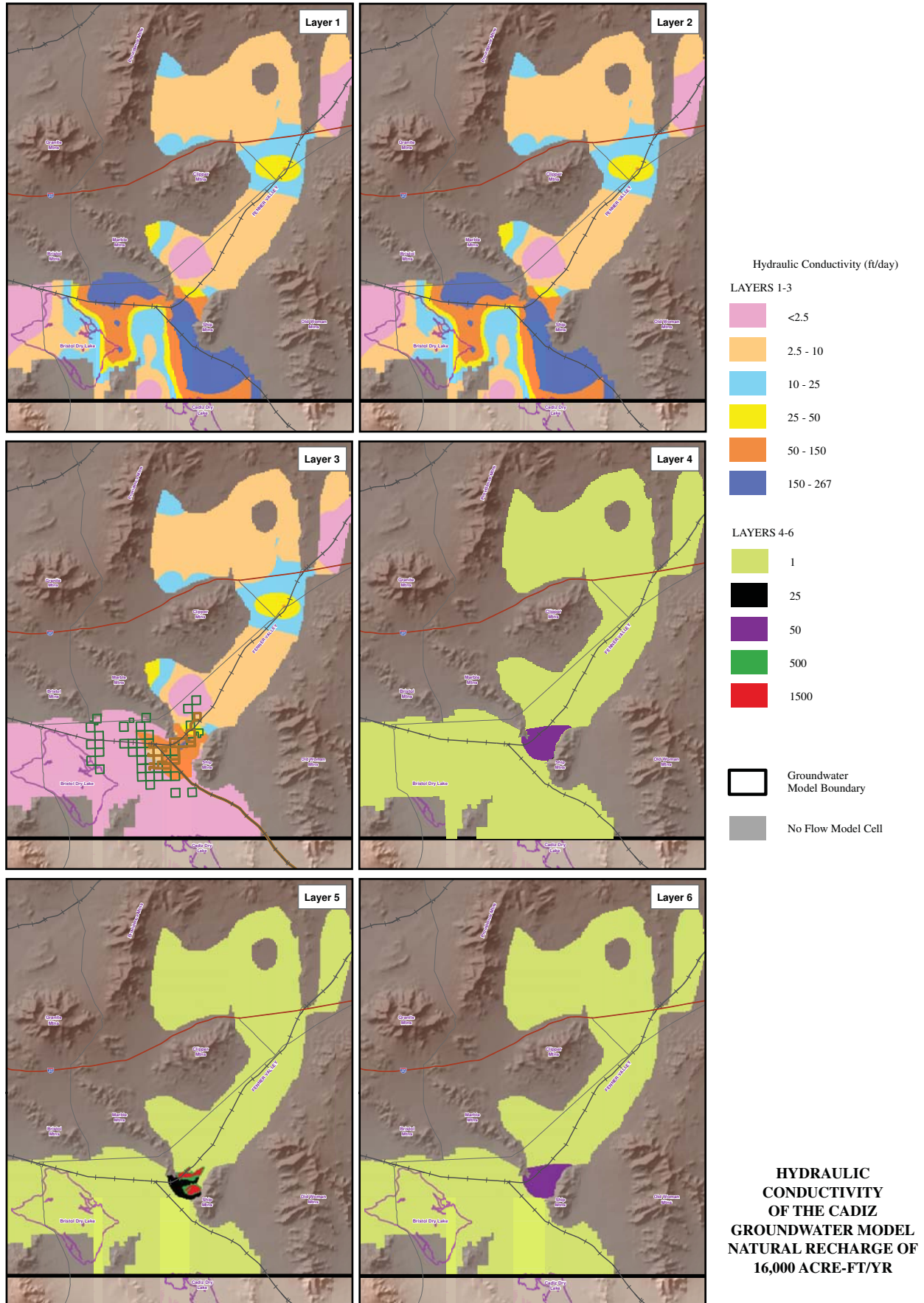
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**Figure 13**



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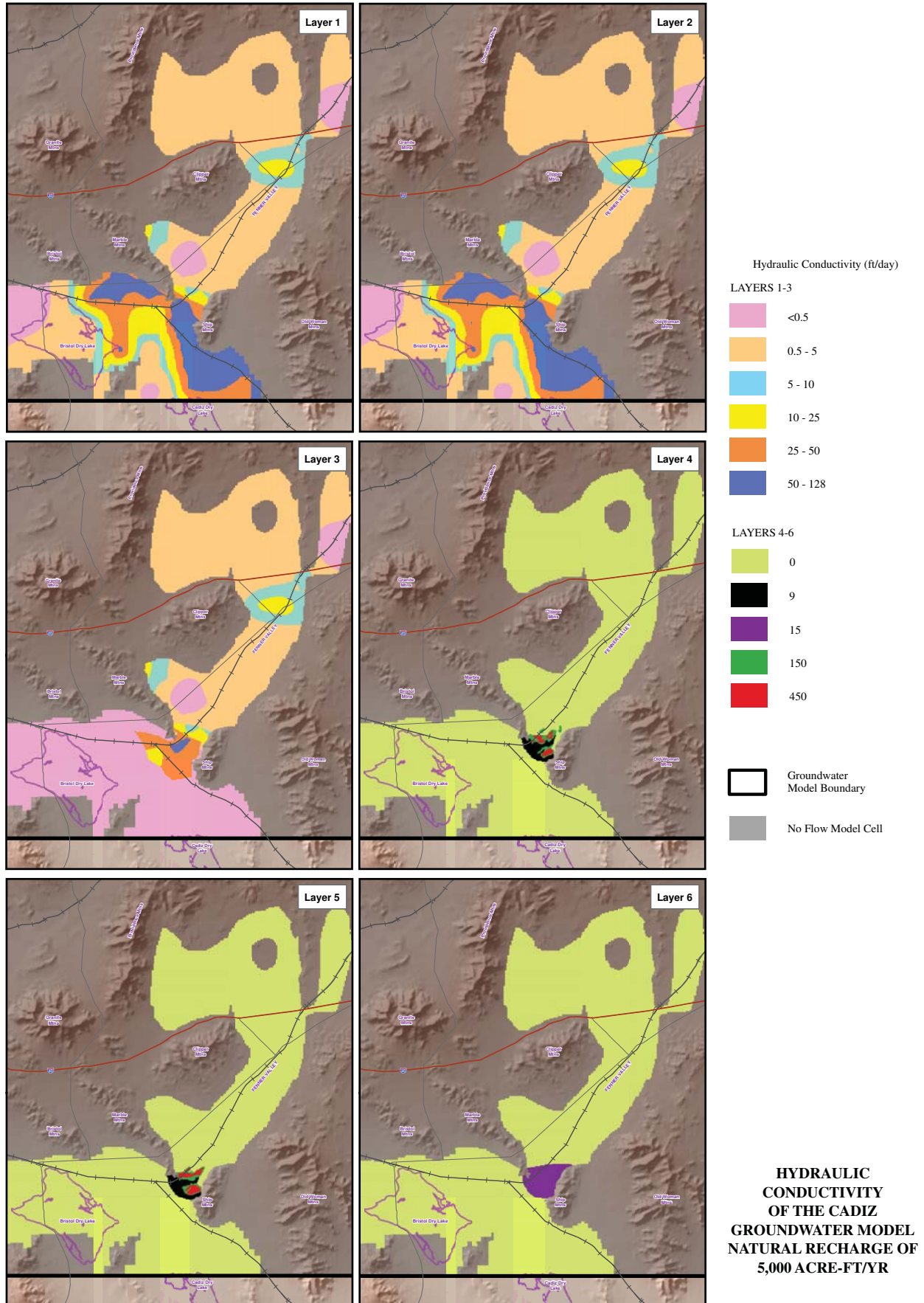


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Figure 14





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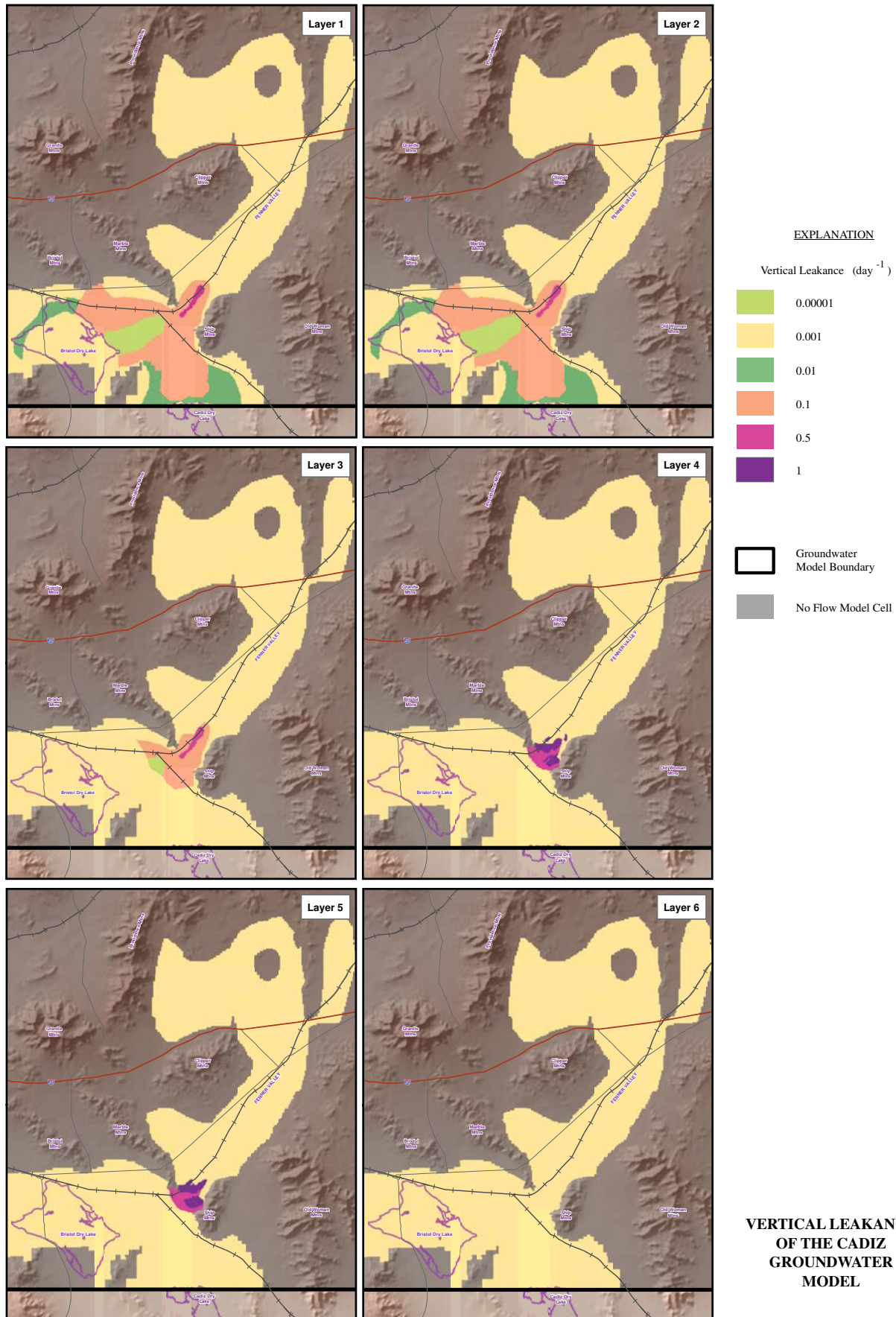
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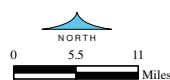
Figure 15



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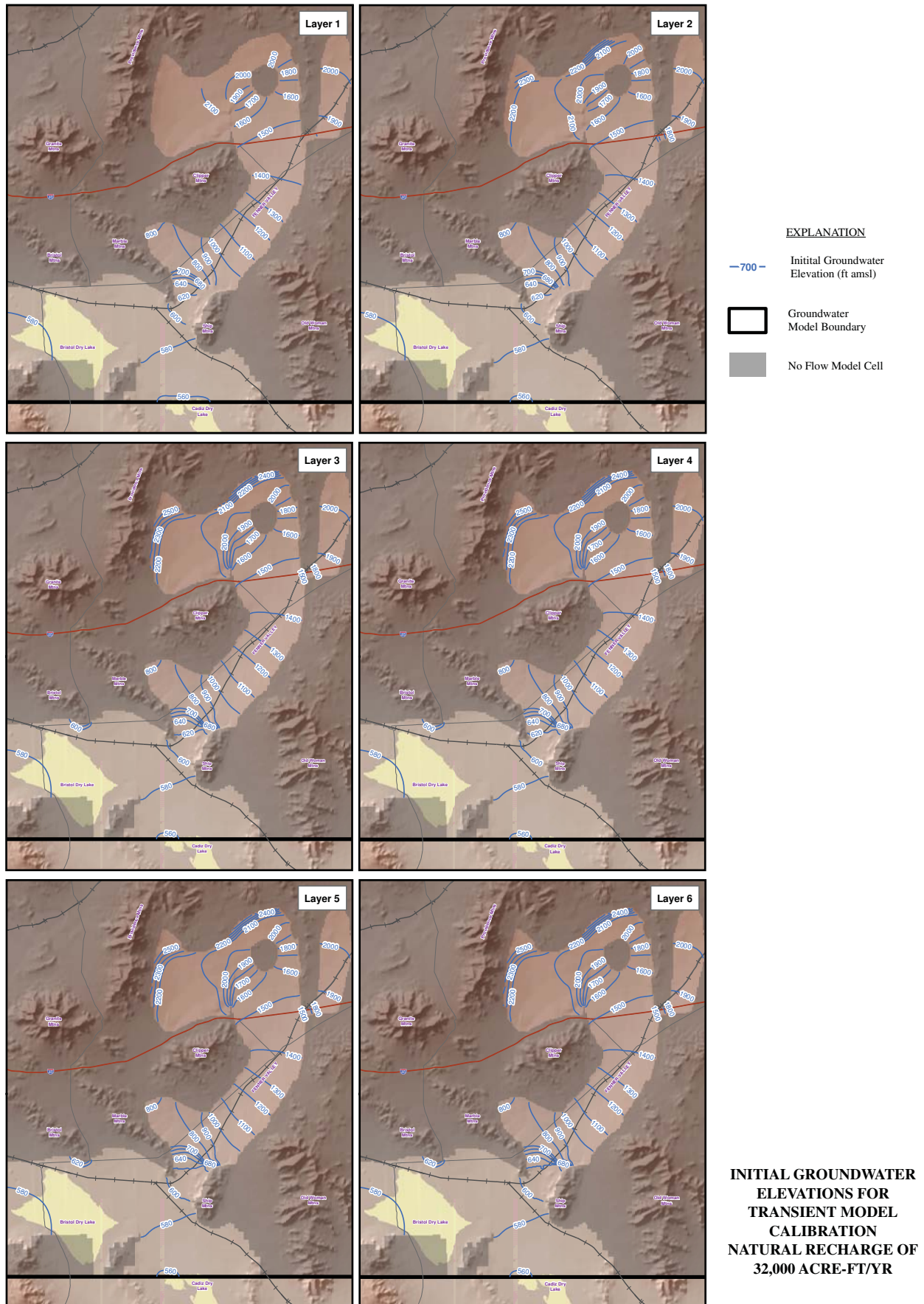


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**Figure 16**





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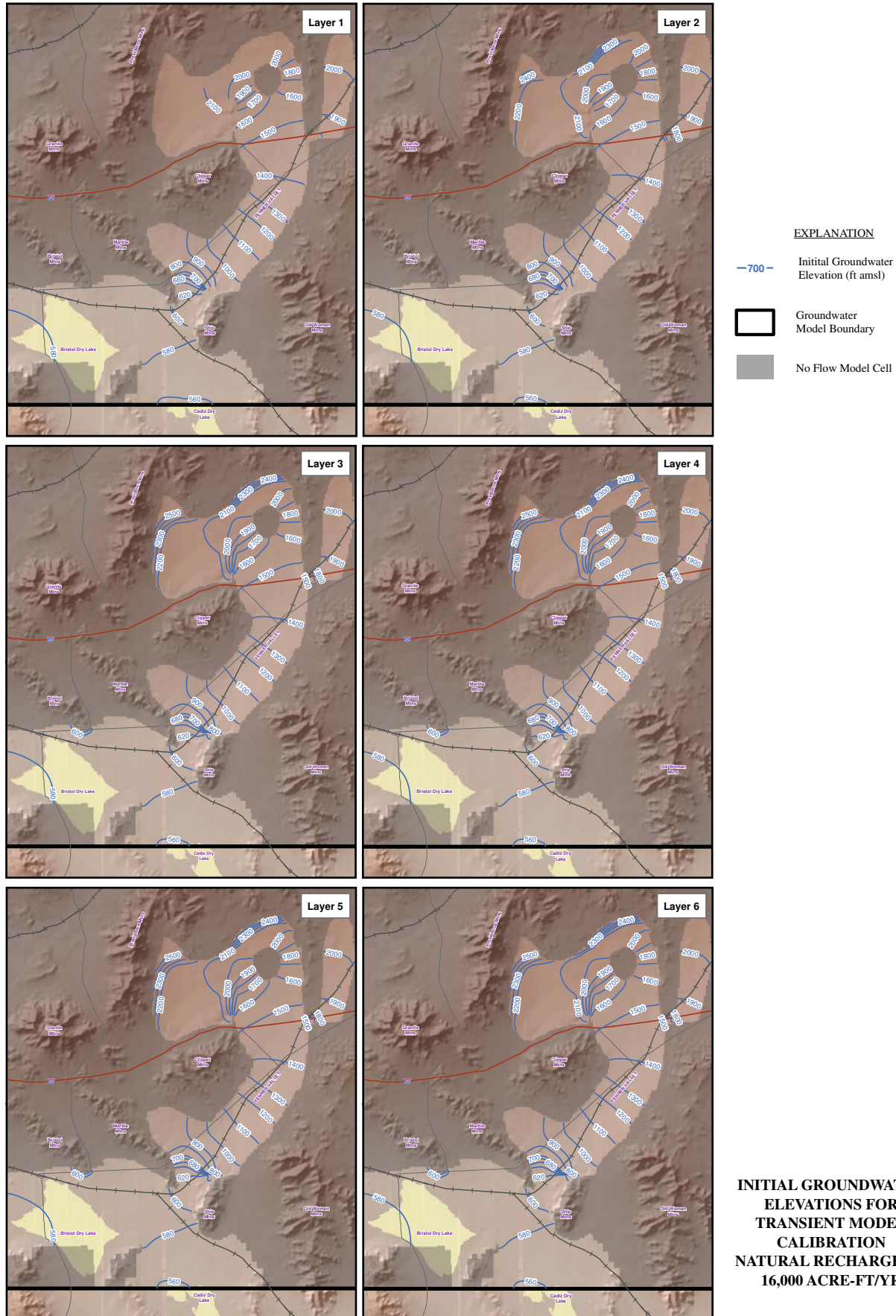
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**Figure 17**



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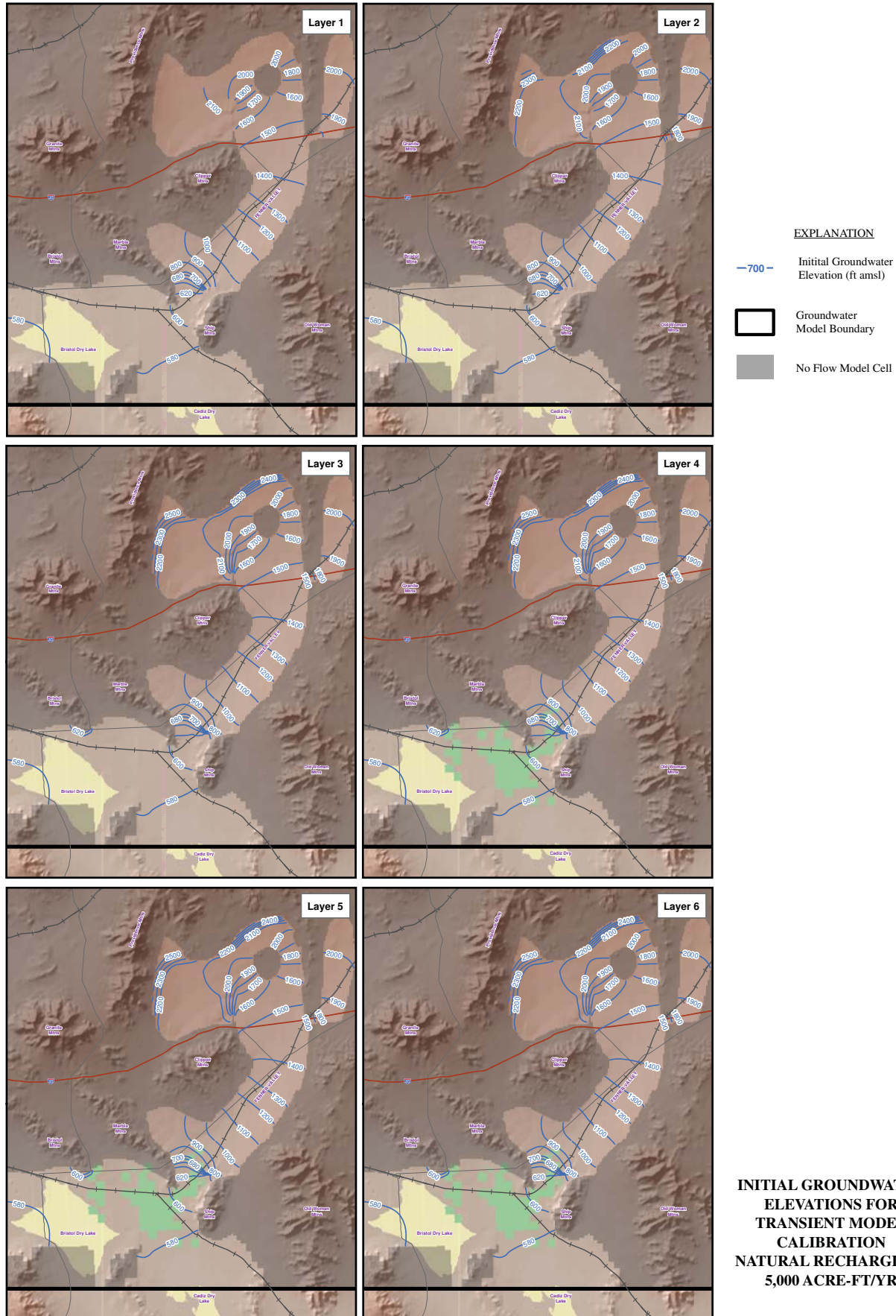


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**Figure 18**





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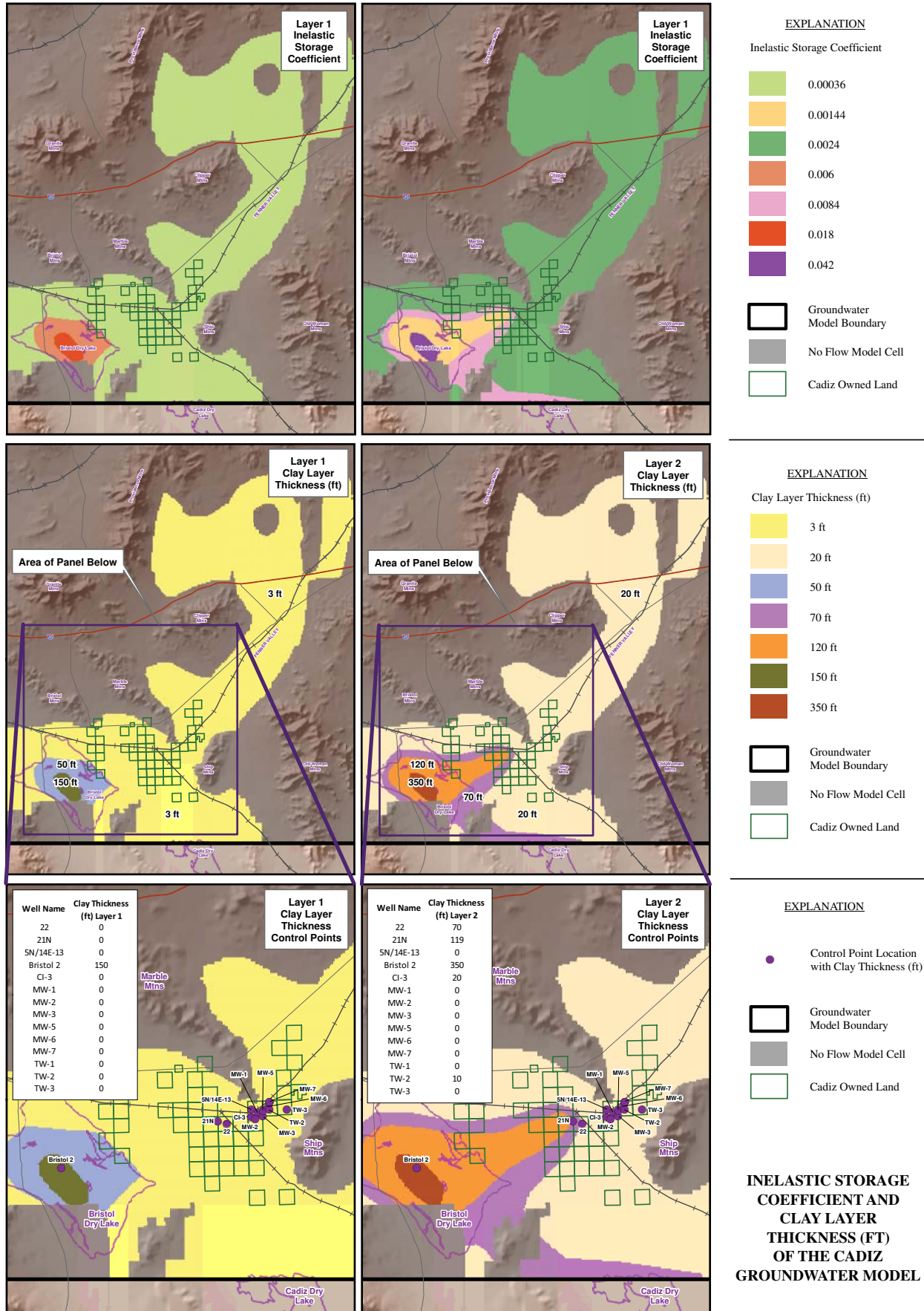
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Figure 19



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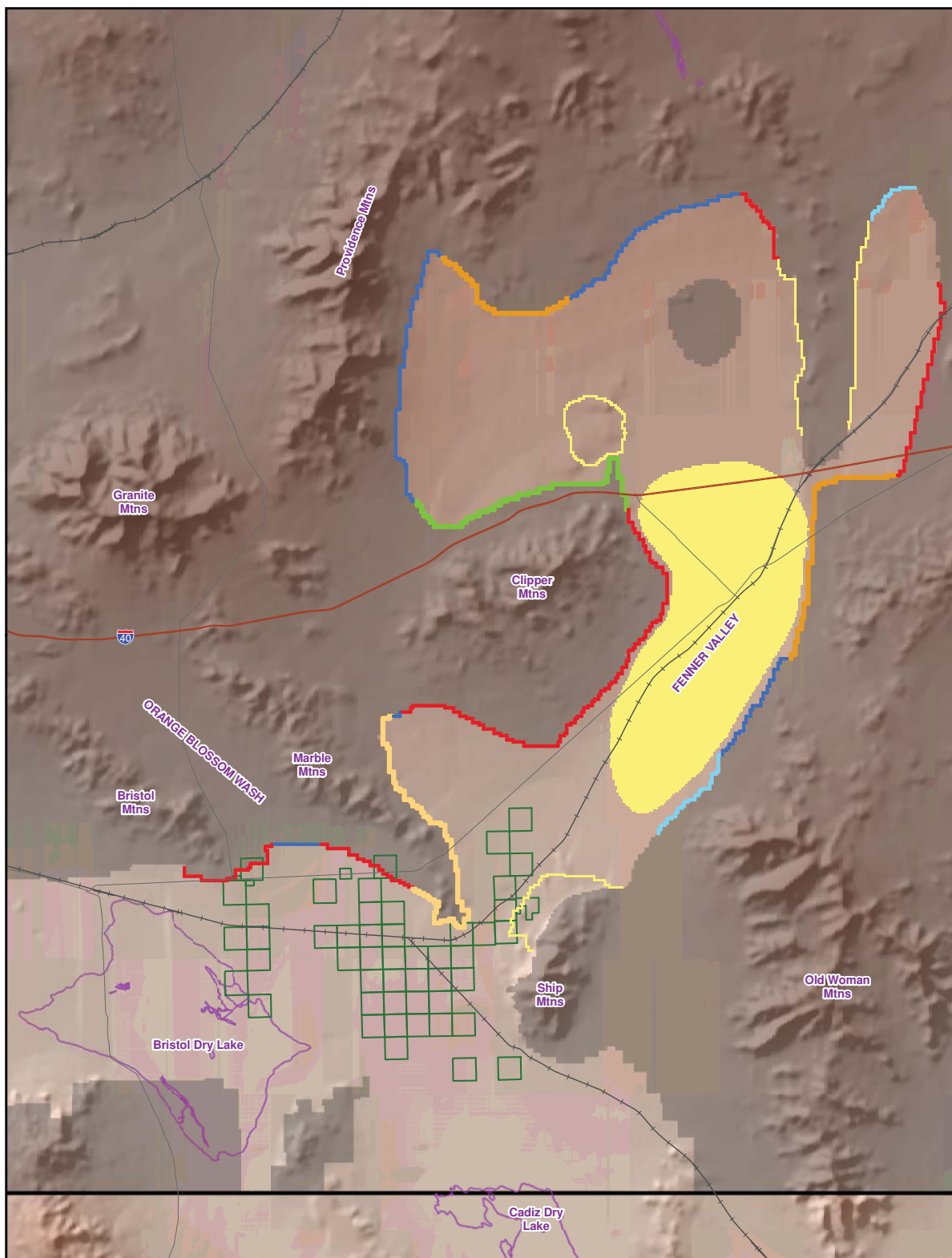


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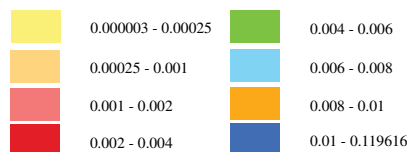
Figure 20





- Groundwater Model Boundary
- No Flow Model Cell
- Cadiz Owned Land

Recharge Rate (ft/day) for Total Natural Recharge of 32,000 ac-ft/yr



**AERIAL DISTRIBUTION OF  
NATURAL RECHARGE RATE  
32,000 AC-FT/YR**

1-Sep-11

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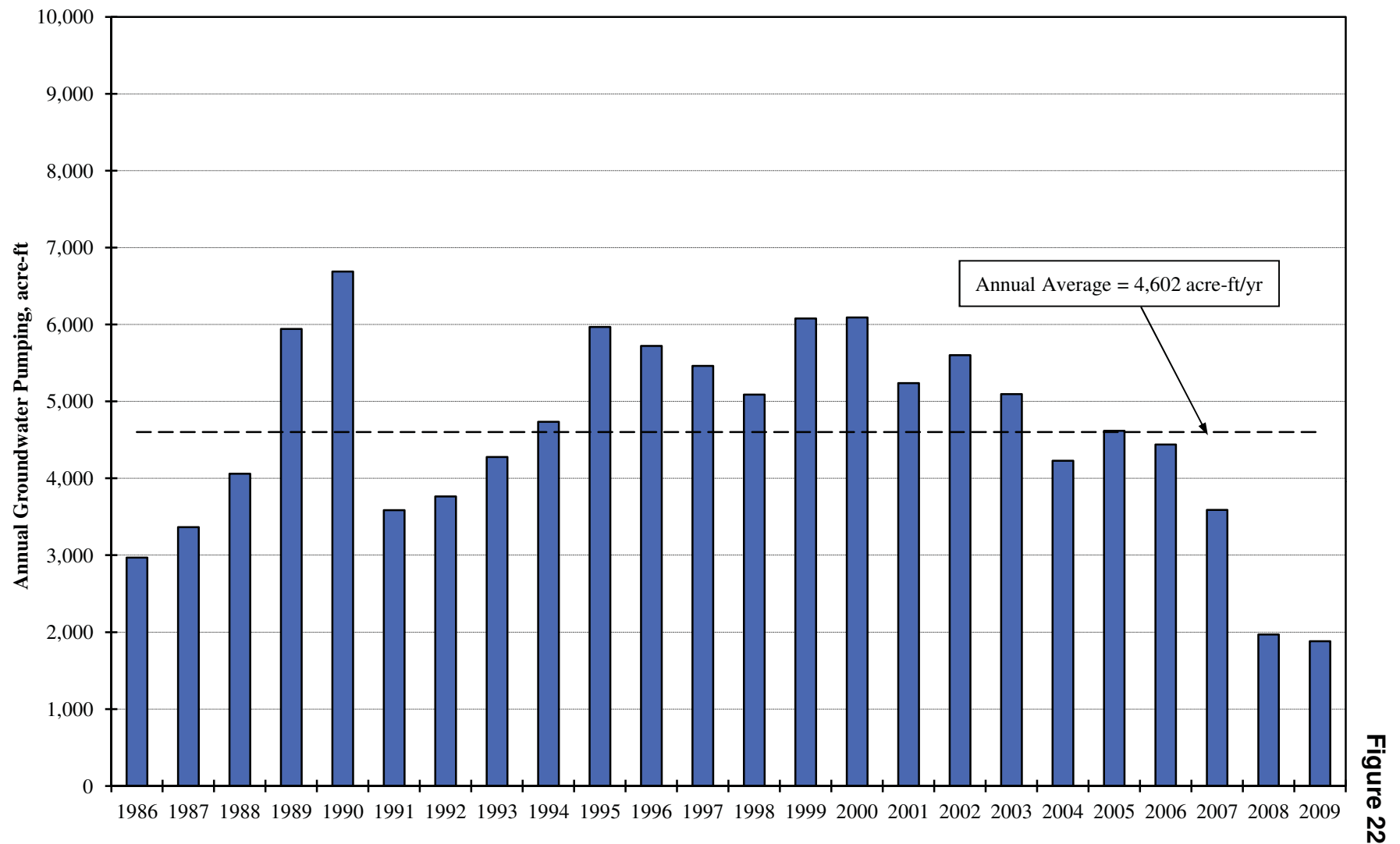


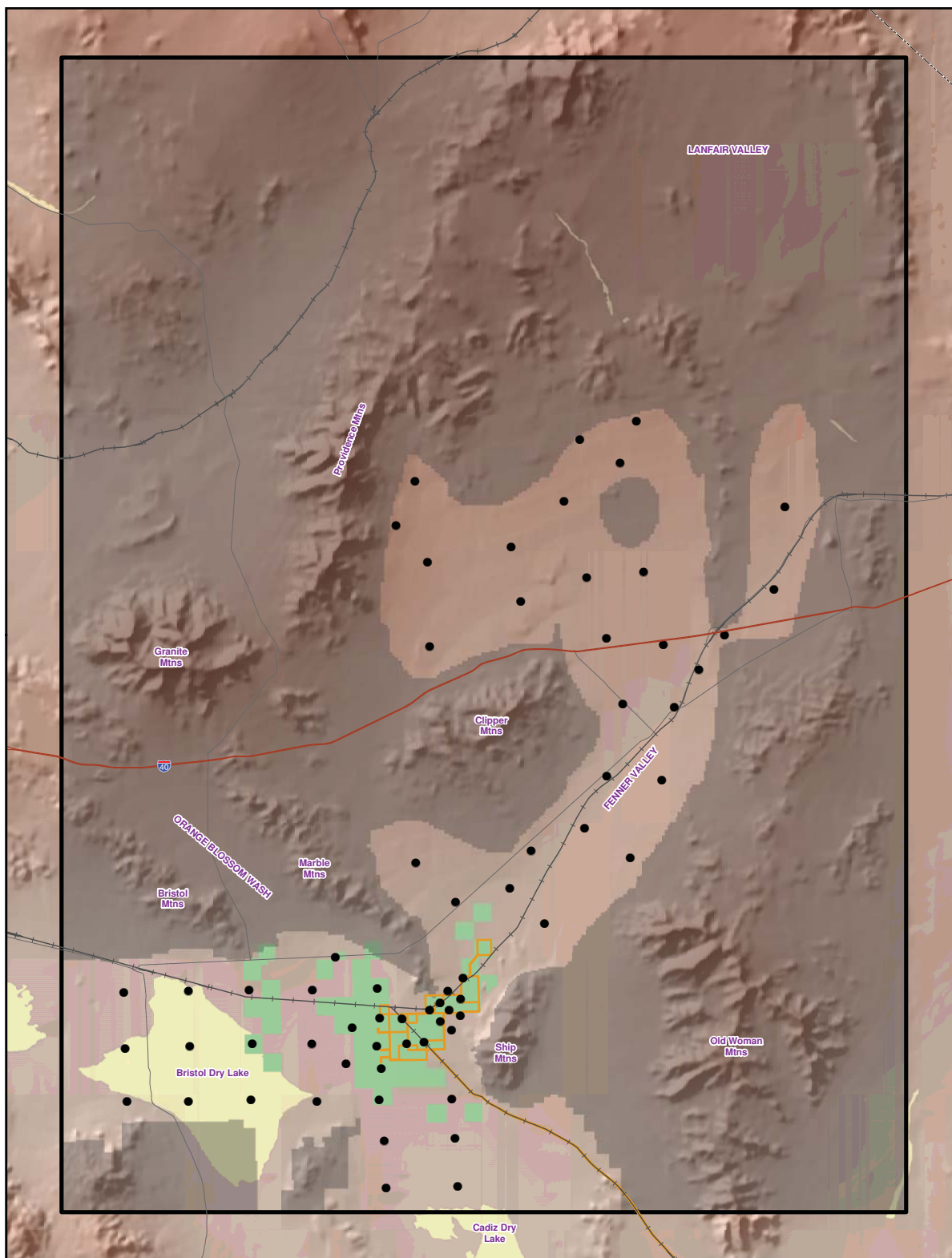
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**Figure 21**

### Annual Groundwater Pumping of Cadiz Agricultural Wells





- |                                                                                     |                            |                                                                                     |                                           |                                                                                     |                                         |
|-------------------------------------------------------------------------------------|----------------------------|-------------------------------------------------------------------------------------|-------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------|
|  | Groundwater Model Boundary |  | Wellfield Development Areas and Pipelines |  | PEST Hydraulic Conductivity Pilot Point |
|  | No Flow Model Cell         |  | Cadiz Owned Land                          |                                                                                     |                                         |

**PEST HYDRAULIC  
CONDUCTIVITY  
PILOT POINTS**

1-Sep-11

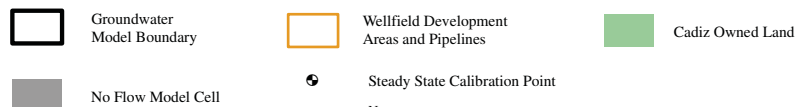
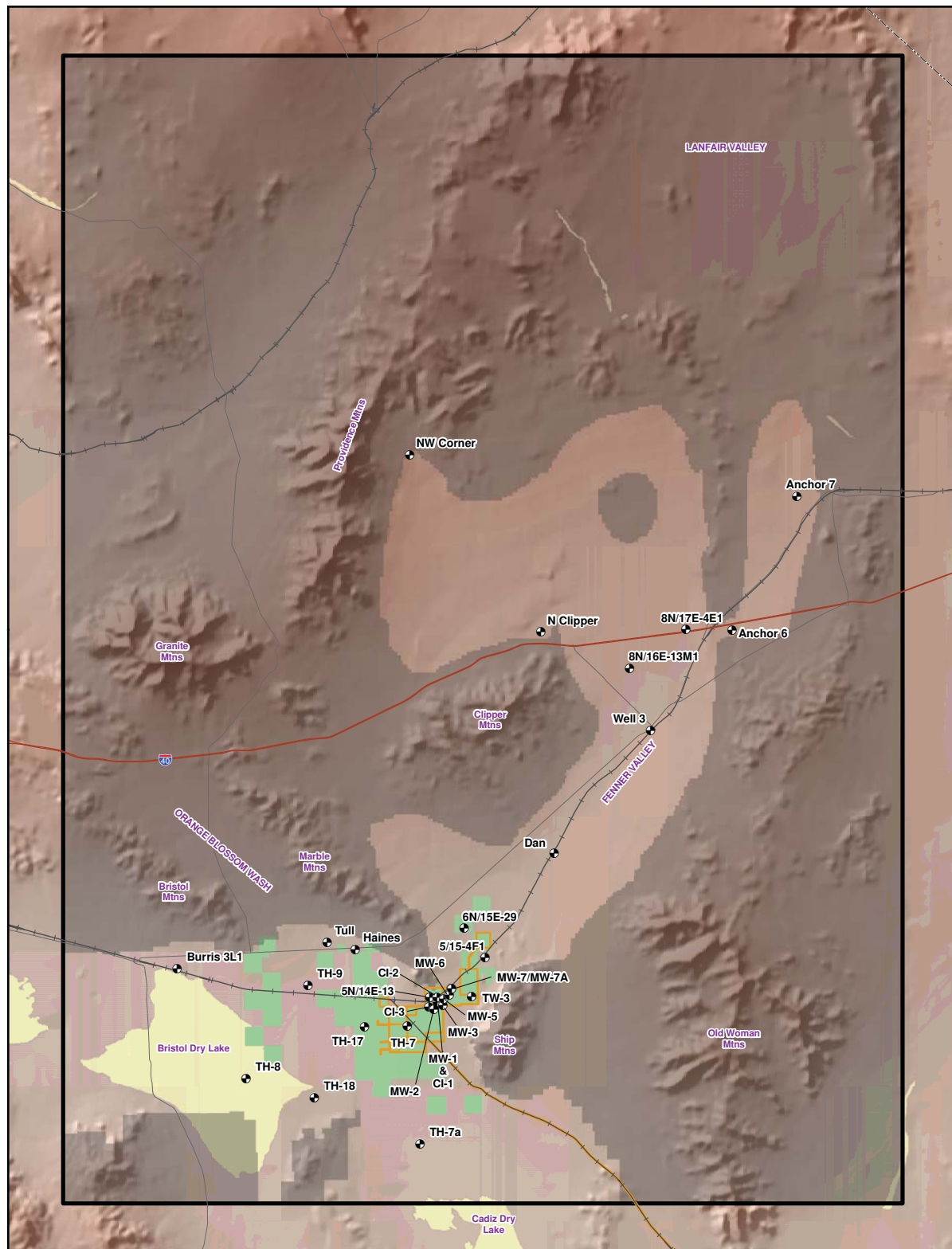
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**Figure 23**



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Notes:  
(1) NW Corner - Based on nearby observed water levels in adjacent valleys.  
(2) N Clipper - Estimated value is approximately 50 ft below ground surface, and is used to prevent simulated water levels from being above ground surface.  
(3) Anchor 6 - Based on three wells to the north that are outside of the model domain.  
(4) Anchor 7 - Based on five wells to the east that are outside of the model domain.

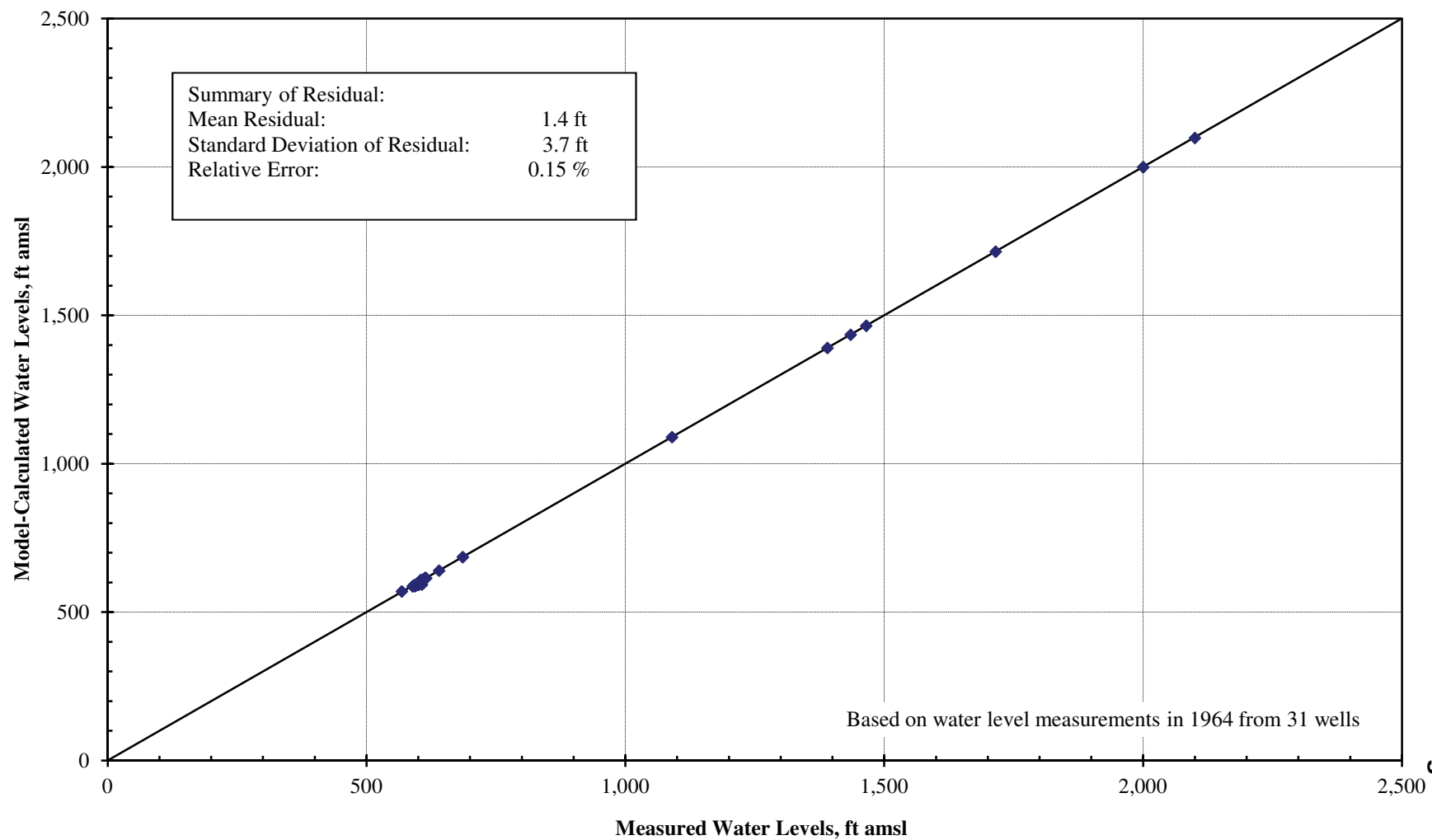
# LOCATION OF WELLS WITH WATER LEVEL DATA USED FOR STEADY STATE MODEL CALIBRATION

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**Figure 24**

**Measured versus Model-Calculated Water Levels**  
**Steady State Model Calibration for Natural Recharge of 32,000 acre-ft/yr**



**Figure 25**

**Measured versus Model-Calculated Water Levels**  
**Steady State Model Calibration for Natural Recharge of 16,000 acre-ft/yr**

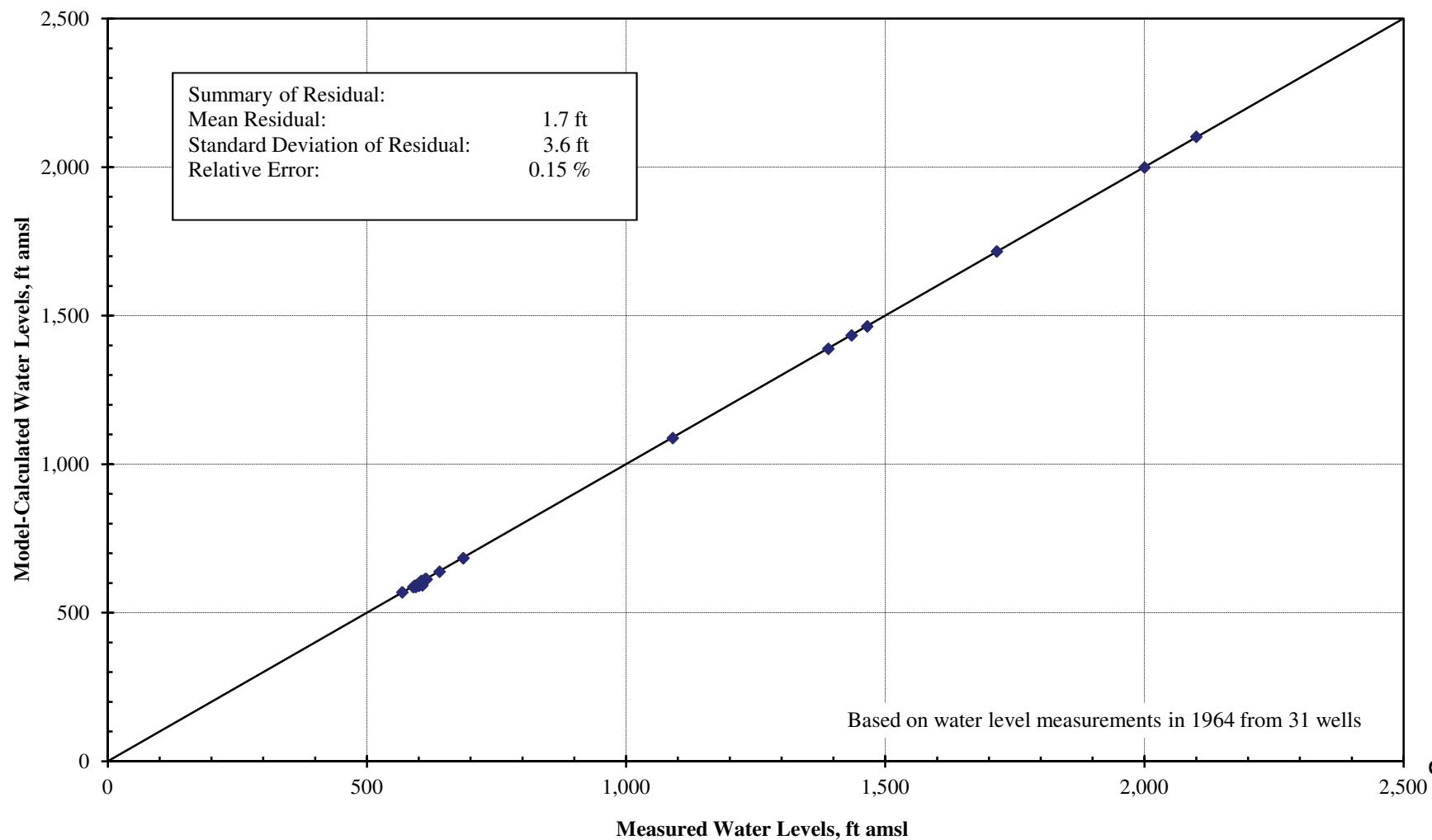


Figure 26

**Measured versus Model-Calculated Water Levels**  
**Steady State Model Calibration for Natural Recharge of 5,000 acre-ft/yr**

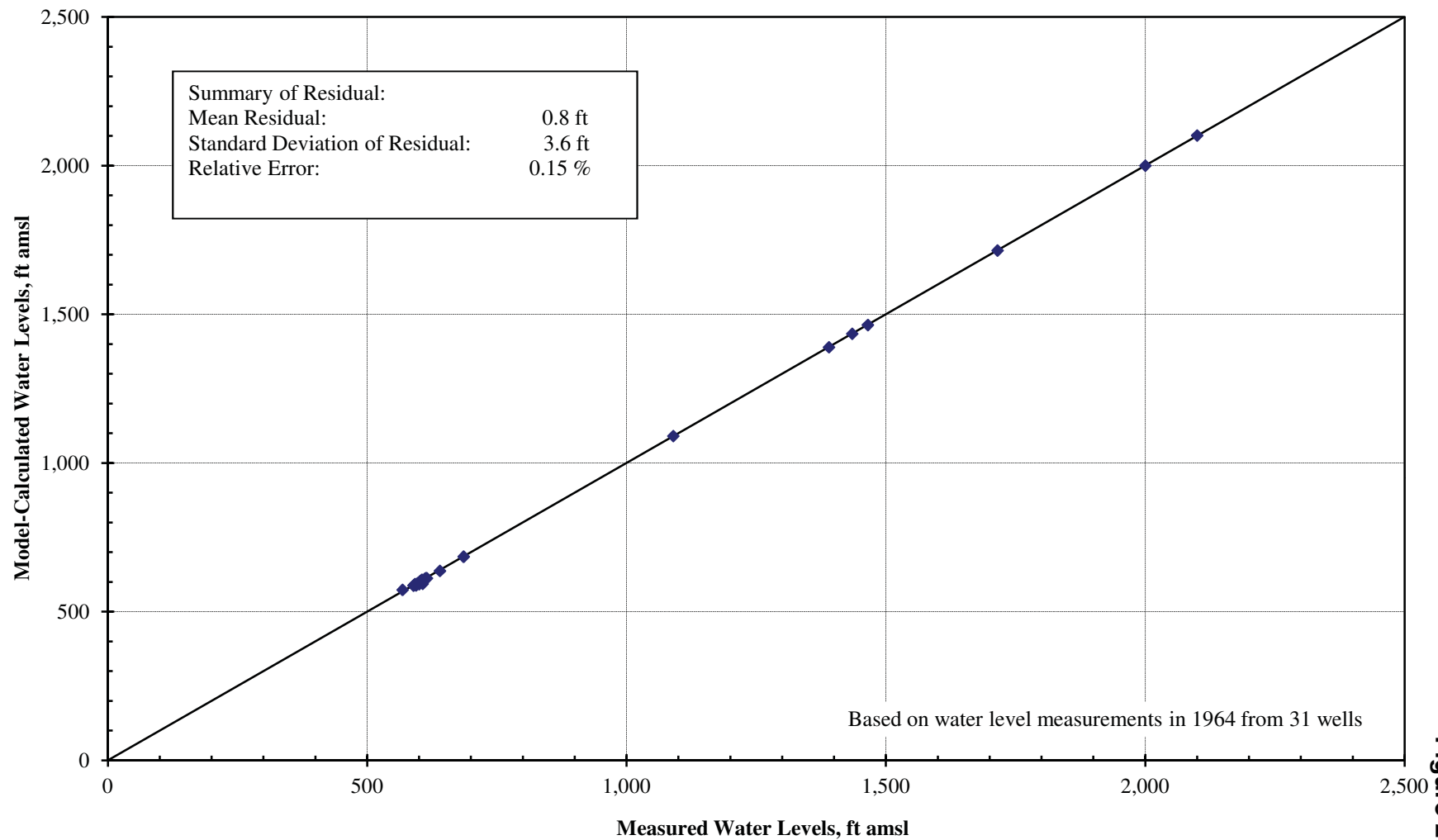
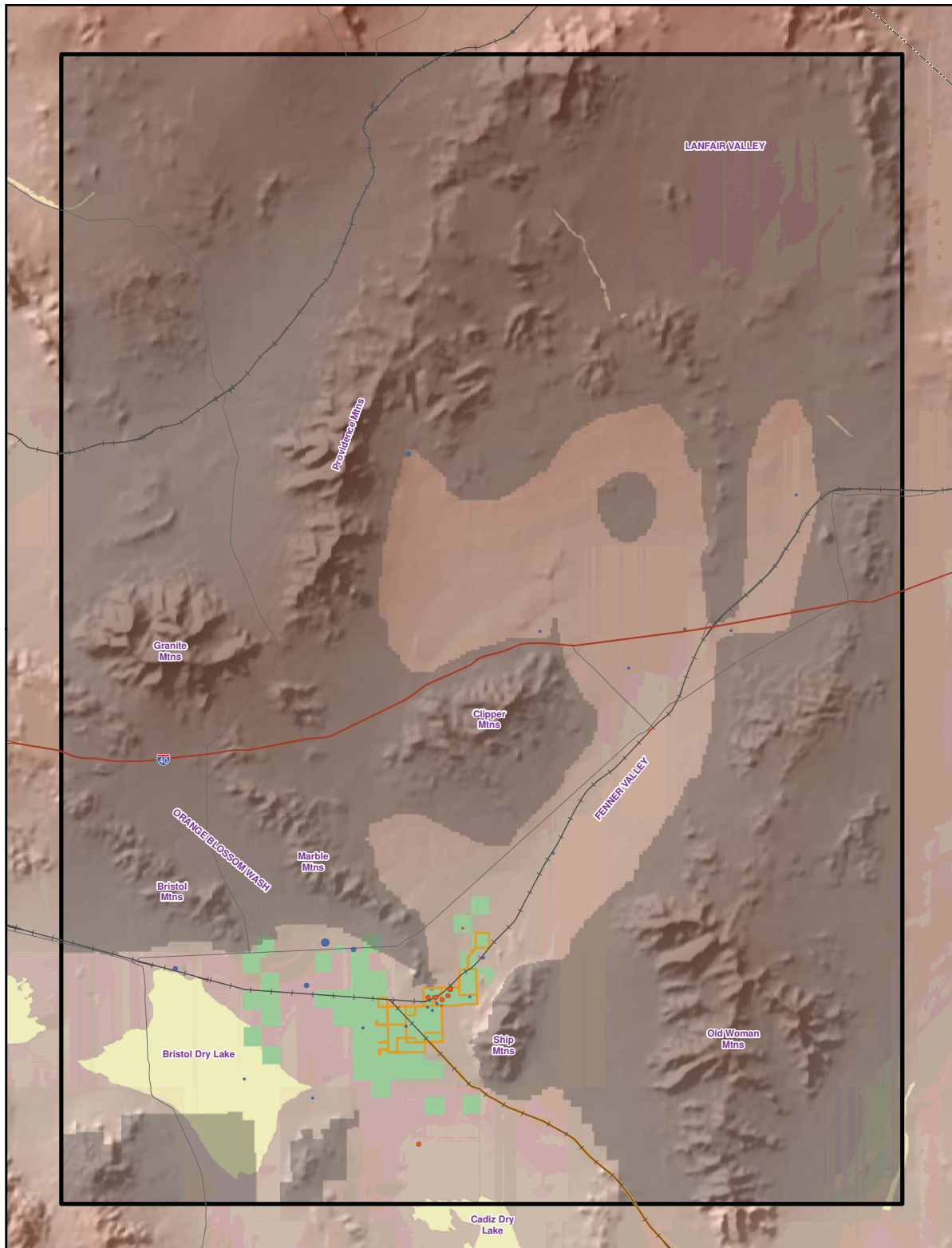
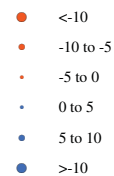


Figure 27





Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)



**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - STEADY STATE  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
32,000 ACRE-FT/YR**

1-Sep-11

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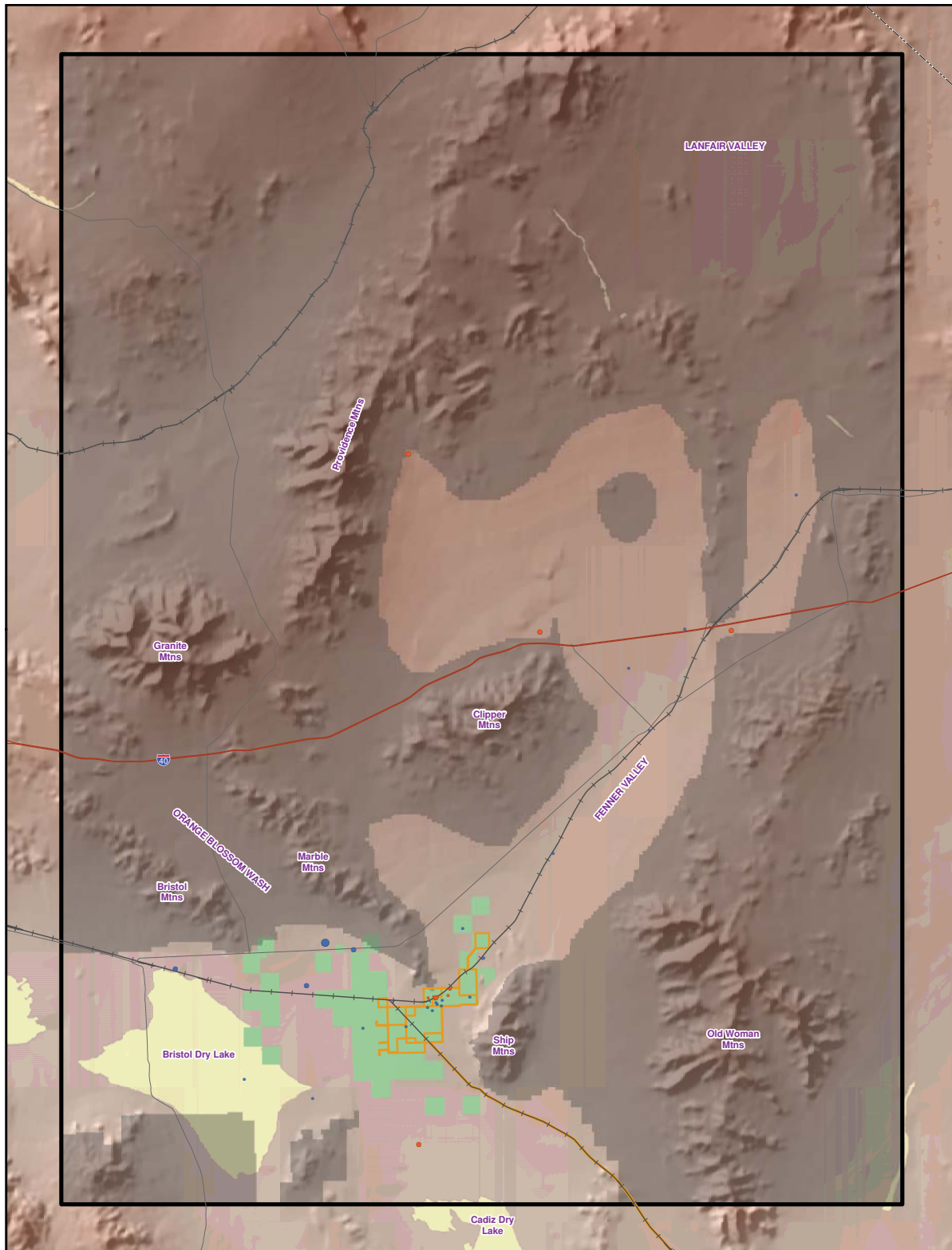
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**Figure 28**





- |                                                                                                                                               |                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
|  Groundwater Model Boundary<br>Cell Size = 500 ft x 500 ft |  Proposed Wellfield Development Areas and Pipeline |
|  No Flow Model Cell                                        |  Cadiz Owned Land                                  |

Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)

-  <-10
-  -10 to -5
-  -5 to 0
-  0 to 5
-  5 to 10
-  >10

**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - STEADY STATE  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
16,000 ACRE-FT/YR**

1-Sep-11

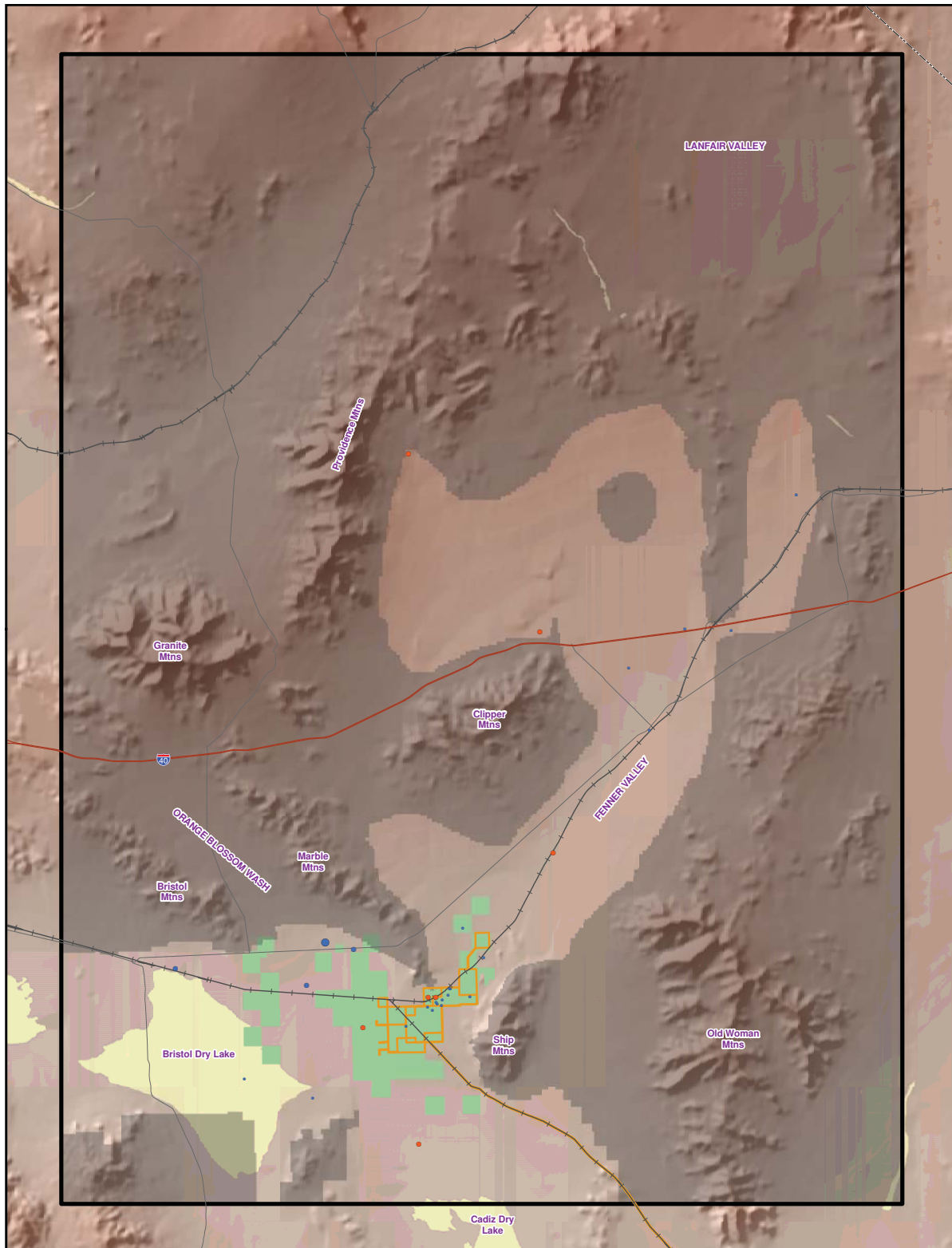
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**Figure 29**



- |                                                                                                                                               |                                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
|  Groundwater Model Boundary<br>Cell Size = 500 ft x 500 ft |  Proposed Wellfield Development Areas and Pipeline |
|  No Flow Model Cell                                        |  Cadiz Owned Land                                  |

Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)

-  < -10
-  -10 to -5
-  -5 to 0
-  0 to 5
-  5 to 10
-  > 10

**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - STEADY STATE  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
5,000 ACRE-FT/YR**

1-Sep-11

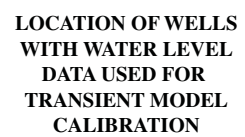
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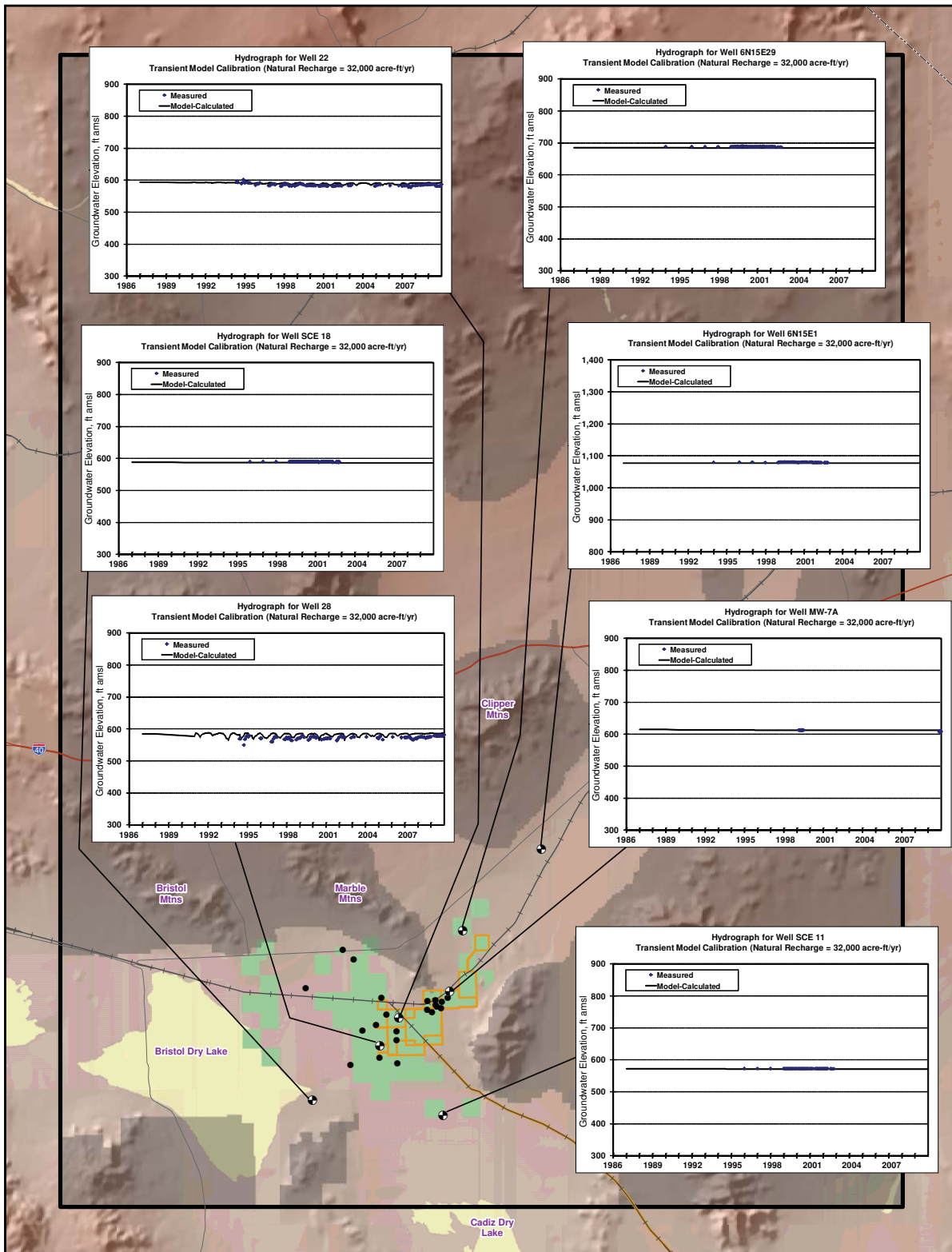
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**Figure 30**



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**Figure 31**



- Groundwater Model Boundary
- Wellfield Development Areas and Pipelines
- Transient Calibration Point with Hydrograph
- No Flow Model Cell
- Cadiz Owned Land
- Transient Calibration Point

**SELECTED HYDROGRAPHS  
OF TRANSIENT MODEL  
CALIBRATION FOR NATURAL  
RECHARGE OF  
32,000 ACRE-FT/YR**

1-Sep-11

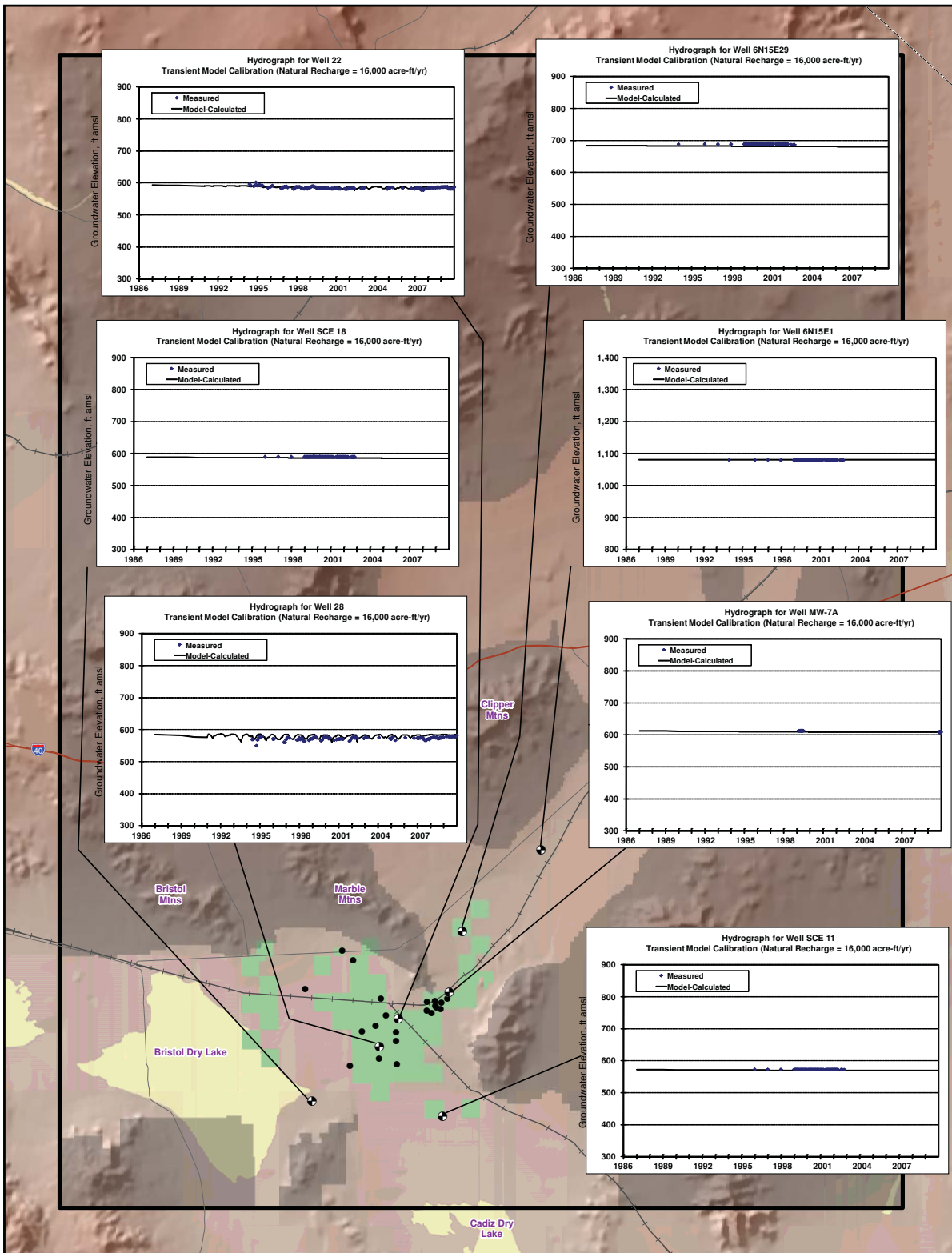
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GIS\_proj\brownstein\_cadiz\_model\_analysis\_9-11\0\_Fig\_32\_32k\_hydrographs\_9-11.mxd

**Figure 32**





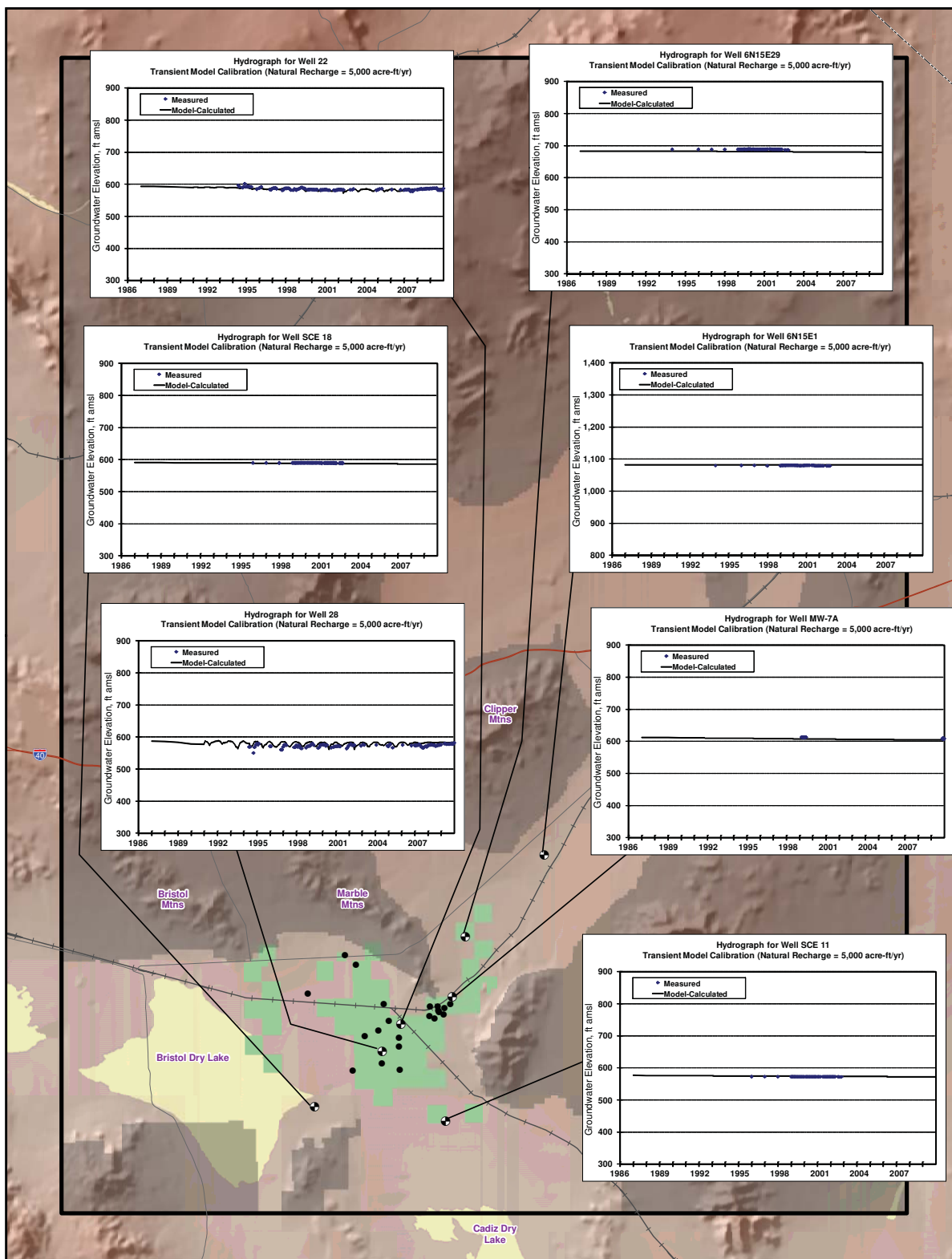
**SELECTED HYDROGRAPHS  
OF TRANSIENT MODEL  
CALIBRATION FOR NATURAL  
RECHARGE OF  
16,000 ACRE-FT/YR**

1-Sep-11

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**Figure 33**



Groundwater  
Model Boundary

Cadiz Owned Land

No Flow Model Cell

Transient Calibration Point  
with Hydrograph

Transient Calibration Point

**SELECTED HYDROGRAPHS  
OF TRANSIENT MODEL  
CALIBRATION FOR NATURAL  
RECHARGE OF  
5,000 ACRE-FT/YR**

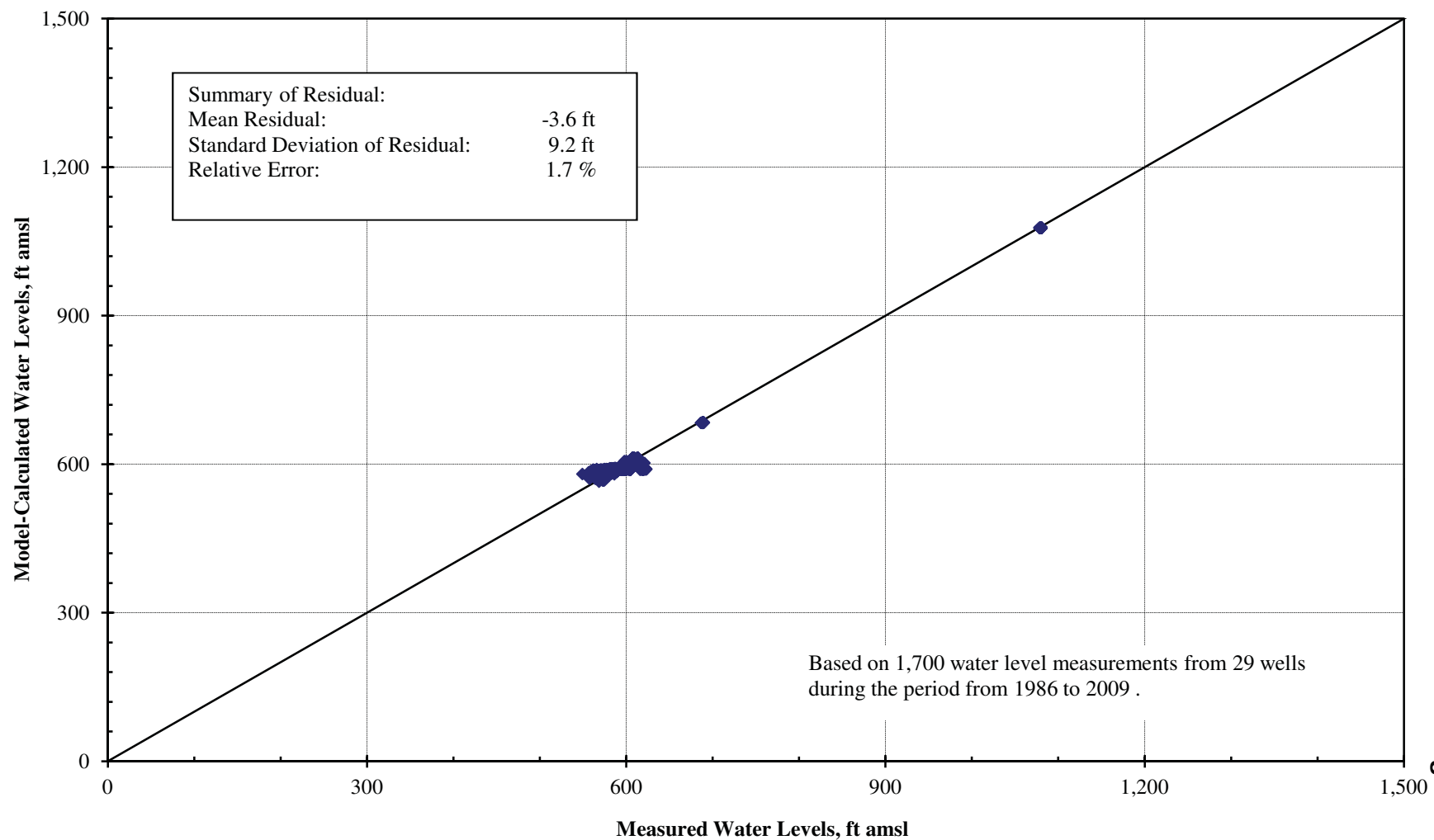
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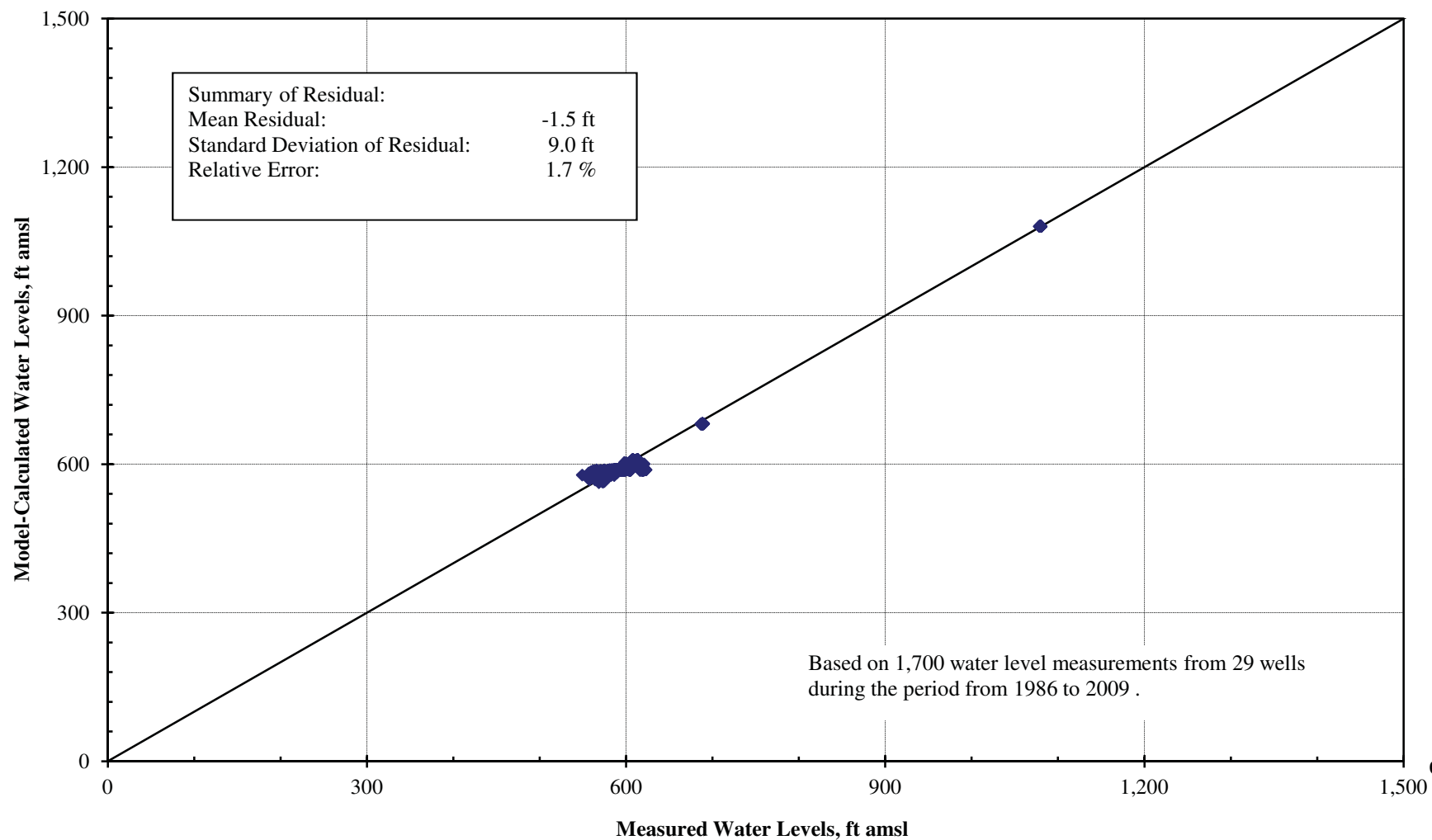
**Figure 34**

**Measured versus Model-Calculated Water Levels**  
**Transient Model Calibration for Natural Recharge of 32,000 acre-ft/yr**



**Figure 35**

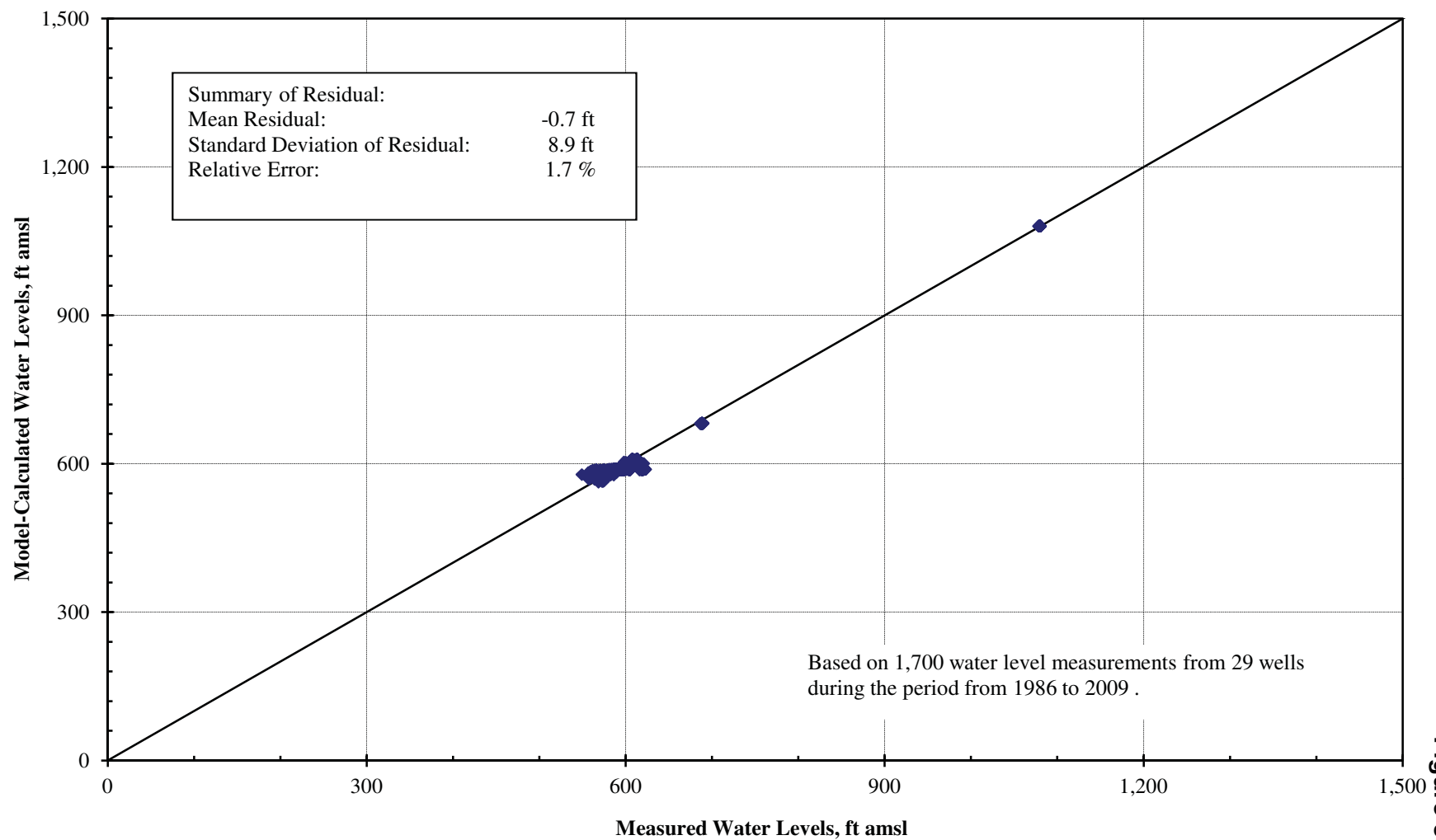
**Measured versus Model-Calculated Water Levels**  
**Transient Model Calibration for Natural Recharge of 16,000 acre-ft/yr**



**Figure 36**



**Measured versus Model-Calculated Water Levels**  
**Transient Model Calibration for Natural Recharge of 5,000 acre-ft/yr**



**Figure 37**

### Histogram of Water Level Residuals Transient Model Calibration for Natural Recharge of 32,000 acre-ft/yr

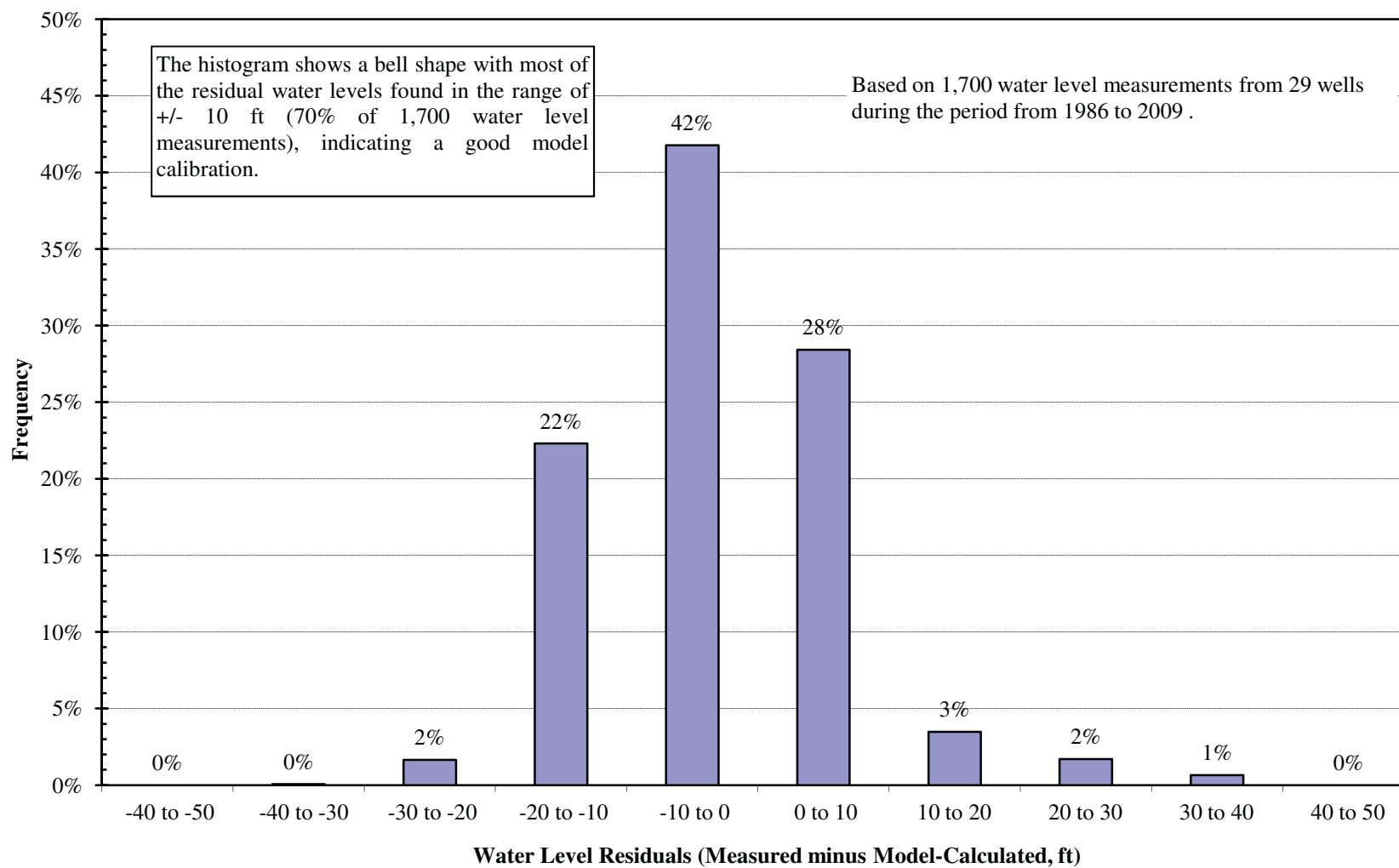


Figure 38

### Histogram of Water Level Residuals Transient Model Calibration for Natural Recharge of 16,000 acre-ft/yr

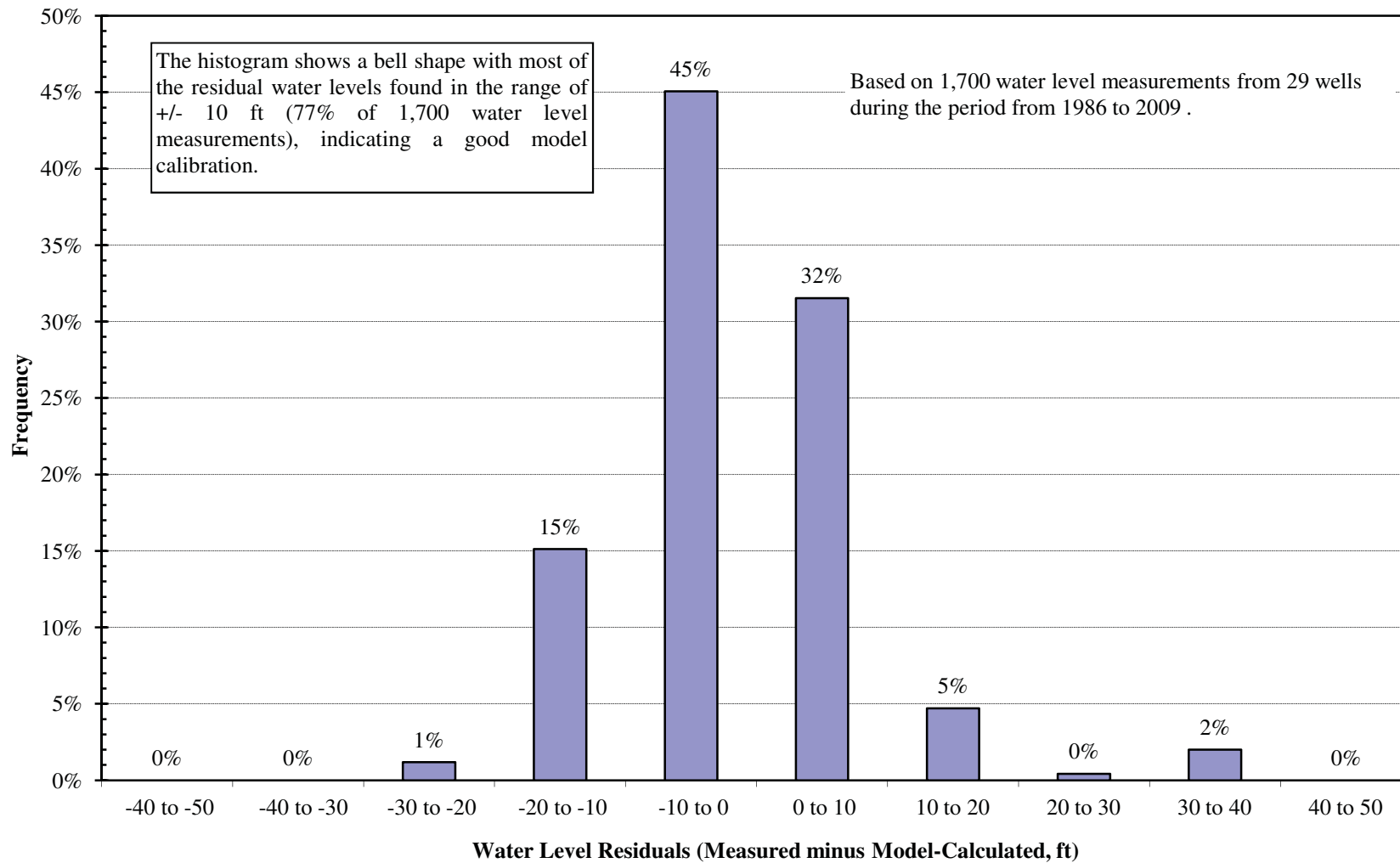


Figure 39

### Histogram of Water Level Residuals Transient Model Calibration for Natural Recharge of 5,000 acre-ft/yr

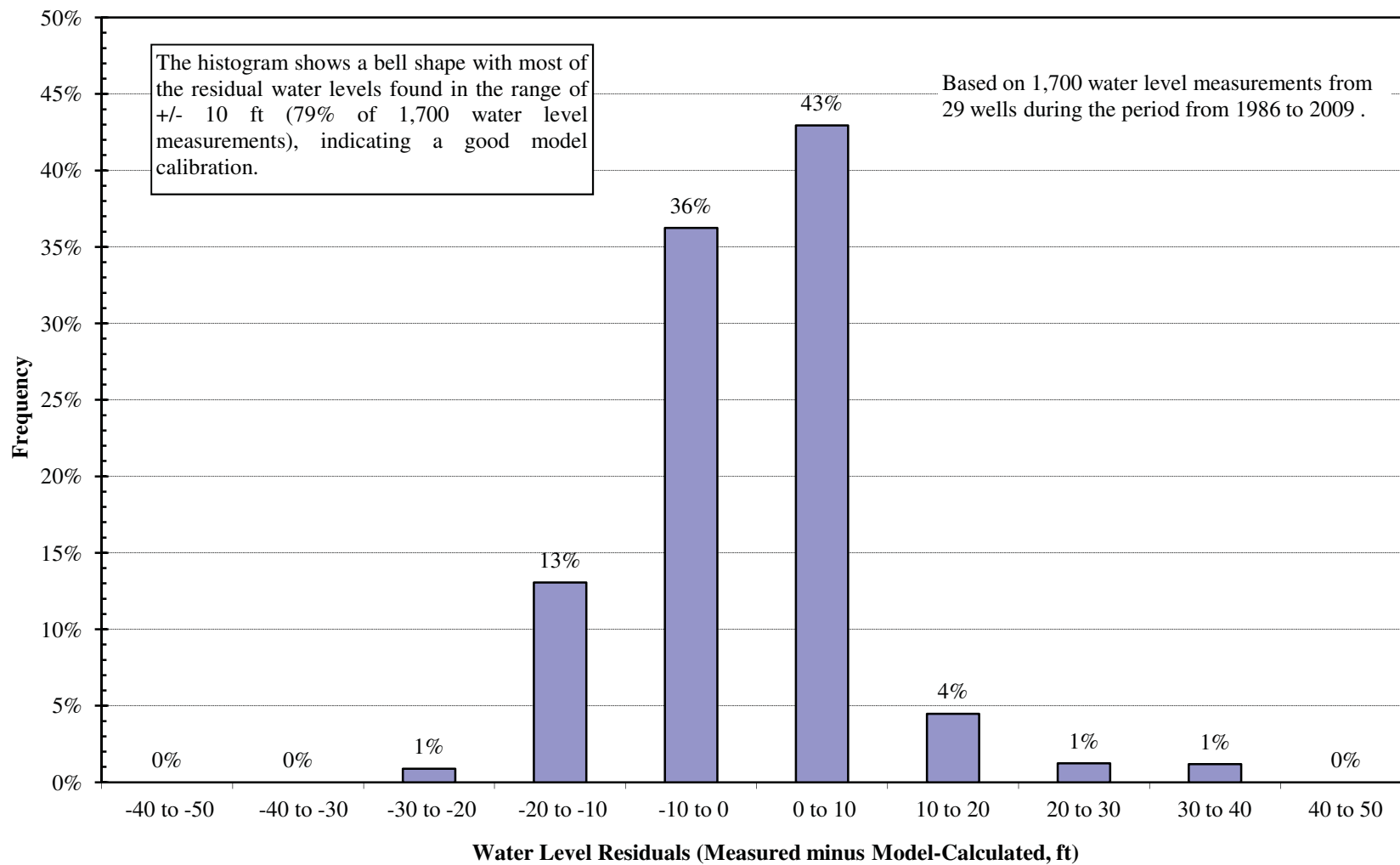
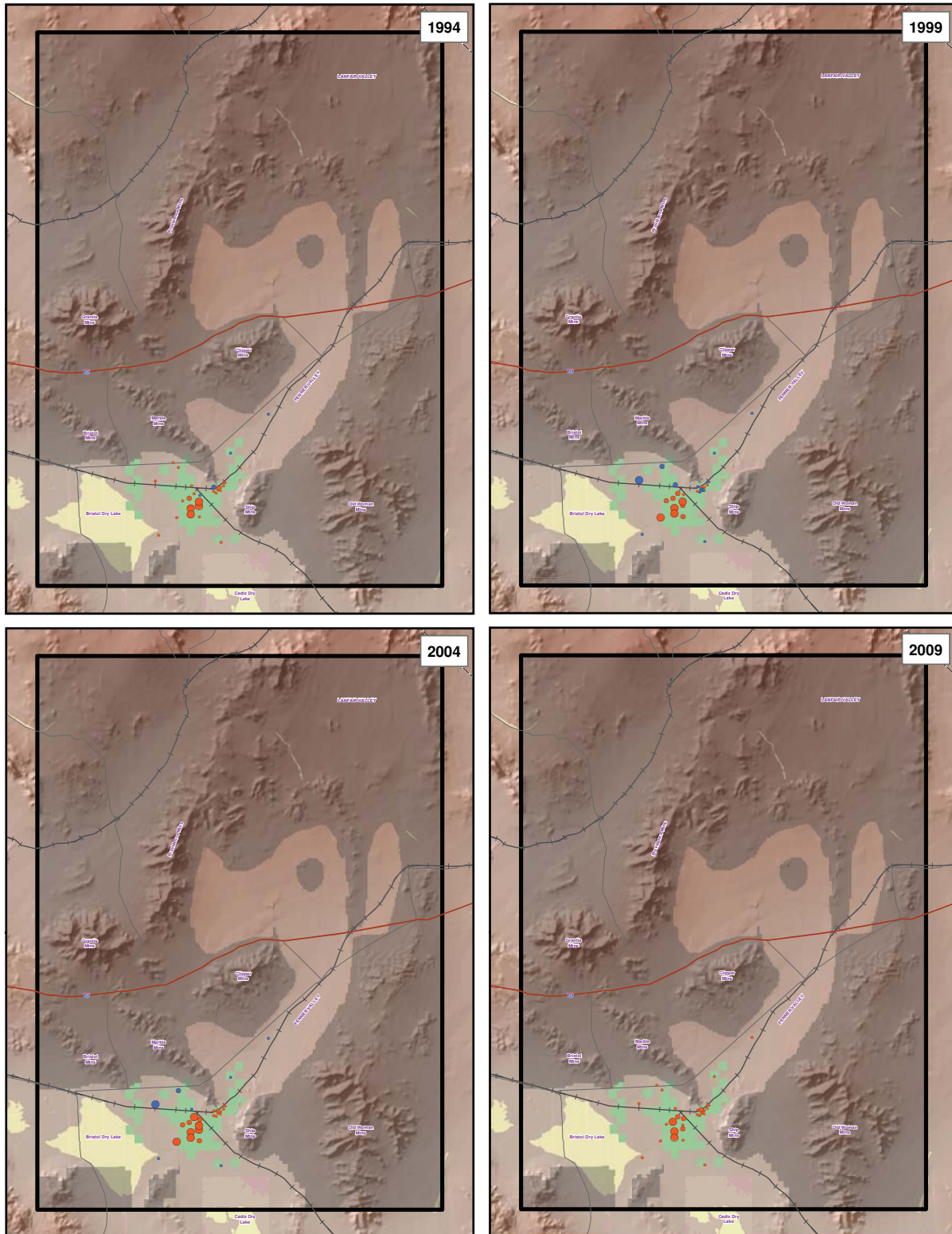
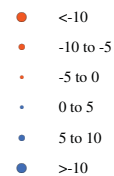


Figure 40



Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)



**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - TRANSIENT  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
32,000 ACRE-FT/YR**

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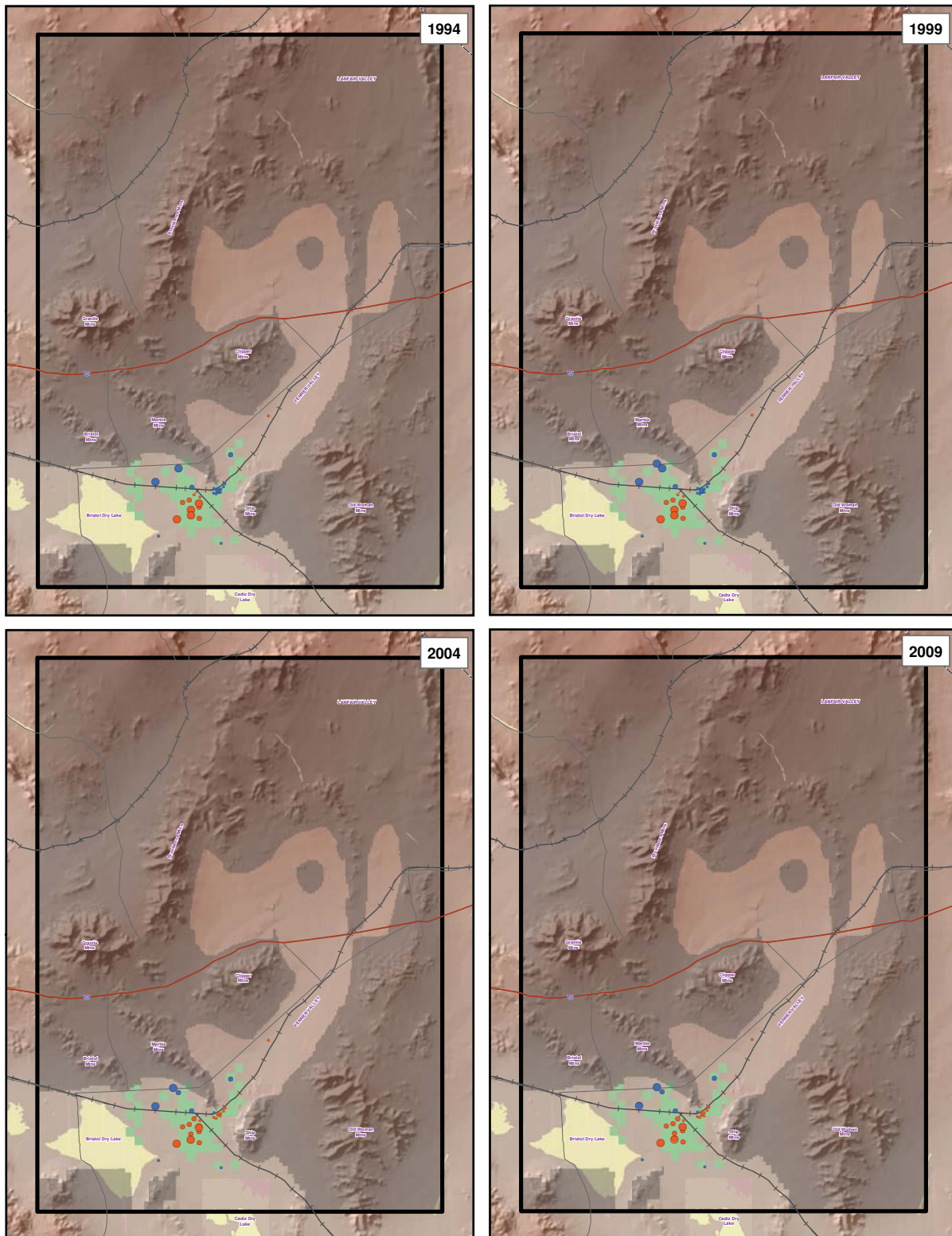
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**Figure 41**



Groundwater Model Boundary

Cadiz Owned Land

No Flow Model Cell

Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)

- <-10
- -10 to -5
- -5 to 0
- 0 to 5
- 5 to 10
- >10

**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - TRANSIENT  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
16,000 ACRE-FT/YR**

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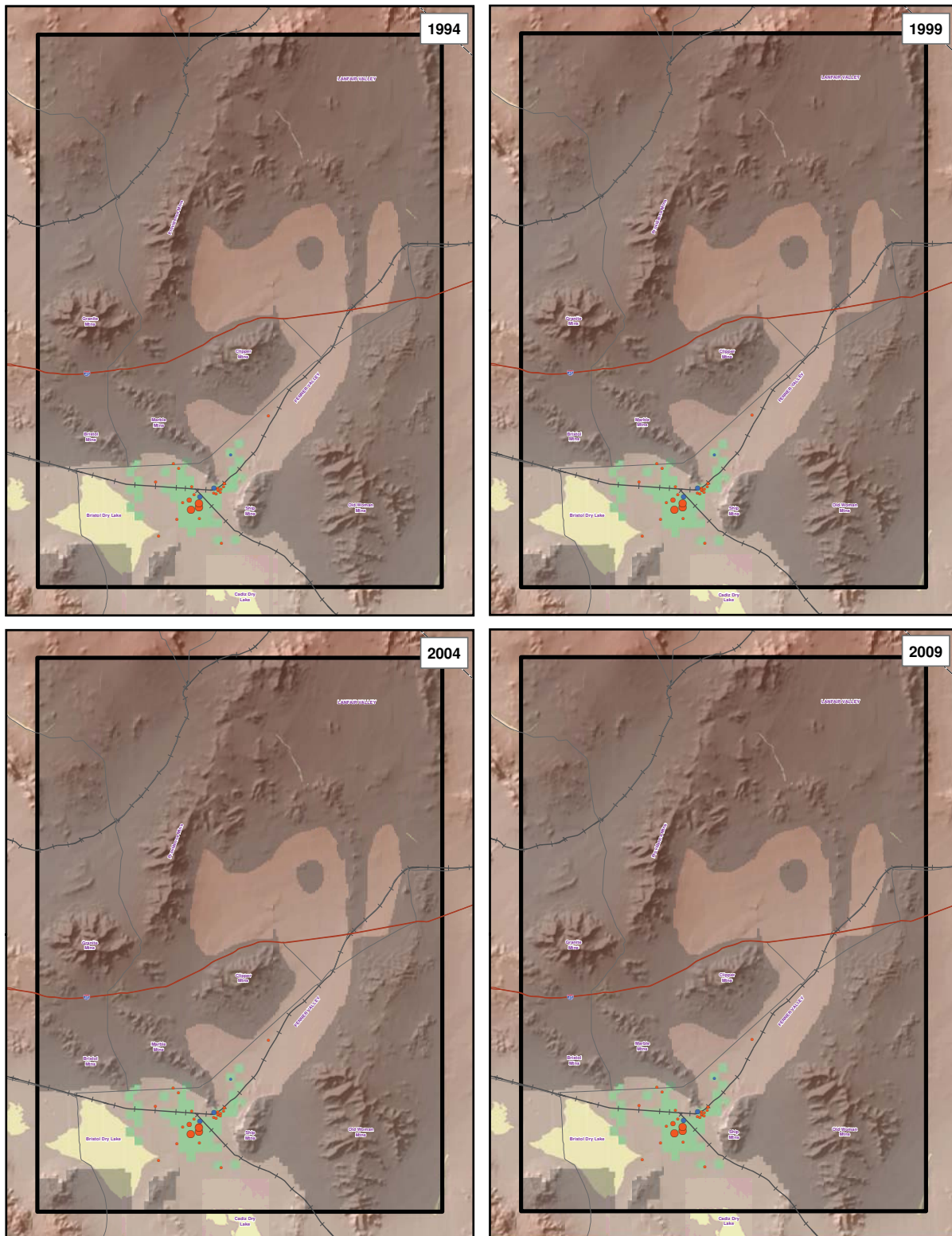
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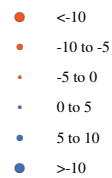
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**Figure 42**





Groundwater Level Residuals (ft)  
(measured water levels minus  
model-generated water levels)



**SPATIAL DISTRIBUTION  
OF WATER LEVEL  
RESIDUALS - TRANSIENT  
MODEL CALIBRATION FOR  
NATURAL RECHARGE OF  
5,000 ACRE-FT/YR**

1-Sep-11

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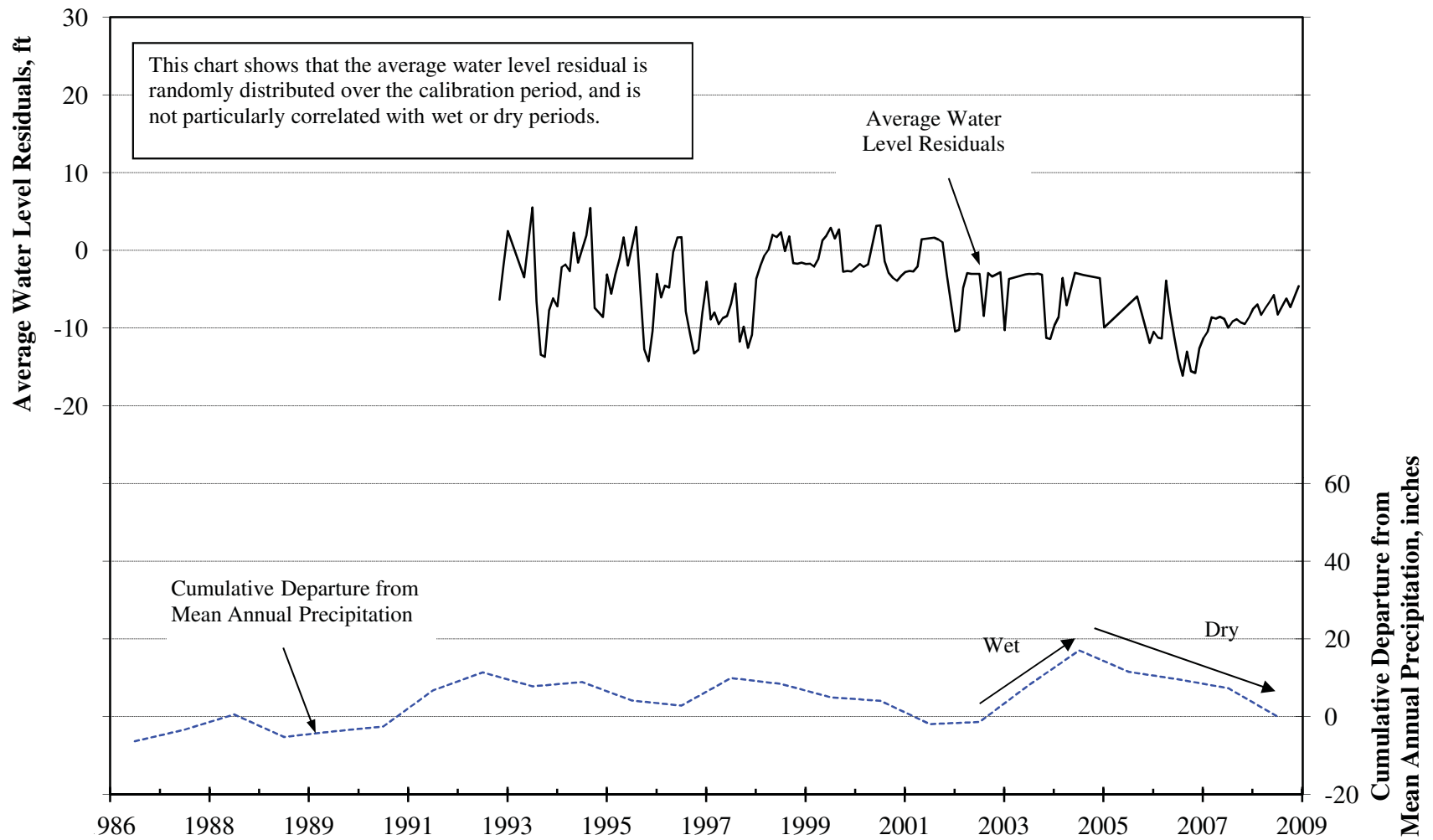
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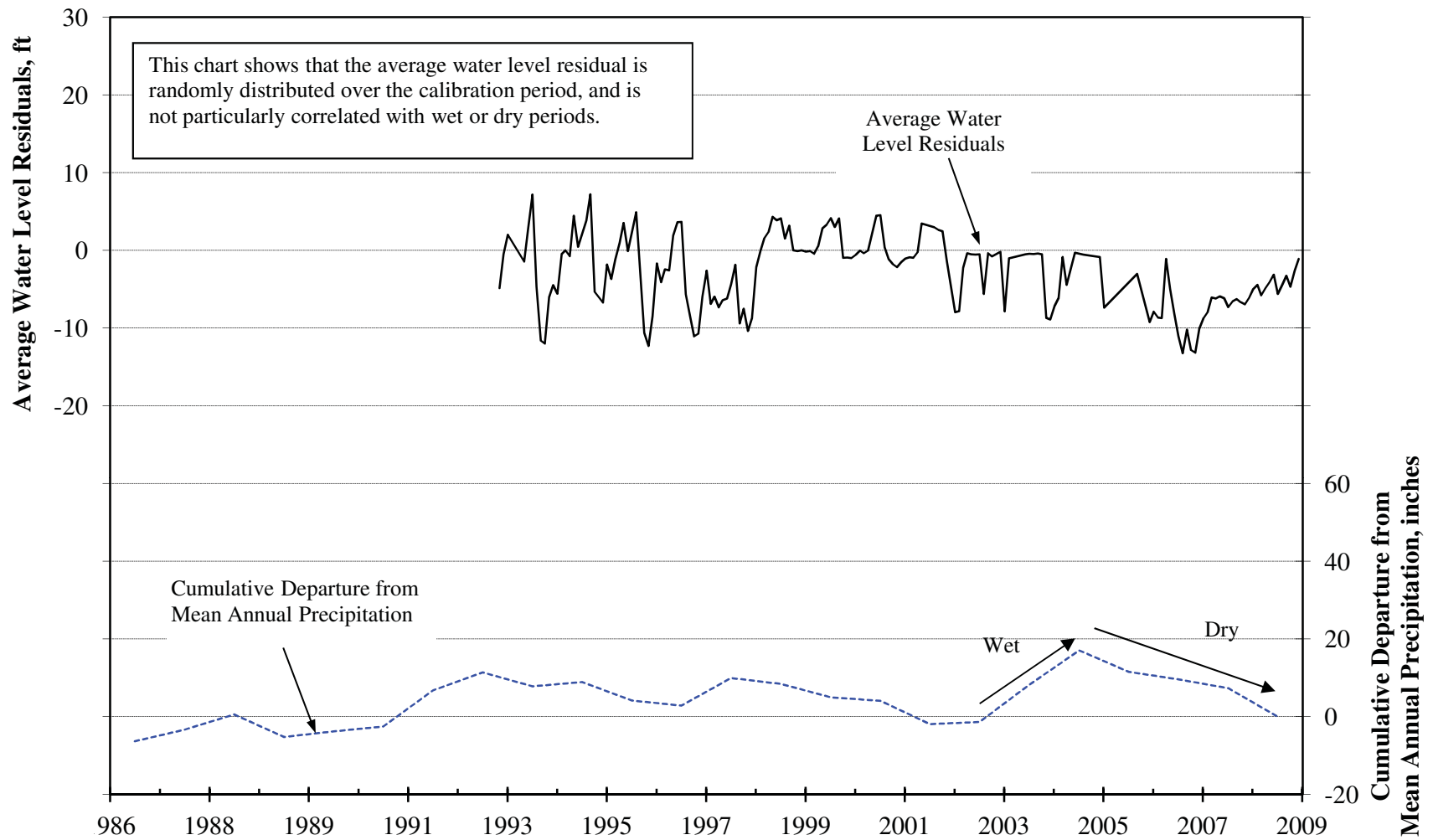
**Figure 43**

**Temporal Distribution of Water Level Residuals**  
**Transient Model Calibration for Natural Recharge of 32,000 acre-ft/yr**



**Figure 44**

**Temporal Distribution of Water Level Residuals**  
**Transient Model Calibration for Natural Recharge of 16,000 acre-ft/yr**



**Figure 45**

**Temporal Distribution of Water Level Residuals**  
**Transient Model Calibration for Natural Recharge of 5,000 acre-ft/yr**

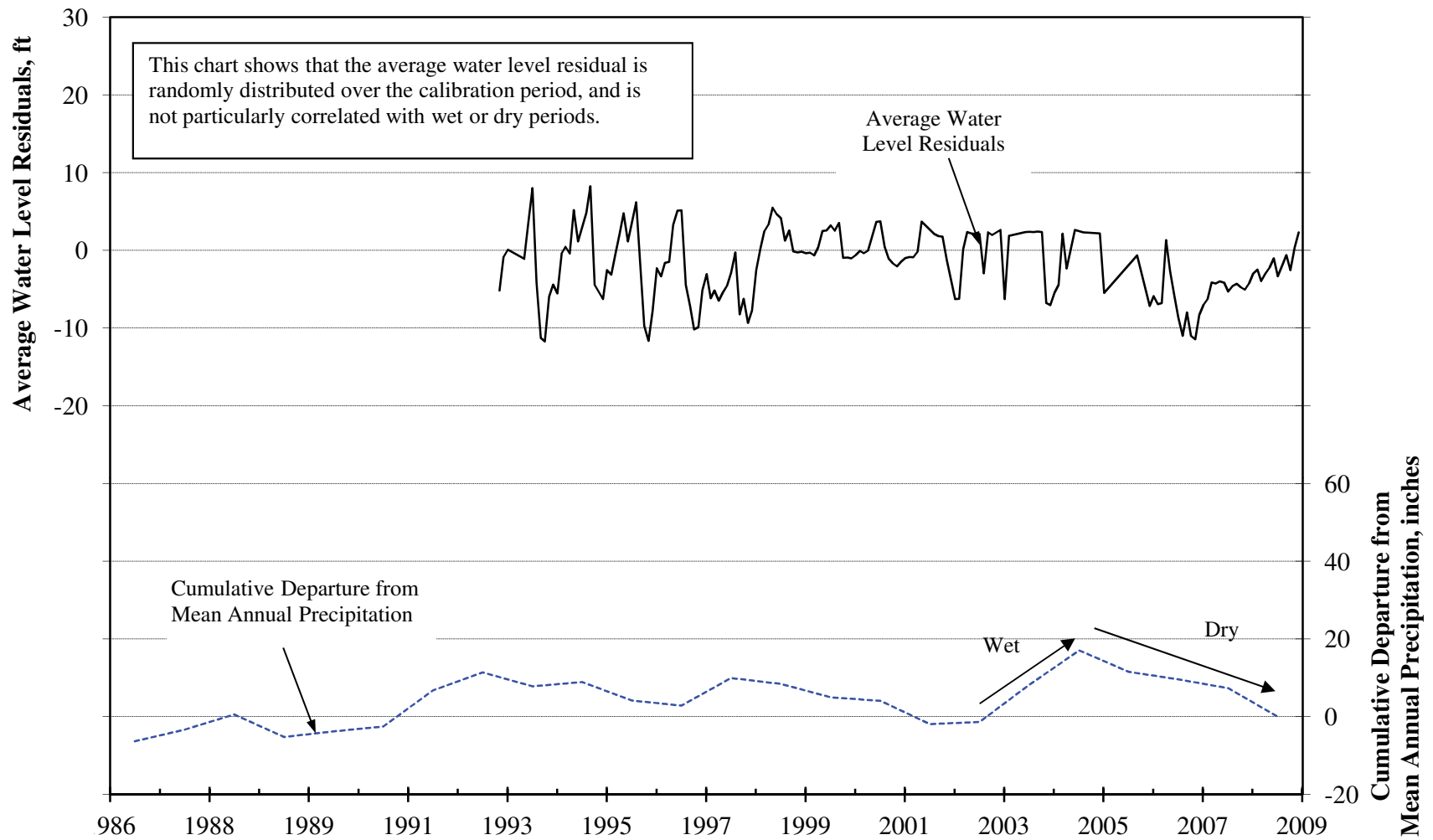


Figure 46

### Normalized Sensitivity of Selected Model Parameters

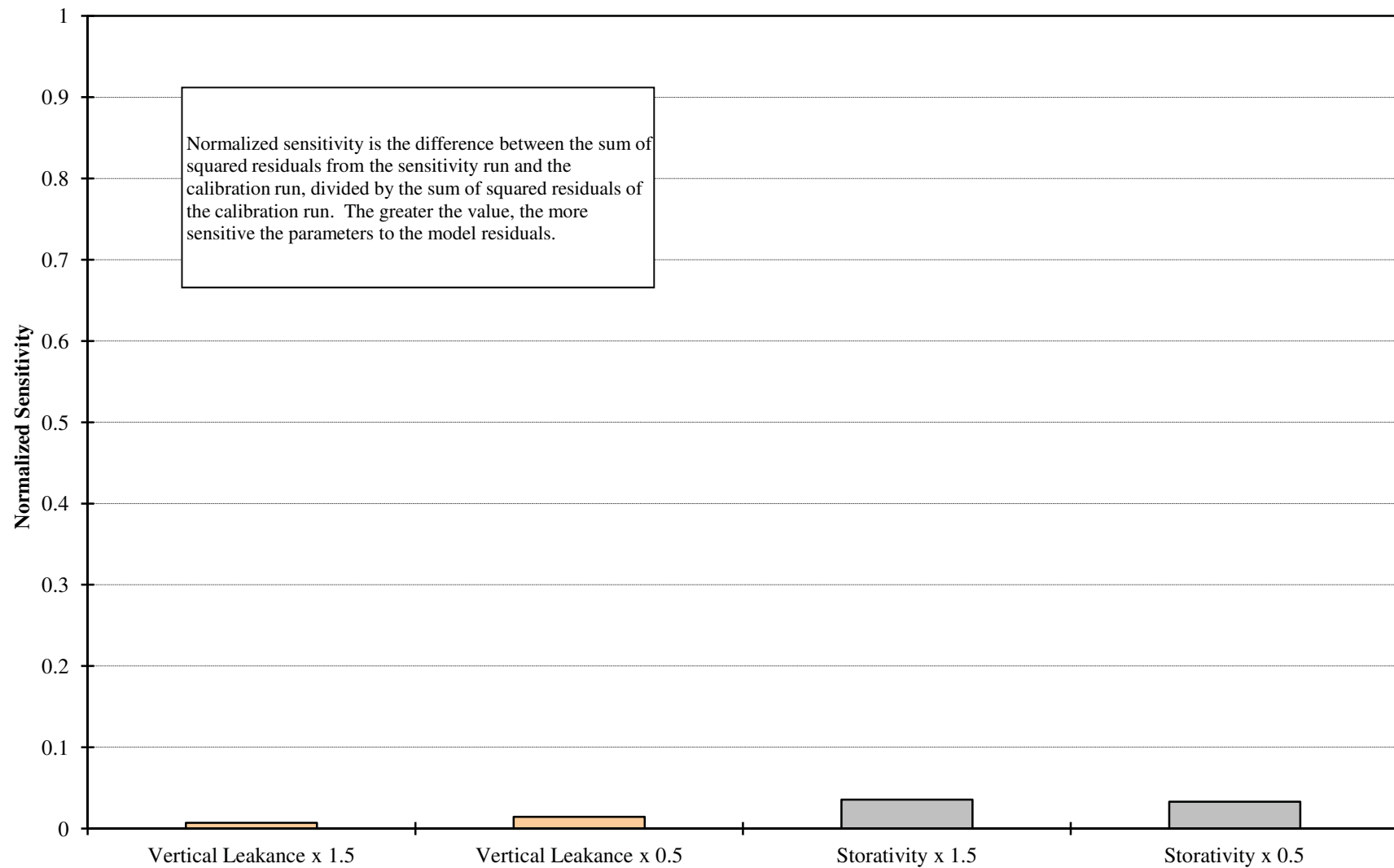
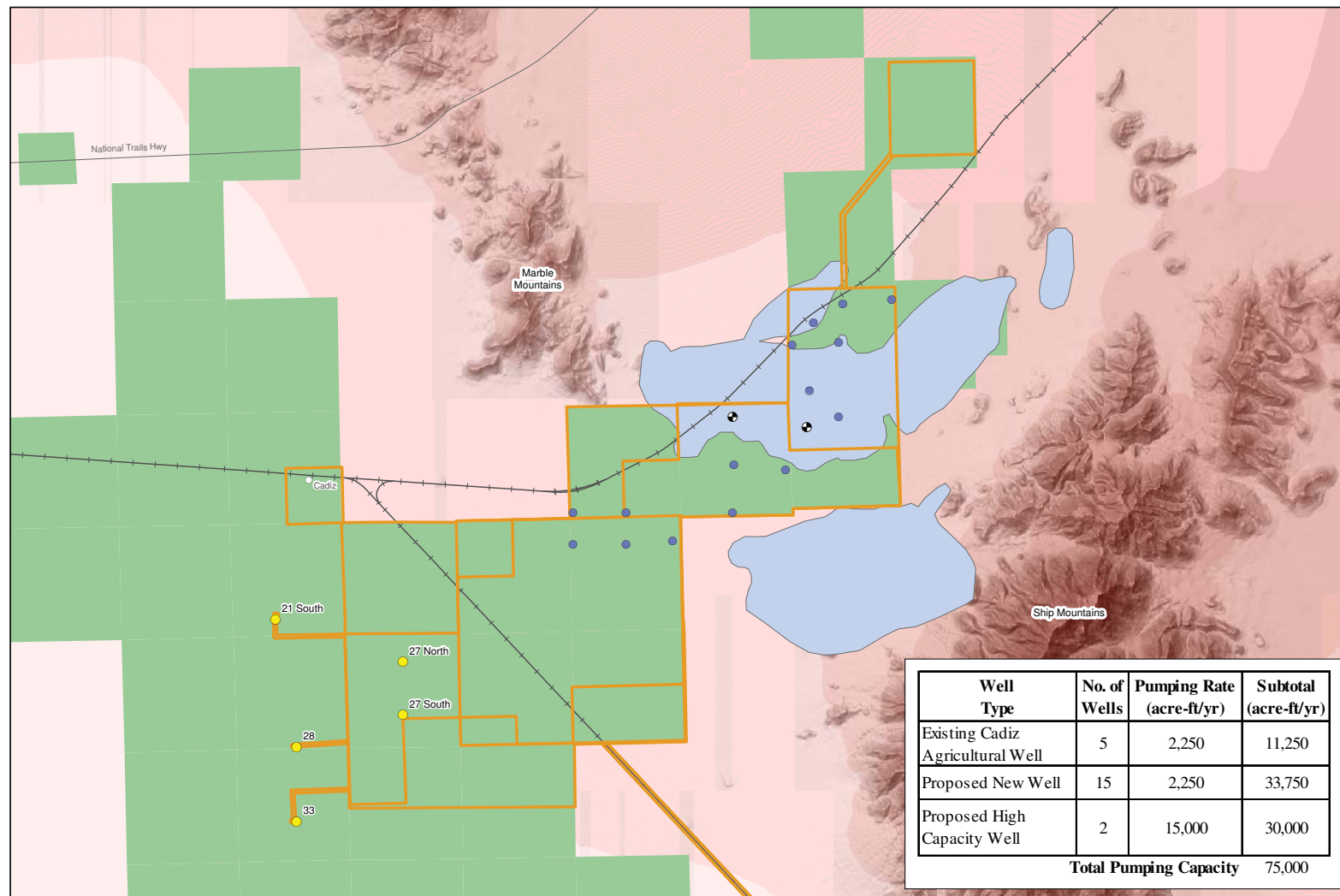


Figure 47

**CADIZ CONSERVATION  
PROJECT SCENARIO  
WELLFIELD  
CONFIGURATION A****EXPLANATION**

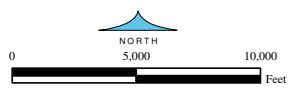
- Cadiz Owned Land
- Proposed Wellfield Development Areas and Pipeline
- Projected Surface Extent of Carbonate Unit (See Appendix B)
- Existing Cadiz Agricultural Well (pumping 2,250 acre-ft/yr each)
- Proposed New Well (pumping 2,250 acre-ft/yr each)
- Proposed High Capacity Well (pumping 15,000 acre-ft/yr each)

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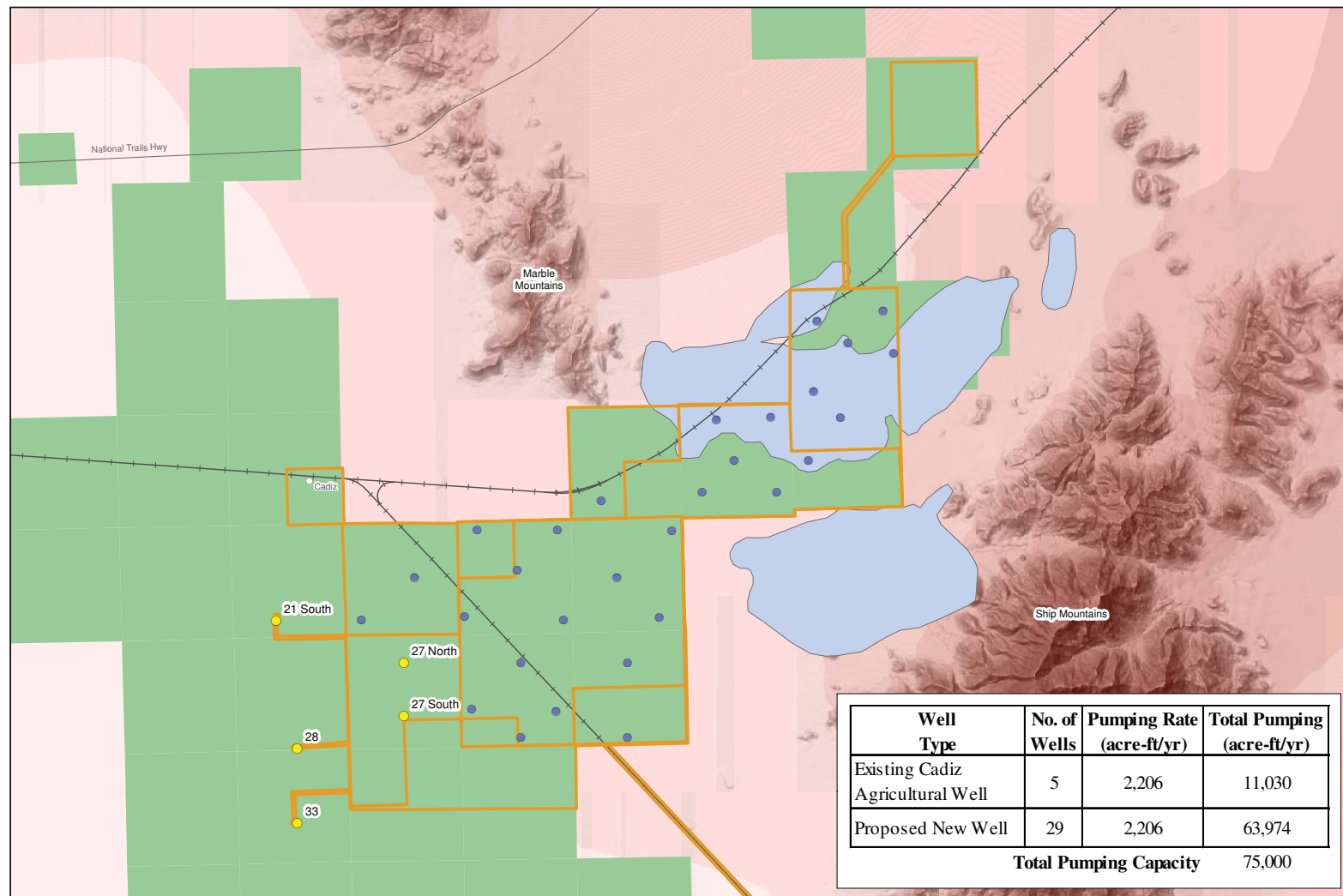
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www.gssiwater.com**Figure 48**



**CADIZ CONSERVATION  
SENSITIVITY SCENARIOS  
WELLFIELD  
CONFIGURATION B**



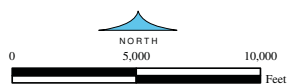
EXPLANATION

- Cadiz Owned Land
- Proposed Wellfield Development Areas and Pipeline
- Projected Surface Extent of Carbonate Unit (See Appendix B)
- Existing Cadiz Agricultural Well (pumping 2,206 acre-ft/yr each)
- Proposed New Well (pumping 2,206 acre-ft/yr each)

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**Figure 49**

### Cadiz Groundwater Conservation and Storage Project Annual Pumping for Project Conservation Scenario

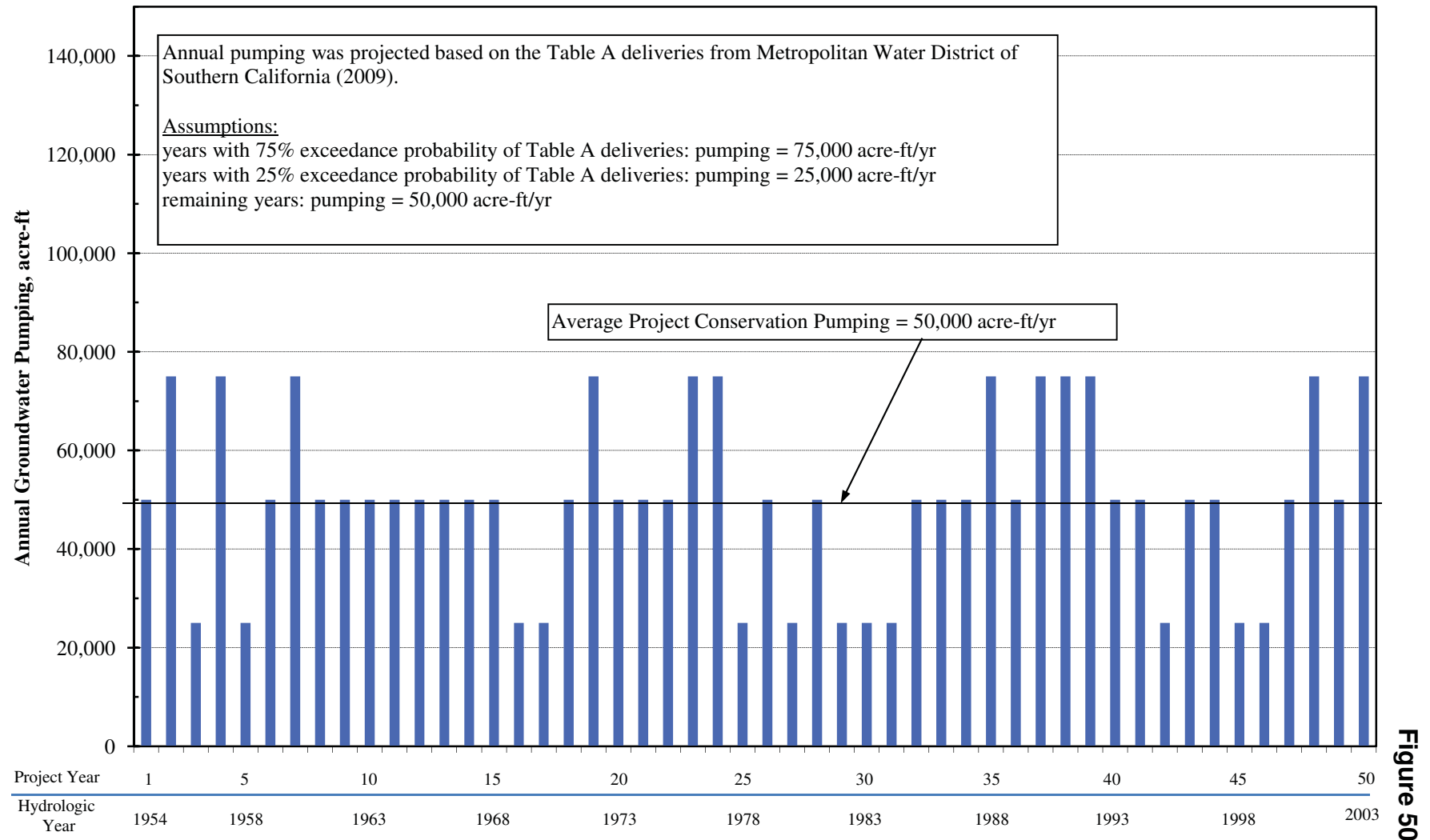
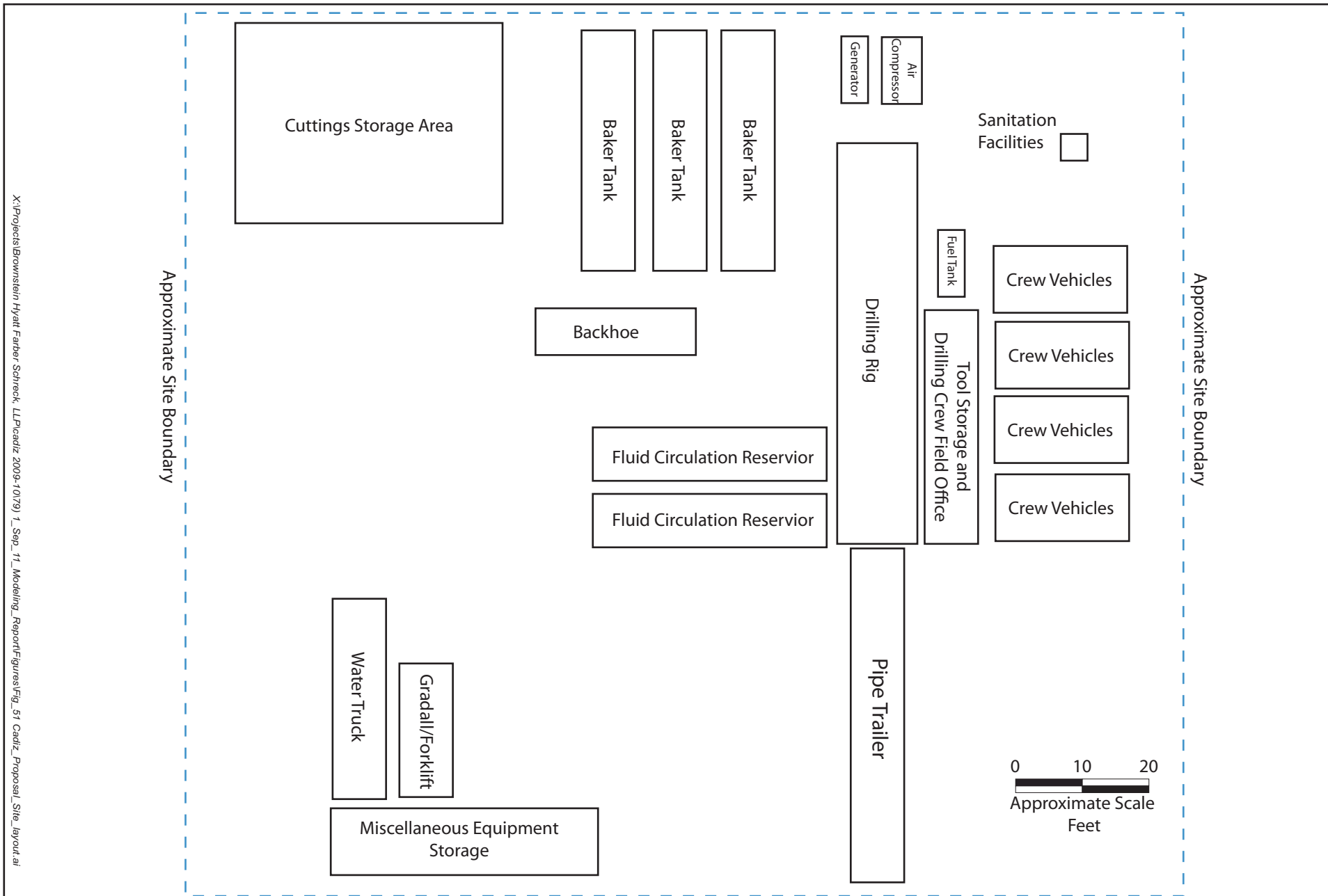


Figure 50



X:\Projects\Brownstein Hyatt Farber Schreck, LLP\cadiz\_2009-10\79\_1\_Sep\_11\_Modeling\_Report\Figures\Fig\_51\_Cadiz\_Proposal\_Site\_Layout.dwg

Figure  
51

Drawn: CSC

Checked:

Approved:

Date: 1-Sep-11

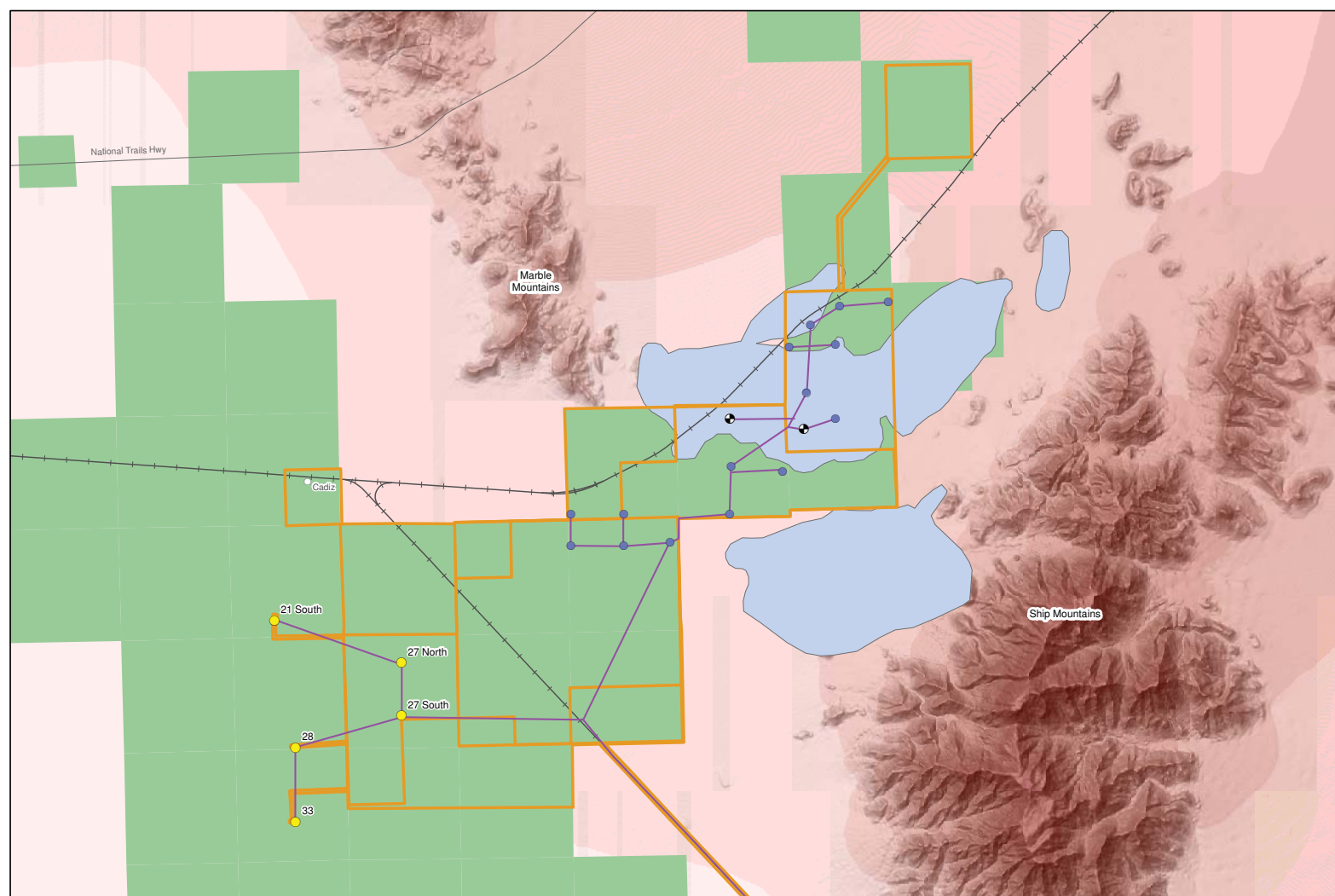
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## CONCEPTUAL DRILL SITE LAYOUT



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# **CADIZ CONSERVATION PROJECT SCENARIO SCHEMATIC OF PROPOSED MANIFOLD SYSTEM**



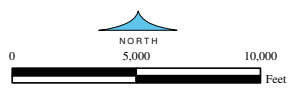
## EXPLANATION

- Cadiz Owned Land
- Proposed Wellfield Development Areas and Pipeline
- Projected Surface Extent of Carbonate Unit (See Appendix B)
- Schematic - Proposed Manifold System
- Existing Cadiz Agricultural Well (pumping 2,250 acre-ft/yr each)
- Proposed New Well (pumping 2,250 acre-ft/yr each)
- Proposed High Capacity Well (pumping 15,000 acre-ft/yr each)

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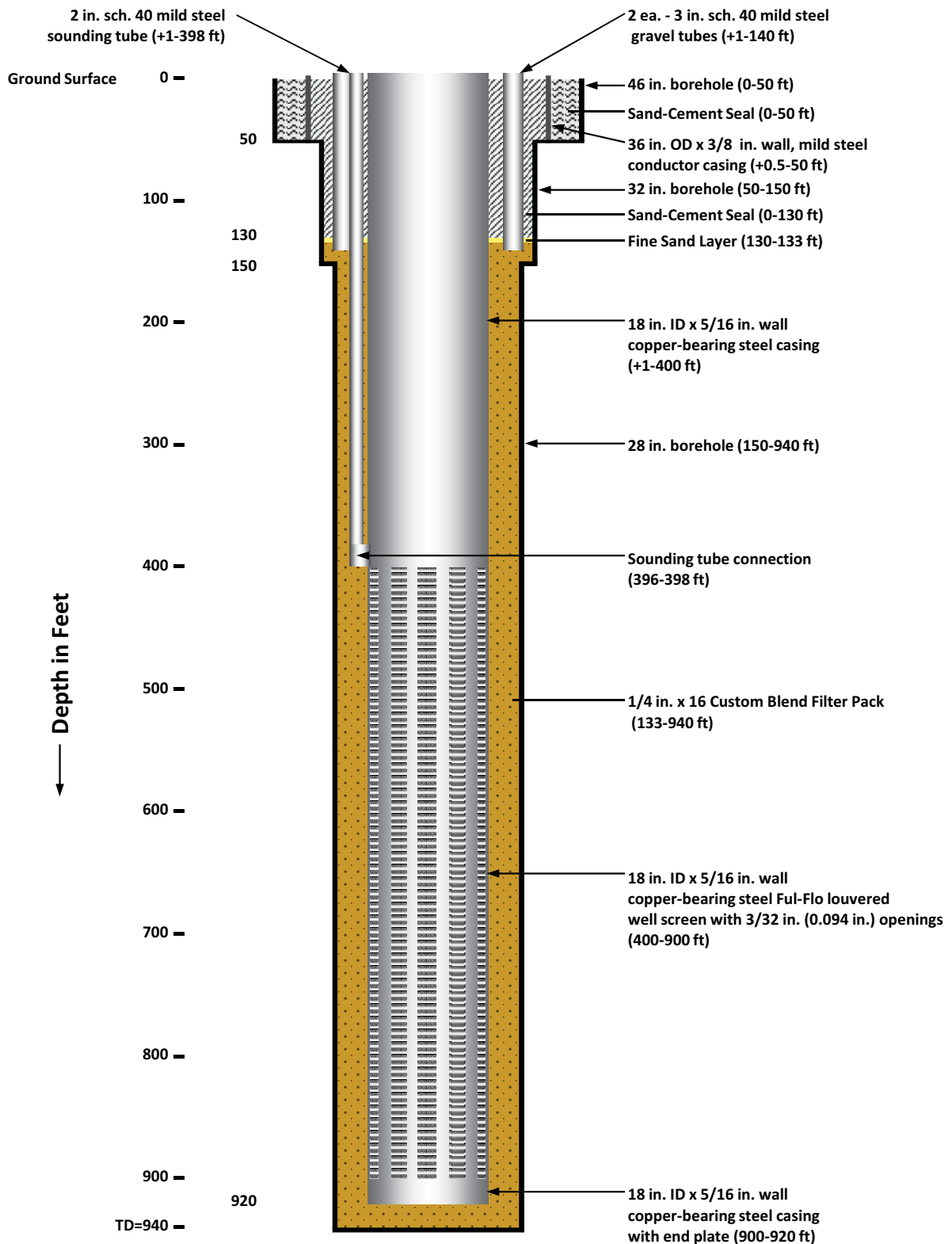
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**Figure 52**



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NOT TO SCALE



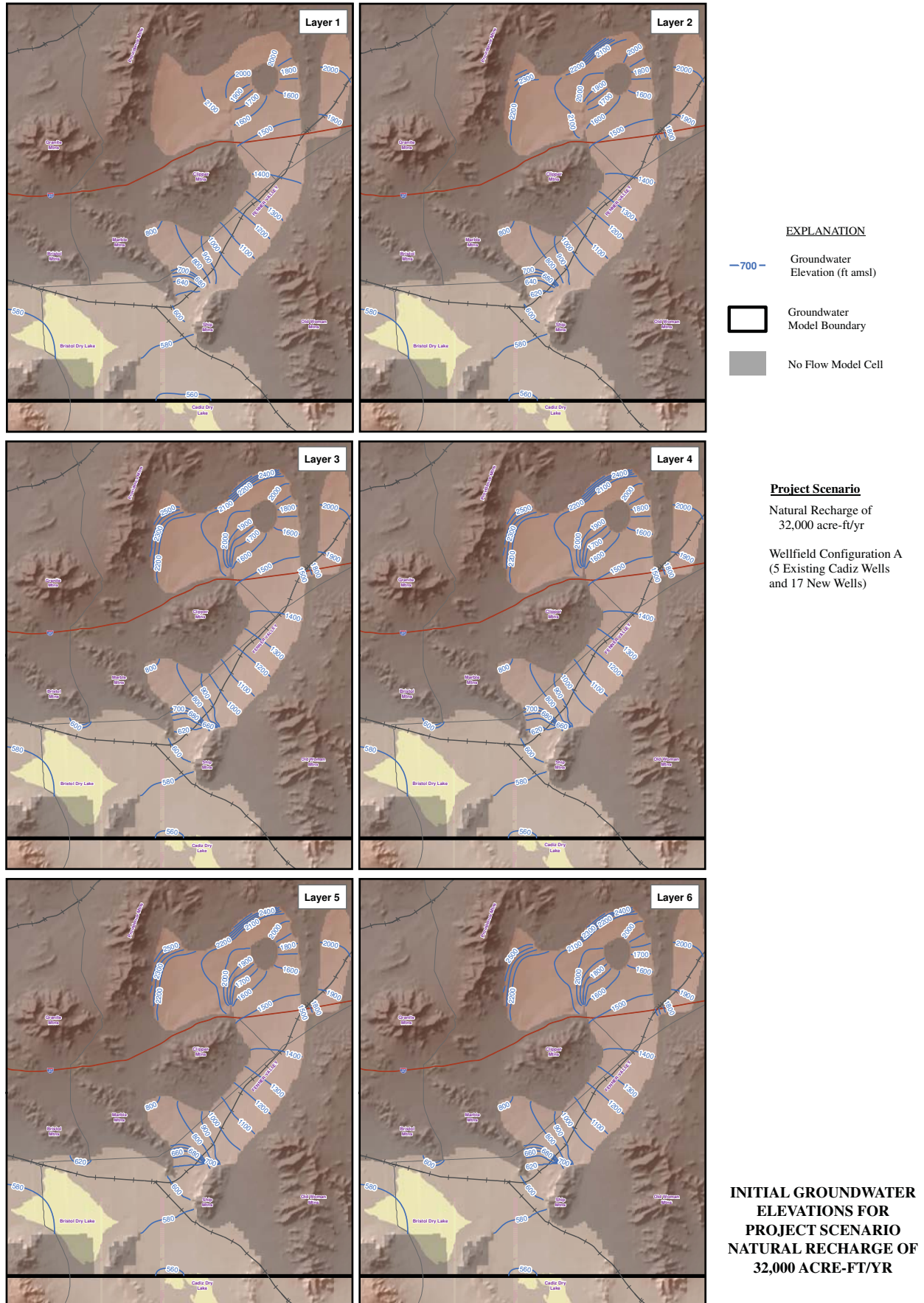
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CONCEPTUAL WELL DESIGN DIAGRAM

**Figure**  
**53**





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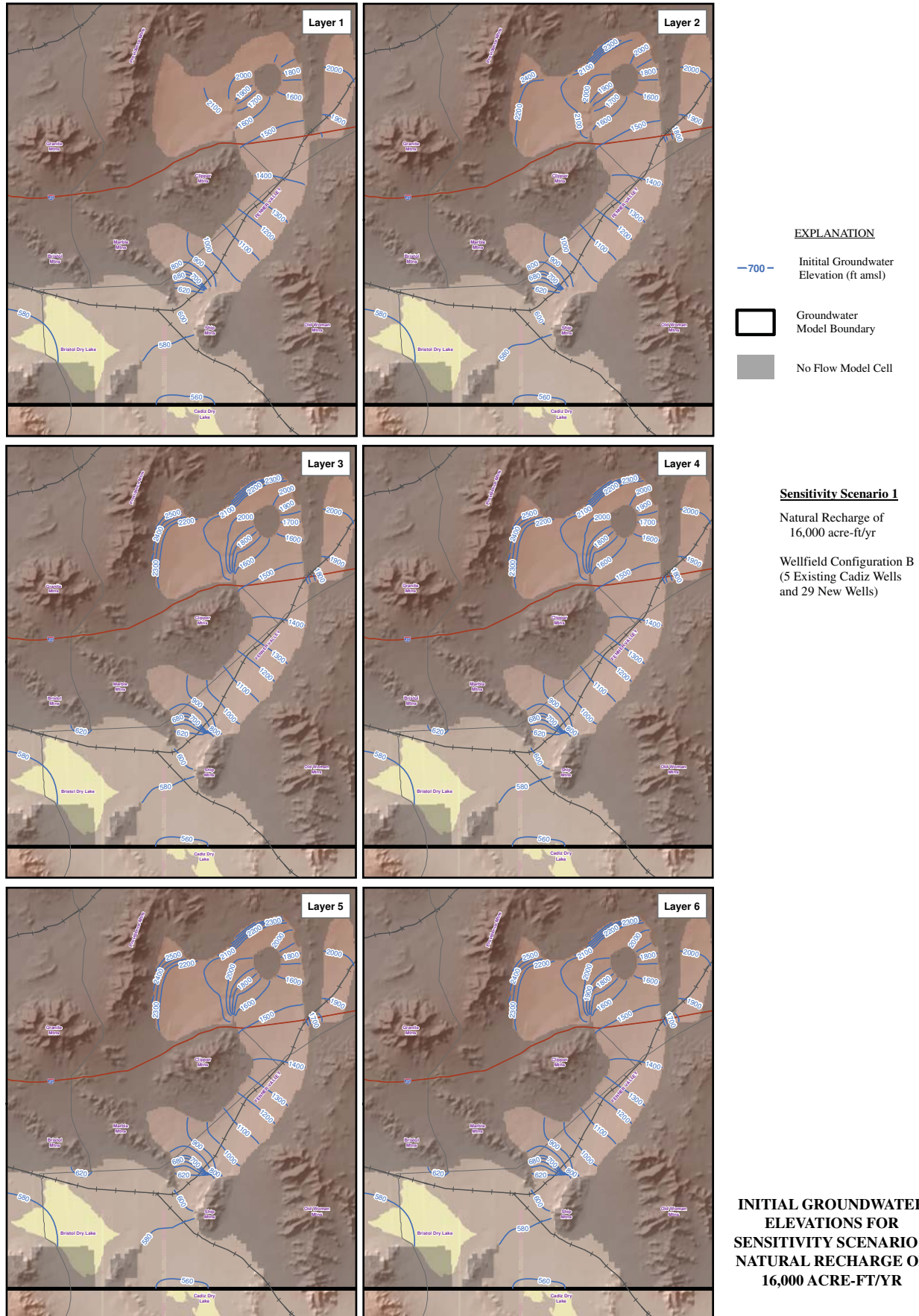


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Figure 54





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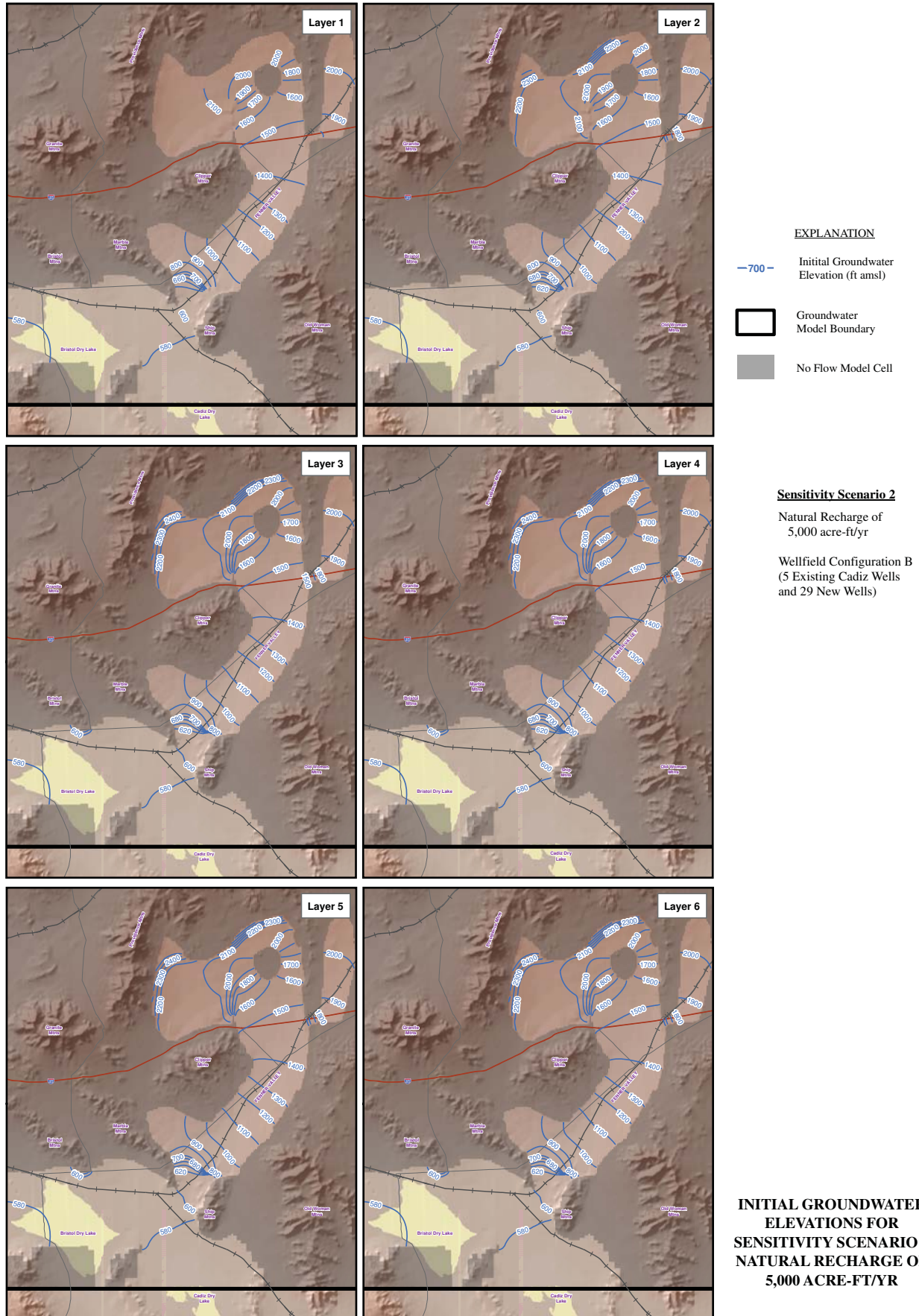
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Figure 55



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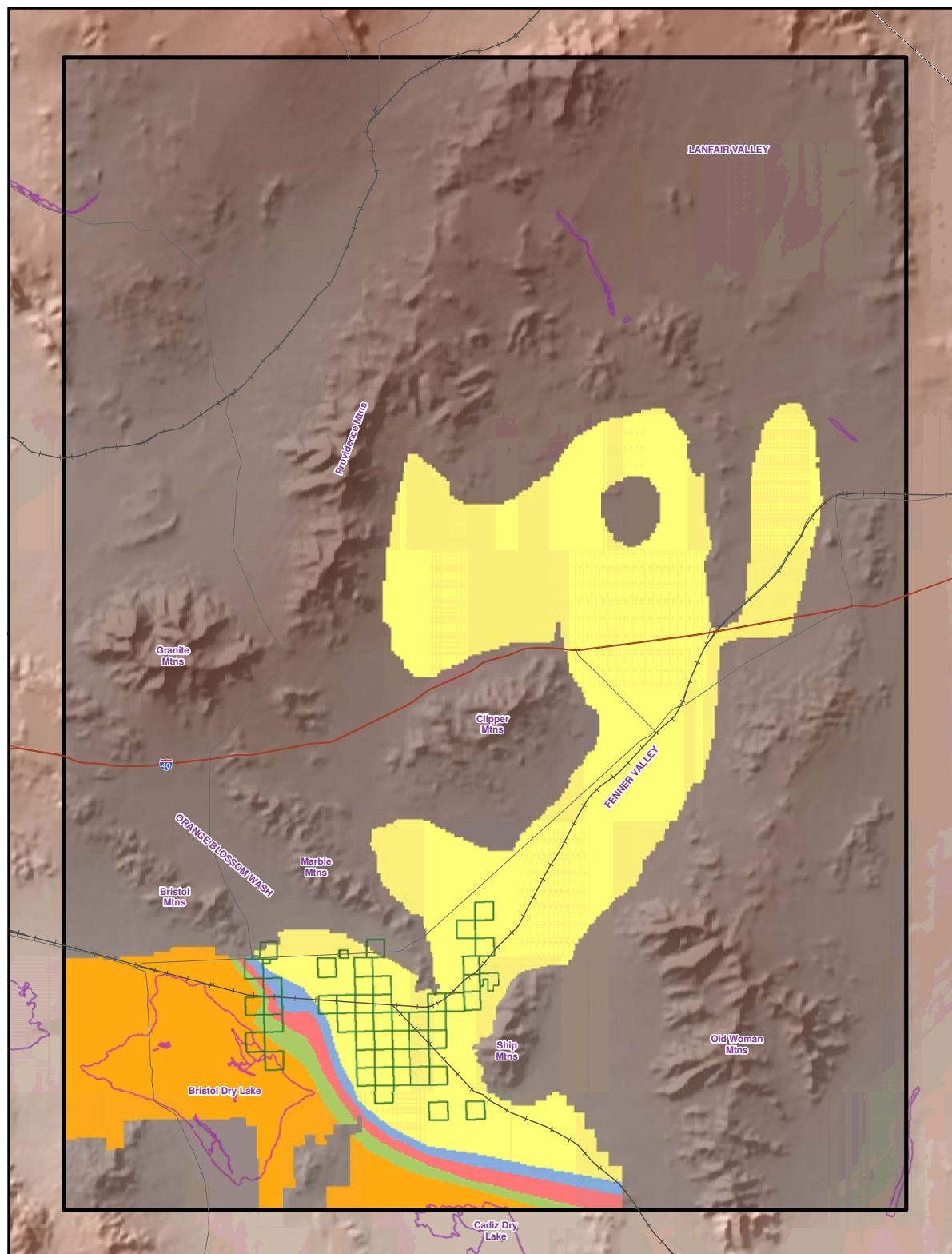


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**Figure 56**





Groundwater Model Boundary  
Cadiz Owned Land  
No Flow Model Cell

Initial TDS Concentration (mg/L)

<500
500 to 1,000
1,000 to 5,000
5,000 to 30,000
30,000 to 35,000

**INITIAL TDS CONCENTRATIONS  
FOR PROJECT SCENARIO,  
SENSITIVITY SCENARIO 1 AND  
SENSITIVITY SCENARIO 2**

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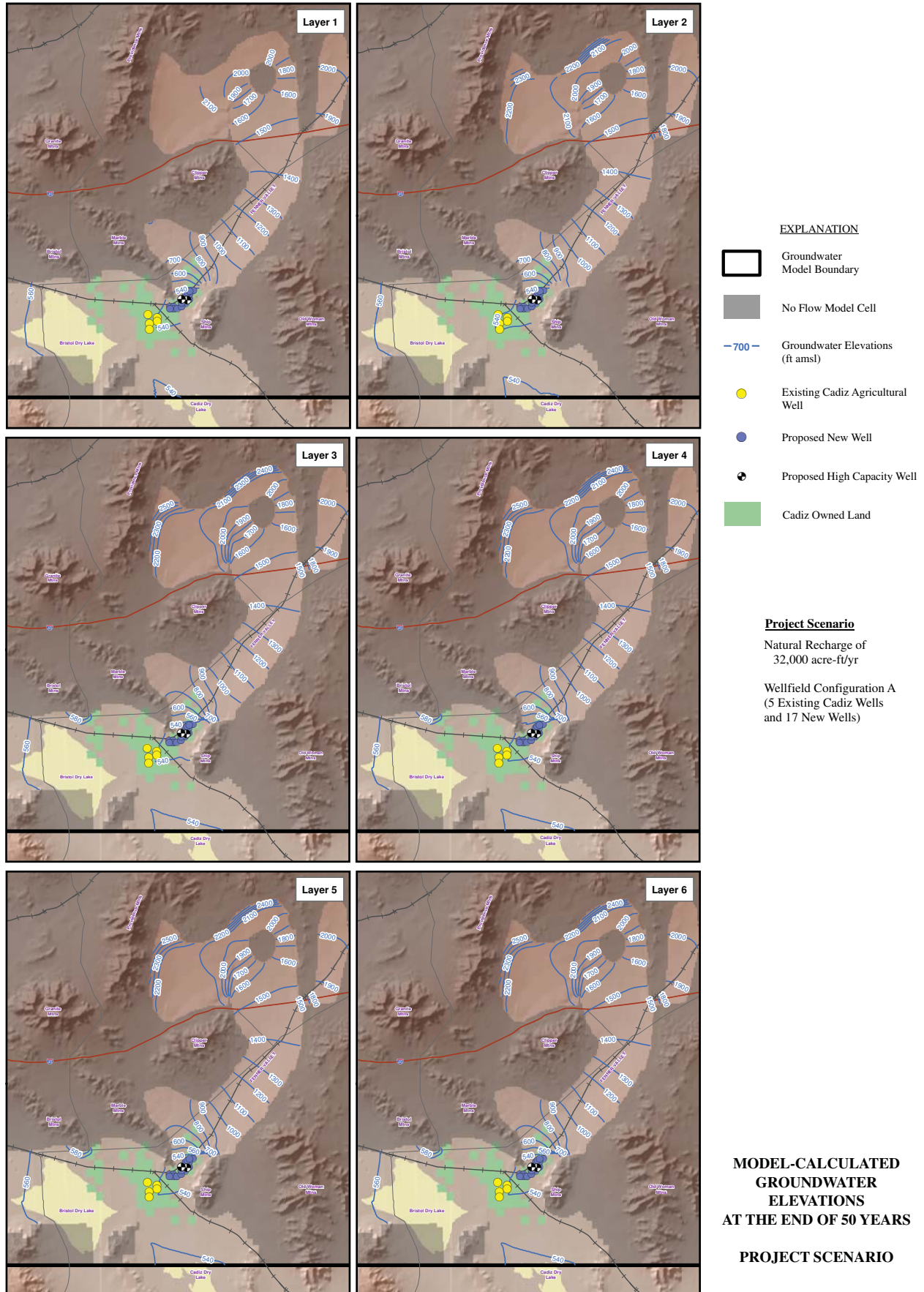
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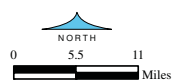
**Figure 57**



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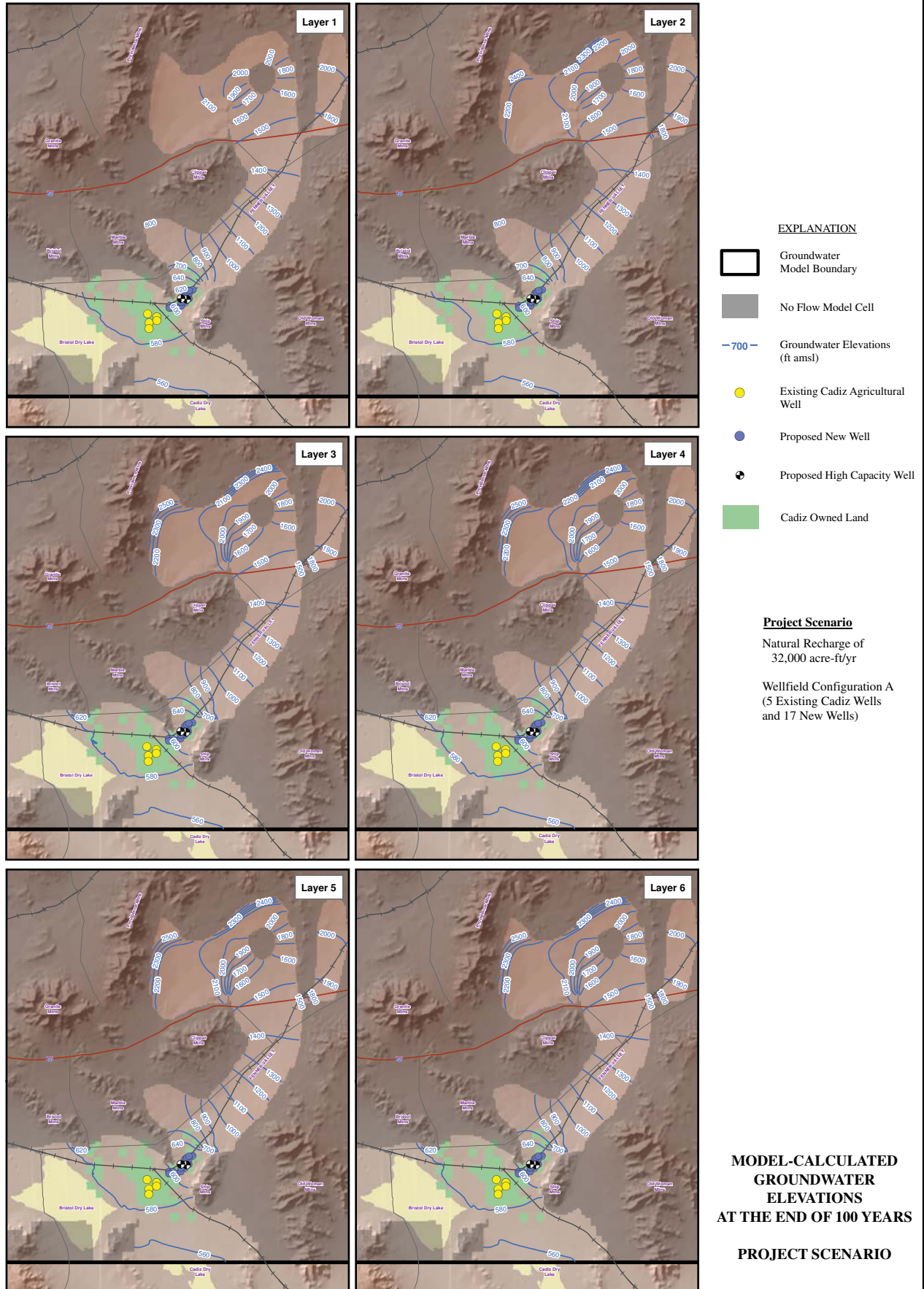


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Figure 58





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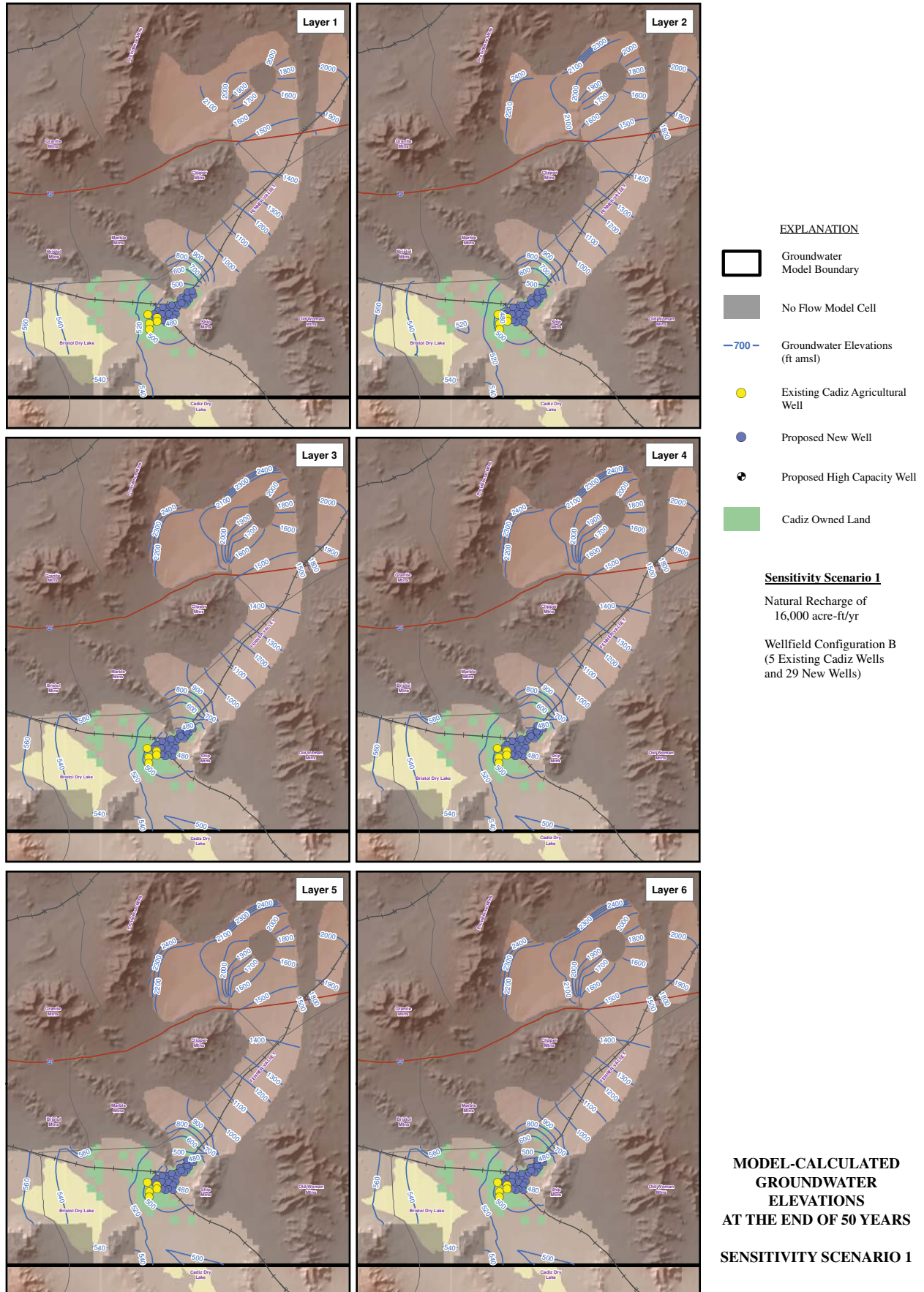
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Figure 59



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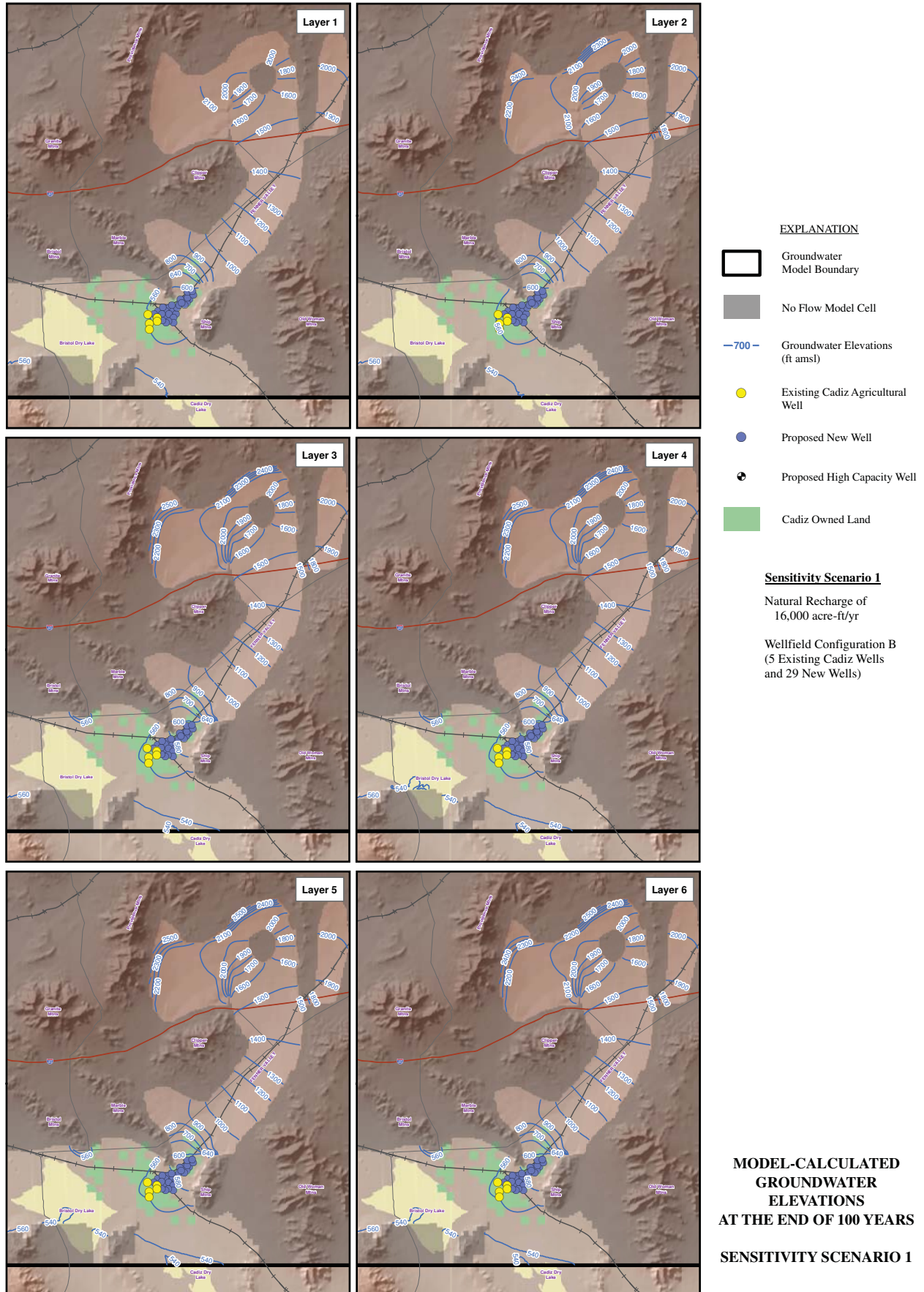


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Figure 60





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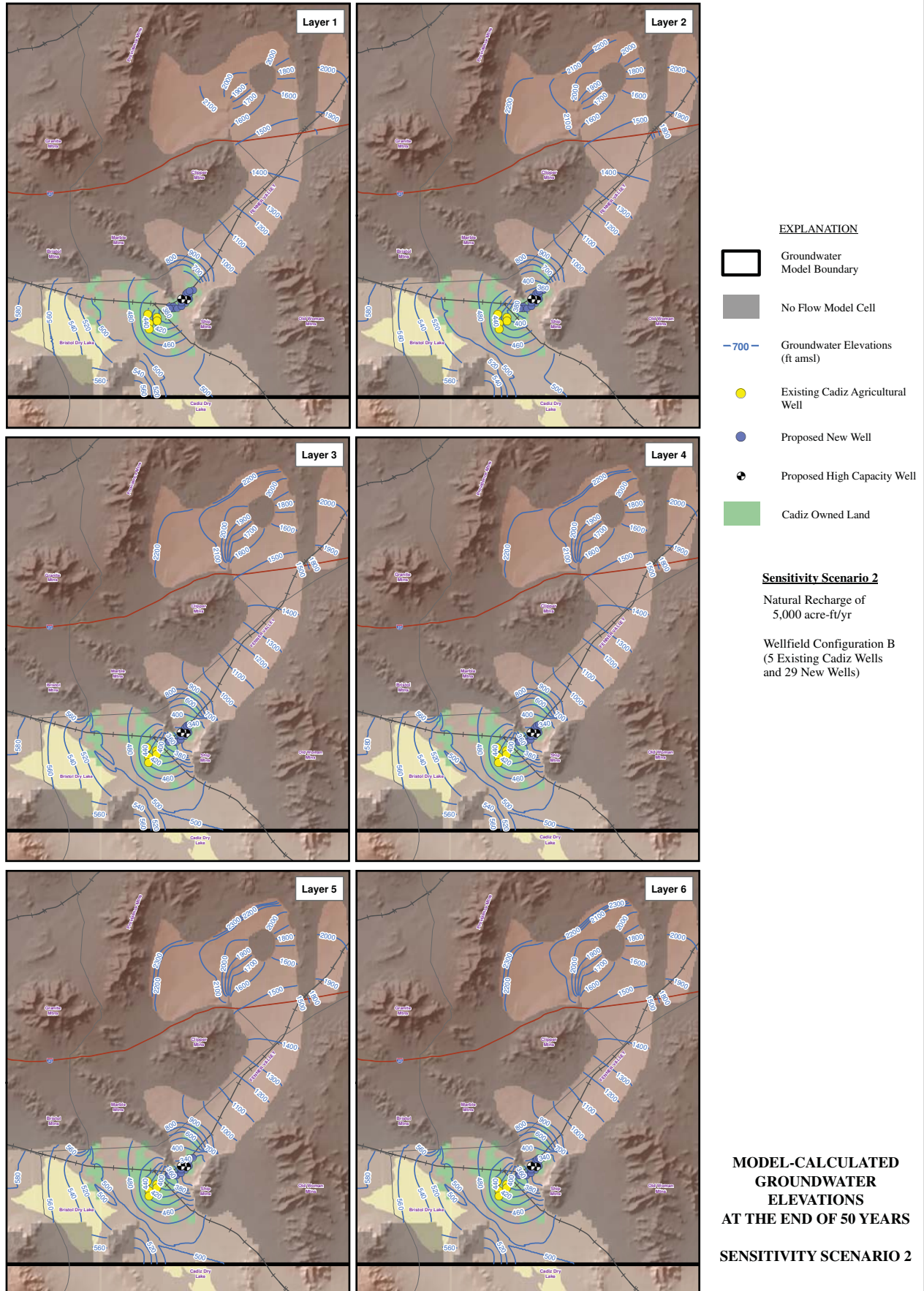
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Figure 61



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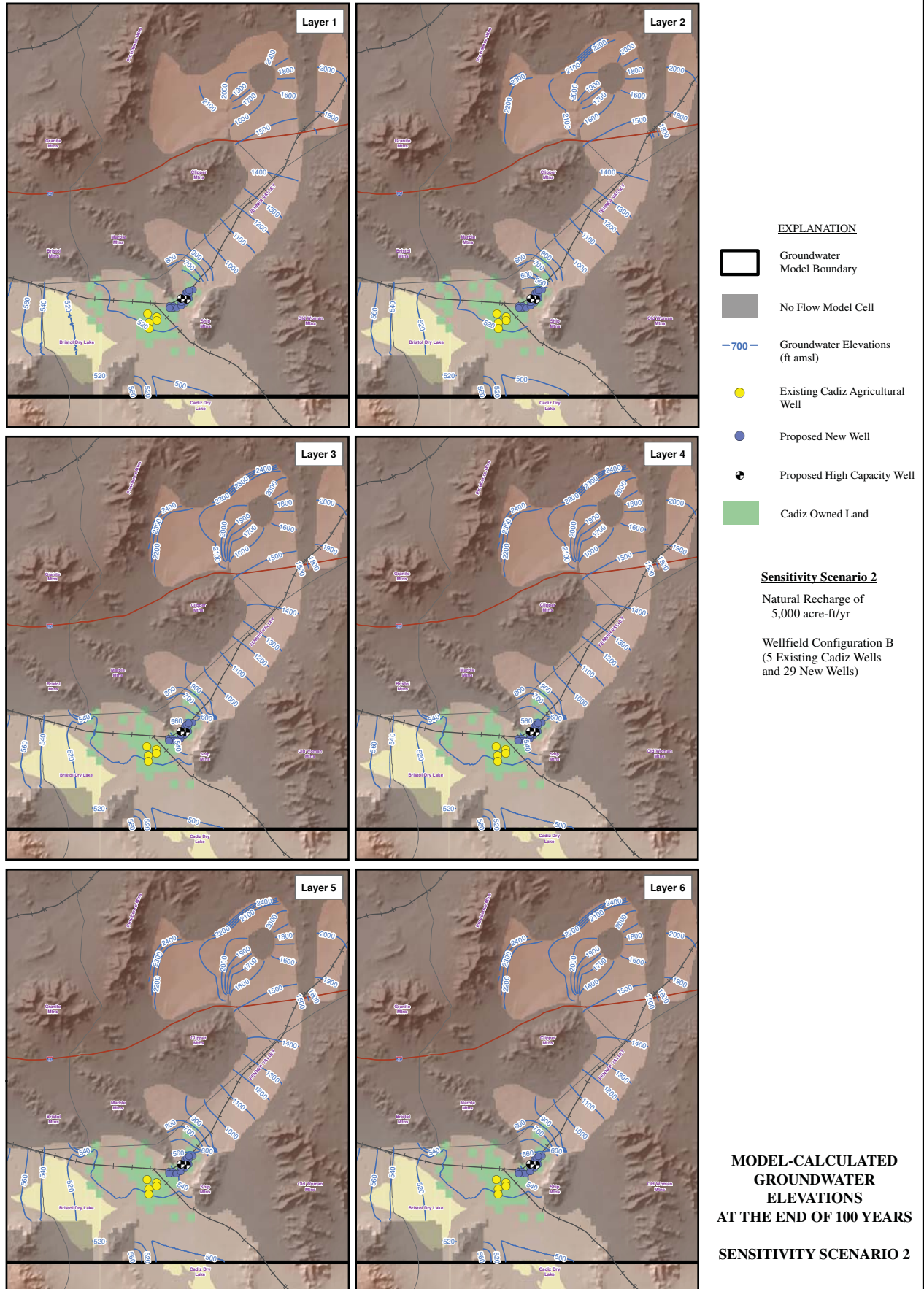


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Figure 62





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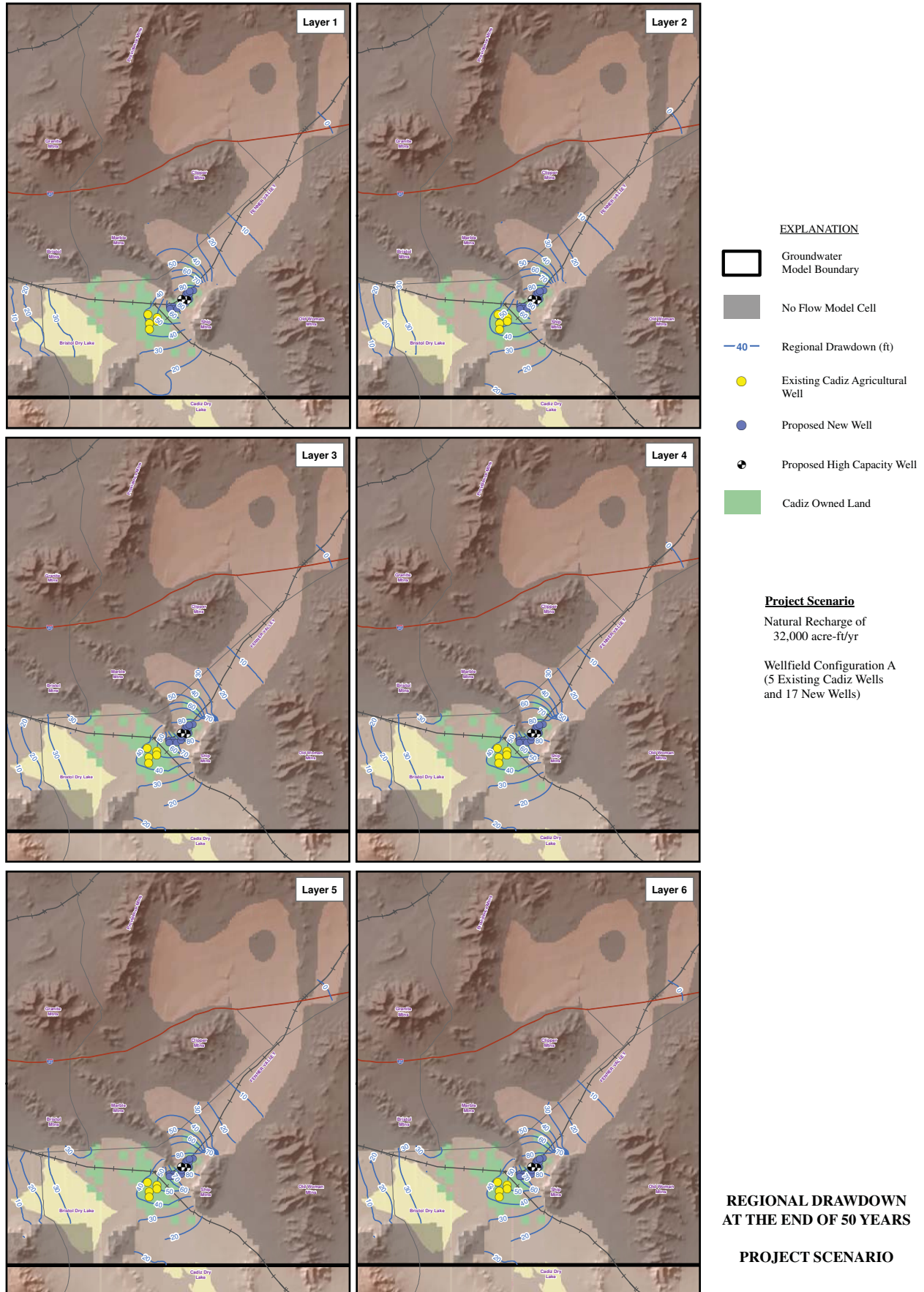
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Figure 63



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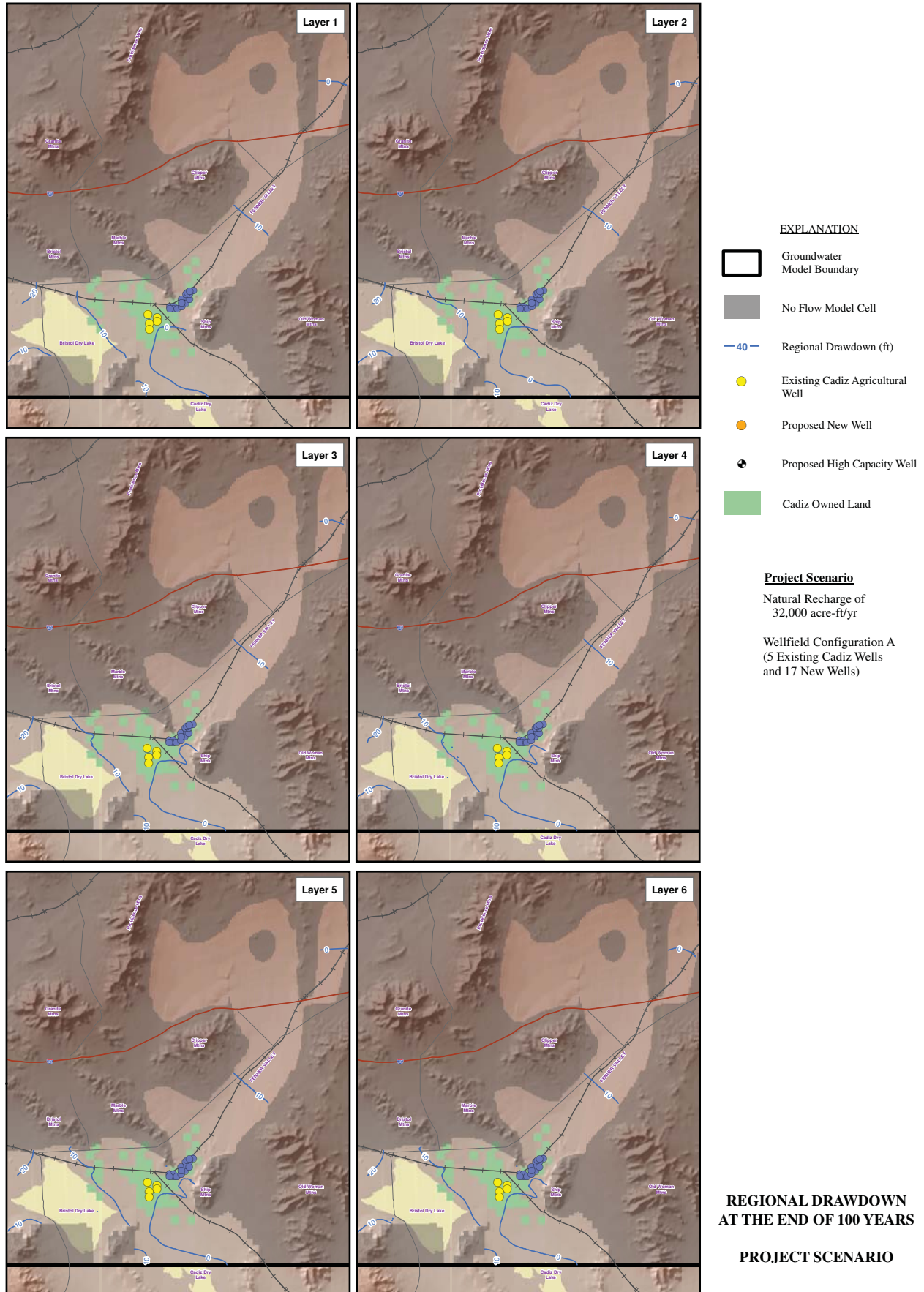


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Figure 64





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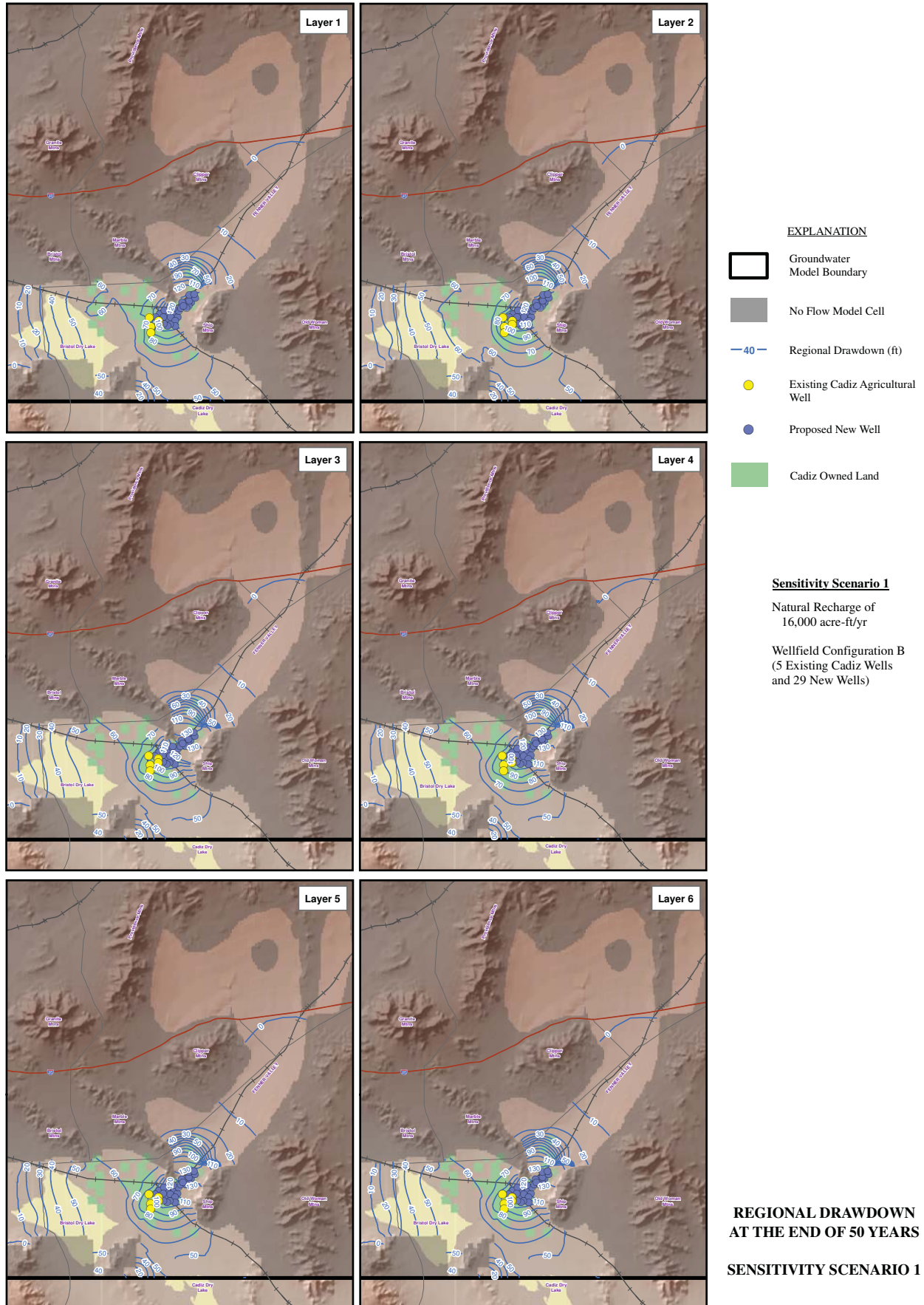
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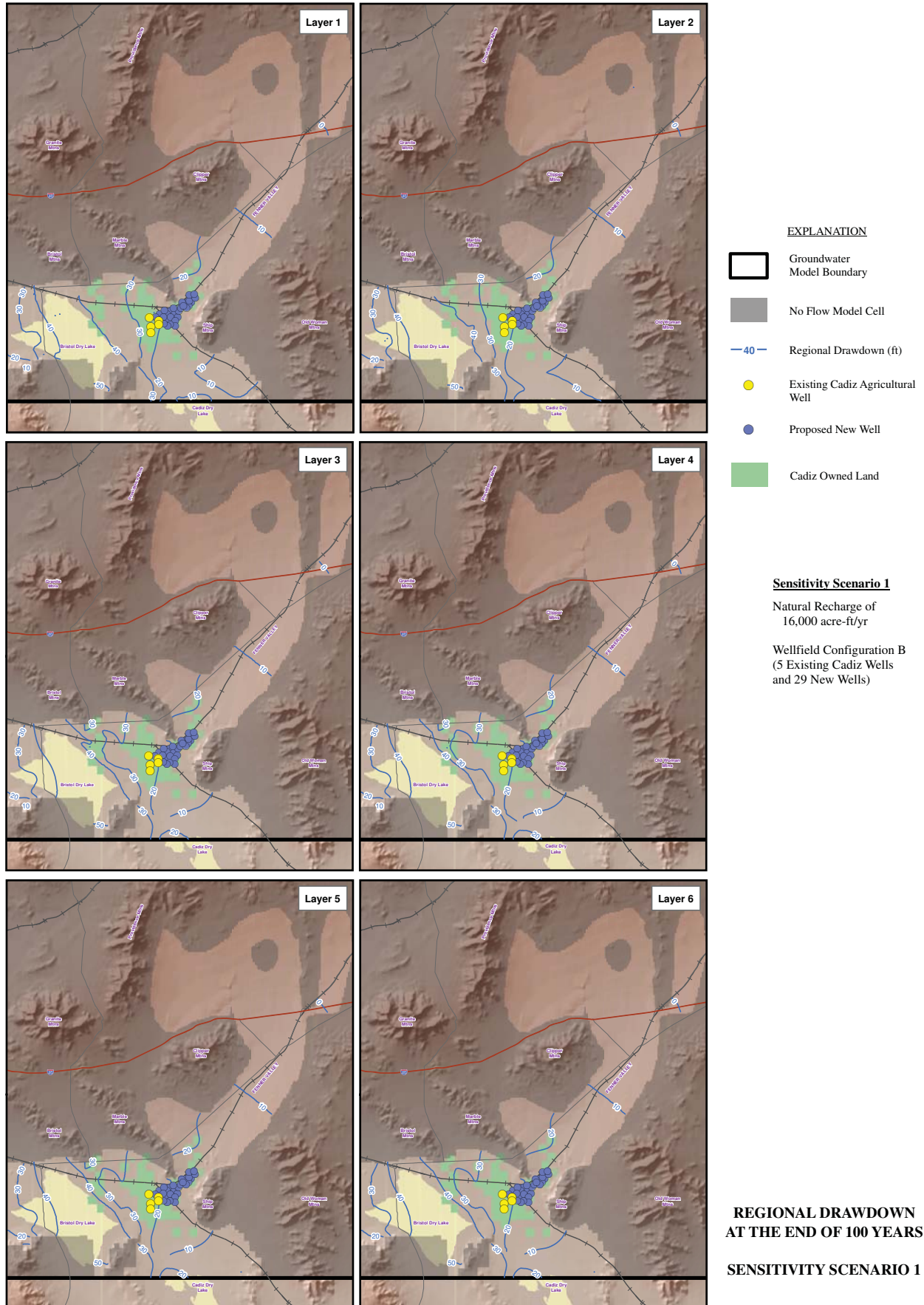


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Figure 66





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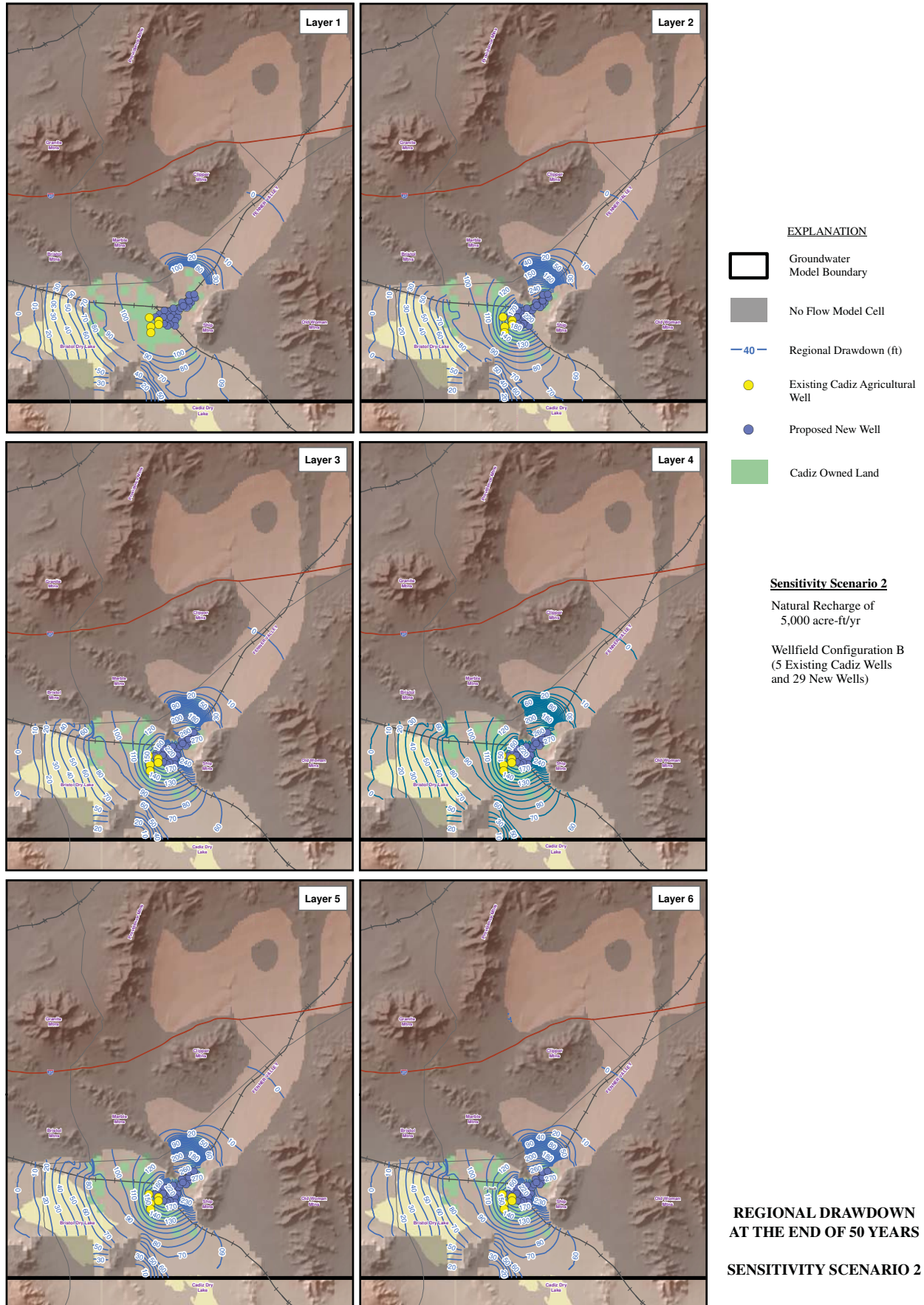
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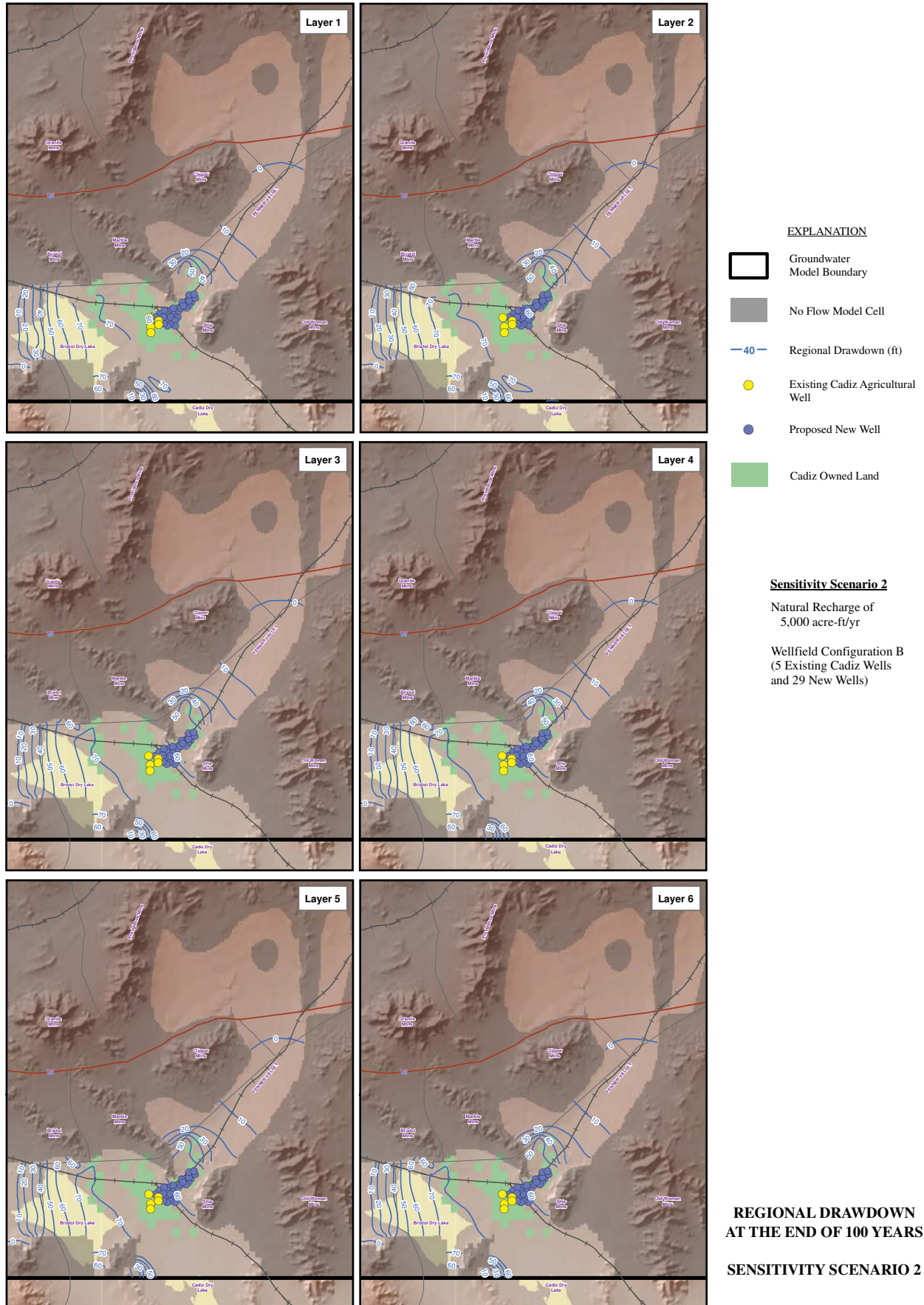


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Figure 68





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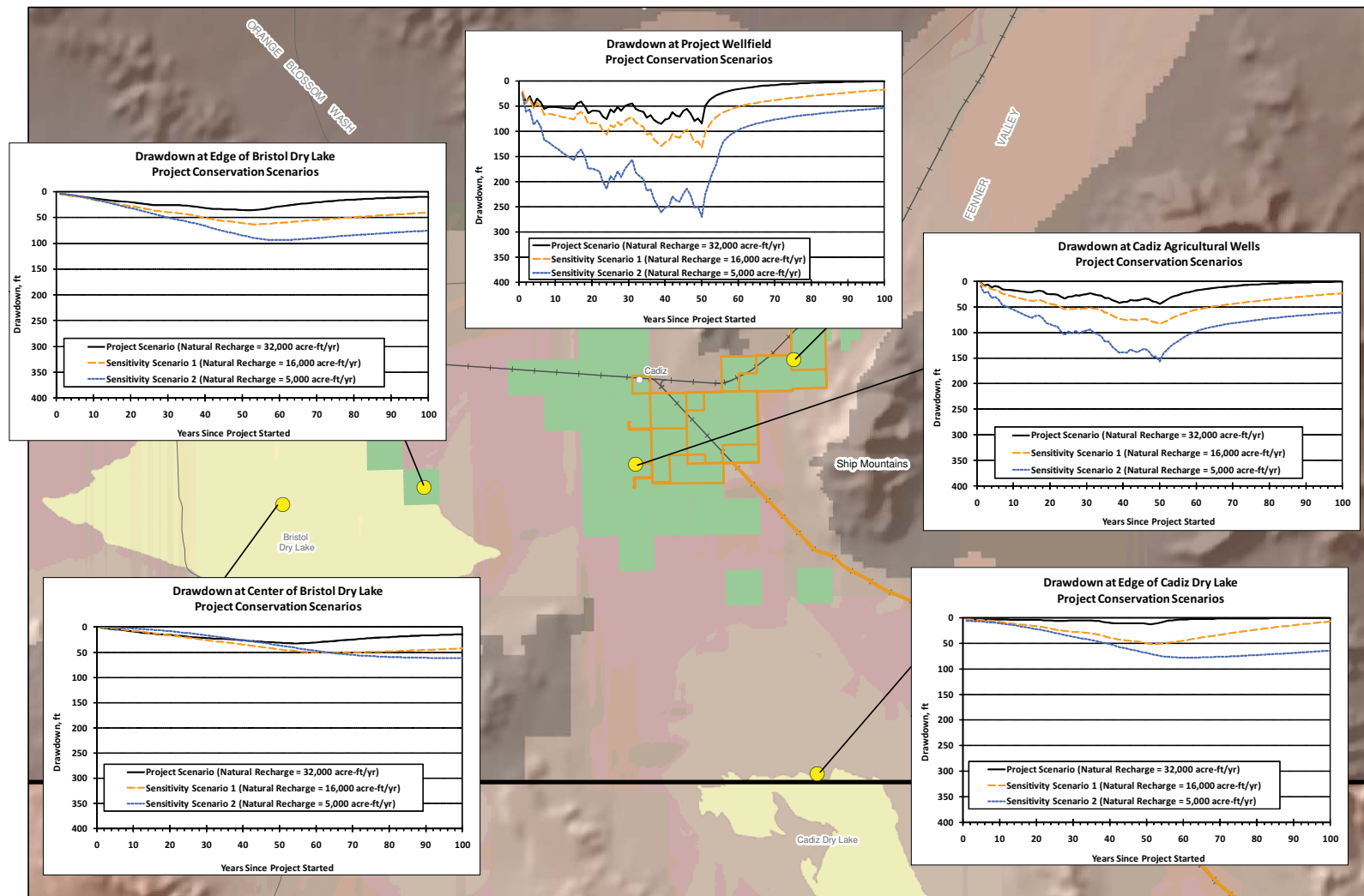


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Figure 69

# MODEL-CALCULATED DRAWDOWN AT SELECTED LOCATIONS



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Figure 70

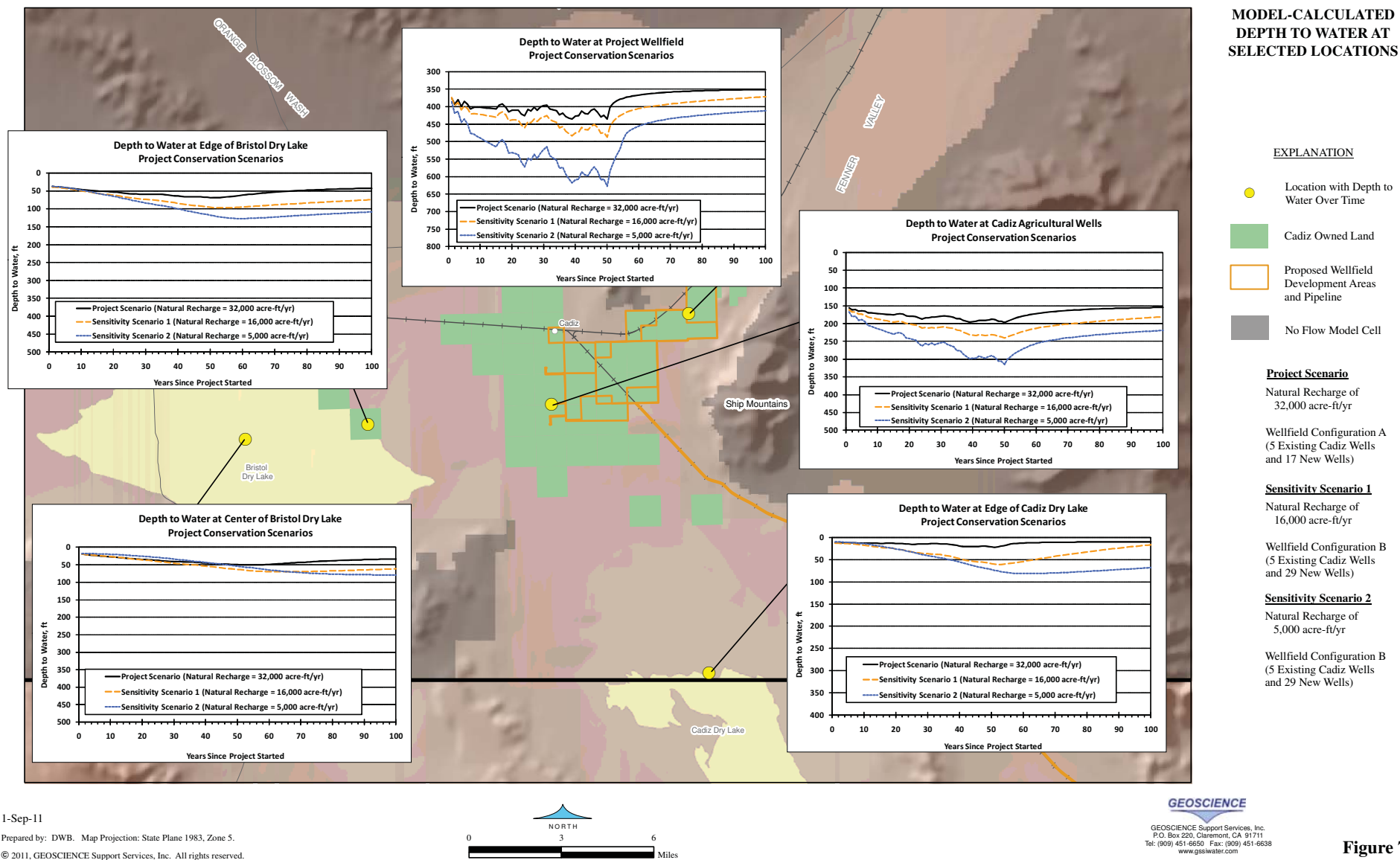
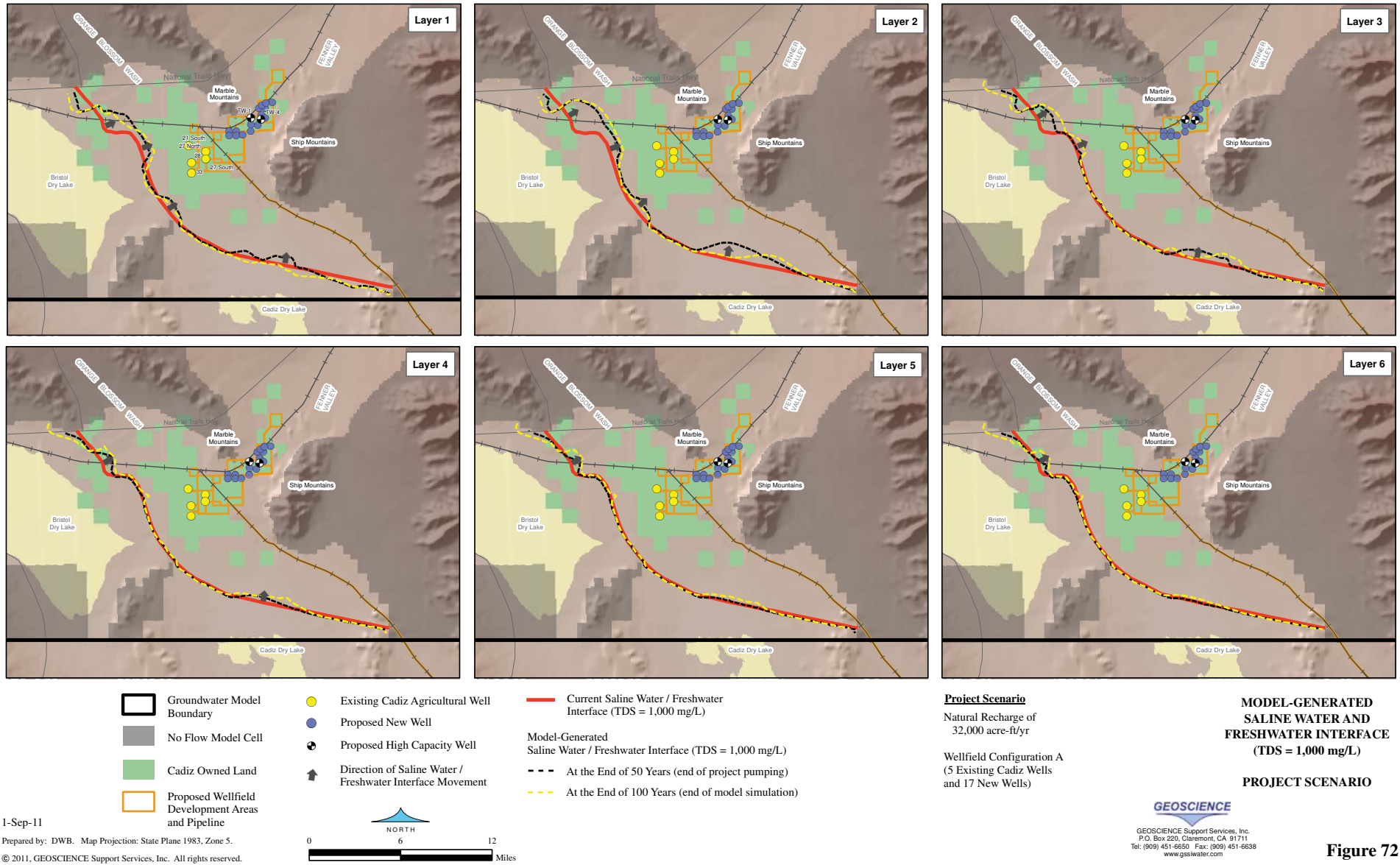
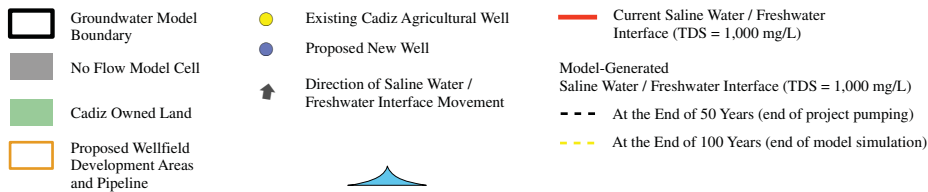
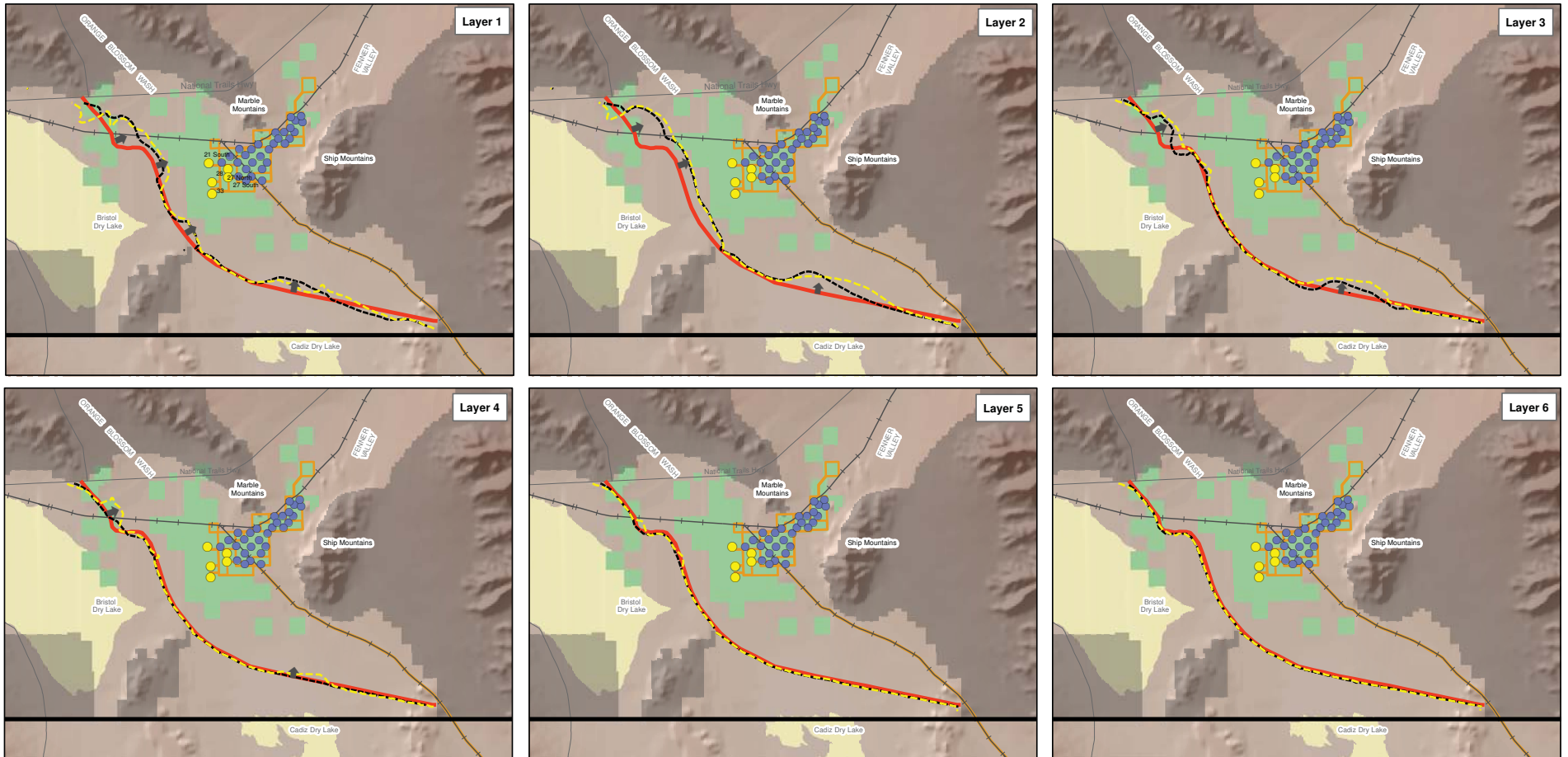


Figure 71







**Sensitivity Scenario 1**

Natural Recharge of  
16,000 acre-ft/yr

Wellfield Configuration B  
(5 Existing Cadiz Wells  
and 29 New Wells)

**MODEL-GENERATED  
SALINE WATER AND  
FRESHWATER INTERFACE  
(TDS = 1,000 mg/L)**

**SENSITIVITY SCENARIO 1**

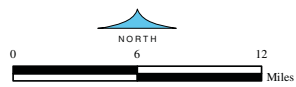
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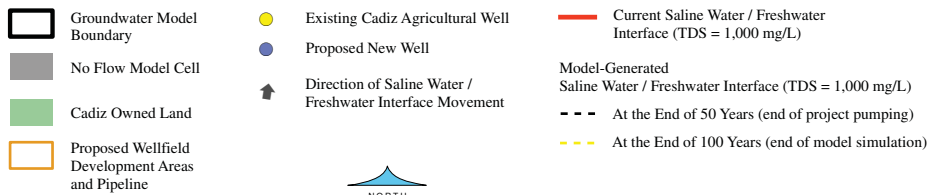
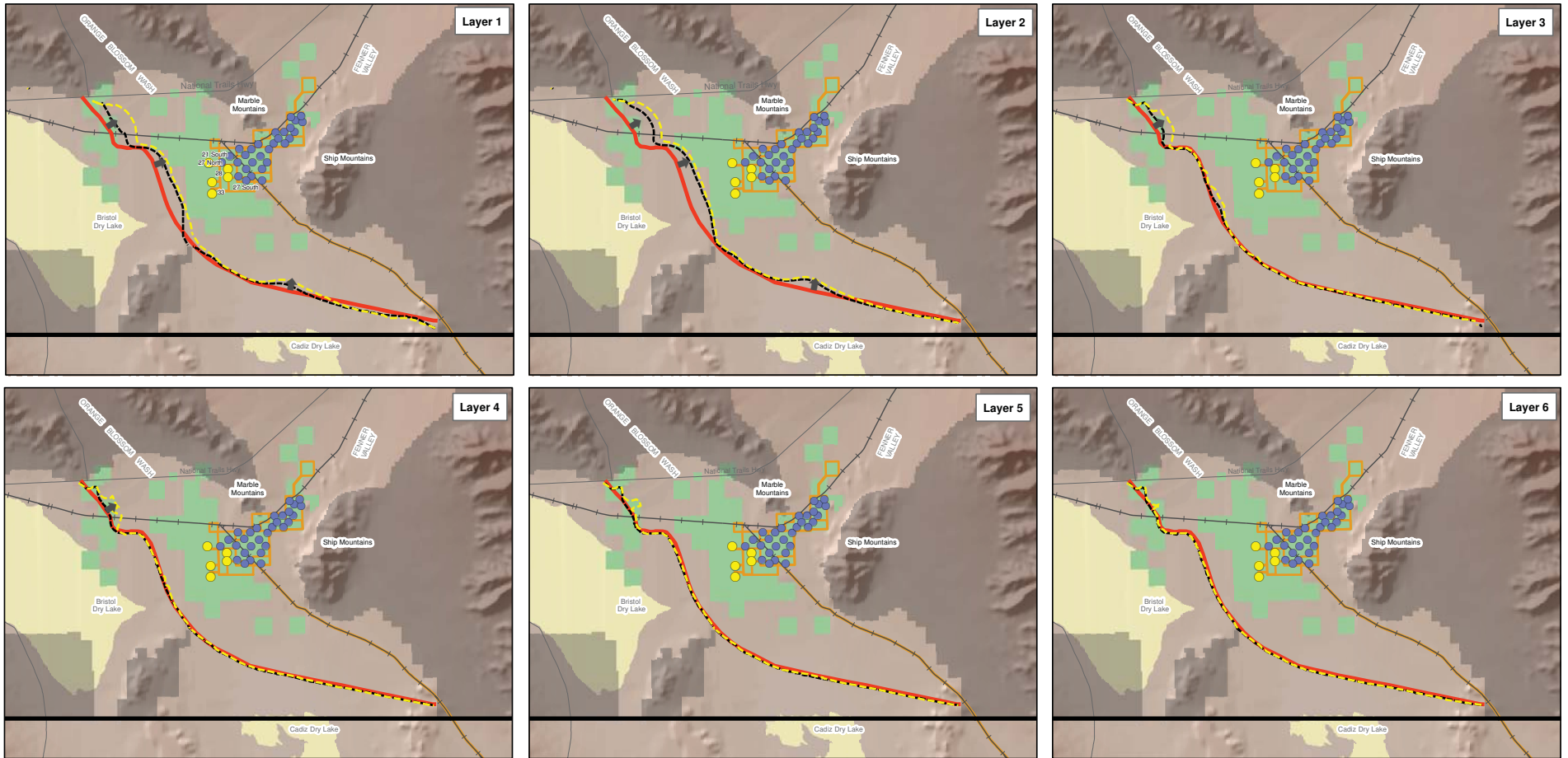
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**Figure 73**



**Sensitivity Scenario 2**

Natural Recharge of 5,000 acre-ft/yr

Wellfield Configuration B (5 Existing Cadiz Wells and 29 New Wells)

**MODEL-GENERATED SALINE WATER AND FRESHWATER INTERFACE (TDS = 1,000 mg/L)**

**SENSITIVITY SCENARIO 2**

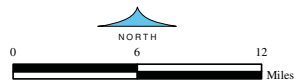
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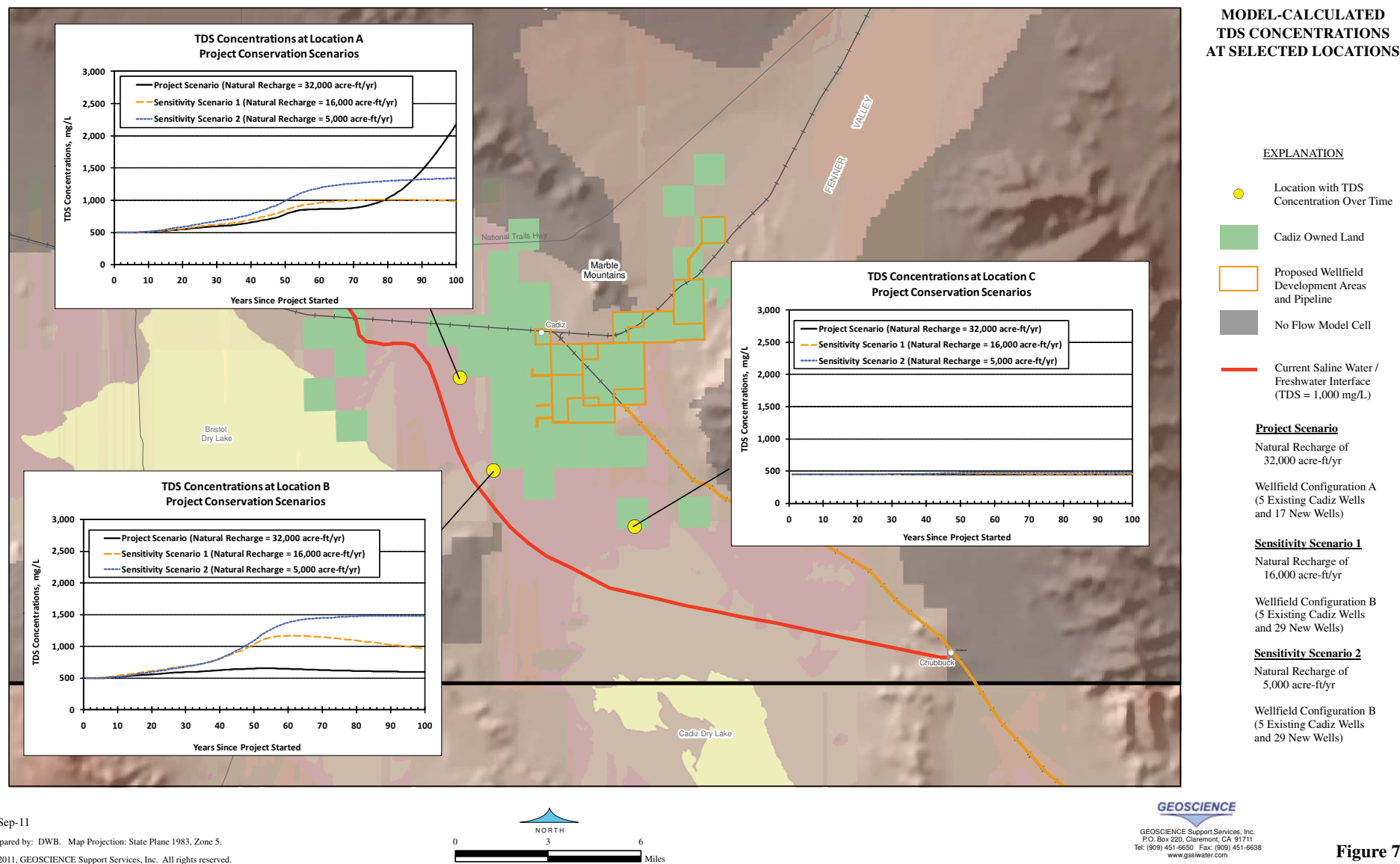
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**Figure 74**





### Cumulative Annual Changes in Groundwater Storage Conservation Scenarios

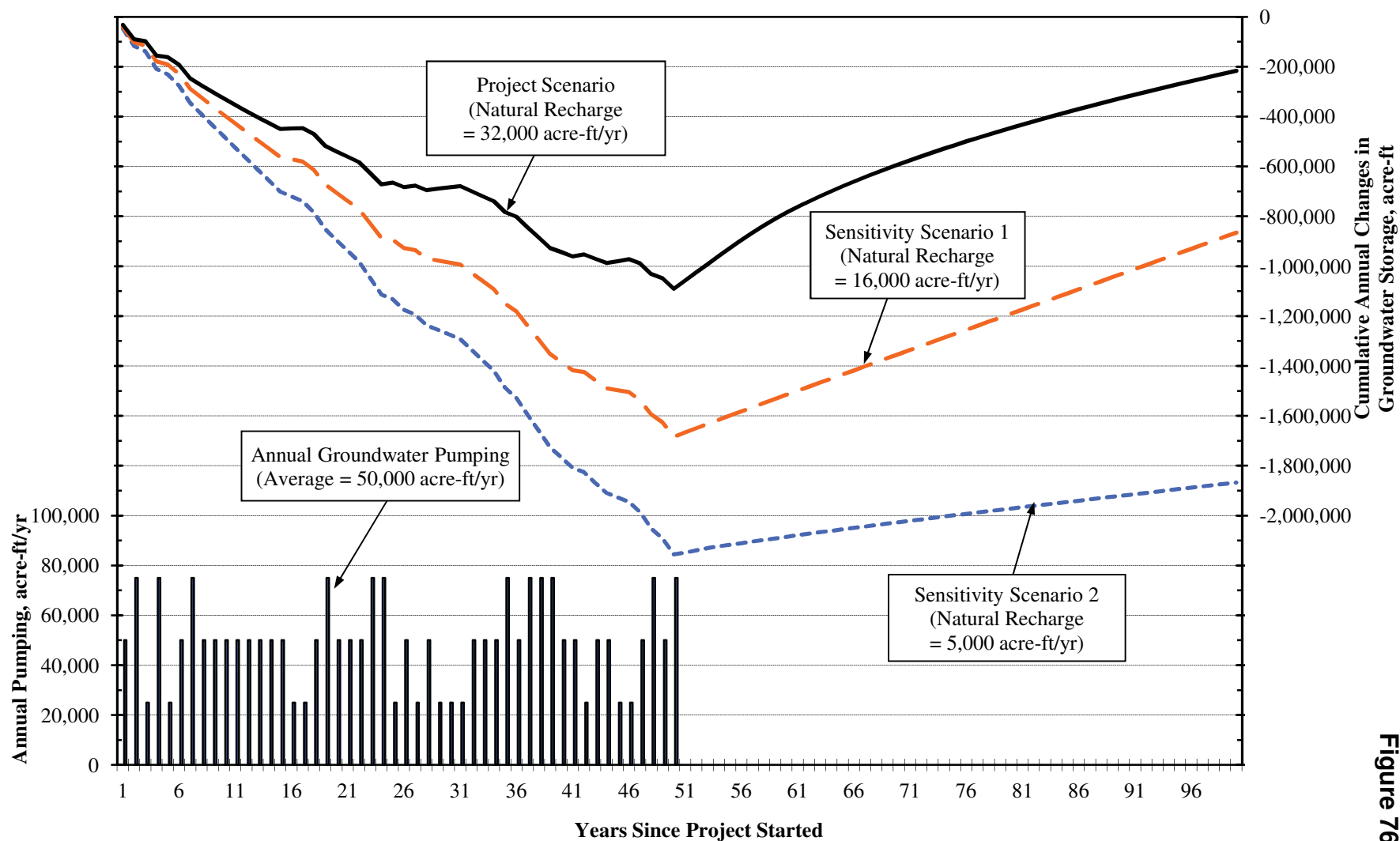
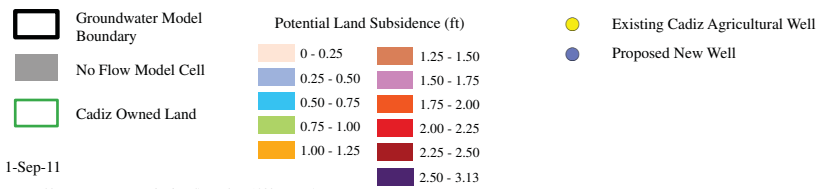
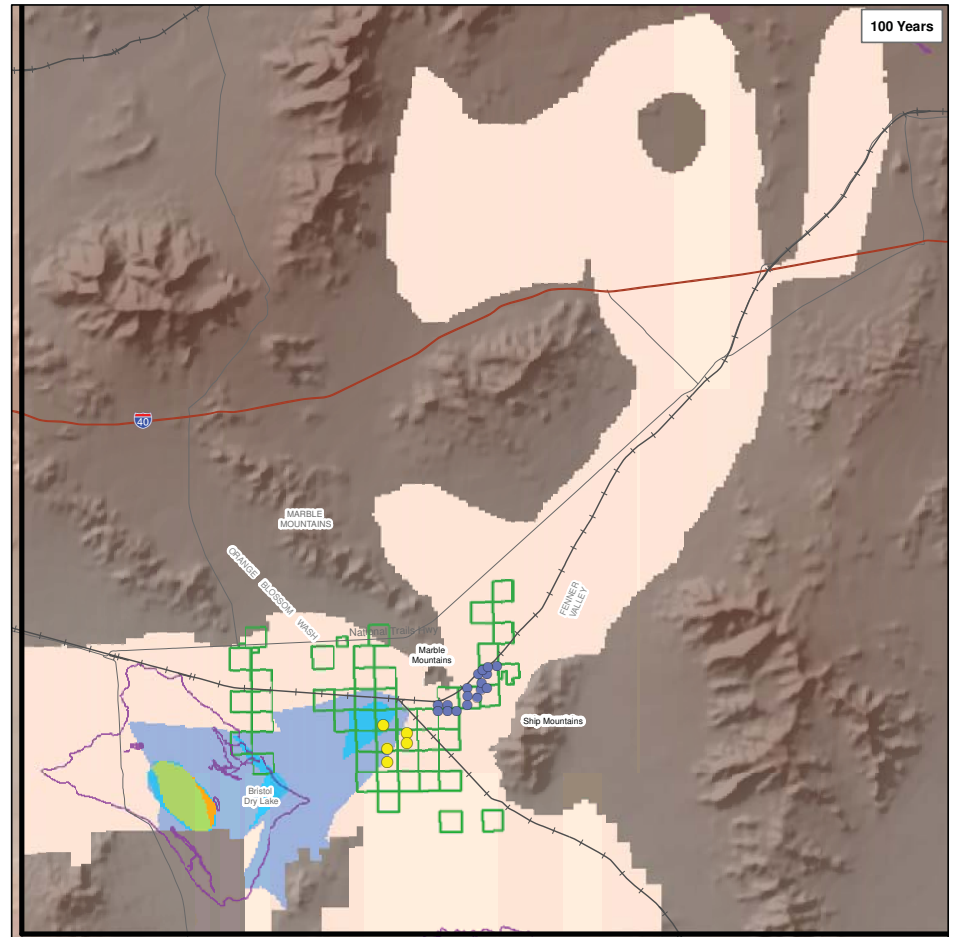
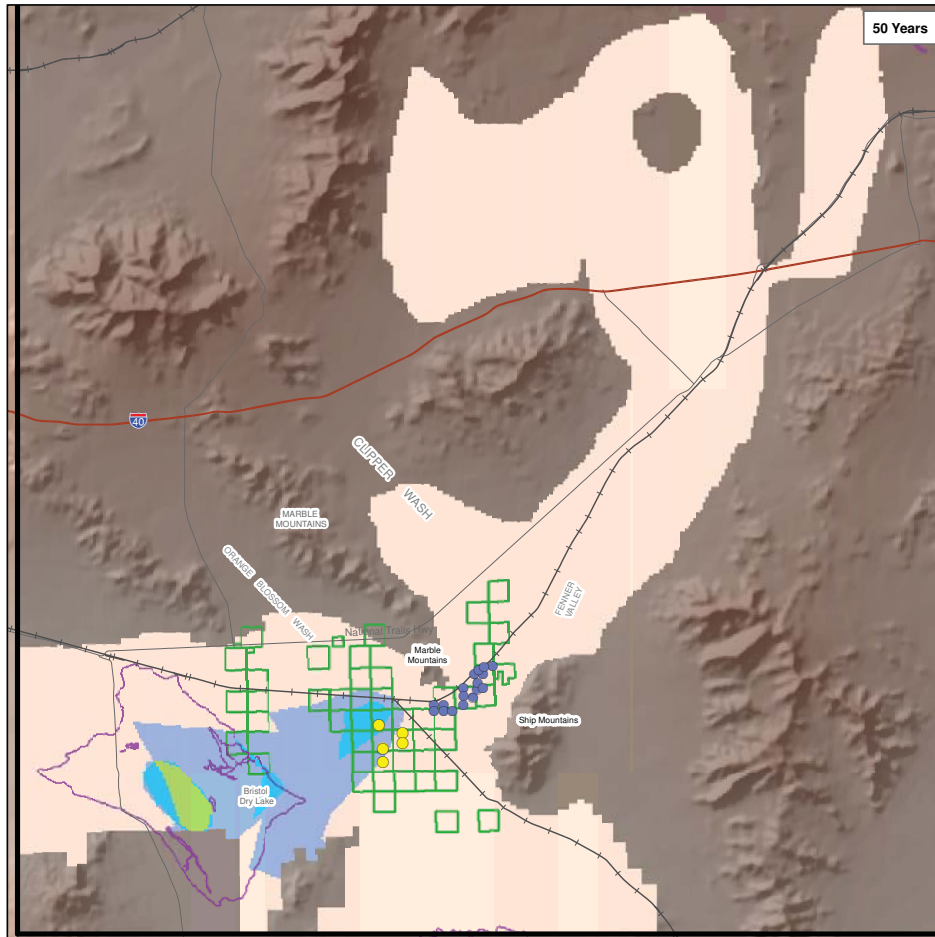


Figure 76



**Project Scenario**

Natural Recharge of  
32,000 acre-ft/yr

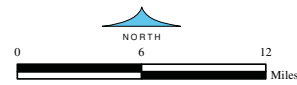
Wellfield Configuration A  
(5 Existing Cadiz Wells  
and 17 New Wells)

**MODEL-CALCULATED  
POTENTIAL LAND  
SUBSIDENCE****PROJECT SCENARIO**

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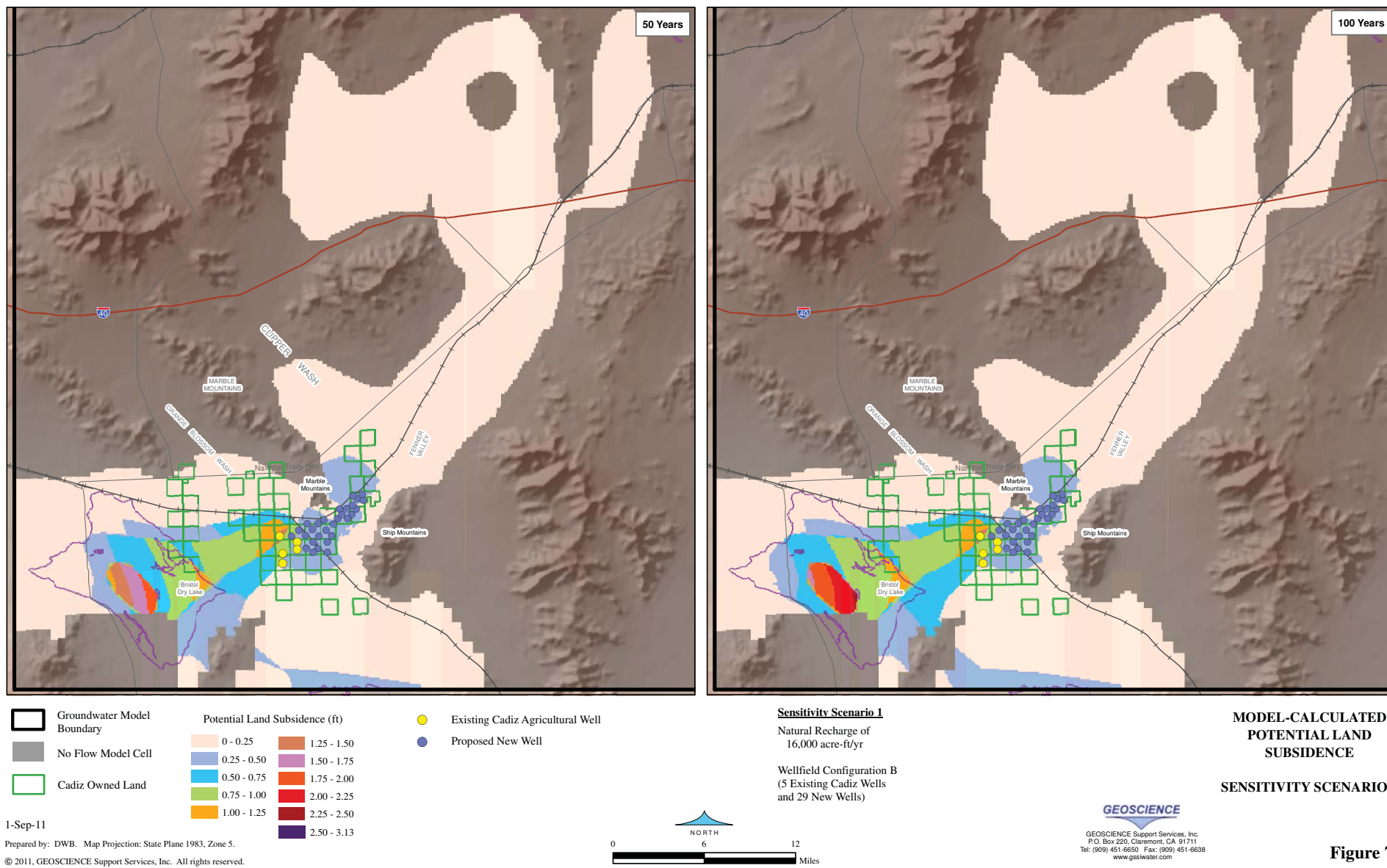
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**Figure 77**



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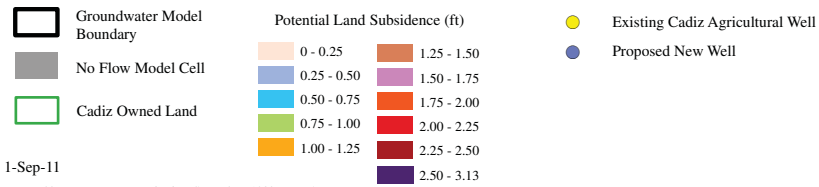
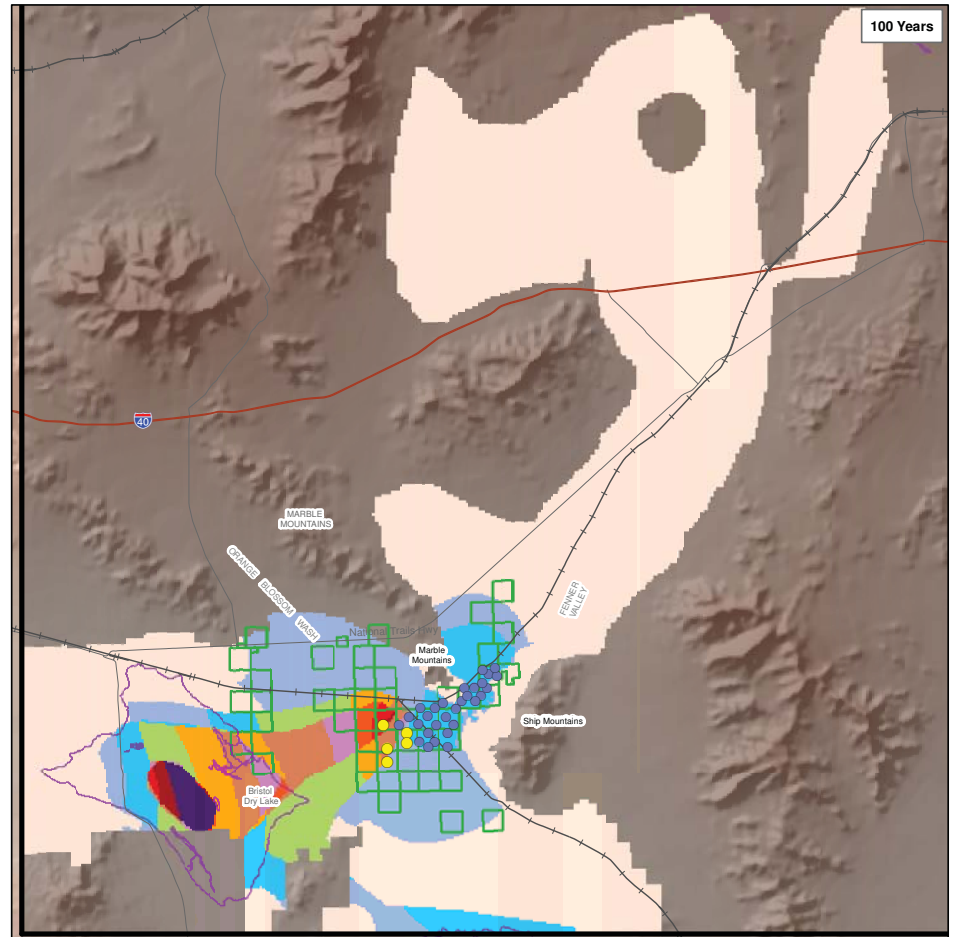
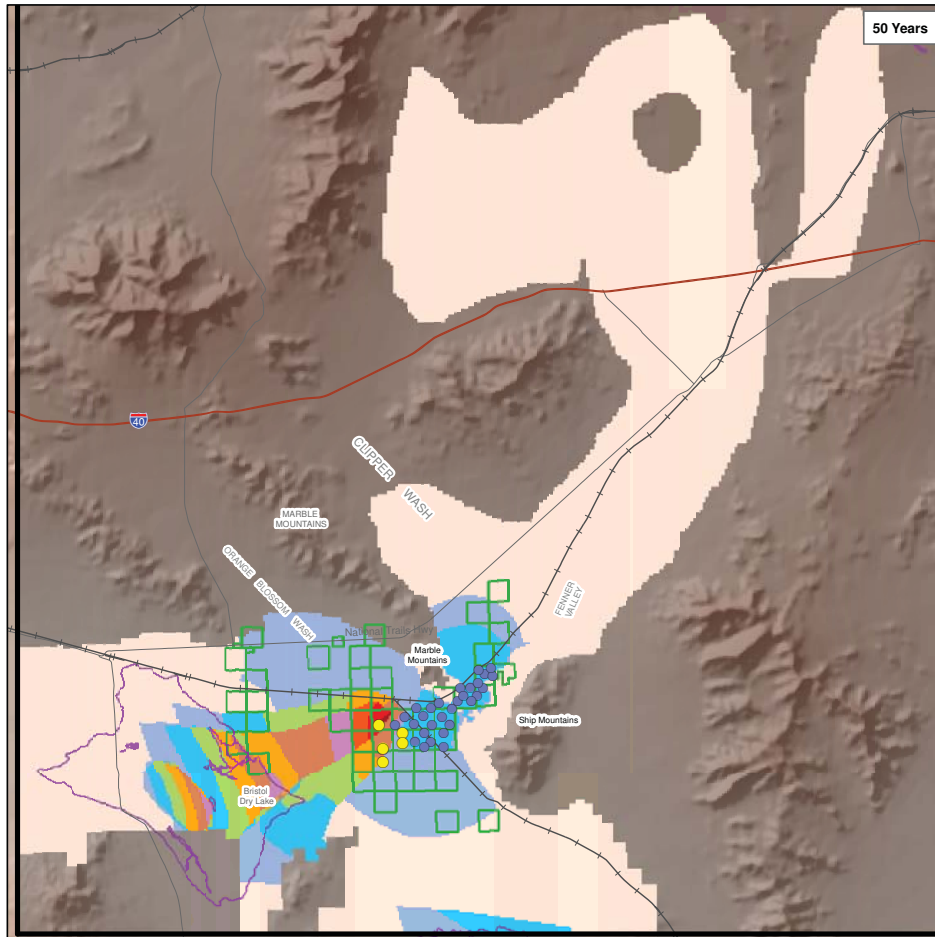
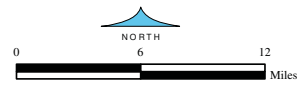
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**Sensitivity Scenario 2**Natural Recharge of  
5,000 acre-ft/yrWellfield Configuration B  
(5 Existing Cadiz Wells  
and 29 New Wells)**MODEL-CALCULATED  
POTENTIAL LAND  
SUBSIDENCE****SENSITIVITY SCENARIO 2****GEOSCIENCE**GEOSCIENCE Support Services, Inc.  
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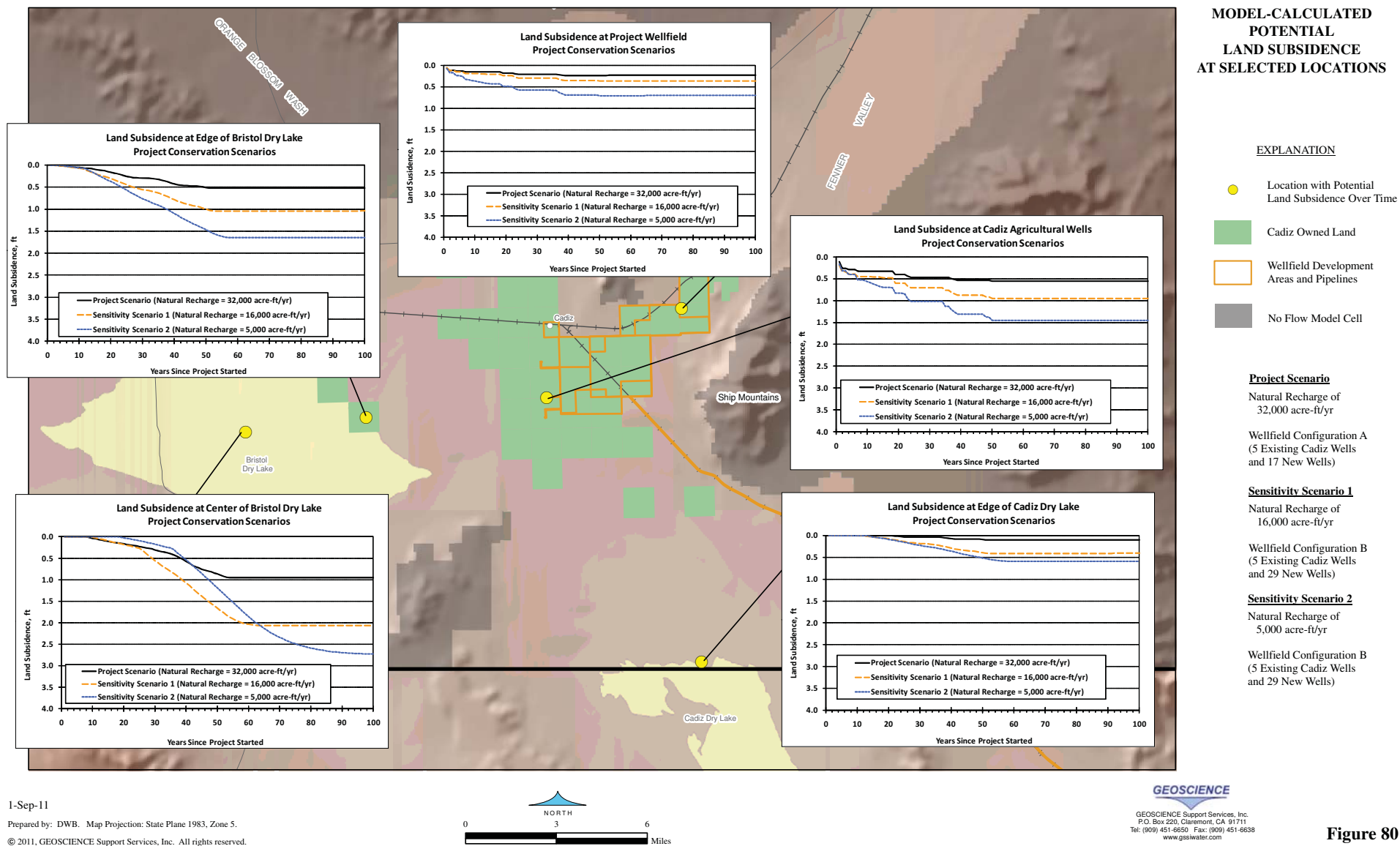
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**Figure 79**

# MODEL-CALCULATED POTENTIAL LAND SUBSIDENCE AT SELECTED LOCATIONS



## TABLES



**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
1	1986	0	570	0	660	840	390	510	0	2,970
2	1987	0	646	0	748	952	442	578	0	3,366
3	1988	0	779	0	902	1,148	533	697	0	4,059
4	1989	0	1,140	0	1,320	1,680	780	1,020	0	5,940
5	1990	0	1,291	0	1,485	1,894	858	1,161	0	6,689
6	Jan-91	0	9	0	11	10	7	11	0	48
7	Feb-91	0	21	0	14	26	20	28	0	109
8	Mar-91	0	17	0	22	17	27	37	0	120
9	Apr-91	0	32	0	87	36	73	93	0	321
10	May-91	0	108	0	93	0	122	161	0	484
11	Jun-91	0	102	0	92	213	39	179	0	625
12	Jul-91	0	134	0	92	275	0	152	0	653
13	Aug-91	0	51	0	96	195	0	115	0	457
14	Sep-91	0	31	0	75	100	0	73	0	279
15	Oct-91	0	43	0	76	71	0	13	0	203
16	Nov-91	0	35	0	52	52	0	12	0	151
17	Dec-91	0	37	0	42	36	0	21	0	136
18	Jan-92	0	2	0	6	0	0	5	0	13
19	Feb-92	0	20	0	56	31	0	36	0	143
20	Mar-92	0	53	0	53	98	0	83	0	287
21	Apr-92	0	90	0	88	107	57	137	0	479
22	May-92	0	102	0	109	158	49	174	0	592
23	Jun-92	0	107	0	121	212	0	154	0	594
24	Jul-92	0	94	0	319	242	0	142	0	797
25	Aug-92	0	59	0	102	131	0	103	0	395
26	Sep-92	0	52	0	17	101	28	87	0	285
27	Oct-92	0	0	0	0	56	0	0	0	56
28	Nov-92	0	0	0	0	46	0	0	0	46
29	Dec-92	0	0	0	0	77	0	0	0	77
30	Jan-93	0	27	0	0	28	7	65	0	127
31	Feb-93	0	43	0	0	61	16	37	0	157
32	Mar-93	0	64	0	0	80	70	14	0	228
33	Apr-93	0	66	0	0	76	83	94	0	319
34	May-93	0	111	0	91	133	139	148	0	622
35	Jun-93	0	181	0	110	118	148	190	0	747
36	Jul-93	0	152	0	117	121	193	198	0	781
37	Aug-93	0	44	0	101	105	118	111	0	479
38	Sep-93	0	24	0	80	85	12	148	0	349
39	Oct-93	0	14	0	61	98	0	122	0	295
40	Nov-93	0	0	0	52	67	0	5	0	125

**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
41	Dec-93	0	0	0	46	0	0	0	0	46
42	Jan-94	0	0	0	40	25	18	5	0	88
43	Feb-94	0	0	0	20	53	45	37	0	155
44	Mar-94	0	7	0	71	111	43	100	0	331
45	Apr-94	0	92	0	127	203	29	168	0	619
46	May-94	0	172	0	197	237	1	189	0	796
47	Jun-94	0	190	0	209	202	117	177	0	895
48	Jul-94	0	221	0	218	163	104	152	0	858
49	Aug-94	0	39	7	137	27	108	156	0	475
50	Sep-94	0	21	21	2	31	65	94	0	235
51	Oct-94	0	15	14	0	1	12	41	0	84
52	Nov-94	0	0	11	0	30	0	5	0	47
53	Dec-94	0	79	10	0	53	12	0	0	154
54	Jan-95	0	0	4	0	22	9	0	0	35
55	Feb-95	0	20	13	23	85	54	55	0	249
56	Mar-95	0	45	19	63	102	62	91	0	382
57	Apr-95	137	82	21	73	107	56	101	0	577
58	May-95	134	110	37	152	199	115	212	0	960
59	Jun-95	205	177	39	152	188	124	348	0	1,233
60	Jul-95	39	158	32	140	148	88	0	0	605
61	Aug-95	106	58	35	145	112	60	108	0	624
62	Sep-95	123	45	38	140	106	48	88	0	589
63	Oct-95	124	17	32	118	94	11	22	0	417
64	Nov-95	53	0	13	35	67	3	0	0	171
65	Dec-95	28	0	3	45	51	0	0	0	127
66	Jan-96	21	16	9	55	21	32	2	0	156
67	Feb-96	33	40	18	65	0	51	68	0	275
68	Mar-96	88	88	35	98	59	84	159	0	612
69	Apr-96	54	148	37	107	139	97	188	0	770
70	May-96	101	164	41	135	178	105	195	0	919
71	Jun-96	120	162	37	151	185	107	190	0	951
72	Jul-96	85	126	41	130	185	95	193	0	855
73	Aug-96	2	35	42	102	106	61	71	0	418
74	Sep-96	13	33	36	94	142	50	61	0	428
75	Oct-96	3	19	32	74	50	17	23	0	217
76	Nov-96	0	3	7	4	36	3	4	0	57
77	Dec-96	1	2	8	30	18	1	2	0	62
78	Jan-97	0	35	7	7	34	0	30	0	114
79	Feb-97	0	59	10	15	48	0	63	0	195
80	Mar-97	67	71	25	93	64	30	82	0	433

**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
81	Apr-97	20	133	33	116	118	85	155	0	659
82	May-97	64	136	41	129	146	94	204	0	814
83	Jun-97	210	177	39	105	148	98	192	0	969
84	Jul-97	187	120	39	129	128	93	166	0	863
85	Aug-97	93	81	37	117	123	51	92	0	593
86	Sep-97	63	51	25	80	75	35	58	0	387
87	Oct-97	18	10	25	83	93	12	21	0	262
88	Nov-97	11	4	5	25	25	6	0	0	76
89	Dec-97	16	6	1	33	37	8	0	0	101
90	Jan-98	6	25	0	27	35	14	14	0	120
91	Feb-98	2	9	0	18	24	11	25	0	88
92	Mar-98	31	43	18	43	44	32	46	0	257
93	Apr-98	70	63	47	56	60	48	98	0	442
94	May-98	196	101	60	64	53	95	190	0	758
95	Jun-98	195	143	97	3	93	97	182	0	810
96	Jul-98	229	124	109	54	114	96	183	0	909
97	Aug-98	194	95	93	71	96	63	164	0	776
98	Sep-98	48	39	89	63	73	11	69	0	393
99	Oct-98	18	30	44	55	62	20	61	0	290
100	Nov-98	23	9	15	18	27	15	6	0	114
101	Dec-98	20	19	10	20	46	6	8	0	130
102	Jan-99	12	7	3	26	36	0	12	0	95
103	Feb-99	27	17	2	25	35	0	38	0	145
104	Mar-99	57	37	1	43	60	2	70	192	461
105	Apr-99	181	128	50	47	74	53	139	106	779
106	May-99	182	137	74	103	142	92	176	47	954
107	Jun-99	198	168	139	112	123	93	160	159	1,151
108	Jul-99	198	138	148	118	109	89	168	261	1,228
109	Aug-99	199	106	114	111	107	9	170	230	1,046
110	Sep-99	146	73	42	96	87	5	124	123	696
111	Oct-99	99	43	44	56	55	6	40	0	344
112	Nov-99	23	8	76	59	12	3	0	0	179
113	Dec-99	9	5	38	32	18	14	0	0	116
114	Jan-00	10	12	29	27	8	20	0	0	106
115	Feb-00	49	24	47	11	19	9	34	0	192
116	Mar-00	85	39	41	39	41	19	86	0	351
117	Apr-00	117	74	71	62	57	37	131	0	550
118	May-00	166	119	115	55	96	71	176	0	799
119	Jun-00	184	161	125	92	123	189	178	0	1,053
120	Jul-00	187	139	99	113	117	61	184	0	900

**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
121	Aug-00	181	83	139	128	101	24	167	0	823
122	Sep-00	157	73	104	83	81	25	131	0	655
123	Oct-00	102	33	87	68	60	50	2	0	401
124	Nov-00	16	16	30	29	22	6	33	0	152
125	Dec-00	9	9	5	31	33	0	23	0	109
126	Jan-01	24	21	23	25	33	0	34	0	159
127	Feb-01	60	67	29	28	51	30	71	0	335
128	Mar-01	62	75	38	25	55	42	80	0	378
129	Apr-01	83	82	48	35	70	61	103	0	482
130	May-01	130	144	108	76	111	56	146	0	771
131	Jun-01	169	157	148	109	129	77	161	0	949
132	Jul-01	165	101	127	98	107	61	150	0	809
133	Aug-01	53	51	98	74	91	20	64	0	452
134	Sep-01	53	41	79	65	64	19	54	0	374
135	Oct-01	63	54	39	33	34	15	55	0	294
136	Nov-01	18	27	10	21	30	8	37	0	151
137	Dec-01	14	5	24	0	22	10	7	0	82
138	Jan-02	24	7	15	9	23	1	10	0	89
139	Feb-02	47	27	0	26	25	0	38	0	164
140	Mar-02	58	50	8	31	31	0	53	0	231
141	Apr-02	89	74	17	47	42	0	74	0	343
142	May-02	216	186	229	219	203	165	162	0	1,380
143	Jun-02	178	147	130	91	98	80	149	0	872
144	Jul-02	161	143	135	108	96	83	157	0	882
145	Aug-02	171	96	103	81	23	69	142	0	684
146	Sep-02	70	77	71	71	0	42	125	0	456
147	Oct-02	12	59	59	48	0	44	78	0	300
148	Nov-02	6	16	31	27	0	11	24	0	116
149	Dec-02	14	5	24	0	22	10	7	0	82
150	Jan-03	4	3	27	23	0	6	10	0	73
151	Feb-03	7	20	15	18	3	14	21	0	98
152	Mar-03	54	43	16	10	21	24	44	0	213
153	Apr-03	84	66	24	42	83	39	73	0	411
154	May-03	178	134	67	109	190	76	140	0	896
155	Jun-03	174	138	114	132	181	79	132	0	950
156	Jul-03	187	130	121	120	203	81	134	0	975
157	Aug-03	141	98	106	101	65	56	100	0	666
158	Sep-03	102	76	19	74	57	30	84	0	442
159	Oct-03	42	56	19	31	59	0	22	0	229
160	Nov-03	18	5	1	22	18	0	0	0	63

**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
161	Dec-03	22	5	0	29	24	0	0	0	82
162	Jan-04	27	23	3	29	21	0	0	0	103
163	Feb-04	16	21	0	19	19	0	0	0	75
164	Mar-04	49	61	9	44	60	15	32	0	270
165	Apr-04	40	167	23	39	68	42	17	0	396
166	May-04	64	85	24	80	92	55	98	0	498
167	Jun-04	75	99	50	70	110	64	117	0	584
168	Jul-04	72	83	101	142	111	31	112	0	652
169	Aug-04	56	65	119	148	88	75	135	0	687
170	Sep-04	80	76	115	127	0	57	105	0	558
171	Oct-04	30	30	52	62	0	22	35	0	231
172	Nov-04	8	3	27	32	0	12	34	0	115
173	Dec-04	7	0	21	27	0	5	1	0	61
174	Jan-05	2	9	10	9	0	2	5	0	37
175	Feb-05	1	16	2	0	0	6	8	0	33
176	Mar-05	30	46	5	13	14	26	48	0	181
177	Apr-05	35	53	15	18	43	31	58	0	252
178	May-05	80	41	49	64	95	58	103	0	490
179	Jun-05	82	178	127	129	157	80	136	0	889
180	Jul-05	78	165	132	122	189	79	140	0	905
181	Aug-05	65	101	57	129	190	76	141	0	760
182	Sep-05	33	52	52	130	101	47	90	0	504
183	Oct-05	19	25	103	94	16	12	31	0	299
184	Nov-05	122	9	34	34	0	3	6	0	208
185	Dec-05	5	0	27	29	0	0	0	0	61
186	Jan-06	6	7	26	32	0	1	4	0	75
187	Feb-06	21	29	23	13	0	0	23	0	109
188	Mar-06	26	37	30	31	22	0	44	0	188
189	Apr-06	30	42	27	34	27	8	86	0	252
190	May-06	69	100	70	89	71	44	62	0	504
191	Jun-06	120	134	106	120	66	68	134	0	748
192	Jul-06	143	118	109	127	7	40	146	0	690
193	Aug-06	157	129	113	129	0	0	138	0	666
194	Sep-06	145	119	111	89	0	0	103	0	567
195	Oct-06	14	62	109	38	0	0	66	0	291
196	Nov-06	0	31	110	106	0	5	30	0	282
197	Dec-06	0	0	27	33	0	0	5	0	64
198	Jan-07	24	3	17	33	5	0	6	0	88
199	Feb-07	1	27	0	26	23	0	10	0	86
200	Mar-07	0	44	26	33	24	0	4	0	130



**Groundwater Pumping for the Transient Model Calibration - 1986 to 2009**

Stress Period	Time	21N	21S	22	27N	27S	28	33	PW-1	Total
		[acre-ft]								
201	Apr-07	200	98	40	53	3	30	48	0	472
202	May-07	62	63	66	80	112	35	94	0	512
203	Jun-07	99	85	110	104	100	0	131	0	629
204	Jul-07	108	87	0	69	100	0	130	0	493
205	Aug-07	88	70	0	147	89	0	34	0	428
206	Sep-07	65	51	0	106	33	0	62	0	317
207	Oct-07	27	34	0	96	0	0	37	0	193
208	Nov-07	16	19	0	103	0	0	16	0	153
209	Dec-07	17	1	18	50	0	0	0	0	86
210	Jan-08	12	2	0	16	28	0	0	0	58
211	Feb-08	11	13	0	8	22	0	0	0	54
212	Mar-08	25	21	0	0	64	0	0	0	109
213	Apr-08	48	44	0	1	76	0	0	0	169
214	May-08	51	46	0	42	60	0	0	0	200
215	Jun-08	100	67	0	78	100	1	0	0	346
216	Jul-08	86	51	0	86	119	1	0	0	344
217	Aug-08	33	23	0	57	80	0	2	0	194
218	Sep-08	40	27	0	50	69	0	1	0	187
219	Oct-08	36	24	0	57	55	0	2	0	174
220	Nov-08	14	8	0	26	40	0	1	0	89
221	Dec-08	8	3	0	14	21	0	0	0	45
222	Jan-09	7	3	0	18	11	0	0	0	38
223	Feb-09	22	6	0	7	14	0	0	0	48
224	Mar-09	23	29	0	52	40	0	0	0	144
225	Apr-09	45	43	0	57	60	0	11	0	216
226	May-09	62	53	3	20	61	0	27	0	226
227	Jun-09	66	78	9	0	0	0	78	0	230
228	Jul-09	158	106	13	0	0	0	120	0	397
229	Aug-09	66	49	13	0	0	0	108	0	236
230	Sep-09	43	0	12	0	0	0	98	0	152
231	Oct-09	48	0	7	0	0	0	60	0	115
232	Nov-09	33	0	4	0	18	0	0	0	55
233	Dec-09	13	0	1	0	12	0	0	0	26
<b>Total</b>		<b>12,356</b>	<b>17,942</b>	<b>7,662</b>	<b>19,514</b>	<b>21,962</b>	<b>10,332</b>	<b>20,680</b>	<b>1,118</b>	<b>111,566</b>

Values in bold indicate the amount of groundwater pumping was estimated based on records from previous year.

**Groundwater Budget for Project Scenario - Natural Recharge of 32,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
1	32,425	726	15,218	50,003	7	-32,078	-32,078
2	32,425	1,033	16,174	75,005	1	-57,722	-89,800
3	32,425	156	15,700	25,002	8	-8,129	-97,928
4	32,425	870	15,319	75,005	0	-57,029	-154,957
5	32,425	277	14,217	25,002	10	-6,527	-161,484
6	32,425	371	13,661	50,003	0	-30,868	-192,352
7	32,425	1,151	12,884	75,005	0	-54,313	-246,666
8	32,425	629	11,295	50,003	2	-28,246	-274,911
9	32,425	638	10,024	50,003	0	-26,964	-301,875
10	32,425	651	9,190	50,003	0	-26,117	-327,992
11	32,425	667	8,520	50,003	0	-25,431	-353,423
12	32,425	670	7,927	50,003	0	-24,835	-378,259
13	32,425	680	7,387	50,003	0	-24,285	-402,544
14	32,425	678	6,873	50,003	0	-23,774	-426,318
15	32,425	672	6,379	50,003	0	-23,285	-449,603
16	32,425	439	5,994	25,002	9	1,859	-447,744
17	32,425	317	6,132	25,002	6	1,602	-446,142
18	32,425	354	6,514	50,003	1	-23,739	-469,881
19	32,425	1,051	6,339	75,005	0	-47,868	-517,749
20	32,425	696	5,423	50,003	2	-22,307	-540,057
21	32,425	642	4,632	50,003	0	-21,568	-561,625
22	32,425	627	4,072	50,003	0	-21,023	-582,649
23	32,425	1,276	3,506	75,005	0	-44,811	-627,459
24	32,425	1,338	2,548	75,005	0	-43,790	-671,250
25	32,425	711	1,621	25,002	16	6,497	-664,753
26	32,425	539	1,392	50,003	1	-18,432	-683,185
27	32,425	448	1,363	25,002	10	6,498	-676,687
28	32,425	330	1,550	50,003	1	-18,799	-695,486
29	32,425	365	1,669	25,002	9	6,110	-689,376

**Table 2**

**Groundwater Budget for Project Scenario - Natural Recharge of 32,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
30	32,425	294	2,004	25,002	6	5,707	-683,669
31	32,425	188	2,574	25,002	4	5,032	-678,637
32	32,425	226	3,111	50,003	1	-20,464	-699,101
33	32,425	209	3,135	50,003	0	-20,504	-719,605
34	32,425	386	2,806	50,003	0	-19,998	-739,603
35	32,425	730	2,269	75,005	0	-44,119	-783,722
36	32,425	667	1,409	50,003	3	-18,323	-802,045
37	32,425	1,228	775	75,005	0	-42,128	-844,173
38	32,425	1,423	386	75,005	0	-41,543	-885,716
39	32,425	1,494	331	75,005	0	-41,417	-927,133
40	32,425	1,080	304	50,003	6	-16,809	-943,942
41	32,425	915	277	50,003	2	-16,942	-960,884
42	32,425	727	249	25,002	12	7,889	-952,995
43	32,425	591	222	50,003	1	-17,210	-970,206
44	32,425	366	200	50,003	0	-17,413	-987,619
45	32,425	500	177	25,002	10	7,736	-979,883
46	32,425	390	153	25,002	7	7,652	-972,231
47	32,425	338	132	50,003	1	-17,373	-989,603
48	32,425	559	113	75,005	0	-42,134	-1,031,738
49	32,425	612	97	50,003	2	-17,065	-1,048,802
50	32,425	1,095	82	75,005	0	-41,568	-1,090,370
51	32,425	654	68	0	28	32,984	-1,057,386
52	32,425	402	53	0	19	32,754	-1,024,633
53	32,425	273	39	0	17	32,642	-991,991
54	32,425	169	27	0	16	32,551	-959,440
55	32,425	102	18	0	15	32,493	-926,947
56	32,425	69	424	0	15	32,054	-894,893
57	32,425	53	2,307	0	14	30,156	-864,737
58	32,425	45	4,343	0	13	28,114	-836,622

**Table 2**

**Groundwater Budget for Project Scenario - Natural Recharge of 32,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
59	32,425	39	6,206	0	12	26,247	-810,376
60	32,425	35	7,818	0	11	24,631	-785,745
61	32,425	32	9,199	0	10	23,248	-762,496
62	32,425	24	10,365	0	8	22,077	-740,420
63	32,425	22	11,344	0	7	21,095	-719,324
64	32,425	17	12,204	0	5	20,232	-699,092
65	32,425	25	12,976	0	8	19,466	-679,627
66	32,425	18	13,665	0	6	18,771	-660,856
67	32,425	13	14,266	0	5	18,167	-642,689
68	32,425	12	14,809	0	5	17,624	-625,065
69	32,425	15	15,307	0	6	17,127	-607,937
70	32,425	15	15,757	0	6	16,677	-591,261
71	32,425	17	16,226	0	7	16,208	-575,052
72	32,425	16	16,650	0	6	15,784	-559,268
73	32,425	9	17,050	0	4	15,381	-543,887
74	32,425	6	17,388	0	3	15,040	-528,847
75	32,425	11	17,722	0	5	14,709	-514,138
76	32,425	8	18,057	0	4	14,372	-499,766
77	32,425	10	18,351	0	5	14,080	-485,686
78	32,425	7	18,619	0	3	13,810	-471,877
79	32,425	10	18,876	0	5	13,555	-458,322
80	32,425	7	19,116	0	3	13,313	-445,009
81	32,425	4	19,352	0	2	13,075	-431,934
82	32,425	7	19,575	0	3	12,854	-419,080
83	32,425	6	19,813	0	3	12,615	-406,465
84	32,425	5	19,991	0	2	12,436	-394,029
85	32,425	5	20,168	0	2	12,259	-381,770
86	32,425	5	20,355	0	2	12,073	-369,697
87	32,425	8	20,558	0	4	11,871	-357,826

**Table 2**

**Groundwater Budget for Project Scenario - Natural Recharge of 32,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
88	32,425	6	20,736	0	3	11,693	-346,134
89	32,425	8	20,886	0	4	11,543	-334,591
90	32,425	4	21,045	0	2	11,381	-323,210
91	32,425	2	21,182	0	1	11,243	-311,966
92	32,425	0	21,313	0	0	11,111	-300,855
93	32,425	4	21,438	0	2	10,989	-289,866
94	32,425	4	21,579	0	2	10,848	-279,018
95	32,425	1	21,710	0	1	10,716	-268,303
96	32,425	5	21,841	0	3	10,587	-257,716
97	32,425	3	21,969	0	2	10,458	-247,258
98	32,425	4	22,090	0	2	10,336	-236,922
99	32,425	0	22,205	0	0	10,220	-226,702
100	32,425	2	22,316	0	1	10,110	-216,592
Average of Year 1 to 50	32,425	660	4,887	50,003	3	-21,807	
Average of Year 1 to 100	32,425	352	9,937	25,002	4	-2,166	

- [1] Model input data  
 [2] Model-calculated  
 [3] Model-calculated  
 [4] Model input data  
 [5] Model-calculated  
 [6] = [1] + [2] - [3] - [4] - [5]  
 [7] cumulative values based on [6]

**Table 2**



**Groundwater Budget for Sensitivity Scenario 1 - Natural Recharge of 16,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
1	16,212	909	5,934	50,003	5	-38,820	-38,820
2	16,212	1,330	5,776	75,005	1	-63,239	-102,059
3	16,212	239	5,427	25,001	6	-13,983	-116,043
4	16,212	1,243	4,941	75,005	0	-62,491	-178,534
5	16,212	387	4,257	25,001	8	-12,667	-191,201
6	16,212	565	3,619	50,003	0	-36,845	-228,046
7	16,212	1,465	3,125	75,005	0	-60,453	-288,499
8	16,212	815	2,542	50,003	1	-35,518	-324,017
9	16,212	857	1,988	50,003	0	-34,922	-358,939
10	16,212	893	1,578	50,003	0	-34,475	-393,414
11	16,212	947	1,272	50,003	0	-34,116	-427,531
12	16,212	1,006	1,062	50,003	0	-33,847	-461,378
13	16,212	1,038	967	50,003	0	-33,720	-495,097
14	16,212	1,066	921	50,003	0	-33,646	-528,743
15	16,212	1,073	875	50,003	0	-33,593	-562,336
16	16,212	773	830	25,001	9	-8,855	-571,191
17	16,212	673	784	25,001	5	-8,905	-580,096
18	16,212	788	739	50,003	0	-33,743	-613,839
19	16,212	1,629	695	75,005	0	-57,859	-671,697
20	16,212	1,114	652	50,003	1	-33,330	-705,027
21	16,212	1,135	609	50,003	0	-33,265	-738,293
22	16,212	1,159	569	50,003	0	-33,200	-771,493
23	16,212	1,896	530	75,005	0	-57,426	-828,919
24	16,212	1,928	492	75,005	0	-57,356	-886,275
25	16,212	1,217	455	25,001	15	-8,043	-894,318
26	16,212	1,195	423	50,003	0	-33,019	-927,336
27	16,212	1,064	392	25,001	10	-8,126	-935,463
28	16,212	1,108	361	50,003	0	-33,044	-968,507
29	16,212	989	331	25,001	8	-8,139	-976,646

**Table 3**

**Groundwater Budget for Sensitivity Scenario 1 - Natural Recharge of 16,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
30	16,212	900	304	25,001	5	-8,197	-984,843
31	16,212	642	279	25,001	3	-8,428	-993,271
32	16,212	931	255	50,003	0	-33,114	-1,026,385
33	16,212	1,073	230	50,003	0	-32,948	-1,059,332
34	16,212	1,157	208	50,003	0	-32,841	-1,092,173
35	16,212	1,711	186	75,005	0	-57,268	-1,149,441
36	16,212	1,378	166	50,003	2	-32,581	-1,182,022
37	16,212	2,063	148	75,005	0	-56,877	-1,238,899
38	16,212	2,124	131	75,005	0	-56,799	-1,295,699
39	16,212	2,162	115	75,005	0	-56,746	-1,352,444
40	16,212	1,658	99	50,003	5	-32,236	-1,384,681
41	16,212	1,591	83	50,003	2	-32,284	-1,416,965
42	16,212	1,360	68	25,001	13	-7,509	-1,424,474
43	16,212	1,330	54	50,003	0	-32,515	-1,456,989
44	16,212	1,368	40	50,003	0	-32,463	-1,489,453
45	16,212	1,190	28	25,001	10	-7,637	-1,497,089
46	16,212	1,066	16	25,001	6	-7,745	-1,504,835
47	16,212	1,108	7	50,003	0	-32,690	-1,537,525
48	16,212	1,635	2	75,005	0	-57,159	-1,594,684
49	16,212	1,076	0	50,003	1	-32,716	-1,627,400
50	16,212	2,028	0	75,005	0	-56,765	-1,684,165
51	16,212	1,230	0	0	28	17,415	-1,666,750
52	16,212	972	0	0	19	17,166	-1,649,584
53	16,212	794	0	0	15	16,992	-1,632,592
54	16,212	679	0	0	13	16,878	-1,615,714
55	16,212	591	0	0	12	16,792	-1,598,922
56	16,212	509	0	0	11	16,710	-1,582,212
57	16,212	443	0	0	11	16,645	-1,565,568
58	16,212	388	0	0	10	16,590	-1,548,977

**Table 3**

**Groundwater Budget for Sensitivity Scenario 1 - Natural Recharge of 16,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
59	16,212	326	0	0	10	16,529	-1,532,448
60	16,212	289	0	0	10	16,492	-1,515,956
61	16,212	157	0	0	6	16,364	-1,499,592
62	16,212	213	0	0	9	16,416	-1,483,177
63	16,212	181	0	0	9	16,384	-1,466,792
64	16,212	125	0	0	7	16,331	-1,450,461
65	16,212	139	0	0	8	16,343	-1,434,119
66	16,212	99	0	0	7	16,304	-1,417,814
67	16,212	106	0	0	8	16,310	-1,401,504
68	16,212	76	0	0	6	16,282	-1,385,222
69	16,212	55	0	0	5	16,262	-1,368,960
70	16,212	63	0	0	6	16,269	-1,352,691
71	16,212	33	0	0	4	16,242	-1,336,449
72	16,212	54	0	0	6	16,261	-1,320,188
73	16,212	53	0	0	6	16,259	-1,303,929
74	16,212	39	0	0	5	16,246	-1,287,683
75	16,212	37	0	0	5	16,245	-1,271,438
76	16,212	33	0	0	5	16,241	-1,255,197
77	16,212	33	0	0	5	16,241	-1,238,957
78	16,212	31	0	0	5	16,238	-1,222,718
79	16,212	38	0	0	6	16,244	-1,206,474
80	16,212	29	0	0	5	16,237	-1,190,237
81	16,212	28	0	0	5	16,235	-1,174,002
82	16,212	17	0	0	3	16,227	-1,157,775
83	16,212	25	0	0	5	16,233	-1,141,542
84	16,212	24	0	0	5	16,232	-1,125,310
85	16,212	23	0	0	5	16,231	-1,109,080
86	16,212	22	0	0	4	16,230	-1,092,850
87	16,212	28	0	0	6	16,234	-1,076,615

**Table 3**

### Groundwater Budget for Sensitivity Scenario 1 - Natural Recharge of 16,000 acre-ft/yr

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
88	16,212	25	0	0	6	16,232	-1,060,383
89	16,212	26	0	0	6	16,232	-1,044,151
90	16,212	13	0	0	3	16,222	-1,027,929
91	16,212	18	0	0	4	16,226	-1,011,704
92	16,212	21	0	0	5	16,228	-995,476
93	16,212	16	0	0	4	16,224	-979,251
94	16,212	20	0	0	5	16,227	-963,024
95	16,212	11	0	0	3	16,220	-946,804
96	16,212	19	0	0	6	16,226	-930,578
97	16,212	10	0	0	3	16,219	-914,359
98	16,212	13	0	0	4	16,222	-898,138
99	16,212	8	0	0	3	16,218	-881,920
100	16,212	16	0	0	5	16,223	-865,697
Average of Year 1 to 50	16,212	1,201	1,091	50,003	2	-33,683	
Average of Year 1 to 100	16,212	683	546	25,002	5	-8,657	

- [1] Model input data  
 [2] Model-calculated  
 [3] Model-calculated  
 [4] Model input data  
 [5] Model-calculated  
 [6] = [1] + [2] - [3] - [4] - [5]  
 [7] cumulative values based on [6]

Table 3

**Groundwater Budget for Sensitivity Scenario 2 - Natural Recharge of 5,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
1	5,066	1,066	2,722	50,003	3	-46,596	-46,596
2	5,066	1,645	2,223	75,005	1	-70,517	-117,113
3	5,066	488	2,105	25,001	3	-21,555	-138,668
4	5,066	1,622	1,992	75,005	0	-70,309	-208,977
5	5,066	622	1,857	25,001	5	-21,176	-230,153
6	5,066	928	1,698	50,003	0	-45,707	-275,860
7	5,066	1,761	1,525	75,005	0	-69,703	-345,563
8	5,066	1,149	1,340	50,003	0	-45,128	-390,691
9	5,066	1,207	1,133	50,003	0	-44,863	-435,554
10	5,066	1,233	908	50,003	0	-44,612	-480,166
11	5,066	1,250	696	50,003	0	-44,383	-524,549
12	5,066	1,274	559	50,003	0	-44,221	-568,770
13	5,066	1,302	474	50,003	0	-44,110	-612,880
14	5,066	1,324	423	50,003	0	-44,035	-656,915
15	5,066	1,344	394	50,003	0	-43,987	-700,901
16	5,066	999	380	25,001	9	-19,325	-720,226
17	5,066	904	372	25,001	5	-19,408	-739,634
18	5,066	1,045	366	50,003	0	-44,258	-783,892
19	5,066	1,932	362	74,354	0	-67,717	-851,609
20	5,066	1,400	356	49,327	1	-43,218	-894,827
21	5,066	1,429	351	49,327	0	-43,183	-938,010
22	5,066	1,463	345	49,327	0	-43,142	-981,152
23	5,066	2,077	339	73,350	0	-66,546	-1,047,698
24	5,066	2,123	333	73,350	0	-66,494	-1,114,191
25	5,066	1,417	326	24,450	15	-18,307	-1,132,499
26	5,066	1,397	319	48,900	0	-42,755	-1,175,254
27	5,066	1,279	311	24,450	11	-18,426	-1,193,680
28	5,066	1,329	303	48,900	0	-42,808	-1,236,488
29	5,066	1,224	295	24,450	9	-18,464	-1,254,952

**Table 4**



**Groundwater Budget for Sensitivity Scenario 2 - Natural Recharge of 5,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
30	5,066	1,143	287	24,450	7	-18,534	-1,273,486
31	5,066	1,082	278	24,450	7	-18,586	-1,292,072
32	5,066	1,176	269	48,900	0	-42,926	-1,334,998
33	5,066	1,335	259	48,900	0	-42,759	-1,377,757
34	5,066	1,448	250	48,900	0	-42,636	-1,420,393
35	5,066	2,033	241	73,350	0	-66,492	-1,486,885
36	5,066	1,667	231	48,900	1	-42,399	-1,529,283
37	5,066	2,286	221	73,255	0	-66,124	-1,595,407
38	5,066	2,330	211	72,953	0	-65,767	-1,661,174
39	5,066	2,355	201	72,225	0	-65,005	-1,726,179
40	5,066	1,900	191	48,150	4	-41,380	-1,767,560
41	5,066	1,838	182	48,150	1	-41,429	-1,808,989
42	5,066	1,662	172	24,075	13	-17,532	-1,826,521
43	5,066	1,659	163	48,150	0	-41,588	-1,868,110
44	5,066	1,727	154	48,150	0	-41,512	-1,909,621
45	5,066	1,585	145	24,075	11	-17,580	-1,927,201
46	5,066	1,498	136	24,075	7	-17,655	-1,944,856
47	5,066	1,537	127	48,150	0	-41,674	-1,986,530
48	5,066	2,012	118	72,225	0	-65,266	-2,051,796
49	5,066	1,816	110	48,150	2	-41,380	-2,093,176
50	5,066	5,106	102	72,077	3	-62,010	-2,155,186
51	5,066	2,065	94	0	30	7,007	-2,148,179
52	5,066	4,072	87	0	39	9,013	-2,139,166
53	5,066	3,561	81	0	54	8,492	-2,130,674
54	5,066	2,326	74	0	49	7,269	-2,123,405
55	5,066	1,727	68	0	62	6,664	-2,116,742
56	5,066	992	63	0	73	5,923	-2,110,819
57	5,066	1,622	57	0	50	6,582	-2,104,237
58	5,066	934	52	0	25	5,923	-2,098,313

**Table 4**

**Groundwater Budget for Sensitivity Scenario 2 - Natural Recharge of 5,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
59	5,066	1,706	48	0	43	6,682	-2,091,631
60	5,066	1,424	43	0	13	6,434	-2,085,197
61	5,066	1,328	39	0	46	6,309	-2,078,888
62	5,066	1,341	34	0	58	6,315	-2,072,573
63	5,066	996	30	0	57	5,974	-2,066,599
64	5,066	614	26	0	22	5,632	-2,060,967
65	5,066	583	23	0	22	5,604	-2,055,363
66	5,066	1,112	20	0	13	6,145	-2,049,218
67	5,066	533	17	0	31	5,551	-2,043,668
68	5,066	509	14	0	26	5,535	-2,038,133
69	5,066	986	12	0	10	6,031	-2,032,102
70	5,066	449	9	0	15	5,490	-2,026,612
71	5,066	901	7	0	13	5,947	-2,020,664
72	5,066	446	5	0	43	5,464	-2,015,200
73	5,066	641	4	0	74	5,630	-2,009,570
74	5,066	654	2	0	11	5,707	-2,003,863
75	5,066	323	1	0	5	5,384	-1,998,479
76	5,066	305	0	0	5	5,366	-1,993,113
77	5,066	291	0	0	5	5,353	-1,987,760
78	5,066	278	0	0	5	5,339	-1,982,421
79	5,066	260	0	0	5	5,321	-1,977,100
80	5,066	246	0	0	5	5,308	-1,971,793
81	5,066	234	0	0	5	5,296	-1,966,497
82	5,066	223	0	0	4	5,284	-1,961,212
83	5,066	212	0	0	4	5,273	-1,955,939
84	5,066	201	0	0	4	5,263	-1,950,676
85	5,066	191	0	0	4	5,253	-1,945,423
86	5,066	182	0	0	4	5,244	-1,940,179
87	5,066	173	0	0	4	5,235	-1,934,944

**Table 4**

**Groundwater Budget for Sensitivity Scenario 2 - Natural Recharge of 5,000 acre-ft/yr**

	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Year	Inflow		Outflow			Changes in Groundwater Storage	Cumulative Changes in Groundwater
	Natural Recharge	Interbed Storage	ET	Project Pumping	Interbed Storage		
	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]	[acre-ft/yr]		
88	5,066	165	0	0	4	5,227	-1,929,717
89	5,066	157	0	0	4	5,219	-1,924,498
90	5,066	149	0	0	4	5,212	-1,919,286
91	5,066	145	0	0	4	5,207	-1,914,080
92	5,066	136	0	0	4	5,198	-1,908,882
93	5,066	129	0	0	4	5,192	-1,903,690
94	5,066	123	0	0	4	5,186	-1,898,504
95	5,066	118	0	0	4	5,180	-1,893,324
96	5,066	113	0	0	4	5,175	-1,888,148
97	5,066	108	0	0	4	5,170	-1,882,978
98	5,066	103	0	0	4	5,165	-1,877,813
99	5,066	98	0	0	4	5,161	-1,872,652
100	5,066	94	0	0	4	5,156	-1,867,496
Average of Year 1 to 50	5,066	1,549	577	49,139	2	-43,104	
Average of Year 1 to 100	5,066	1,137	298	24,570	11	-18,675	

- [1] Model input data  
 [2] Model-calculated  
 [3] Model-calculated  
 [4] Model input data and was adjusted by model due to dry cells  
 [5] Model-calculated  
 [6] = [1] + [2] - [3] - [4] - [5]  
 [7] cumulative values based on [6]

**Table 4**

# VOLUME I

***GEOSCIENCE***

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