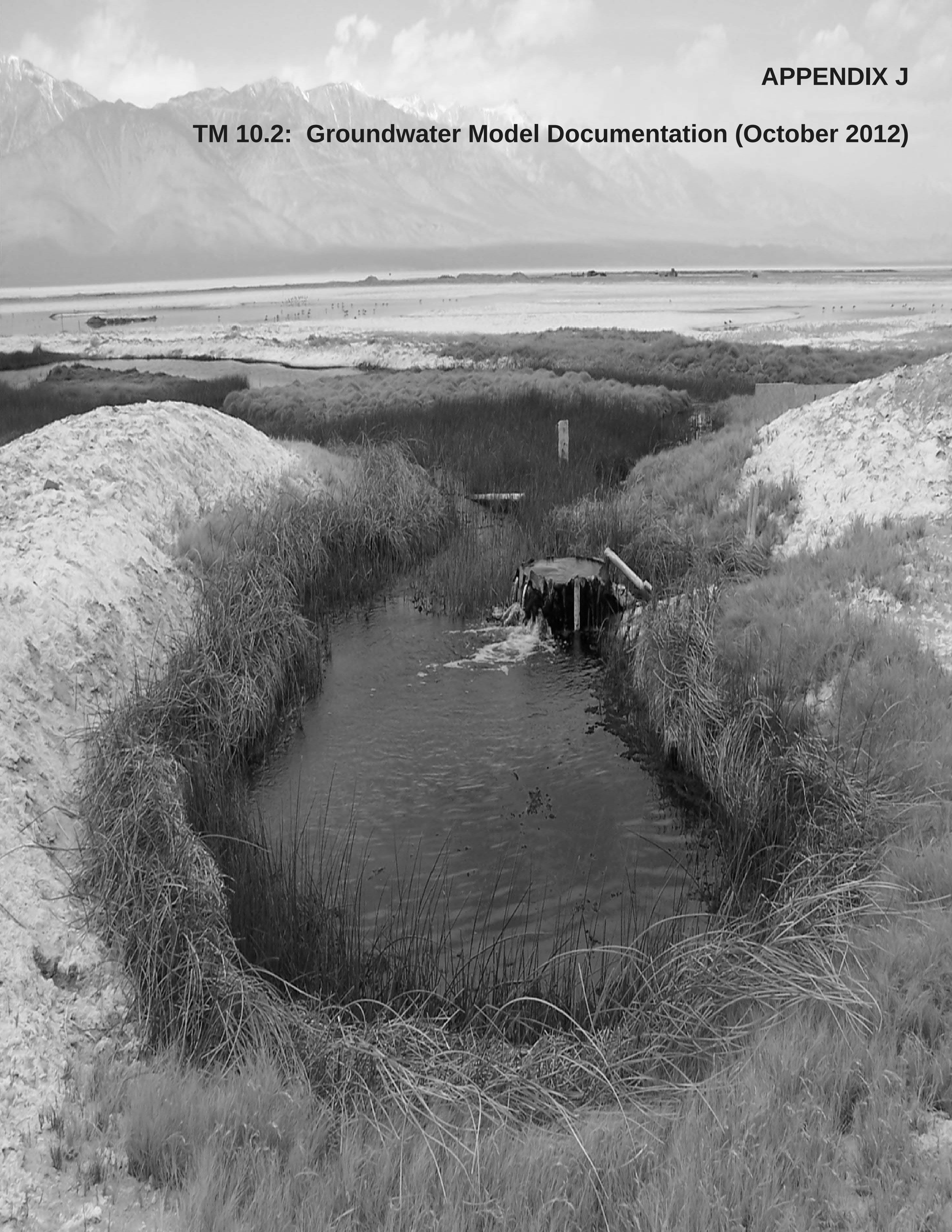
APPENDIX J

TM 10.2: Groundwater Model Documentation (October 2012)



MWH
BUILDING A BETTER WORLD

Technical Memorandum

TO:	*LADWP*	DATE:	*October 2012*
FROM:	*MWH*	REFERENCE:	*Task 401.1.10*
SUBJECT:	*TM 401.10.2 – Final OLGEP Groundwater Model Documentation*		

1.0 Introduction

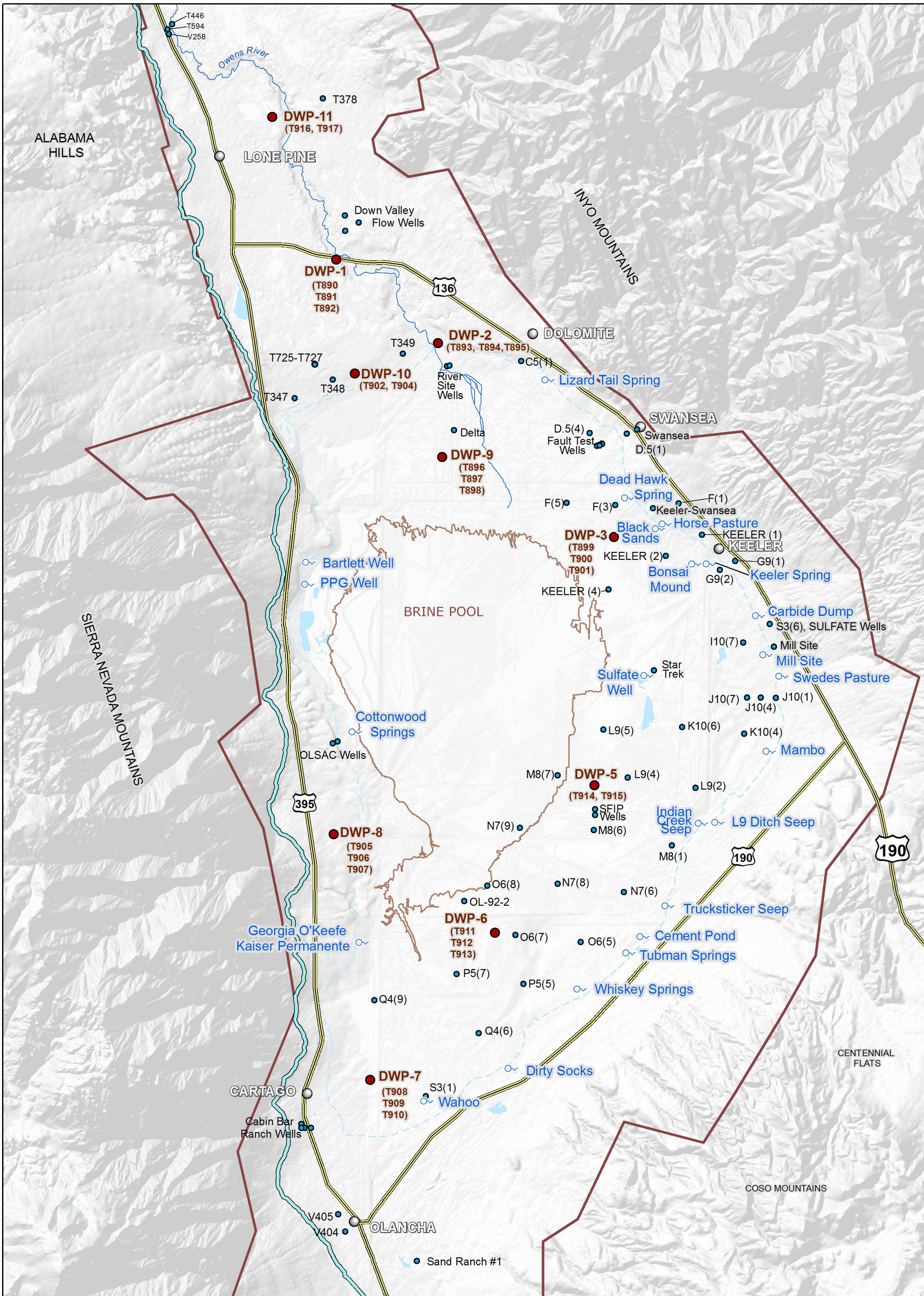
Under Agreement 47830 between MWH and the Los Angeles Department of Water & Power (LADWP), MWH is conducting the Owens Lake Groundwater Evaluation Project (OLGEP) for the LADWP. The purpose of the OLGEP is to evaluate the feasibility of using groundwater in the study area (as shown on **Figure 1**) for a portion of the dust mitigation activities on Owens Lake. The project involves compilation of existing hydrogeologic and related data, development of a preliminary conceptual model, identification of data gaps, installation of monitoring wells and collection of additional field data to fill data gaps, revision of the conceptual model, as well as development and application of a numerical groundwater model.

In Task 401.1.5, entitled *"Numerical Groundwater Model Update and Development,"* (LADWP, 2009), MWH evaluated and developed a numerical groundwater model for the OLGEP study area (**Figure 1**). Originally, the OLGEP groundwater model was completed in January 2012, and results of model development and calibration were documented in a draft Technical Memorandum (TM). The draft TM highlighted unique characteristics of the OLGEP model, along with a suite of recommendations. In March 2012, the Blue Ribbon Panel and Partner Agencies provided expert review and input on the draft TM and groundwater model. Based in part on this input, MWH and LADWP identified a set of model improvements to be implemented. In addition, longer-term aquifer tests and associated monitoring were conducted between January - August 2012 by LADWP at four locations in the study area, thereby providing additional data for model calibration.

Task Order 401.1.10 entitled, *"Perform Groundwater Model Improvements, Calibration, and Groundwater Pumping Simulation"* (LADWP, 2012) was authorized in order to:

1. Perform additional groundwater model improvements as identified by LADWP, Partner Agencies, and the Blue Ribbon Panel to the model completed in January 2012.
2. Conduct additional groundwater model calibration and sensitivity analysis using new recent aquifer test data with the improved groundwater model.

Table 1 tabulates the model improvements, testing, and calibration that were implemented under Task 401.1.10, the approach, and challenges associated with each item, and where they are addressed in this document.



Key to Features

- OLGEP Test Well
- Calibration Well
- Spring
- Highways
- Roads
- Los Angeles Aqueduct
- Owens River
- OLGEP Study Area Boundary
- Owens Lake (Historic Shoreline)

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Task 5: OLGEP Groundwater Model Documentation

Study Area Map Showing Location of Calibration Wells and Springs

Los Angeles Department of Water & Power

Figure 1

MWH.

This map has been designed to print size 11'' by 17''.

Table 1

Description, Approach, Challenges, and Report Location for Model Improvements, Testing, and Calibration Implemented under Task 401.1.10

Item No.	Item	Description of Activity	Comments in Scope	Approach	Report Reference
1	Modify Hydraulic Conductivity	Modify the areal extent and the hydraulic conductivity in layer 1 to simulate shallow sand layers north and northeast of Brine Pool.	This area has potential for shallow production wells. Historically, high conductivity in this area could not be reconciled with pump tests. The addition of faults may be necessary.	Initial K_h and K_v values were estimated by reviewing lithology and thickness from boring logs and applying typical hydraulic conductivity value from literature.	2.0 Groundwater Model Attributes, Model Zonation
2	Faults	Add Owens Valley Fault with estimated conductance.	There is little field information to support a conductance value, suggesting the need for sensitivity testing.	In MODFLOW coverage setup, barrier package is applied to simulate all the fault lines. Data from the isotope study and Southern model calibration will be reviewed and incorporated as it applies.	2.0 Groundwater Model Attributes, Faults within the Model
3	Storage Coefficient	Complete comprehensive review of storage coefficient (or specific storage values) in comparison to hydrostratigraphy - revise as necessary. Cross reference the storage coefficient with conceptual model hydrostratigraphy.	Blue Ribbon Panel (BRP) recommendation. Data from new pump testing will be useful.	Initial Ss value was assigned based on pumping test results and literature values. This is then cross-checked against known lithology at specific locations and conceptual model.	Attachment B
4	Playa Boundary Condition	Evaluate application of both the ET and Drain package on the playa, where appropriate.	Allows utilization of the benefits of either package. Utilize data from shallow piezometers installed by GBUAPCD.	Both ET and drain packages are applied. ET data based on published studies.	2.0 Groundwater Model Attributes, Boundary Conditions
5	Southern Model	Revise OLGEP model parameter values in the area overlapping with the Southern Model such that they match (or if not, a reasonable explanation exists).	Southern Model has been improved and recalibrated using pumping test data at W416. In addition.	Export/Import parameter zone shape file.	2.0 Groundwater Model Attributes, Model Zonation
6	Wastewater Returns	Review and update wastewater return value used in the model.	Develop estimates based on Lone Pine supply values provided by LADWP.	Used average annual production and assumed percentage of waste water return for the estimation.	3.0 Steady State Calibration Results, Water Budget
7	Boundary Condition Check	Determine if there are any unrealistic discharge rates from single cells via the drain or constant head packages. Recalibrate as necessary.	A "heat" map of discharge per unit area would be appropriate for this. If discharge per unit area exceeds estimated ET from seep areas, overland flow is indicated.	Export water budget data for all the cells that apply drain package.	Attachment B
8	Model Zonation	Use OLGEP monitoring well data to evaluate the zonation pattern and aquifer characteristics in layers 11 and 12. Test increasing K of layers 11, 12 to be more consistent with short-term testing of OLGEP monitoring wells.	These layers are strong candidates for future production wells	Review monitoring well data and modify K_h value and recalibrate the model.	2.0 Groundwater Model Attributes, Model Zonation
9	Parameter Sensitivity	Sensitivity analysis	Conduct sensitivity analysis for selected parameters only: K in layer 11, K in layer 2, storage coefficient, and conductivity of Owens Valley Fault. Also assess the impact that DCMs have on deeper flow regime and seep zones, and the effect that variable brine pool size has on the deeper groundwater regime.	Vary parameter values while maintaining constant pumping rate. Discharge data at spring areas were summarized and compared.	2.0 Groundwater Model Attributes, Faults within the Model
10	Aquifer Tests	Utilize new aquifer testing and monitoring data from the following sites:	Expected to reduce uncertainty in the effects of faulting, storage coefficient(s), and hydraulic conductivity values.		4.0 Transient Calibration Results Attachment D
		Deep River Site		Varied K_h, Ss, Vertical Anisotropy, Fault Conductance	
		Shallow River Site		Varied K_h, Ss, Vertical Anisotropy, Fault Conductance	
		Fault Test Site		Varied K_h, Ss, Vertical Anisotropy, Fault Conductance	
		South Flood Irrigation Project Well		Varied K_h, Ss, Vertical Anisotropy, Fault Conductance	
11	Well W390	Utilize variable pumping rate of W390 in the Lone Pine area during calibration efforts	BRP discussion comment	Varied K_h, Ss, Vertical Anisotropy, Fault Conductance	

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The purpose of this TM is to provide the complete and documentation for the OLGEP groundwater model. As such, this TM supersedes and replaces the February 2012 model documentation TM. The TM is organized as follows:

- Introduction
- Groundwater Model Attributes
- Steady-State Calibration Results
- Transient Calibration Results
- Modeling of the Dust Control Measures (DCMs)
- Unique Characteristics of the OLGEP Model
- Conclusions and Recommendations
- References

2.0 Groundwater Model Attributes

MWH (2011b) outlined a preliminary modeling strategy that incorporates necessary groundwater model attributes. The model code used for this effort was MODFLOW 2000 (Harbaugh et al., 2000). As described in the model strategy, the model has cells of 500 feet by 500 feet and a 6-month long stress period. This section describes the final model attributes assigned during the model calibration effort.

2.1 Boundary Conditions and Associated MODFLOW Packages

Boundary conditions and use of MODFLOW packages (Harbaugh et al., 2000) to simulate these boundary conditions are listed in **Table 2**. Background information associated with these boundary conditions is discussed in the model strategy TM (MWH, 2011b) and the Updated Conceptual Model Report (MWH, 2011c).

The OLGEP study area (**Figure 1)** was delineated previously in MWH (2011b), and generally includes the unconsolidated deposits along the long axis of the Owens Lake Basin (not including the Alabama Hills) from the Alabama Gates (approximately 5 miles north of the town of Lone Pine) south to the southern end of North Haiwee Reservoir, approximately 35 miles in total length. At its widest, the study area is approximately 13 miles wide. The purpose for including an area that is a relatively large distance north of Owens Lake is to evaluate the interaction of pumping near Lone Pine, dust control efforts, and the impacts of the Lower Owens River Project. The east and west boundaries of the model domain are governed by bedrock boundaries.

Table 2
Model Boundary Conditions

Boundary Location	Boundary Condition
Playa	Head Dependent Flux: Drain Package, Evapotranspiration (ET) Package
Northern Boundary of Unconsolidated Deposits of Owens Valley	Head Dependent Flux: General Head
Southern Boundary at North Haiwee	Constant Head
Southern Boundary West of North Haiwee	No Flow
Eastern Perimeter of Domain	No Flow
Western Perimeter of Domain	No Flow and Fixed Flux
Owens River	Head Dependent Flux: River Package
Brine Pool	Constant Head
Springs and Seeps	Head Dependent Flux: Drain Package
Flowing wells	Head Dependent Flux: Drain Package
Wastewater Return Flow	Specified Flux: Recharge Package
Evapotranspiration	Head Dependent Flux: ET Package

2.1.1 Head Dependent Flux Boundary Condition: ET Package and Drain Package

The groundwater discharge to the playa surface to the environment (seep, evaporation, transpiration) is represented by the Drain and ET MODFLOW packages. The Drain and ET packages have similarities. The ET package allows the user to specify maximum ET and the drain package allows control of discharge via the conductance term. The ET package allows discharge to occur when the water table is below the surface, which closely represents field conditions. The Drain package was used to simulate surface discharge of groundwater that occurs when the hydraulic head is above ground surface. The use of both packages significantly improved model stability when compared to use of a single (Drain) boundary condition.

Drains remove water from the groundwater system depending on the head gradient between the drain elevation and groundwater system. The flow is calculated based on the gradient and a conductance term. The drain conductance is not a field measured term; the term is determined via calibration. The conductance is a lumped term describing all of the head loss between the drain and the region of the cell with the drain, the characteristics of the convergent flow pattern toward the drain, and the characteristics of the drain in itself and its immediate environment (e.g. well screen). Listed below are summary statistics for the conductance terms used for the drain conductance:

Drain Conductance (ft^2/day):
- Minimum: 1
- Maximum: 38,000
- Mean: 182
- Mode: 100

The ET package was also used to simulate the effect of plant transpiration and direct evaporation by removing water from cells during a simulation. This package is applied where the initial depth to water is less than 30 feet. The ET boundary specification consists of an elevation, an ET extinction depth, and a maximum ET rate. The elevation is an absolute elevation and the ET extinction depth (measured positive downward) is relative to the specified elevation. If the water table rises above the specified elevation, the evapotranspiration occurs at the maximum ET rate. If the water table falls below the ET extinction depth, evapotranspiration ceases. If the water table elevation lies between these two extremes, the evapotranspiration rate varies linearly with depth. In the Lone Pine area where the OLGEP model domain overlaps the Southern Model domain, average ET rate from EDYS (MWH, 2010) model simulation was applied. The maximum ET rate used on the playa was based on Tyler at al. (1997), where a rate of 0.0008 and 0.0009 ft/day was assigned to the clay-dominated and sand-dominated areas, respectively. A higher maximum ET rate of 0.008 ft/day was used to simulate ET on the wetland area.

2.2.2 Constant Head Boundary Condition

The use of constant head was limited to the Brine Pool and Haiwee Reservoir.

The size of the Brine Pool varies over time as a function of runoff. During model review, questions arose about the rationale for the constant head assumption for the Owens Lake due to this variation. To determine if a time-varying head condition would be more appropriate, a sensitivity analysis was completed. This sensitivity analysis evaluated the impacts of changing the Brine Pool cells in the OLGEP model from constant head boundaries to the Drain and Evapotranspiration (ET) package boundary condition (similar to the Owens Lake Playa). With the Brine Pool using a constant head boundary condition, it is analogous to a pool of standing water. The constant head boundary can add or remove water from the system to remain constant. With a Drain and ET boundary condition, it is similar to a dry Brine Pool that can discharge groundwater if the hydraulic head is above the ground surface or ET extinction depth.

The analysis reviewed water level impacts with no constant head condition (dry Brine Pool), with constant head replaced with drain and ET similar to the playa, and with a larger constant head condition – when the Brine Pool was full. The difference in water level in any layer of the model is 0.2 feet. The constant head condition was used because it has little impact on the model water levels, represents the shallow system accurately, and improves model stability. This evaluation is attached as **Attachment A**.

2.2.3 Head Dependent Flux Boundary Condition: River Package

The River package was used to simulate the Owens River. Rivers contribute water to the groundwater system or drain water from it depending on the head gradient between the river and groundwater system. The flow is calculated based on the gradient and a conductance term. The river conductance is not a field measured term. The conductance is the length of the stream in the cell multiplied by the width, multiplied by the hydraulic conductivity of the streambed material, divided by the distance of flow (thickness of the streambed layer). Therefore the conductance can vary significantly; given a hydraulic of 20 ft/d, a length of 2,000 ft, and a width of 40 ft, the conductance could be as high as 1.6×10^6. Listed below are summary statistics for the conductance terms used for the river conductance:

River Conductance (ft^2/day):
- Minimum: 74
- Maximum: 1,500,410
- Mean: 138,742
- Mode: 600,000

2.2.4 Specified Flux: Well Package

Local private wells in the southern portion of the model domain were included in the model for wells producing over 1 acre-foot per year (AF/yr). If no published data were available, then the annual production rate was estimated based upon an annual consumptive use rate considering the number of homes served and irrigated land. **Table 3** lists the wells and associated production assumptions incorporated into the southern portion of model. Pumping in the northern portion of the model is based on data compiled for the Southern Model (MWH, 2010).

Table 3
Summary of Existing Production Wells Incorporated in the OLGEP Groundwater Model

Private Well	Estimated Consumptive Use (AF/yr)[1]	Rationale
Pangborn CSD	5.5	Assume 5 connections at 1.1 AF/yr.
Shoshone Reservation	14	Assume population of 25 at 500 gallons per day (gpd).
Hidden Valley Ranch	1.1	Assume 1.1 AF/yr per well.
Spainhower/Anchor Ranch	1.1	Assume 1.1 AF/yr per well.
Interagency Visitor Center	1.7	Use for water fountains, bathroom, minimal landscaping.
Boulder Creek RV Park	7.5	67 spaces plus landscaping and pool. Assume 100 gpd per space (includes landscaping).
Dolomite Wells	0.1	Assume only part-time use.
Swansea Area Private Wells	1.1	Assume 1.1 AF/yr per well.
Dunn Production Well	1.1	Assume 1.1 AF/yr per well.
Keeler Community Services District Wells	54	Reported to serve 180 people, with 49 active connections. Assume 1.1 AF/yr per connection per Anheuser-Busch EIR (JMM, 1990).
LADWP Sulfate Facility	0.2	For process water only, assumed 200 gal per day.
Olancha Private Wells	108	2010 population of 192, consumption of 500 gal per capita per day.
Butterworth/Haiwee Private Wells	1.1	Assume 1.1 AF/yr per well.
Cartago Mutual Water Company Well	34	Based on meter records published in Anheuser Busch, 1991 Environmental Impact Report.
Cartago town wells (lumped)	22	There are about 20 active wells. Assume 1.1 AF/yr per well.
Rio Tinto Well	1.1	Assume 1.1 AF/yr per well.
Cottonwood Powerhouse	1.1	Assume 1.1 AF/yr per well.
OLSAC Wells	1.1	Assume 1.1 AF/yr per well.
Carol Creek Domestic Wells	1.1	Assume 1.1 AF/yr per well.
Cabin Bar Ranch Private Wells	1.7	Assume three permanent residents.
Crystal Geyser Roxane Bottling Plant	300	Based on information from Crystal Geyser Roxane.

1. Consumptive Use Estimated at 50% of total pumping except for Crystal Geyser Roxane.

2.2.4 Specified Flux: Recharge Package

The recharge package was used for wastewater return flows at the Lone Pine wastewater facility. The recharge is for treated wastewater discharged to percolation basins adjacent to the facility.

2.2 Model Layering

Recent interpretation of extensive surface seismic data on the lake identified 10 significant stratigraphic sequences that can be correlated over the entirety of the OLGEP study area (MWH, 2011a). These stratigraphic sequences correspond to with prominent aquifers and aquitards in the delta area of Owens Lake. Stratigraphic sequences identified by geophysics analysis (MWH, 2011a) and summarized in the Updated Conceptual Model Report (MWH, 2011c) form the basis for model layers with two exceptions:

- The shallowest stratigraphic sequence is divided into two layers to provide flexibility in accurately representing the shallowest aquifer water level and controlling flow to numerous springs.
- The deepest stratigraphic sequence is divided into two layers. The deepest layer represents the transmissivity of the sediments below the depth of drilling and seismic exploration, while the layer above it represents the deepest zone identified during field drilling.

The OLGEP model has 12 model layers. **Table 4** lists the aquifer units and associated OLGEP groundwater model layer. The vertical discretization into these stratigraphic sequences will allow significant flexibility for simulation of pumping from any one of the five discrete aquifer units identified in the delta area.

Table 4
Summary of Model Layers and Owens Lake Aquifer Units

Aquifer Unit	Model Layer
Aquifer 1	Layer 3
Aquifer 2	Layer 5
Aquifer 3	Layer 7
Aquifer 4	Layer 9
Aquifer 5	Layers 11 and 12

A uniform cell dimension of 500 feet is used for the OLGEP model. With the large spatial area of the model domain, this size represents a reasonable tradeoff between computational time and model accuracy. This 500-foot grid spacing is consistent with previous models constructed in the Owens Valley.

The orientation of the model grid is 17 degrees in the counterclockwise direction. This orientation corresponds to the boundaries of active cells used in the in the Danskin (1998) model and MWH (2010) Southern Owens Valley model. This orientation also minimizes the total inactive model cells.

2.3 Model Zonation of Aquifer Parameters within Layers

The hydraulic properties used in the model include horizontal and vertical hydraulic conductivity, specific yield for an unconfined aquifer, vertical anisotropy, and the specific storage for confined aquifers.

For each layer, the model domain is subdivided into a number of zones of assumed similar parameter values. The model zonation is primarily based on geological and hydrogeologic data sources described below [and further described in the model strategy TM (MWH, 2011b)]:

- Geophysical studies (MWH, 2011a), combined with correlation of data from recent OLGEP drilling efforts, identified stratigraphic sequences that provide an excellent model layering basis that mimics geologic structure.
- Lithologic logs of wells from various sources including the Great Basin Unified Air Pollution Control District (GBUAPCD), California Department of Water Resources (CDWR), and LADWP (including the new wells constructed as part of the OLGEP project).
- Various reports and publications on wells, pump tests, and monitoring reports performed in the Owens Lake study area were obtained from the GBUAPCD and various consulting firms. Other reports and models were utilized for portions of the model that overlapped the Southern Model (MWH, 2010), completed by MWH in 2010.

Subsequent to compilation and georeferencing of well logs, individual lithologic records and associated descriptions were consolidated and incorporated into a single Microsoft Access™ database. Each lithologic description was categorized by its relative permeability. This database was set up to allow for automated geostatistical analysis that included the thickness-weighted permeability class at each well in each layer, variogram analyses of permeability class in each layer, analysis of spatial variation structure, kriging models based on the weighted permeability value at each well location, using the best-fit variogram model and parameters, and to generate permeability grids for each model layer. These results were then reviewed by a geologist to consider numerical results in conjunction with depositional models, regional geophysics, regional structure, and pump tests to prepare preliminary zonation maps (MWH, 2011c).

The preliminary zone maps were revised by parameter value, spatial extent, and number (added or removed) during the calibration process until the final zonation was achieved following calibration of the transient and steady-state models. **Table 5** lists the zone properties by layer and parameter. **Figure 2** through **Figure 13** present the model parameter zonation maps for layers 1 through 12.

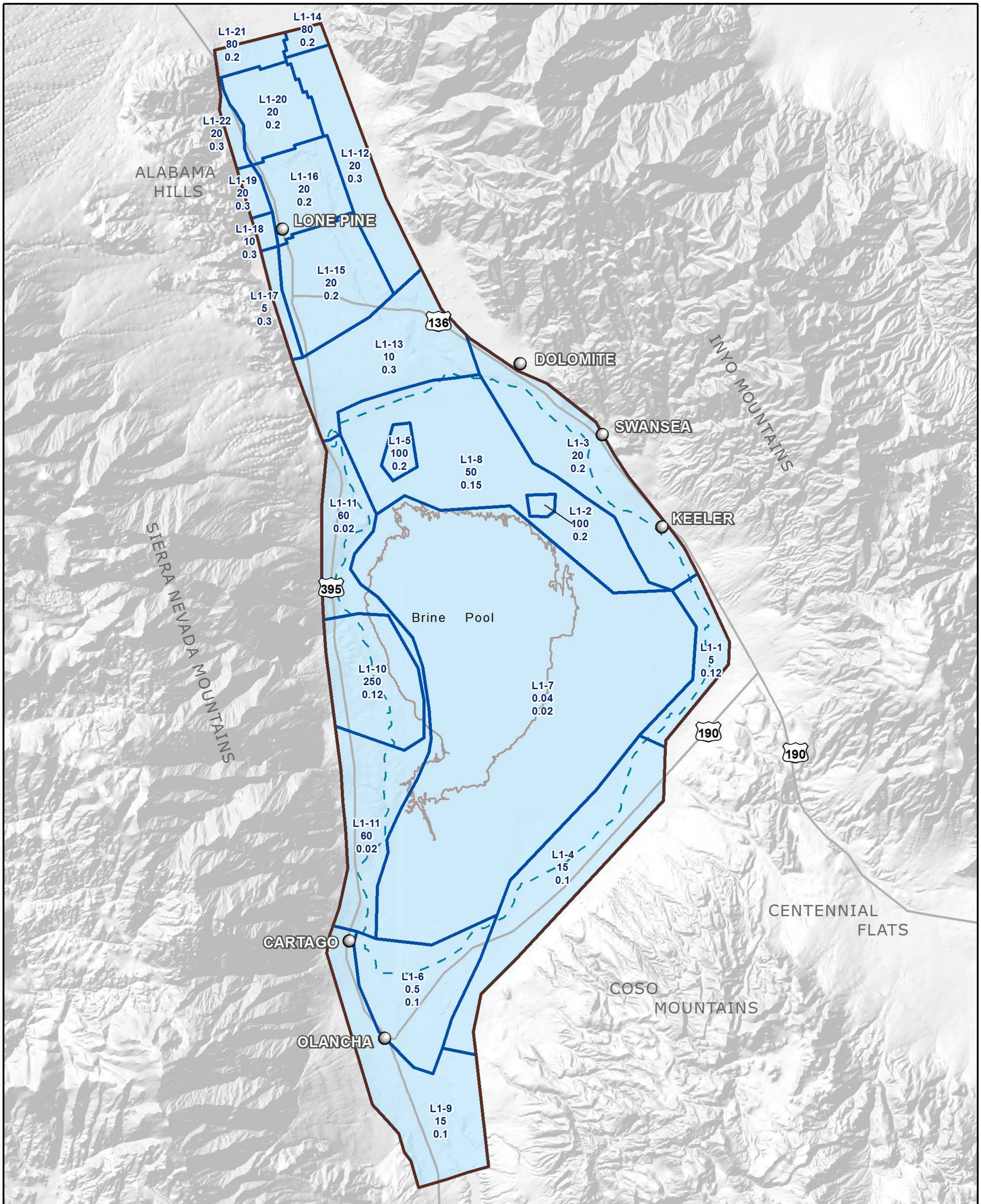
The calibrated parameter values listed in **Table 5** fall within the range of published hydraulic conductivity and storage coefficients for similar lithologic types as observed in the study area (Freeze and Cherry, 1979). **Attachment B** presents a review of published specific storage values and where calibrated storage parameters used in the model fall within those published values.

The hydraulic conductivity values range from a high of 250 feet/day (representing clean sands and gravels), to a low of 1×10^{-6} feet/ day (representing clays). The specific yield values in layer 1 range from a high of 0.3 to a low of 0.01. Specific storage values in layers 2 through 12 ranges from high of 5×10^{-4} to a low of 1×10^{-9} (elevated bedrock to the east of the Alabama Hills).

Using the GMS pre-processor for MODFLOW, vertical hydraulic conductivity is not defined. Instead, a vertical to horizontal anisotropy ratio is used. The vertical anisotropy ratios for the model vary from 1 to 2000. These values fall within the normal range for modeling applications (Anderson and Woessner, 1992), and were determined during the calibration process.

Table 5
Calibrated Model Layer Zone Properties

Name	Layer	Hydraulic Conductvity (ft/d)	Vertical Anisotropy (-)	Specfic Storage (1/ft)	Specific Yield (%)
L1-1	1	5	10	0.12	0.12
L1-2	1	100	10	0.20	0.20
L1-3	1	20	10	0.20	0.20
L1-4	1	15	10	0.10	0.10
L1-5	1	100	10	0.20	0.20
L1-6	1	1	10	0.10	0.10
L1-7	1	0.04	2,000	0.02	0.02
L1-8	1	50	30	0.15	0.15
L1-9	1	15	10	0.10	0.10
L1-10	1	250	10	0.12	0.12
L1-11	1	60	10	0.12	0.02
L1-12	1	20	10	0.30	0.30
L1-13	1	10	80	0.30	0.30
L1-14	1	80	250	0.20	0.20
L1-15	1	20	250	0.20	0.20
L1-16	1	20	250	0.20	0.20
L1-17	1	5	20	0.30	0.30
L1-18	1	10	10	0.30	0.30
L1-19	1	20	10	0.30	0.30
L1-20	1	20	250	0.20	0.20
L1-21	1	80	250	0.20	0.20
L1-22	1	20	10	0.30	0.30
L2-1	2	1	30	1.00E-04	0.10
L2-2	2	10	2	1.00E-04	0.12
L2-3	2	0.001	650	5.00E-04	0.02
L2-4	2	20	2	1.00E-04	0.10
L2-5	2	50	20	1.00E-04	0.12
L2-6	2	0.001	600	5.00E-04	0.02
L2-7	2	2	500	1.00E-05	0.20
L2-8	2	2	200	1.00E-05	0.10
L2-9	2	50	10	1.00E-05	0.20
L2-10	2	20	10	1.00E-05	0.20
L2-11	2	12	60	2.50E-06	0.10
L2-12	2	0	100	1.00E-06	0.10
L2-13	2	20	200	1.00E-05	0.20
L2-14	2	40	200	1.00E-05	0.20
L2-15	2	20	10	1.00E-05	0.20
L3-1	3	15	20	1.00E-04	0.10
L3-2	3	100	20	1.00E-04	0.12
L3-3	3	0	10	1.00E-04	0.15
L3-4	3	0	200	1.00E-04	0.15
L3-5	3	20	250	1.00E-07	0.12
L3-6	3	30	200	1.00E-05	0.12
L3-7	3	120	20	1.00E-04	0.15
L3-8	3	30	10	1.00E-04	0.10
L3-9	3	150	20	1.00E-04	0.15
L3-10	3	22	300	1.00E-05	0.20
L3-11	3	2	10	1.00E-05	0.20
L3-12	3	7	100	5.00E-05	0.20
L3-13	3	30	400	1.00E-07	0.20
L3-14	3	2	10	5.00E-06	0.20
L3-15	3	12	60	2.50E-06	0.10
L3-16	3	0	100	1.00E-06	0.10
L3-17	3	120	10	1.00E-06	0.20
L3-18	3	60	10	1.00E-06	0.20
L3-19	3	8	10	1.00E-06	0.20
L4-1	4	30	10	1.00E-05	0.10
L4-2	4	2	10	1.00E-05	0.10
L4-3	4	0.0002	2,000	1.00E-04	0.01
L4-4	4	0.01	2,000	1.00E-05	0.10
L4-5	4	30	10	1.00E-04	0.15
L4-6	4	30	10	1.00E-05	0.10
L5_12	5	20	200	1.00E-05	0.12
L5_13	5	0	100	1.00E-06	0.02
L5_14	5	25	400	1.00E-07	0.12
L5_15	5	40	150	1.00E-06	0.12
L5_16	5	8	10	1.00E-06	0.02
L6-1	6	30	10	1.00E-05	0.10
L6-2	6	2	10	1.00E-05	0.10
L6-3	6	2	800	1.00E-06	0.10
L6-4	6	5	800	1.00E-05	0.15
L6-5	6	0.00008	200	1.00E-04	0.01
L6-6	6	2	400	1.00E-06	0.10
L6-7	6	30	10	1.00E-04	0.15
L6-8	6	30	10	1.00E-05	0.10
L6-9	6	100	20	1.00E-04	0.15
L6-10	6	5	200	1.00E-05	0.12
L6-11	6	2	10	1.00E-06	0.02
L6_12	6	12	60	2.50E-06	0.02
L6_13	6	0.001	100	1.00E-06	0.02
L6_14	6	25	200	1.00E-05	0.12
L6_15	6	8	10	1.00E-06	0.02
L7-1	7	30	10	3.20E-05	0.12
L7-2	7	50	1	1.00E-04	0.12
L7-3	7	50	1	1.00E-04	0.10
L7-4	7	7	10	3.00E-06	0.12
L7-5	7	7	10	1.00E-04	0.12
L7-6	7	7	10	1.00E-04	0.12
L7-7	7	50	2	1.00E-04	0.15
L7-8	7	50	1	1.00E-04	0.10
L7-9	7	250	1	1.00E-04	0.15
L7-10	7	40	600	1.00E-05	0.12
L7-11	7	2	10	1.00E-05	0.12
L7-12	7	2	10	1.00E-06	0.02
L7_13	7	12	60	2.50E-06	0.02
L7_14	7	0.001	100	1.00E-06	0.02
L7_15	7	20	100	1.00E-07	0.12
L7_16	7	1	100	1.00E-05	0.12
L7_17	7	8	10	1.00E-06	0.02
L8-1	8	30	10	1.00E-05	0.10
L8-2	8	2	10	1.00E-05	0.10
L8-3	8	0.000001	800	1.00E-04	0.01
L8-4	8	0.001	800	1.00E-06	0.10
L8-5	8	30	10	1.00E-04	0.15
L8-6	8	30	10	1.00E-05	0.10
L8-7	8	100	1	1.00E-04	0.15
L8-8	8	0.00005	1,000	1.00E-06	0.15
L8-9	8	0.00005	1	1.00E-07	0.03
L8-10	8	0.0001	30	1.00E-05	0.12
L8-11	8	1	1	1.00E-05	0.12
L8-12	8	0.00005	1	1.00E-05	0.12
L9-1	9	50	1	1.00E-04	0.12
L9-2	9	30	1	1.00E-04	0.10
L9-3	9	5	200	1.00E-05	0.15
L9-4	9	25	200	1.00E-05	0.12
L9-5	9	50	2	1.00E-04	0.15
L9-6	9	50	1	1.00E-04	0.10
L9-7	9	250	1	1.00E-04	0.15
L9-8	9	30	600	1.00E-05	0.15
L9-9	9	50	10	1.00E-05	0.12
L9-10	9	70	30	1.00E-05	0.12
L9-11	9	20	30	1.00E-05	0.12
L9-12	9	0.0002	100	1.00E-09	0.02
L10-1	10	20	1	1.00E-05	0.05



Key to Features

Layer 1 Zones

L1-3	Layer 1 Zone 3
20	Horizontal Hydraulic Conductivity (ft/day)
0.2	Specific Yield (%)

- Town
- Highways
- OLGEP Model Domain
- Owens Lake (Historical Shoreline)

N

0 1.5 3 Miles

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\TM40115\UpdateOct2012\ModelZonationMap.mxd

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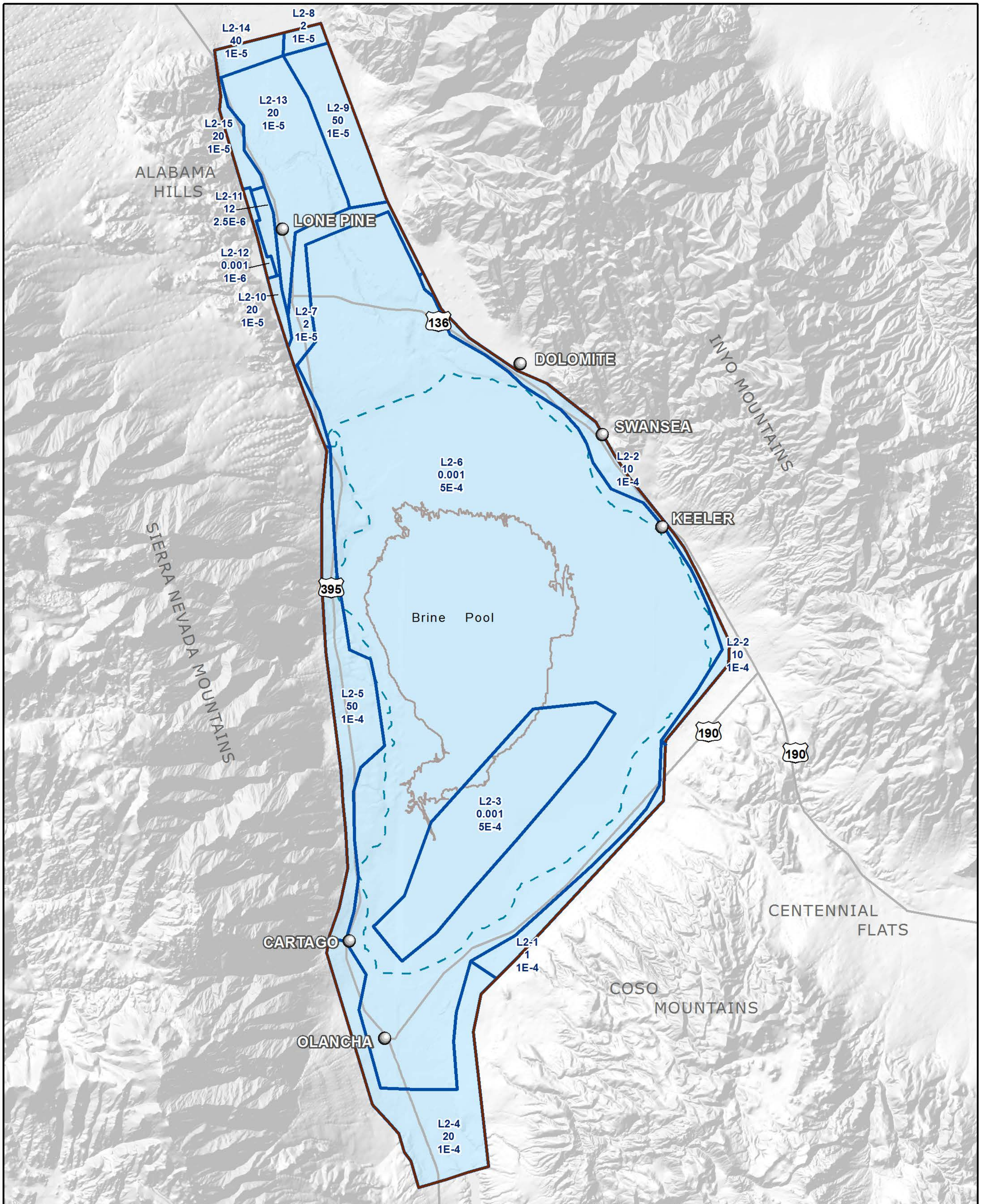
Layer 1 Model Parameter Zonation Map

Figure 2

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Layer 2 Zones

L2-3	Layer 2 Zone 3
0.001	Horizontal Hydraulic Conductivity (ft/day)
5E-4	Specific Storage (1/ft)

- Town
- Highways
- OLGEP Model Domain
- Owens Lake (Historical Shoreline)

N

0 1.5 3 Miles

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Layer 2 Model Parameter Zonation Map

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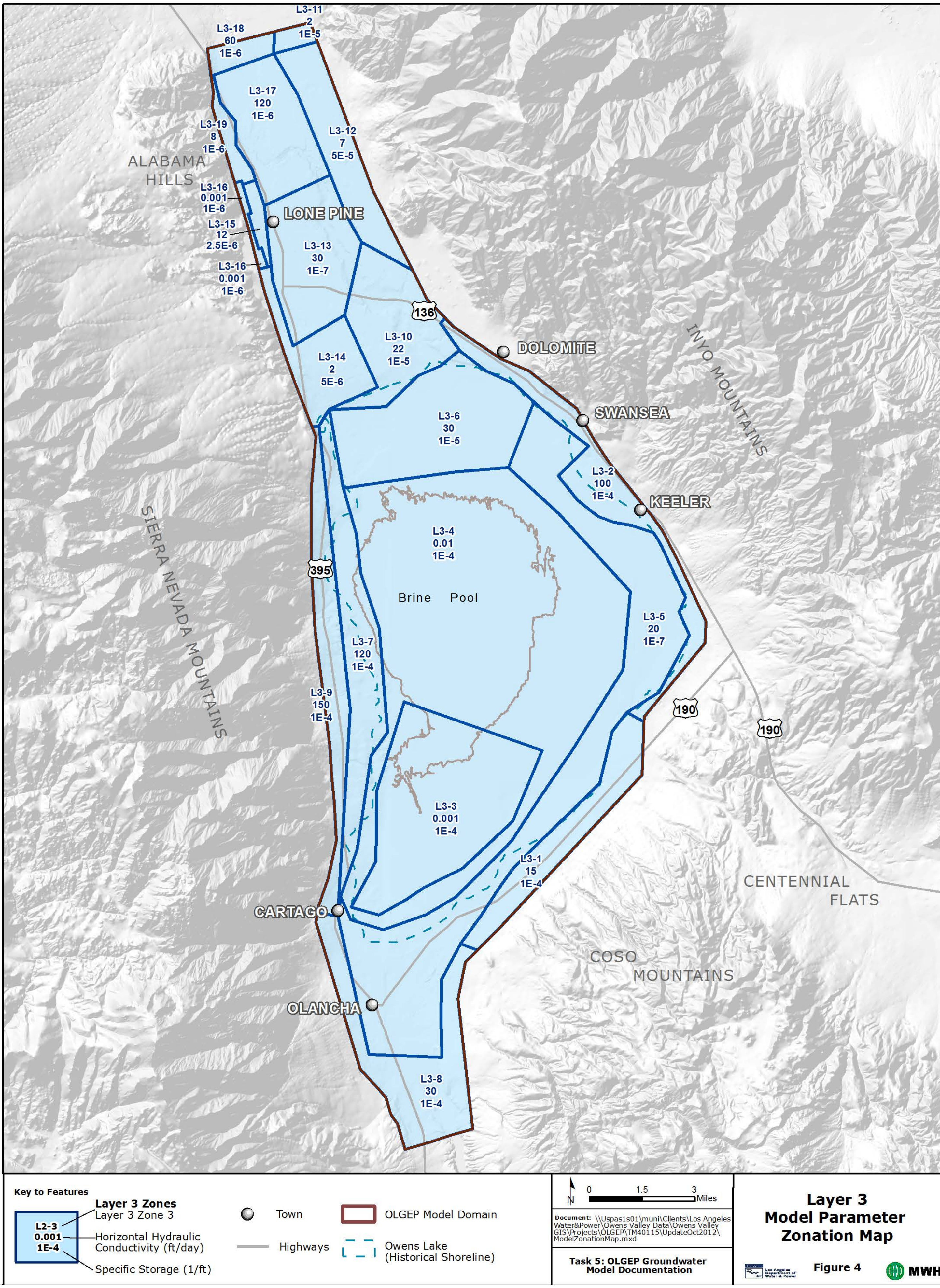
Figure 3

MWH

This map has been designed to print 8.5" x 11".



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Layer 3 Model Parameter Zonation Map

Figure 4

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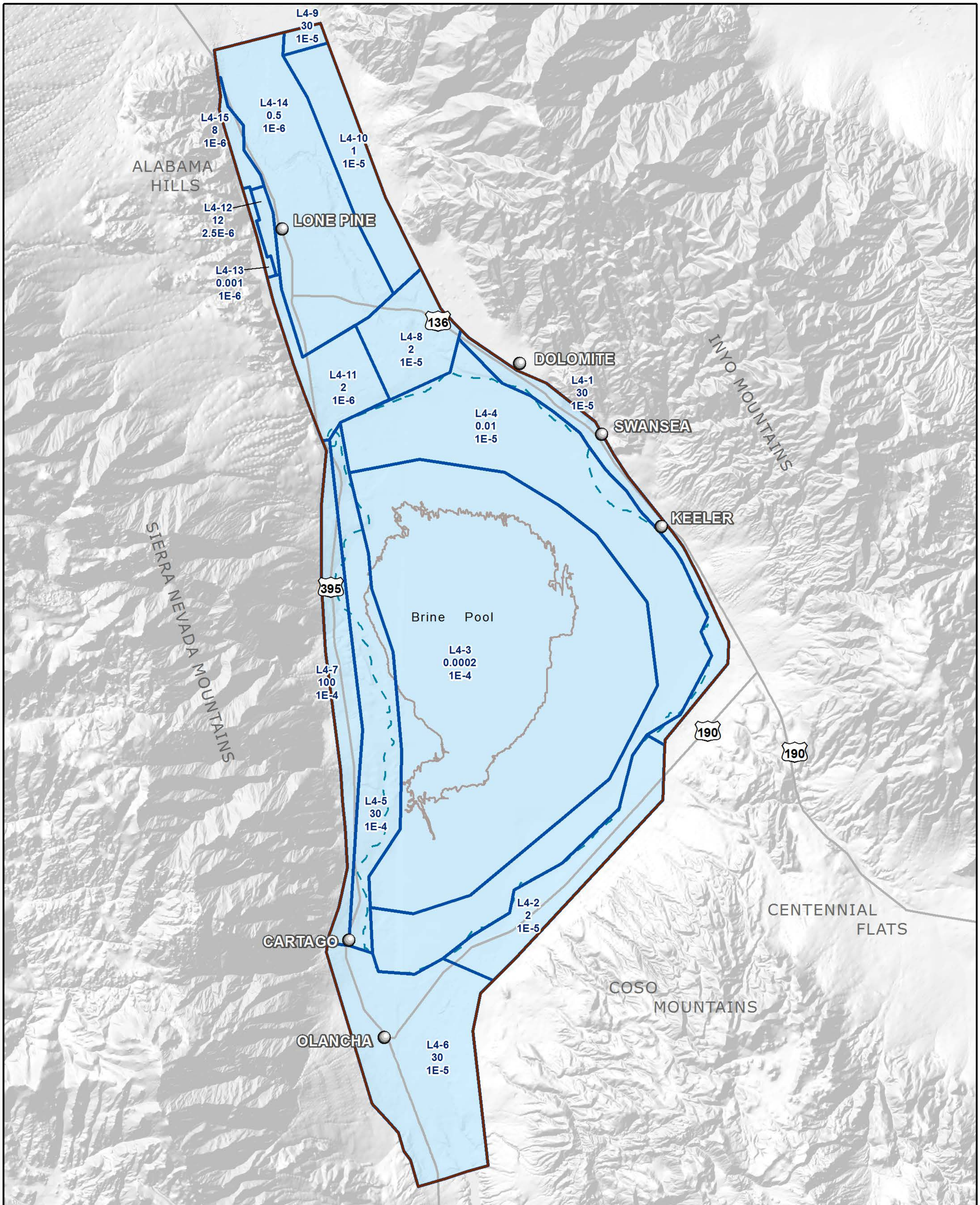
MWH

This map has been designed to print 8.5" x 11".



Key to Features

Layer 4 Zones

L4-3	Layer 4 Zone 3
0.0002	Horizontal Hydraulic Conductivity (ft/day)
1E-4	Specific Storage (1/ft)

Town

Highways

OLGEP Model Domain

Owens Lake (Historical Shoreline)

0 1.5 3 Miles

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Layer 4 Model Parameter Zonation Map

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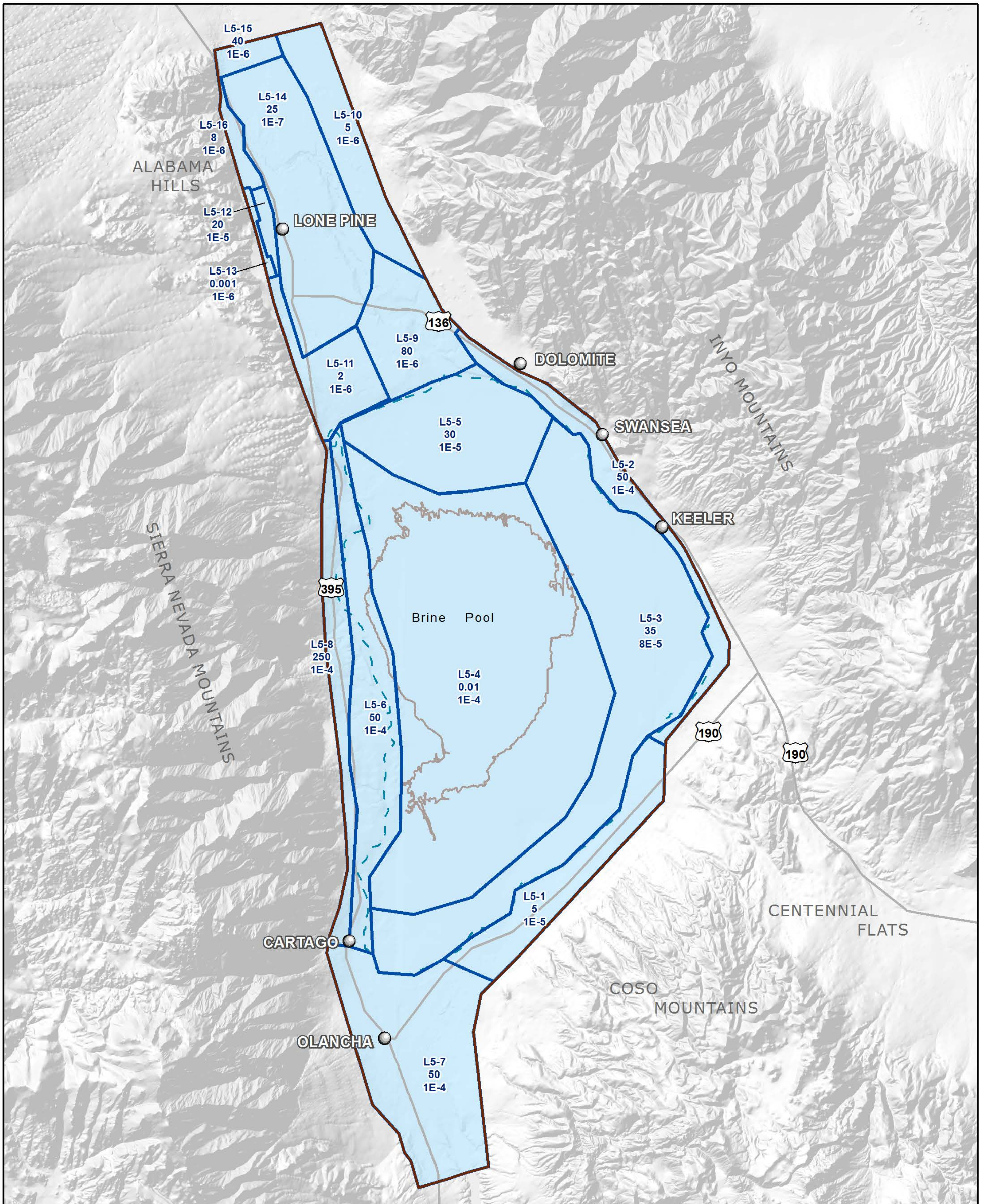
Figure 5

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Layer 5 Zones
Layer 5 Zone 3 — L5-3
Horizontal Hydraulic Conductivity (ft/day) — 35
Specific Storage (1/ft) — 8E-5

Town

Highways

OLGEP Model Domain

Owens Lake (Historical Shoreline)

N

0 1.5 3 Miles

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Layer 5 Model Parameter Zonation Map

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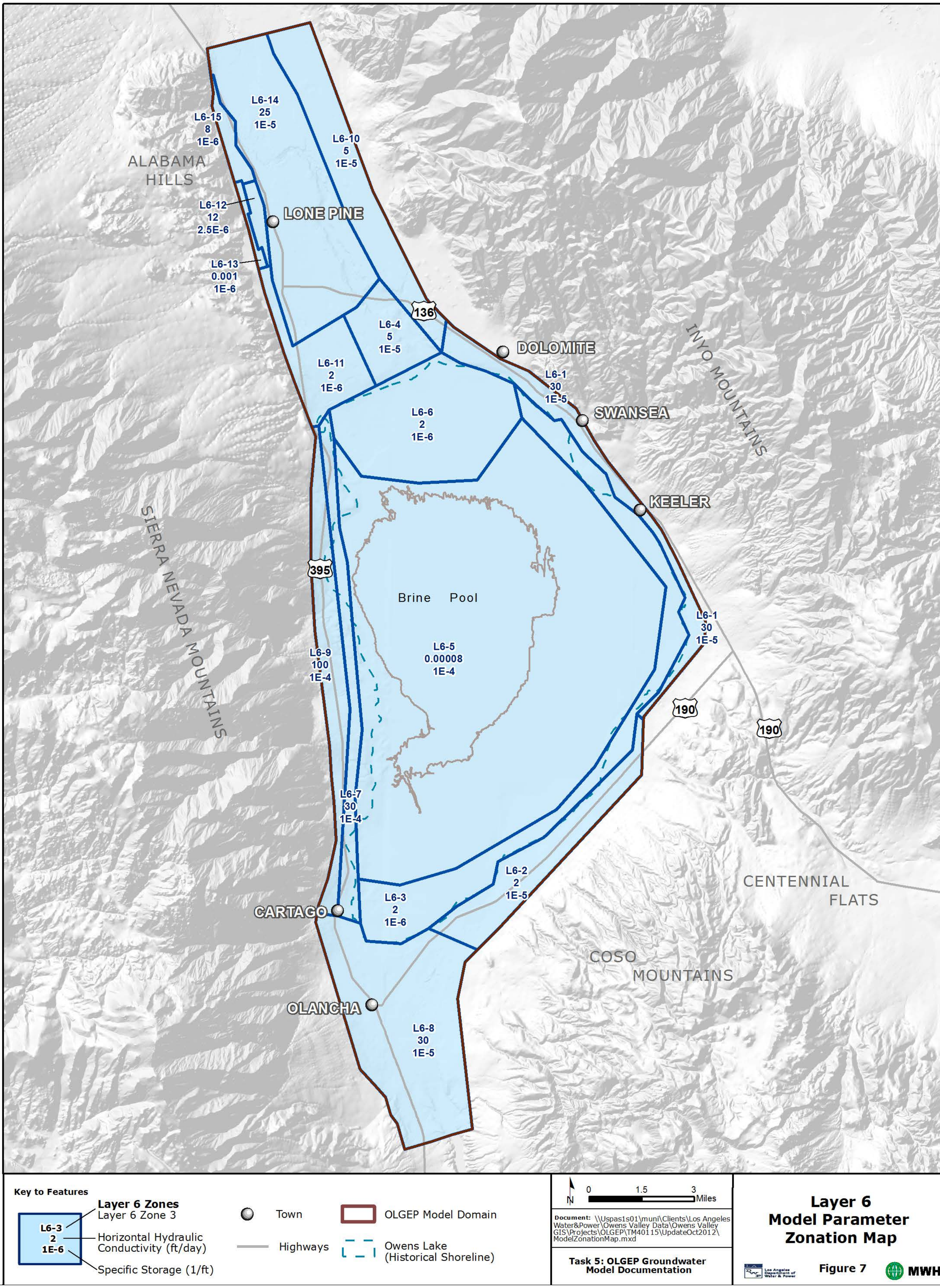
Figure 6

MWH

This map has been designed to print 8.5" x 11".



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Layer 6 Model Parameter Zonation Map

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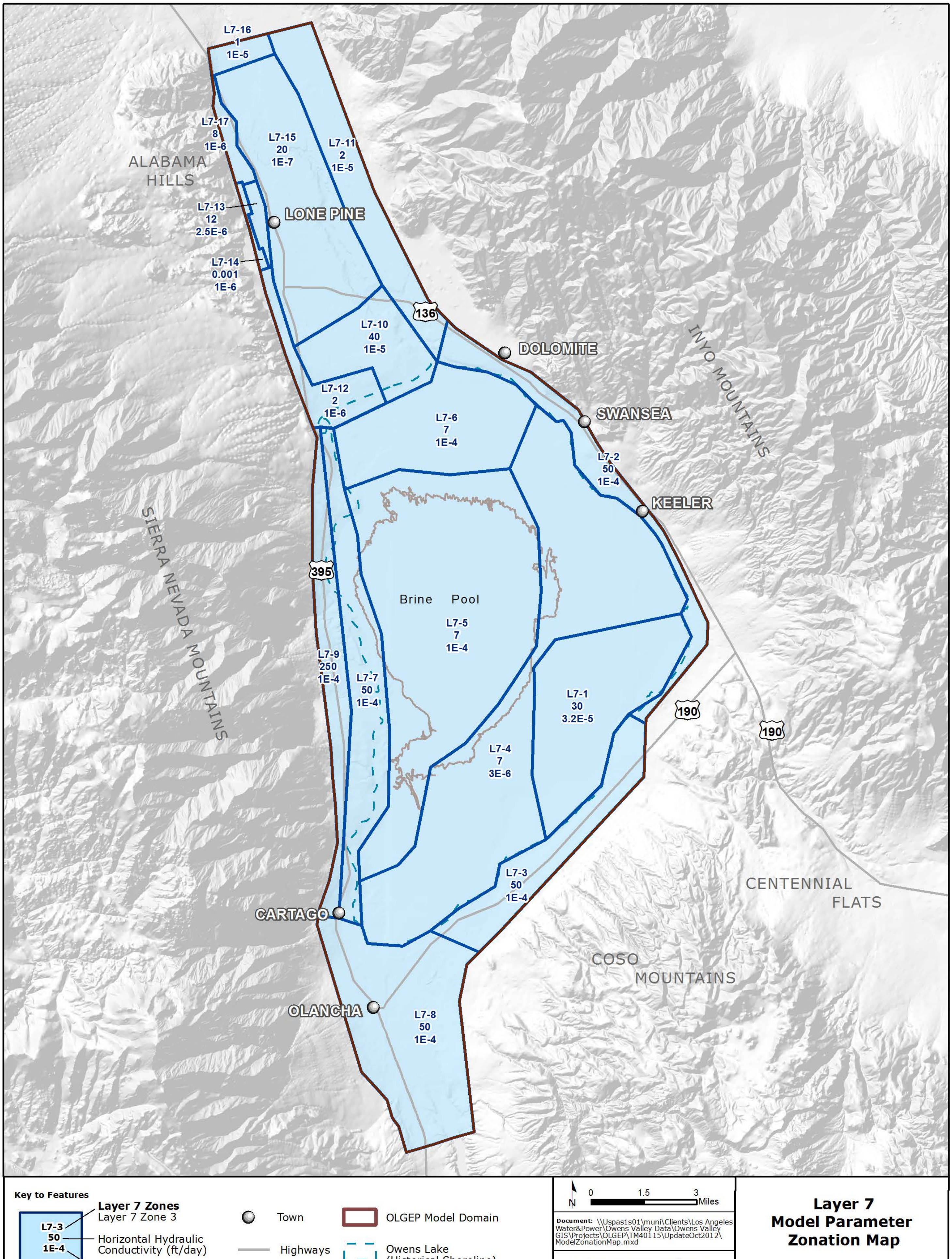
Figure 7

MWH

This map has been designed to print 8.5" x 11".



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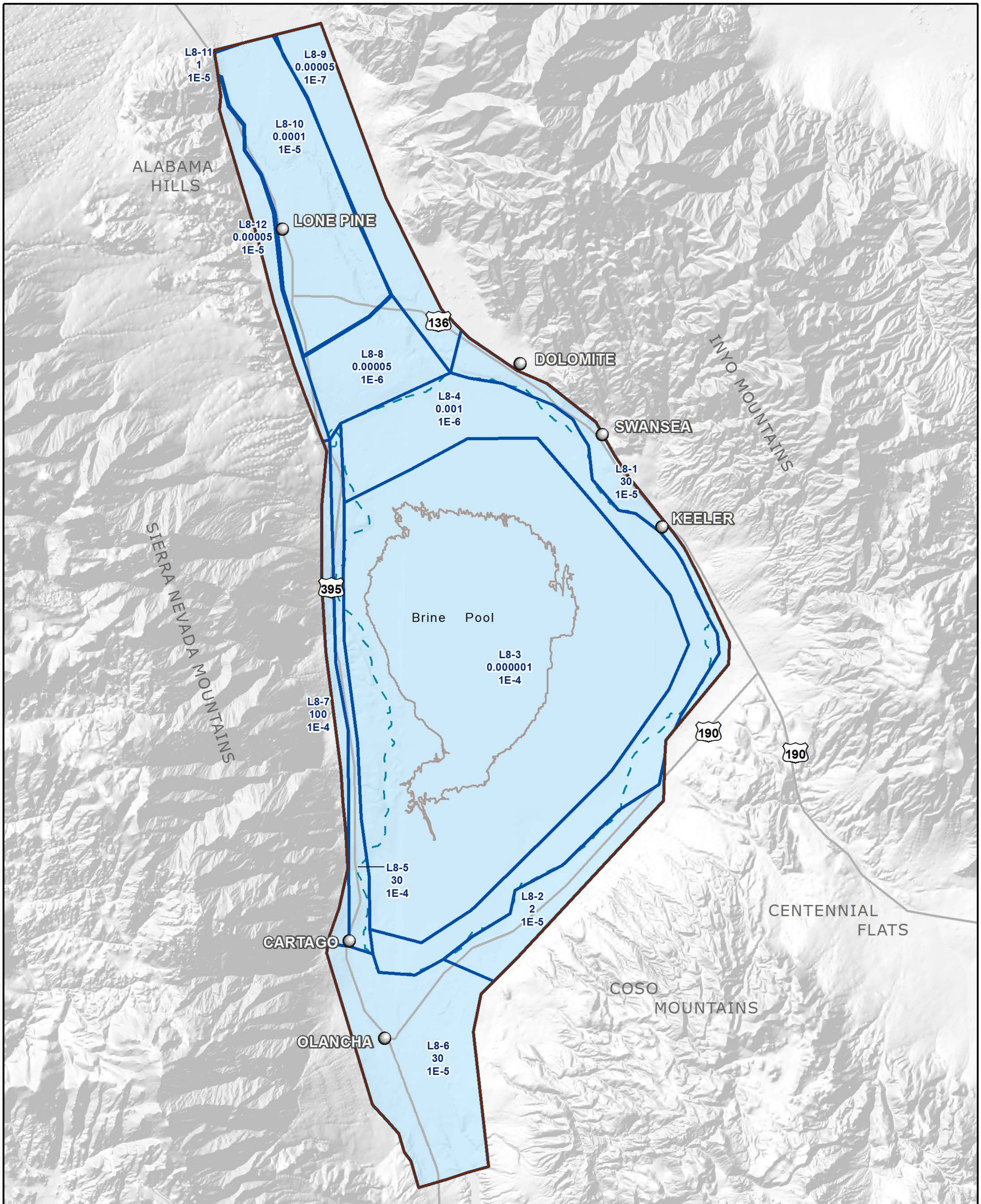
Layer 7 Model Parameter Zonation Map

Figure 8

Los Angeles Department of Water & Power | MWH

This map has been designed to print 8.5" x 11".



Key to Features

Layer 8 Zones
L8-3 — Layer 8 Zone 3
0.000001 — Horizontal Hydraulic Conductivity (ft/day)
1E-4 — Specific Storage (1/ft)

Town

Highways

OLGEP Model Domain

Owens Lake (Historical Shoreline)

N
0 1.5 3 Miles

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Layer 8 Model Parameter Zonation Map

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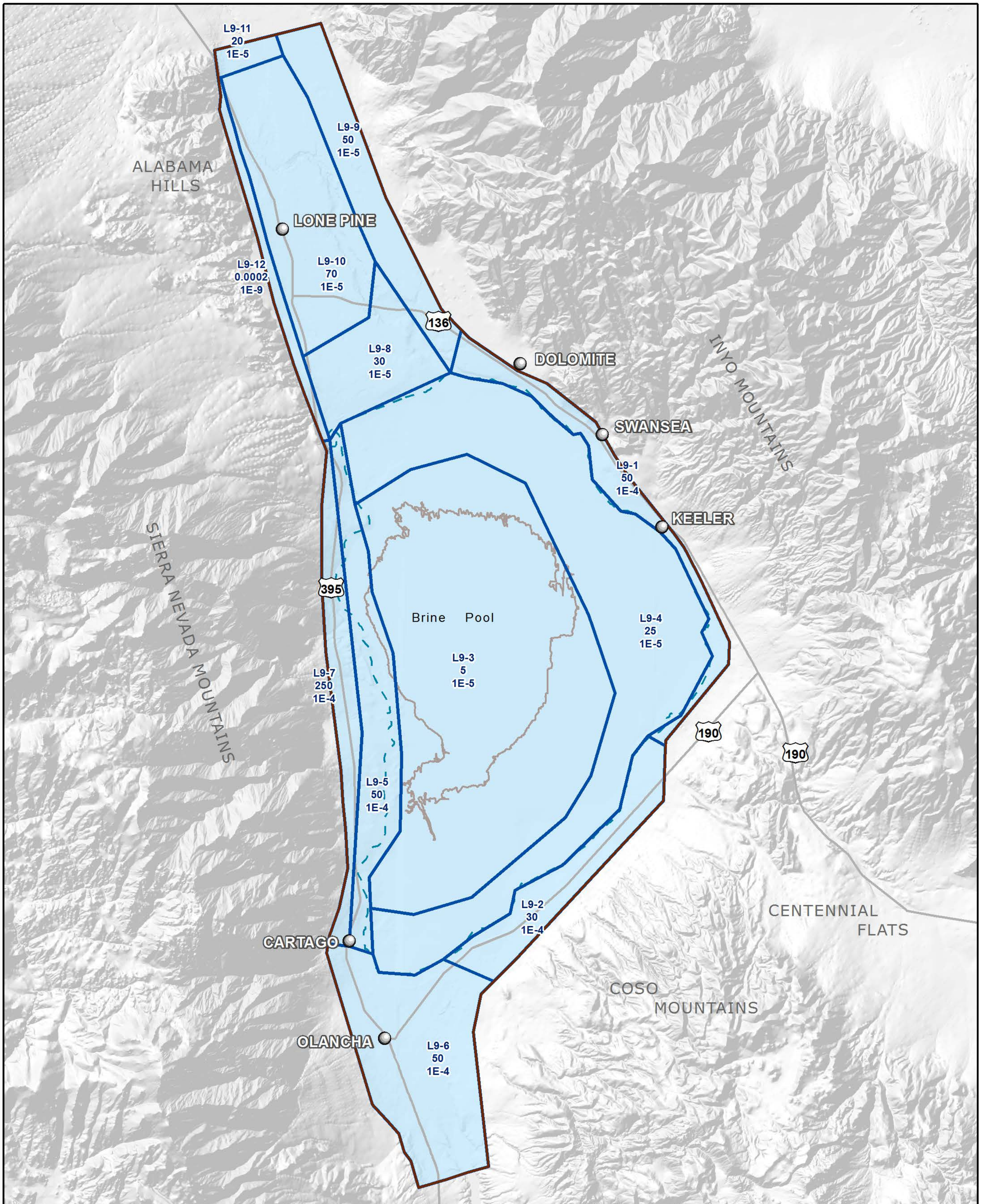
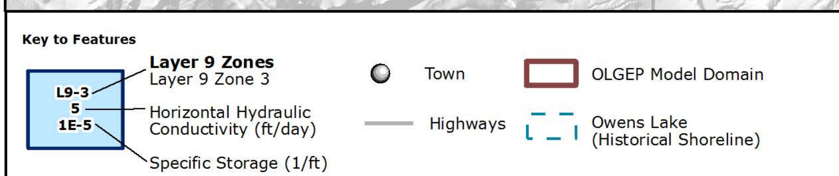
Figure 9

MWH

This map has been designed to print 8.5" x 11".



Key to Features



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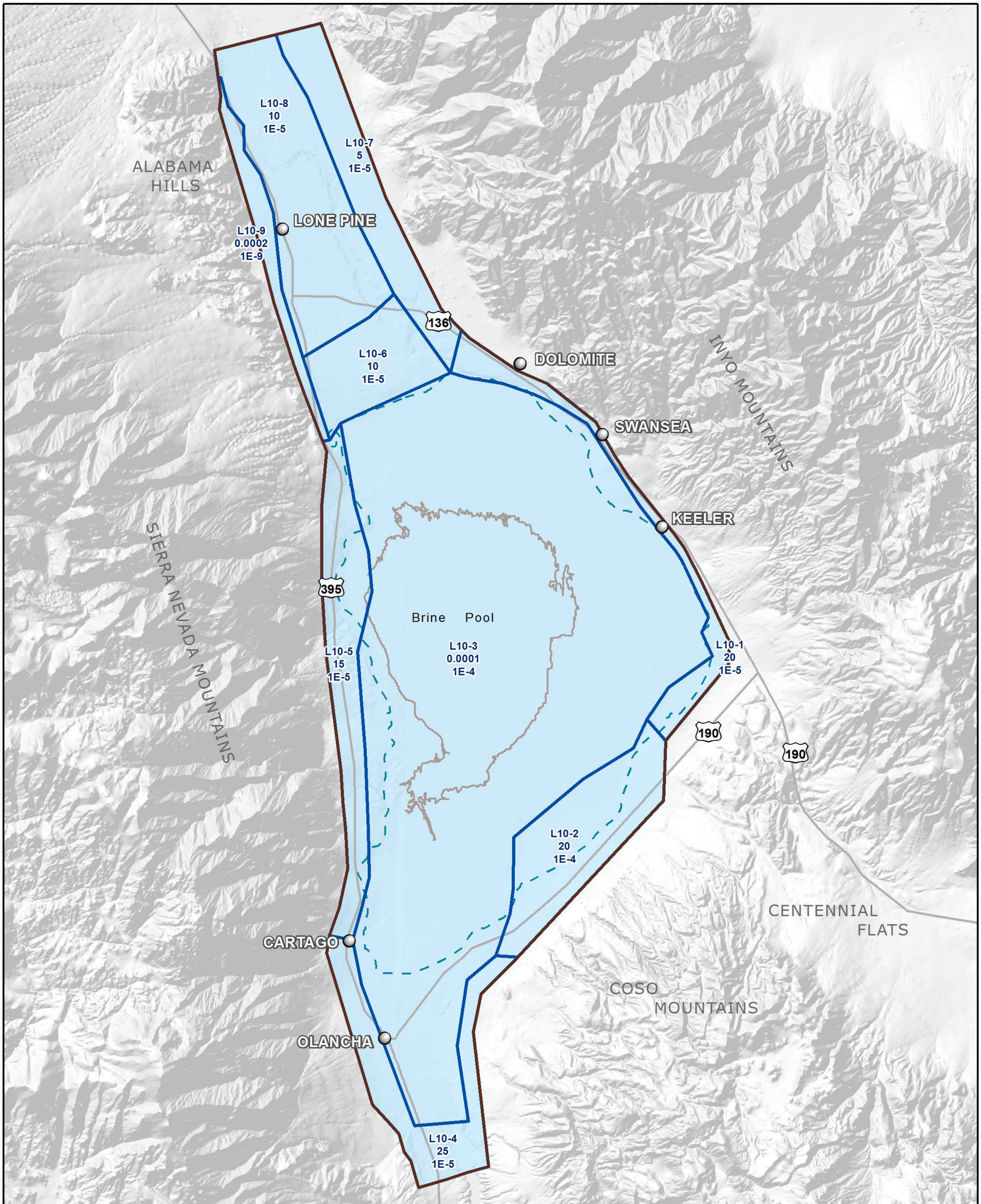
Layer 9 Model Parameter Zonation Map

Figure 10

This map has been designed to print 8.5" x 11".



Key to Features

Layer 10 Zones
L10-3 — Layer 10 Zone 3
0.0001 — Horizontal Hydraulic Conductivity (ft/day)
1E-4 — Specific Storage (1/ft)

Town

Highways

OLGEP Model Domain

Owens Lake (Historical Shoreline)

N

0 1.5 3 Miles

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Layer 10 Model Parameter Zonation Map

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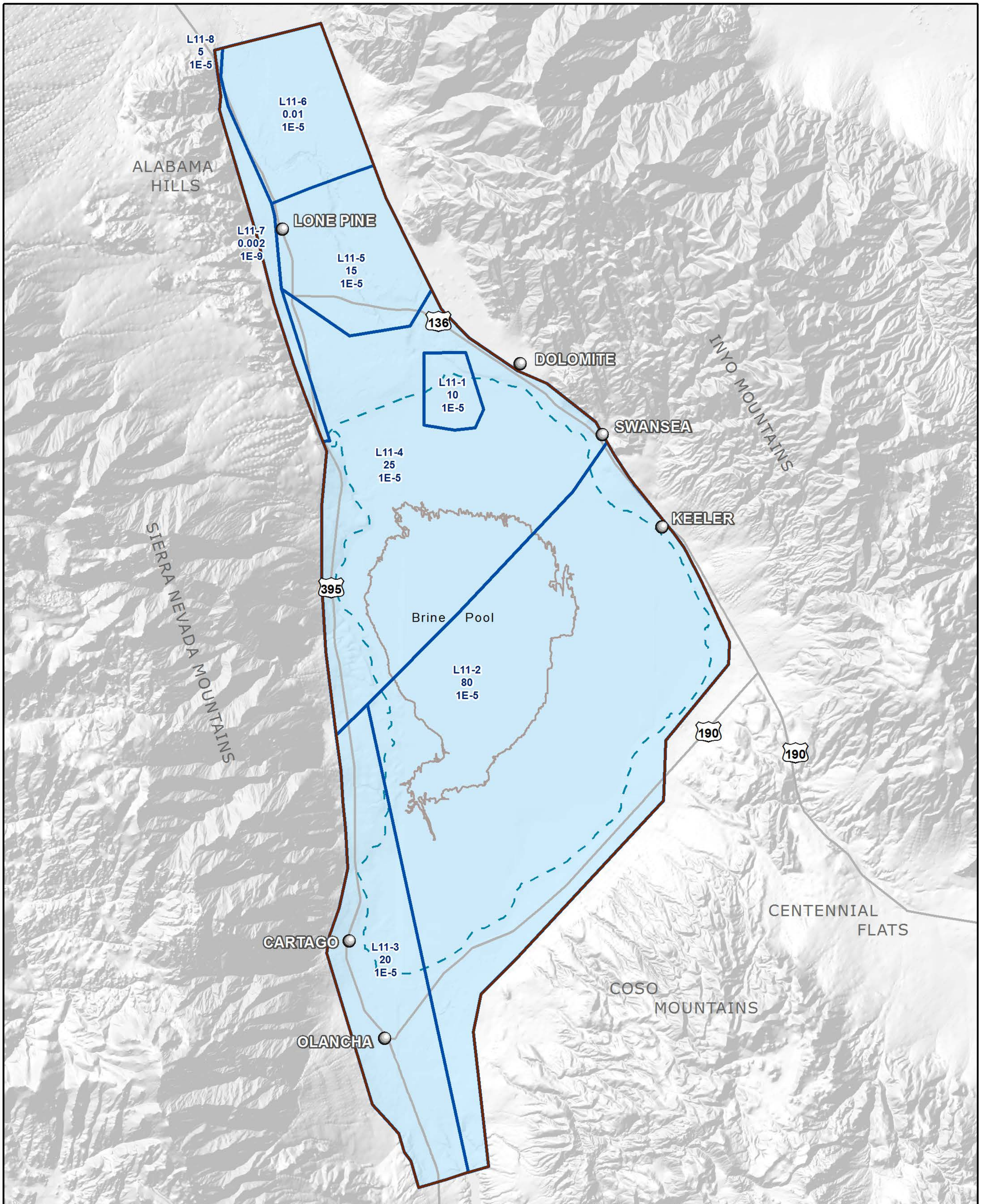
Figure 11

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Layer 11 Zones
Layer 11 Zone 3 — L11-3
Horizontal Hydraulic Conductivity (ft/day) — 20
Specific Storage (1/ft) — 1E-5

Town
Highways
OLGEP Model Domain
Owens Lake (Historical Shoreline)

N
0 1.5 3 Miles

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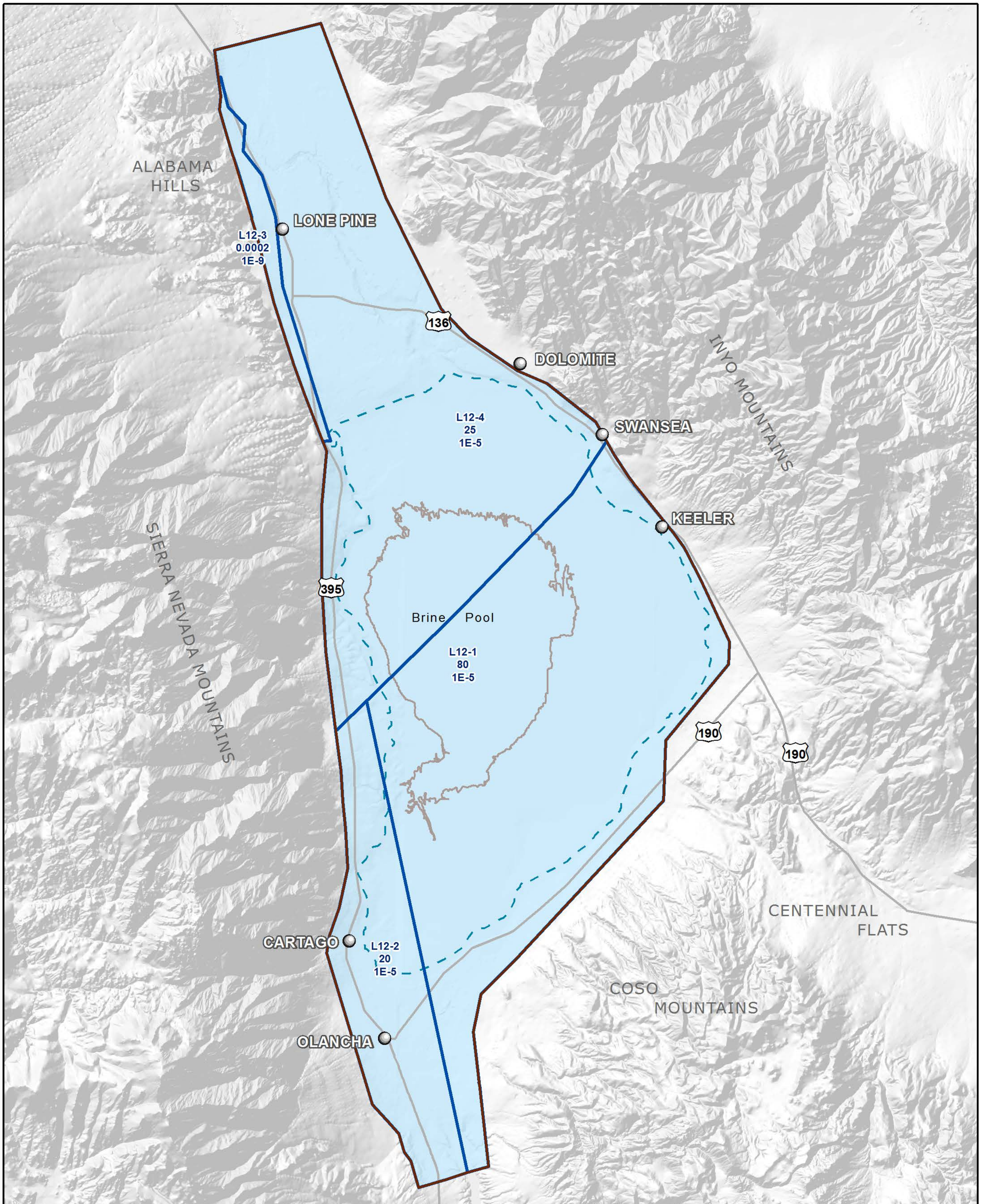
Layer 11 Model Parameter Zonation Map

Figure 12

This map has been designed to print 8.5" x 11".



Key to Features

Layer 12 Zones
Layer 12 Zone 3

L12-3 — Layer 12 Zone 3
0.0002 — Horizontal Hydraulic Conductivity (ft/day)
1E-9 — Specific Storage (1/ft)

Town

Highways

OLGEP Model Domain

Owens Lake (Historical Shoreline)

N
0 1.5 3 Miles

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Layer 12 Model Parameter Zonation Map

Figure 13

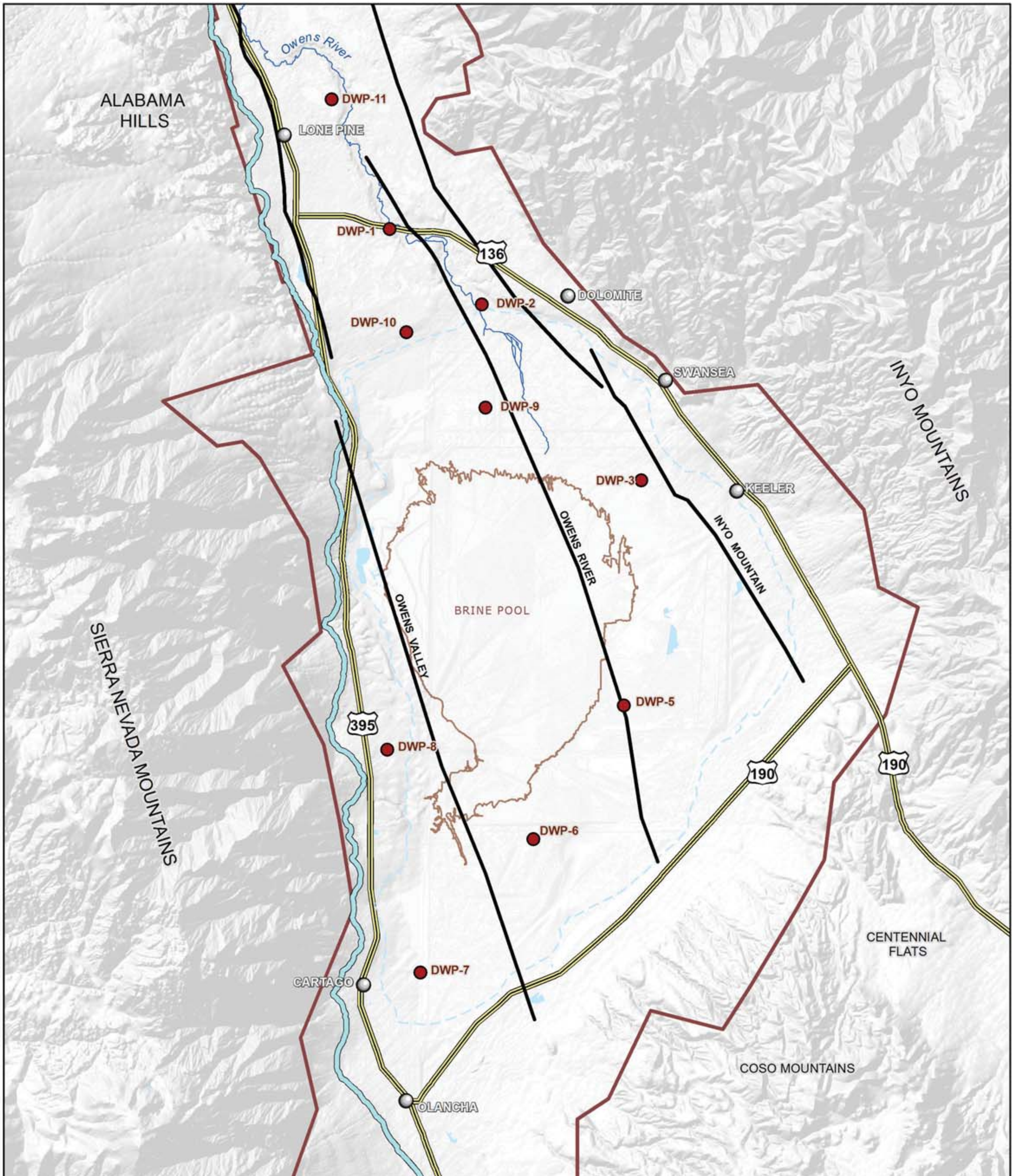
This map has been designed to print 8.5" x 11".

2.4 FAULTS

Fault zones have been described in several previously-published references (Pakiser et al., 1965; Hollett et al. 1991; and MWH 2011a). The evaluation of geophysical data for incorporation into the OLGEP groundwater model (MWH, 2011a) provides transects through numerous fault zones. The faults are generally high angle with displacement spread across multiple fault strands rather than a single fault plane. This is typical of faulting in strike-slip structural styles. The OLGEP geophysical study was utilized to provide the bulk of the faults zones used placed in the model. **Figure 14** shows these fault zone locations. Fault zones were generalized in a single fault plane.

Faults that juxtapose sediments of low and high hydraulic conductivity are potential barriers to groundwater flow. Crushed material and clay gouge along the fault zones may further restrict groundwater flow. Conversely, fracturing and cracking of consolidated sediments may actually act as conduits or preferential pathways to groundwater flow. Although seismic data does not allow for direct interpretation of the hydraulic impact of faults, it does allow for quantification of displacement that is not possible using borehole data alone. It is expected that the degree to which faults act as barriers is related to the degree to which fault displacement places relatively impermeable material adjacent to permeable aquifers. There is little field data to validate neither the presence nor lack of low conductivity fault materials.

The Owens Valley, Owens River, and Inyo Mountain Front fault zones were assigned properties such that they act as a barrier to flow. This is based on pump test results at the River Site for the Owens River and Inyo Mountain Front fault zones. This pump test clearly indicated these faults zones did not transmit pressure changes as a result of pumping the River Site Well. The Owens Valley Fault zone was also assigned properties that made the fault act as a barrier to flow. The low conductance for the zone was based on pump test results and an isotope study. The pump test Well 416W, south of Lone Pine, clearly indicated that the fault in that area acts as a barrier to flow (MWH, 2010). An isotope study was conducted to determine the source region of Owens Lake groundwater recharge and determine the age of the groundwater. The results of this study indicated that relatively young water that drains from the Sierra Nevada apparently does not recharge Owens Lake; Owens Lake is recharged via down Valley flow. One reasonable explanation is that the Owens Valley Fault zone acts as a barrier preventing recharge to the lake from the Sierra Nevada.



Key to Features

- OLGEP Test Well
- Calibration Well
- Calibration Spring
- Owens River
- Highways
- Los Angeles Aqueduct
- OLGEP Study Area Boundary
- Owens Lake (Historic Shoreline)
- Simplified fault line used in GMS

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Task 5: OLGEP Groundwater Model Documentation

Modeled Faults

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Figure 14

MWH.

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3.0 Steady-State Calibration Results

Both steady-state and transient calibration was completed for the OLGEP groundwater model. The two calibration steps were competed in an iterative process. The preliminary steady-state model was calibrated, converted to a transient model, and then calibrated based on pump test data. The steady-state model was then rechecked with the updated transient calibration. This section reviews the steady-state calibration.

Steady-state calibration targets can be categorized into four areas:

- Water level data (wells) from LADWP and GBUAPCD wells within the model domain
- Overall groundwater flow pattern, whereby flow pattern should match general pattern based on field observations
- Spring flow locations and flow amounts
- Water budget

A brief description of each calibration target area and how the calibrated model performed relative to the observed, or estimated, data follows.

3.1 Water Level Data

Wells used for steady-state calibration to calibrate water levels for specific locations and depth intervals are shown on **Figure 1** and listed in **Table 6**. **Table 6** also lists the calibration residual at each calibration well. **Table 7** is a statistical residual summary for the steady-state OLGEP model.

- The **Mean Error** (ME) is the average difference between observed and simulated head in feet. If this value is close to zero, then it indicates the residual is normally distributed around zero. The ME for this model is -0.44 feet. The negative value indicates that, overall, the model tends to under predict water levels.
- The **Mean Absolute Error** (MAE) is the mean error after taking the absolute value of the errors. The MAE for the model is 3.52 feet, which means that the average simulated head is about ± 4 feet from an observed head. This value indicates the average elevation residual of the calibrated model.
- The **Root Mean Square Error** (RMSE) is a measure of precision of the model results. This statistic is calculated by summing the square of the residuals, dividing by the number of observations, and taking the square root. The lower the RMSE the better the model fit; this model has a RMSE of 4.59 feet. The RMSE is often used to calculate the percent error, which is the RMSE divided by the total change in the observation type being calculated with the RMSE. The percent error for the OLGEP model is 3.95 percent. Typically a calibrated model should have a value less than less than 10 percent.

Table 6
Calibration Wells and Steady-State Calibration Head Residual

Well ID	Easting (m)	Northing (m)	Ground Surface Elevation (ft)	Well Depth (ft)	Top of Perforated Interval (ft bgs)	Residual (ft)
CBR-MW-1	408,027	4,018,881	3,629	600	150	9.5
CBR-MW-2	407,810	4,018,885	3,669	615	165	9.6
CBR-MW-3	407,701	4,019,012	3,687	420	200	10.2
CBR-PW-1	407,700	4,018,890	3,690	650	200	-11.1
DVF East Lower	409,637	4,049,466	3,666	709	645	-5.7
DVF East Middle	409,637	4,049,466	3,666	709	505	-5.7
DVF East Upper	409,637	4,049,466	3,666	709	189	-10.5
DVF North Lower	409,176	4,049,704	3,669	722	662	-6.4
DVF North Middle	409,176	4,049,704	3,669	722	512	-7.4
DVF North Upper	409,176	4,049,704	3,669	722	212	-9.0
DVF South Lower	409,188	4,049,176	3,667	719	659	-6.0
DVF South Middle	409,188	4,049,176	3,667	719	518	-5.6
DVF South Upper	409,188	4,049,176	3,667	719	205	-10.7
Fault Test T1	417,685	4,041,923	3,587	726	551	3.6
Fault Test T3	417,855	4,041,991	3,592	430	260	3.2
Fault Test T4	417,860	4,041,980	3,591	168	63	-0.5
Fault Test T5	417,772	4,041,953	3,590	425	255	2.9
Fault Test T6	417,779	4,041,935	3,590	173	67.5	-0.5
Keeler-Swansea Lower	419,578	4,039,812	3,614	390	220	2.9
Keeler-Swansea Middle	419,578	4,039,812	3,614	190	160	5.5
Keeler-Swansea Upper	419,578	4,039,812	3,614	135	100	8.4
Mill Site Lower	423,666	4,035,136	3,618	400	220	-4.3
Mill Site Upper	423,666	4,035,136	3,618	400	110	-1.2
OL-92-2	413,206	4,026,544	3,552	1059	749.1	-8.9
OLSAC-MW-1	408,760	4,031,867	3,658	650	200	-3.9
OLSAC-MW-2	408,926	4,031,941	3,605	402	59	-3.2
River Site Lower	412,624	4,044,605	3,590	220	485	-2.8
River Site Upper	412,624	4,044,605	3,590	585	155	-5.0
Shallow River Production	412,708	4,044,628	3,590	225	170	-2.2
Deep River Production	412,708	4,044,628	3,590	555	485	-8.5
Sand Ranch #1	411,609	4,014,395	3,656	N/A	N/A	#N/A
SFIP MW	417,624	4,029,651	3,560	902	700	-1.9
SFIP PW	417,626	4,029,449	3,560	810	700	-1.4
Star Trek	419,616	4,034,332	3,563	774	644	4.2
T347	407,483	4,043,533	3,635	22	N/A	-4.0
T348	408,766	4,044,160	3,643	20.2	N/A	0.6
T349	411,125	4,045,031	3,637	38.26	N/A	3.8
T378	408,430	4,053,649	3,680	36.6	N/A	-1.1
T725	408,152	4,044,678	3,667	20	10	0.8
T726	408,167	4,044,680	3,667	20	10	0.2
T727	408,162	4,044,663	3,667	20	10	0.9
T258	403,191	4,055,987	3,658	200	N/A	-2.8
T890 (DWP-1)	408,870	4,048,004	3,667	1500	1150	-6.0
T891 (DWP-1)	408,870	4,048,010	3,667	540	480	-4.1
T892 (DWP-1)	408,868	4,048,016	3,667	390	290	-10.2
T893 (DWP-2)	412,319	4,045,191	3,599	1530	1430	-0.5
T894 (DWP-2)	412,325	4,045,196	3,600	1270	1170	-4.8
T895 (DWP-2)	412,331	4,045,201	3,600	960	860	-5.0
T896 (DWP-9)	412,454	4,041,348	3,572	1601	1280	-4.5
T897 (DWP-9)	412,454	4,041,340	3,572	880	780	-0.3
T898 (DWP-9)	412,453	4,041,332	3,572	340	240	-3.9
T899 (DWP-3)	418,255	4,038,644	3,573	1003	920	0.6
T900 (DWP-3)	418,260	4,038,647	3,573	720	660	0.6
T901 (DWP-3)	418,265	4,038,652	3,573	190	150	-2.1
T902 (DWP-10)	409,502	4,044,157	3,631	1500	1290	-7.7
T904 (DWP-10)	409,501	4,044,174	3,631	380	300	2.8
T905 (DWP-8)	408,815	4,028,606	3,544	1500	1200	-1.5
T906 (DWP-8)	408,807	4,028,605	3,544	530	450	-3.8
T907 (DWP-8)	408,800	4,028,605	3,543	330	250	-4.8

Table 6
Calibration Wells and Steady-State Calibration Head Residual

Well ID	Easting (m)	Northing (m)	Ground Surface Elevation (ft)	Well Depth (ft)	Top of Perforated Interval (ft bgs)	Residual (ft)
T908 (DWP-7)	410,017	4,020,293	3,582	1470	1360	1.5
T909 (DWP-7)	410,017	4,020,299	3,582	800	740	1.3
T910 (DWP-7)	410,019	4,020,305	3,582	260	200	-0.5
T911 (DWP-6)	414,252	4,025,254	3,564	1500	1420	-6.6
T912 (DWP-6)	414,248	4,025,249	3,564	1080	1020	-4.6
T913 (DWP-6)	414,256	4,025,260	3,565	312	260	-1.8
T914 (DWP-5)	414,581	4,030,257	3,566	1500	1360	-3.4
T915 (DWP-5)	417,576	4,030,253	3,566	1088	760	-3.2
T916 (DWP-11)	406,754	4,052,839	3,679	1500	1220	-7.6
T917 (DWP-11)	406,749	4,052,843	3,669	990	930	-9.2
V258	403,191	4,055,987	3,658	200	N/A	-2.8
6(2)	416,574	4,043,092	3,578	10	9	2.7
C5(1)	415,125	4,044,786	3,580	10	9	-1.7
D.5(1)	418,696	4,042,328	3,596	10	9	-11.4
D.5(4)	417,437	4,042,351	3,578	10	9	4.8
D.5(7)	412,863	4,042,449	3,572	10	9	-0.1
DeltaE(1)	412,863	4,042,449	3,583	10	9	6.3
DeltaE(3)	412,863	4,042,449	3,570	10	9	4.1
DeltaW(1)	412,863	4,042,449	3,581	10	9	0.1
DeltaW(3)	412,863	4,042,449	3,567	10	9	-0.2
F(1)	420,446	4,039,970	3,586	10	9	-2.9
F(3)	418,298	4,039,925	3,570	10	9	5.4
F(5)	416,664	4,039,997	3,564	10	9	1.6
G9(1)	422,353	4,038,029	3,583	10	9	-8.6
G9(2)	421,832	4,037,725	3,578	10	9	-2.5
I10(7)	422,626	4,035,273	3,572	10	9	1.7
J10(1)	423,722	4,033,405	3,581	10	9	1.6
J10(4)	423,223	4,033,414	3,574	10	9	0.9
J10(7)	422,758	4,033,422	3,571	10	9	1.0
K10(4)	422,657	4,032,202	3,574	10	9	0.9
K10(6)	420,560	4,032,418	3,567	30	29	2.8
KEELER(1)	421,233	4,038,912	3,581	10	9	-2.5
KEELER(2)	420,014	4,038,203	3,570	10	9	1.5
KEELER(4)	418,072	4,037,071	3,558	10	9	1.5
L9(2)	421,010	4,030,371	3,572	10	9	3.3
L9(4)	418,728	4,030,717	3,563	30	29	1.0
L9(5)	417,903	4,032,337	3,559	10	9	1.5
M8(1)	420,216	4,028,421	3,580	10	9	-0.3
M8(7)	416,362	4,030,788	3,558	10	9	1.3
M8(6)	417,577	4,028,941	3,560	30	29	-1.8
N7(6)	418,596	4,026,851	3,572	10	9	-0.3
N7(9)	415,088	4,029,020	3,559	10	9	2.0
N7(8)	416,362	4,027,134	3,562	30	29	-16.5
O6(5)	417,138	4,025,168	3,572	10	9	-1.5
O6(7)	414,932	4,025,397	3,561	30	29	-9.4
O6(8)	413,979	4,027,066	3,559	10	9	3.5
P5(5)	415,198	4,023,753	3,574	10	9	2.3
P5(7)	412,944	4,024,080	3,560	30	29	-7.9
Q4(6)	413,688	4,022,088	3,573	10	9	5.4
Q4(9)	410,170	4,023,201	3,568	10	9	1.6
S3(1)	411,904	4,019,959	3,596	10	9	6.7
S3(6)	423,517	4,035,897	3,562	10	9	4.1
SULFATE(3)	423,517	4,035,897	3,568	10	9	2.7
SULFATE(4)	423,517	4,035,897	3,567	10	9	1.8

Table 7
Calibration Statistics for the OLGEP Model

Calibration Statistic	Value
Mean Error (ft)	-0.44
Mean Absolute Error (ft)	3.52
Root Mean Squared Error (ft)	4.59
Percent Error	3.95

Figure 15 is a plot of all observed and corresponding model-simulated heads for the steady-state calibration. Each symbol type represents a calibration point in a different layer. Perfect simulation would result in a straight line where the simulated head would equal the observed head. All of the points are distributed closely around the diagonal line. The points that do deviate from the diagonal line appear to be randomly distributed.

Figure 16 is a histogram of the model residuals. A histogram is a frequency plot prepared by placing the residuals in regularly-spaced intervals, or bins, and plotting each bin frequency. This figure illustrates an approximately normal distribution of residuals produced by the Owens Lake model. Based on the residual distribution, 59% of simulated values are within two and one half feet of the observed values, 83% of the simulated values are within five feet of the observed, and 98% of the simulated values are within 10 feet of the observed values.

Causes of residuals include the following:

- **Known Non-Contemporaneous Data Points**. Water level measurements for the steady-state calibration were taken at different times, separated by months and even years in some cases. If these data were all that were available at some locations, then they were used in the calibration but may not be representative.
- **Partially-Penetrating Piezometers within a Layer with a Known Gradient**. There are a disproportionate number of calibration wells on the lakebed in layer one of the model. The majority of these lakebed wells are shallow piezometers installed as part of the GBUAPCD Owens Lake Shallow Hydrology Monitoring Program. The piezometers installed for this program are completed at depths of 4 feet, 10 feet, and 30 feet, all with the bottom foot of casing screened. The pressure varies vertically on the lake bed (generally increasing with depth); given that these piezometers are all in the same layer, they will produce residuals.
- **Unaccounted for Heterogeneity**. The Owens Lake model domain covers a considerably large area. Estimates of aquifer parameters have been made between known lithologic data points (wells with a lithologic log) and geophysical cross-sections, but there is a significant area between these data points. A particular area of uncertainty is below the Brine Pool portion of Owens Lake, because no data exists for this area.
- **Numerical Model Cell Size**. The model necessarily generalizes computed water levels over a 500 by 500 foot area. This generalized or average water level may not be representative of water levels measured in the field at a particular point, particularly in an area of high groundwater gradients.

Figure 15
Comparison of Observed and Simulated Water Levels

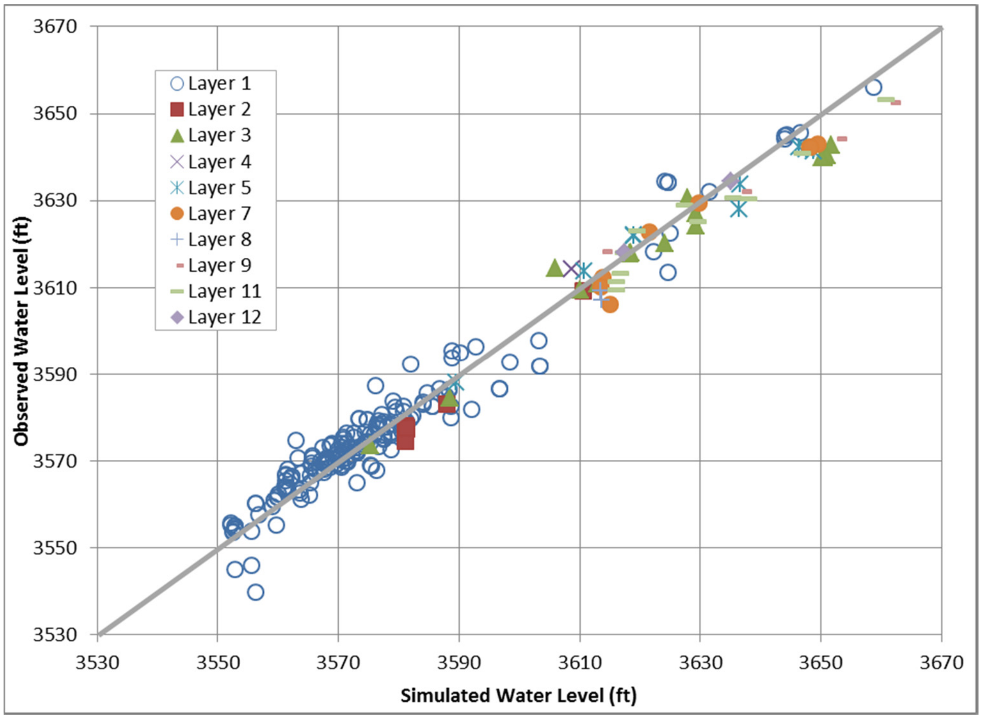
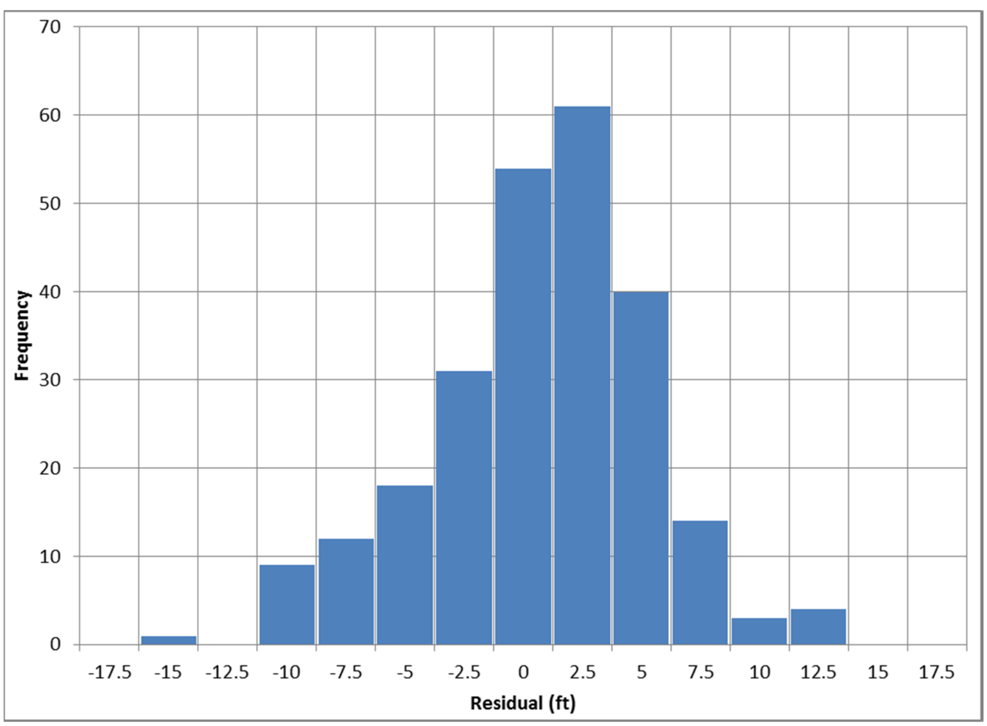


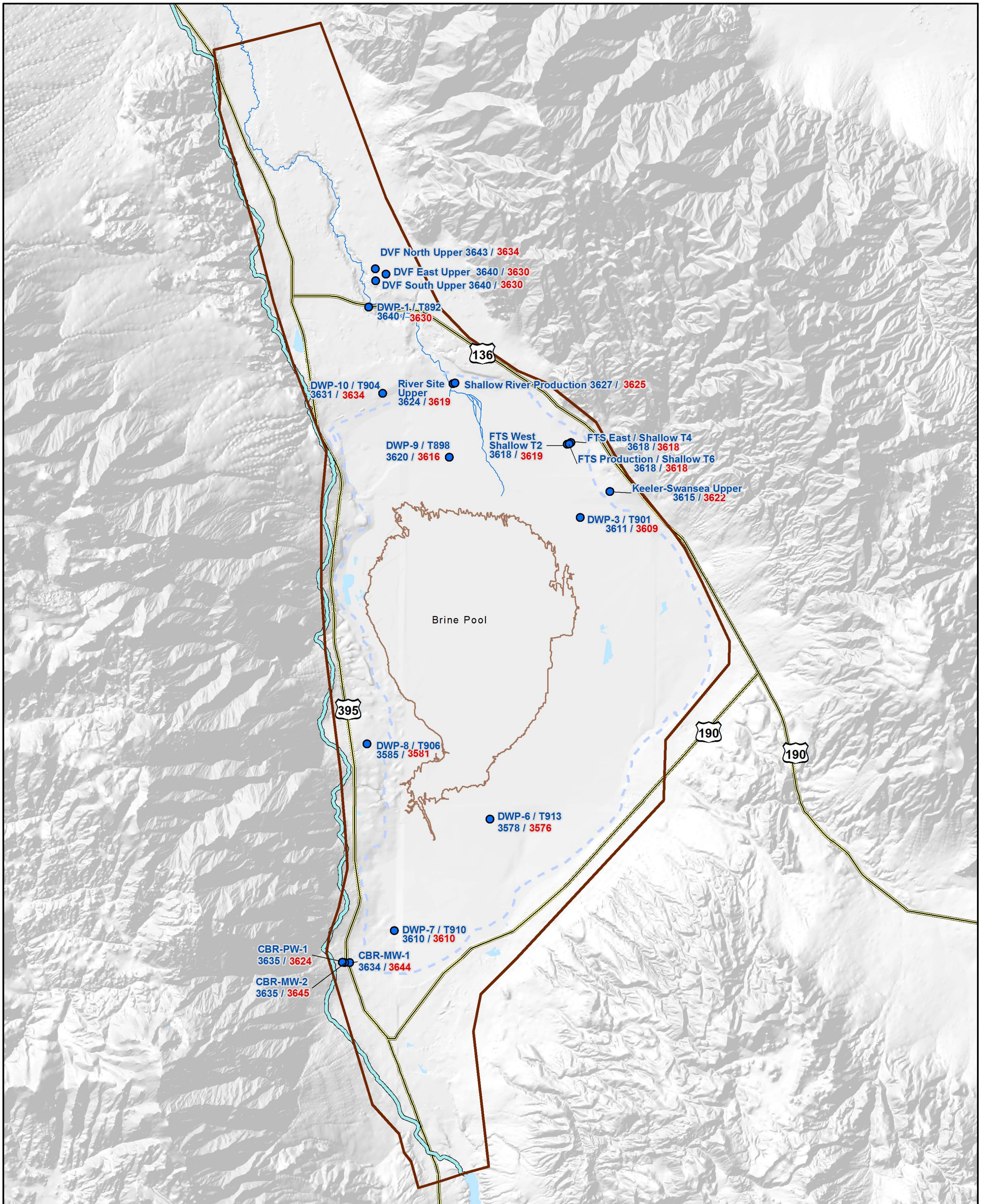
Figure 16
Histogram of Model Residuals



3.2 Groundwater Flow Pattern

Another method of evaluating the model fit is to review model-wide head results for general flow relationships. **Figure 17** illustrates observed and simulated groundwater levels in Aquifer 1 (layer 3). Shallow groundwater flow directions are consistently toward the brine pool. **Figure 18** through **Figure 21** show the observed and simulated head at calibration points for Aquifers 2 through 5 (odd numbered layers 5 through 11). For Aquifer 2, the model often over predicts water levels for the calibration points, although there are only eight points. For the Aquifers 3, 4, and 5 the model typically also over predicts. Within Aquifers 2, 3, 4, and 5, residuals are as high as 9 feet. For Aquifer 1, residuals are as high as 11 feet; the highest residuals are in model layers 1 and 2.

Vertical gradients in the Owens Lake area are measured at new OLGEP monitoring wells. The model attempted to match the vertical gradient at these locations. **Table 8** lists selected wells with vertical gradient data, their location, and the corresponding observed and simulated heads. Observed and simulated heads are similar (low residual) and the vertical gradient typically matches.



Key to Features

Observed and Simulated Water Level Comparison:

3,635 (Observed, ft msl)
3,645 (Simulated, ft msl)

Highways
Los Angeles Aqueduct
Owens River
OLGEP Study Area
Other Water Bodies
Owens Lake (Historic Shoreline)

N
0 1.5 3 Miles

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\TM40115\UpdateOct2012\ObsSimHead.mxd

Task 5: OLGEP Groundwater Model Documentaion

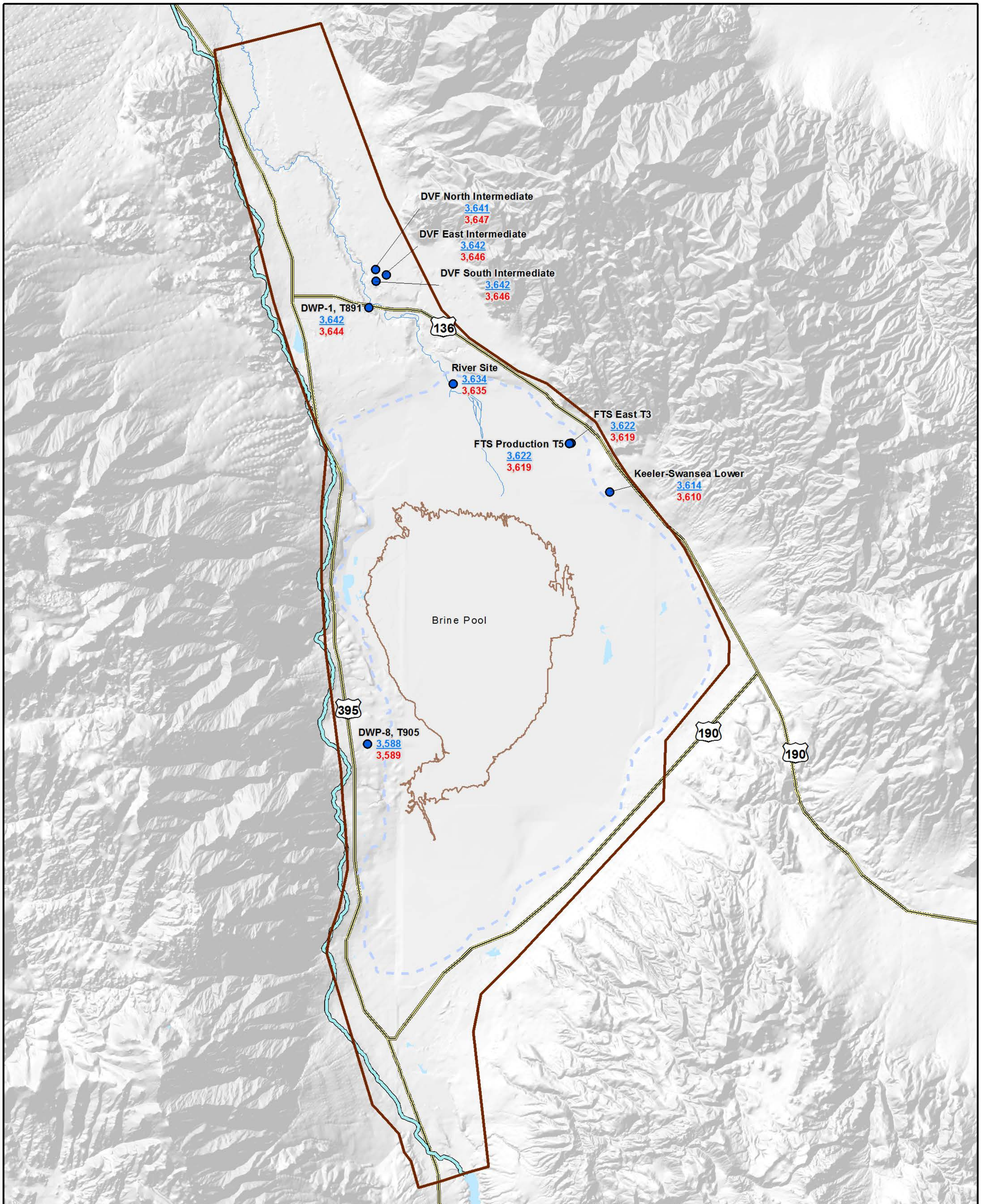
Observed and Simulated Head Aquifer 1

Los Angeles Department of Water & Power

Figure 17

MWH

This map has been designed to print 8.5" x 11''.



Key to Features

Observed and Simulated Water Level Comparison:

3,642 (Observed, ft msl)
3,644 (Simulated, ft msl)

Highways
Los Angeles Aqueduct
Owens River
OLGEP Study Area
Other Water Bodies
Owens Lake (Historic Shoreline)

N
0 1.5 3 Miles

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\TM40115\UpdateOct2012\ObsSimHead.mxd

Task 5: OLGEP Groundwater Model Documentaion

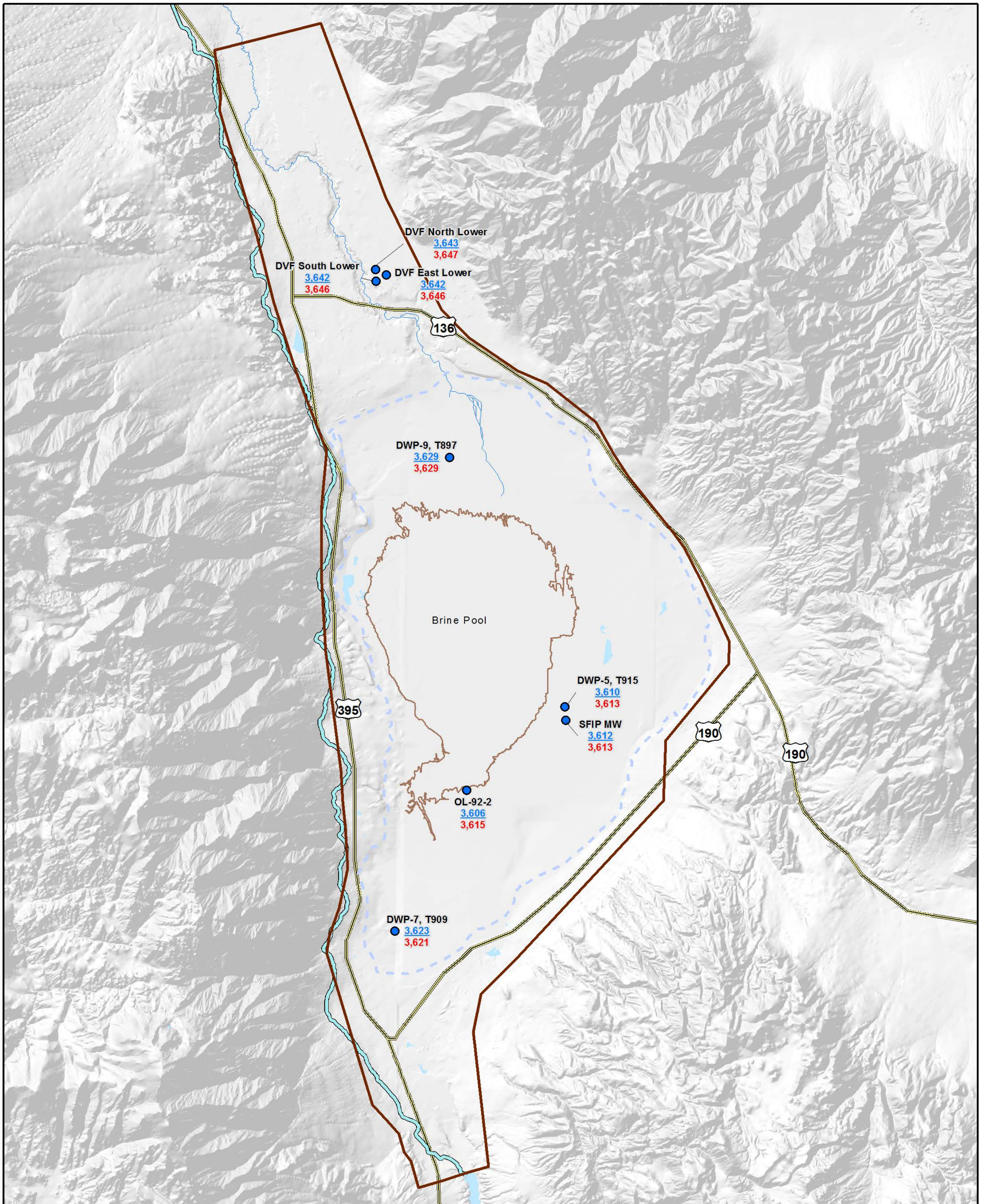
Observed and Simulated Head Aquifer 2

Los Angeles Department of Water & Power

Figure 19

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Observed and Simulated Water Level Comparison:

3,642 (Observed, ft msl)
3,646 (Simulated, ft msl)

Highways
Los Angeles Aqueduct
Owens River
OLGEP Study Area
Other Water Bodies
Owens Lake (Historic Shoreline)

N
0 1.5 3 Miles

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS \Projects\OLGEP\TM40115\UpdateOct2012\ ObsSimHead.mxd

Task 5: OLGEP Groundwater Model Documentaion

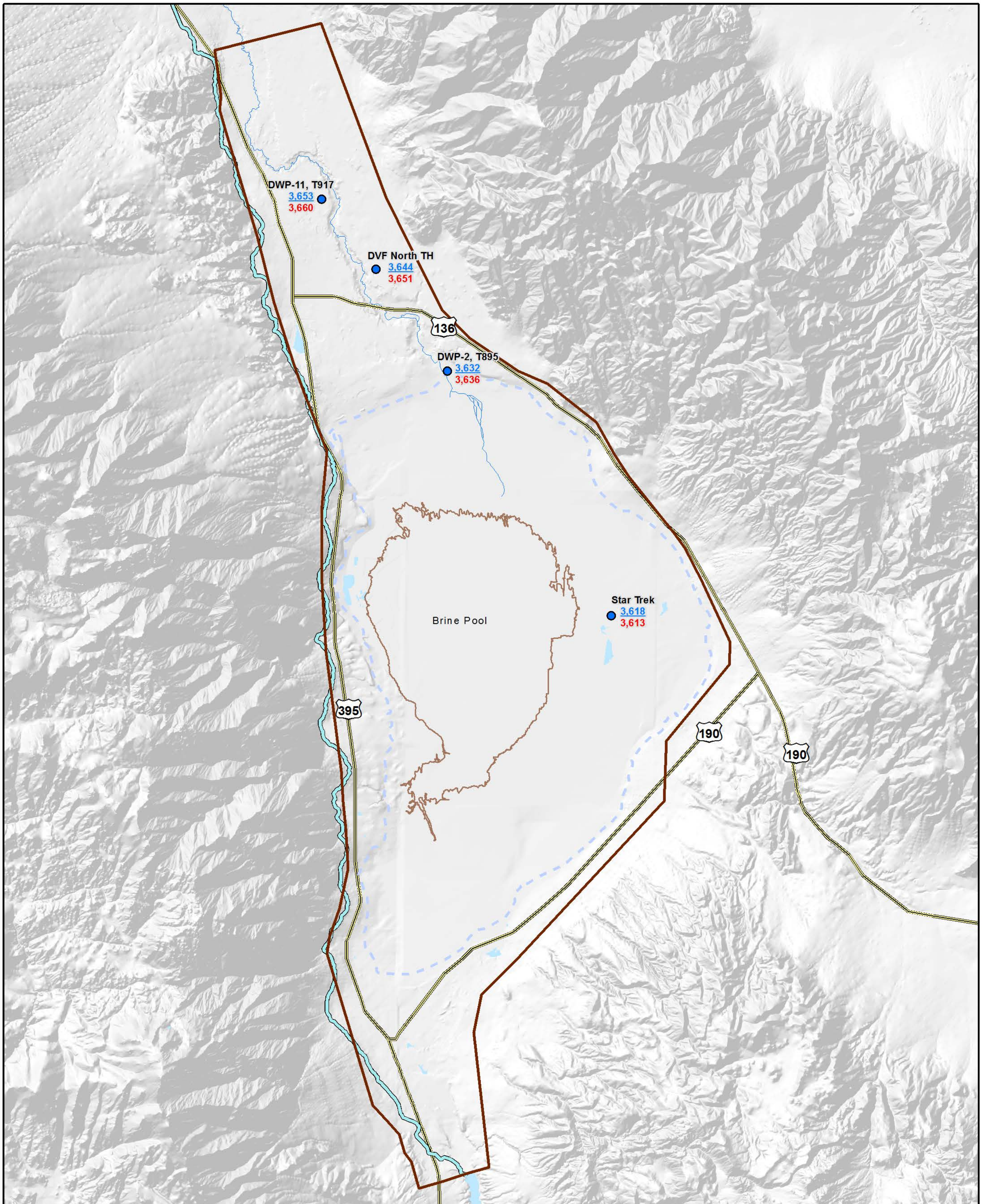
Observed and Simulated Head Aquifer 3

Los Angeles Department of Water & Power

Figure 19

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Observed and Simulated Water Level Comparison:

3,653 (Observed, ft msl)

3,660 (Simulated, ft msl)

Highways

Los Angeles Aqueduct

Owens River

OLGEP Study Area

Other Water Bodies

Owens Lake (Historic Shoreline)

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\TM40115\UpdateOct2012\ObsSimHead.mxd

Task 5: OLGEP Groundwater Model Documentaion

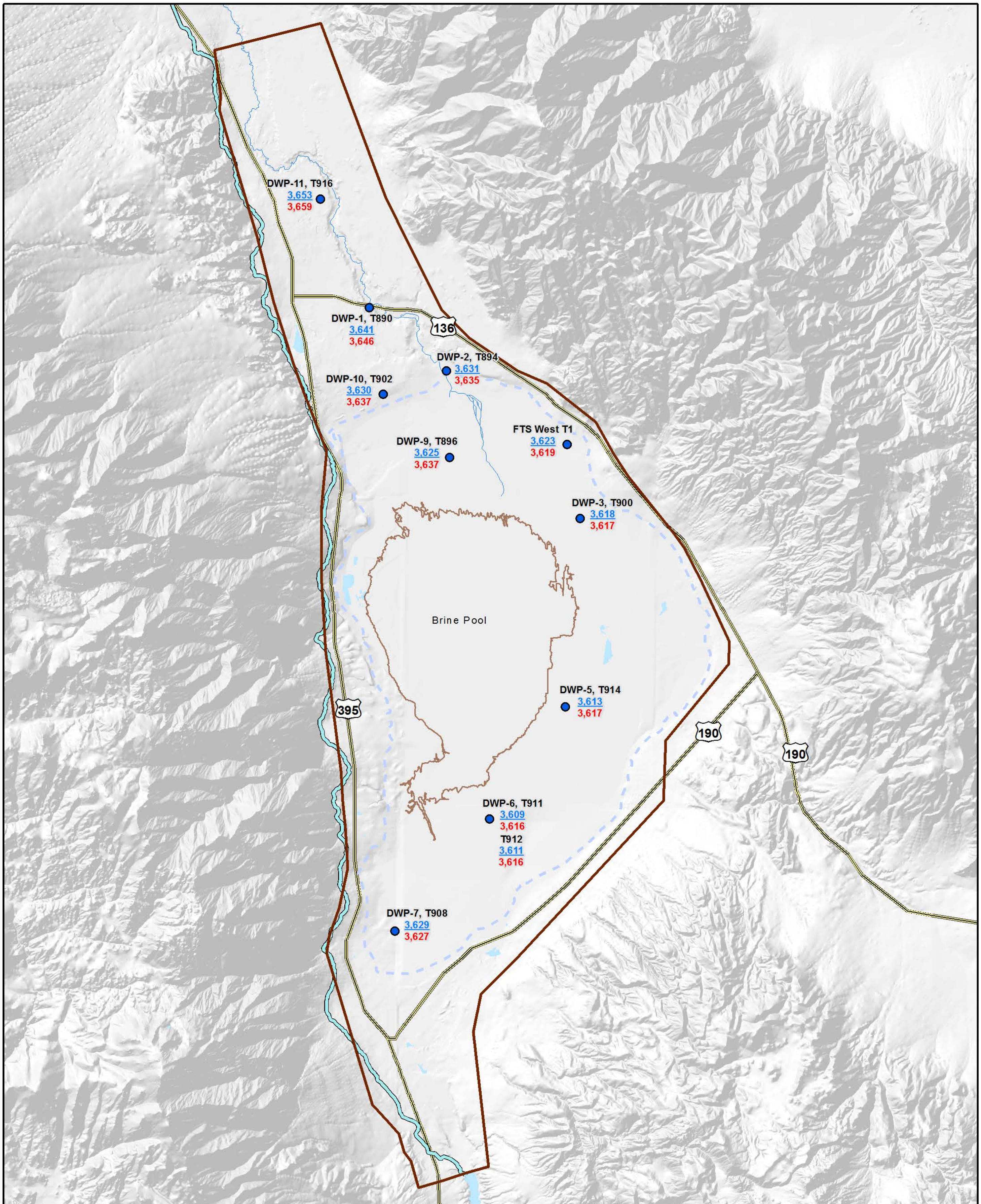
Observed and Simulated Head Aquifer 4

Los Angeles Department of Water & Power

Figure 20

MWH

This map has been designed to print 8.5" x 11".



Key to Features

Observed and Simulated Water Level Comparison:

3,653 (Observed, ft msl)
3,659 (Simulated, ft msl)

Highways
Los Angeles Aqueduct
Owens River
OLGEP Study Area
Other Water Bodies
Owens Lake (Historic Shoreline)

0 1.5 3 Miles

Document: \\Uspas1s01\muni\Clients\Los Angeles Water&Power\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\TM40115\UpdateOct2012\ObsSimHead.mxd

Task 5: OLGEP Groundwater Model Documentaion

Observed and Simulated Head Aquifer 5

Los Angeles Department of Water & Power

Figure 21

MWH

This map has been designed to print 8.5" x 11".

Table 8
Summary of Vertical Gradient Calibration

Well ID	Well Depth (ft)	Well Location	Observed Groundwater Level (ft)	Simulated Groundwater Level (ft)	Residual
T890 (DWP-1)	1,500	North	3,641	3,647	6.0
T891 (DWP-1)	540		3,642	3,646	-4.1
T892 (DWP-1)	390		3,640	3,650	-10.2
T893 (DWP-2)	1,530	North Delta	3,634	3,635	-0.5
T894 (DWP-2)	1,270		3,631	3,635	-4.8
T895 (DWP-2)	960		3,632	3,637	-5.0
T896 (DWP-9)	1,601	Delta	3,625	3,630	-4.5
T897 (DWP-9)	880		3,629	3,630	-0.3
T898 (DWP-9)	340		3,620	3,624	-3.9
T899 (DWP-3)	1,003	East	3,618	3,617	0.6
T900 (DWP-3)	720		3,618	3,617	0.6
T901 (DWP-3)	190		3,611	3,613	-2.1
T902 (DWP-10)	1,500	Northwest Lake	3,630	3,638	-7.7
T904 (DWP-10)	380		3,631	3,628	2.8
T905 (DWP-8)	1,500	West	3,588	3,590	-1.5
T906 (DWP-8)	530		3,585	3,588	-3.8
T907 (DWP-8)	330		3,583	3,588	-4.8
T908 (DWP-7)	1,470	South Lake	3,629	3,627	1.5
T909 (DWP-7)	800		3,623	3,622	1.3
T910 (DWP-7)	260		3,610	3,610	-0.5
T911 (DWP-6)	1,500	Southeast / Lakebed	3,609	3,616	-6.6
T912 (DWP-6)	1,080		3,611	3,616	-4.6
T913 (DWP-6)	312		3,574	3,575	-1.8
T914 (DWP-5)	1,500	Southeast / Lakebed	3,613	3,617	-3.4
T915 (DWP-5)	1,088		3,610	3,613	-3.2
T916 (DWP-11)	1,500	Lone Pine Area	3,653	3,661	-7.6
T917 (DWP-11)	990		3,653	3,662	-9.2

3.3 Seeps, Springs, and Flowing Wells

A characterization of springs was conducted to identify sources of springs and relationships to aquifer units (MWH, 2011c). Springs within the model domain can be categorized as natural seeps and springs (springs) and flowing wells, which are uncapped artesian wells. **Table 9** lists the springs and flowing wells, only flowing wells were used for calibration. The locations of these wells and springs are also shown on **Figure 1**.

Flowing wells within the model area include:

- Dirty Socks
- Horse Pasture
- Black Sands
- Sulfate Well
- Keeler Spring
- PPG Well
- Bartlett Well
- Duck Wells

Although some flowing well construction data was obtained via video inspection, many flowing wells lack construction information. Therefore, the results of the spring characterization and sourcing effort were used for initial layering assignments for flowing wells. These wells were simulated as MODFLOW drains with the layer setting ultimately based on head and simulated discharge during calibration. The final layering assignments for flowing wells are listed in **Table 9**.

In many cases, the surface expression of springs is diffuse and spread over a large area. It is this surface expression that makes springs difficult to use as calibration points as there is often no method to quantify discharge. Shallow springs are used during calibration for comparison to approximate general spring discharge patterns. During calibration, measured springs were used for guidance only.

Table 9
Flowing Wells and Springs Calibration Model Results

Flowing Well Name	Row	Column	Model Layer	Average Recorded Discharge (gpm)	Minimum Recorded Discharge (gpm)	Maximum Recorded Discharge (gpm)	Simulated Discharge (gpm)
Bartlett	148	54	5	92.6	49	217.9	220.1
Black Sands	163	130	3	59.1	50	81	80.6
Dirty Socks	268	64	5	151.2	55	280	208.0
Horse Pasture	162	131	3	444.8	395	460	482.6
Keeler Spring	175	138	1	13.9	0	70	32.2
PPG Metal Plate	153	51	5	26.1	13.8	45.8	16
Sulfate Well	193	118	5	386.8	345	526.6	538.5

3.4 Water Budget

For the OLGEP study area, the water budget is an accounting of groundwater recharge (inflow) and outflows. The water budget was developed as long-term average condition without reference to a particular year, as an approximation of a steady-state condition. There is no true “steady-state”, but the water budget attempts to balance annual average historic inflows and outflows to/from the OLGEP study area. As described in the Model Strategy (MWH, 2011b), the Owens Lake groundwater system has little variation in groundwater level and can be considered essentially in a steady-state condition.

The OLGEP study area is delineated by hydraulic boundaries (either bedrock boundaries or a groundwater divide) with the exception of the northern boundary. To the north, the study area is bounded by the Alabama Hills north and west of Lone Pine, which has caused a narrowing of the Owens Valley. Significant groundwater flow takes place across this northern boundary. The southern boundary is defined by the topographic divide between North and South Haiwee Reservoir, which also acts as a groundwater divide, resulting in a no-flow groundwater boundary. East and west boundaries are delineated based on the bedrock contact, with the Sierra Nevada, Inyo, and Coso mountain ranges.

Table 10 summarizes the model-simulated inflow and outflow for the Owens Lake Basin under steady-state conditions. When total inflow is equal to total outflow, there is no change in groundwater storage.

Prescribed ranges of values by water budget component were prepared and documented in the Updated Conceptual Model Report (MWH, 2011c). The purpose of these values was not to conclusively apply fixed numbers to the groundwater model, but to provide guidance and reasonable limits to the groundwater modeling effort. All elements of the groundwater model's water budget fit within the recommended range prescribed in the updated conceptual model report (MWH, 2011c). The steady-state total inflow/outflow to the groundwater body in the model area is approximately 57,500 acre-feet per year.

One modification to the water budget previously published in the Updated Conceptual Model Report is the return flows from the Lone Pine wastewater facility. A 40-year average return to groundwater was determined based on local water use records. Local public groundwater pumping records were prepared for the areas that send wastewater to the Lone Pine wastewater facility for the period of 1972 to 2011. Using these records, a 60 percent indoor use rate was assumed to determine the flow to the wastewater facility. Once treated and discharged, a 56 in/yr ET rate was assumed for the 13 acres ponds at the facility. The result was a 40-year annual wastewater recharge to groundwater minimum of 264 AF/yr, average of 750 AF/yr, and maximum of 1,671 AF/yr. The 40-year average of 750 AF/yr was used in the model.

Table 10
Steady-State Water Budget Summary

Budget Element	Steady State Water Budget		
	IN (AF/yr)	**OUT (AF/yr)**	**Net (AF/yr)**
Storage	**0**	**0**	**0**
Constant Heads	**8,034**	**(8,761)**	**(727)**
Brine Pool	0	(8,761)	(8,761)
Haiwee Reservoir	8,034	0	8,034
Drains	**0**	**(11,734)**	**(11,734)**
General Heads	**12,840**	**(821)**	**12,019**
Rivers	**16,572**	**(20,537)**	**(3,965)**
Owens River	12,649	(18,703)	(6,054)
Lone Pine Streams	4,106		4,106
Diaz Lake	242	(340)	(98)
Wells	**17,524**	**(2,092)**	**15,432**
Recharge	**2,464**		**2,464**
Evapotranspiration	**0**	**(13,616)**	**(13,616)**
Total Source/Sink	**57,433**	**(57,561)**	**(127)**

In the case of Owens Lake Basin, detailed data on outflow from the groundwater system is not available. For example, private groundwater pumping from most wells is not gaged, and the amount of pumped water from those wells that returns to the aquifer through deep percolation is a further unknown. Additionally, although flow is monitored in several springs and artesian wells, they represent only a small fraction of the flow from springs and seeps that exist near the lake. Outflow from the groundwater system is a model-derived variable. Note on the water budget that the difference between the inflow and outflow is negligible, thereby representing a steady-state condition in which there is no change in storage.

A review of the ET and drain discharge was conducted at a cell level to determine if the location and magnitude of discharge were reasonable. ET rates do not exceed 36 in/yr in any cell. The maximum drain discharge rates are located on the periphery of the Owens Lake historical shoreline where groundwater originating from recharge on the alluvial fans meets lower conductivity materials and discharges. The maximum rate is about 107 AF/year, or 66 gallons per minute (gpm) from a single cell. The review summary is provided in **Attachment C**.

4.0 TRANSIENT CALIBRATION RESULTS

As described in the Model Strategy TM and other published documents (MWH, 2011b; MWH, 2012a), the Owens Lake groundwater system has little variation in groundwater level and can be considered essentially in a steady-state condition. Because no recent significant transient perturbation has occurred in the area, the transient calibration was completed using available pump test data. At the conclusion of preliminary steady-state model calibration, the steady-state model was converted to a transient model and calibrated with data from three previously pump tests:

- Variable pumping rate at W390, W344, W346 and the two River Site Production wells along with the great observation data at Down Valley Flow Site (DVFS) monitoring wells.
- The Fault Test Site production well T5 was tested at an average flow rate of 250 gpm from October 24, 2011 to November 22, 2011.
- The Deep River Site production well was pumped from December 14, 2011 to January 17, 2012 at an average flow rate of 1,335 gpm.
- The Shallow River Site pump test was initiated on February 23, 2012 and ended on March 26, 2012 at an average flow rate of 2,133 gpm.
- The SFIP (South Flood Irrigation Project) well was pump tested from June 18, 2012 to July 2, 2012 at an average flow rate of 1,000 gpm.

Provided herein is a brief description of each of the selected pumping tests. Calibration graphs comparing simulated and observed drawdown for these pump tests are provided in **Attachment D**. **Table 11** summarizes maximum drawdown observed, observation well distance from pumping well, and simulated maximum drawdown at each monitoring well. The model cell spacing is a uniform 500 feet; therefore, monitoring data at a radius of greater than 1,000 feet were preferred for the calibration. Using an observation well within two model cells is not recommended for model calibration as drawdown will not be representative. For this reason, calibration efforts focused on simulating the general pattern of drawdown, but reproducing the exact absolute value of drawdown as needed at a single point was neither attempted, nor recommended.

Variable pumping rate at W390, W344, W346 and River Site wells. During the 1999 constant rate pumping test at the River Site production wells, drawdown impact was observed at DVFS monitoring wells, which are located roughly 3 miles north-northwest of the River Site. Further examination of the hydrographs at DVFS wells and pumping record at W390, W344 and W346 showed that the sinusoidal characteristics of the hydrograph were due to the seasonal pumping at W390, W344 and W346 and the sporadic pumping at the two River Site production wells (see the hydrographs in **Attachment D**). These drawdown data and average monthly pumping rates were used as a longer period pump test for calibration. The matching of simulated to observed water levels was completed within layers 3, 5, and 7. Differences between simulated and observe decrease with layer depth. All differences are typically less than 2.5 feet.

Fault Test Site – T5. The Fault Test Site – T5 Well pump test was completed on November 22, 2011 for 29 days with groundwater production from layer 5 of the model. The pumping rate used on the simulation for production well was 250 gpm. This pump test calibration consists of 34 deep monitoring wells, although a response was observed in only three wells. Shown in **Attachment D** are the drawdown responses at the three wells. All calibration points were in layer 5 of the model; the simulated results are typically within four feet of the observed data. Although in close proximity to the pumping well, these were used only as guidance and not used for calibration.

Deep River Site. The Deep River Site pump test was completed on January 17, 2012 for 34 days with groundwater production from layer 5 and layer 6 of the model. Data for this pump test were provided by LADWP. Calibration to this pump test consists of the same monitoring components as those for the above pumping test at the Fault Test Site (T5). At this site there are two production wells: Shallow River and Deep River. The pumping rate used on the simulation for Shallow River production well was 1,335 gpm. The difference between the observed and simulated water level increases with depth. Primary responses to pumping are at the Down Valley Flow Site and well T903. These monitoring wells are 18,870 and 10,630 feet away from the pumping well, respectively. A third monitoring well was used during calibration, but due to its close proximity to the pumping well it was primarily used for calibration guidance. Within the shallow layers, the difference is less than one foot (see the graphs in **Attachment D** or **Table 11**). Down Valley Flow Site and well T903 the drawdown curve matches well and is typically within 0.5 feet.

Shallow River Site. The Shallow River Site pump test was completed on March 26, 2012 for 35 days with groundwater production from layer 3 of the model. The pumping rate used on the simulation for Shallow River production well was 2,133 gpm. Components monitored for this test includes water levels in 36 deep monitoring wells, production wells and four shallow piezometers. In addition, flow at Dead Hawk, Lizard Tail, Bartlett and PPG springs and flowing well sites were also monitored. A response to pumping was only observed at three monitoring wells: T892, T88, and T904 (see graphs in **Attachment D** or **Table 11**). For each of the monitoring wells the simulated drawdown curve is similar to the observed drawdown and is typically within 1.5 feet.

South Flood Irrigation Project Well (SFIP). The SFIP pump test was completed on July 2, 2012 for 15 days with groundwater production from layer 7 of the model. The pumping rate used for the simulation for the production well was 1,000 gpm. Components monitored for this test includes water levels in 19 deep monitoring wells at Mill Site, OL-92-2, SFIP, DWP-8 (T905, T906 and T907), DWP-7 (T908, T909 and T910) DWP-6 (T911, T912 and T913) and DWP-5 (T913, T914 and T915). In addition, water levels and flow were also monitored in shallow piezometers and flume at Sulfate Well, Tubman Channel and Whiskey Spring. Measureable water level change was only observed in three wells: the SFIP monitoring well, T915, and OL-92-2. Maximum simulated and maximum observed drawdown for each of these wells is within one foot. Hydrographs are shown in **Attachment D** and the data are presented in **Table 11**.

Pump tests provided the most valuable piece of transient calibration data to the OLGEP groundwater model. These data not only helped to quantify calibration parameters such as vertical hydraulic conductivity, horizontal hydraulic conductivity, storage coefficients, but also to identify faults, which act as barriers to groundwater flow. A specific example is the River Site pump test. This test helped confirm the hydraulic impact of the Owens River Fault Zone. These data helped identify the location of northwest/southeast trending faults. Additional data of this type and in other locales would reduce overall uncertainty in the model.

Table 11
Summary of Calibration Pump Test Data

Pumping Well	Date	Duration (days)	Pumping Rate (gpm)[1]	Observation Data					Model Data	
				Location	Static Water level	Lower most Pumping Water Level (ft)	Maximum Drawdown Observed (ft)	Distance from pumping well (ft)	Maximum Drawdown Calculated (ft)	Layer
W390, W344, W346, River Site Shallow and Deep Production Wells	Historical	1,460 (Approx)	Actual monthly averages used and vary over time	DVFS-East Pad-Upper	3641.8	3637.3	4.5	W344: 16,800 W346: 16,760 W390: 12,940	7.2	3
				DVFS-East Pad-Intermediate	3644.3	3640.0	4.3		4.8	5
				DVFS-East Pad-Lower	3644.7	3641.0	3.7		4.7	7
				DVFS-North Pad-Upper	3644.2	3639.3	5.0		6.4	3
				DVFS-North Pad-Intermediate	3644.1	3639.4	4.8		4.6	5
				DVFS-North Pad-Lower	3645.4	3641.6	3.8		4.5	7
				DVFS-South Pad-Upper	3642.1	3637.1	5.0		7.1	3
				DVFS-South Pad-Intermediate	3645.1	3639.8	5.2		4.8	5
				DVFS-South Pad-Lower	3644.5	3640.6	4.0		4.6	7
Fault Test Site (FTS) Production well - T5[2]	October 24 to November 22, 2011	29	250	FTS - T5	3624.1	3609.6	14.6	0	13.7	5
				FTS - T2L	3625.4	3617.4	7.9	300	10.7	5
				FTS - T3	3627.0	3617.9	9.1	300	13.4	5
River Site Deep Production Well	December 14, 2011 to January 17, 2012	34	1,335	River Site-Lower Piezometer	36.5.67	3595.7	40.0	325	37.1	5
				DVFS-South Pad-Intermediate	3644.8	3642.1	2.7	18,870	2.6	5
				T903	3634.7	3630.0	1.9	10,630	2.1	5
River Site Shallow Production Well	February 23 to March 26, 2012	35	2,133	T892	3639.8	3636.1	3.7	16,830	4.0	3
				T898	3619.7	3612.4	7.3	10,850	8.7	3
				T904	3629.7	3621.5	8.2	10,670	6.8	3
South Flood Irrigation Project (SFIP) Well	June 18 to July 2, 2012	15	1,000	SFIP_MW	3610.8	3568.4	42.5	660	43.5	7
				T915	3610.4	3588.5	21.9	2,640	21.1	7
				OL-92-2	3601.7	3600.7	1.0	17,350	0.4	7

1. If pumping occurs in multiple layers, the rate per layer is calculated based upon the layer hydraulic conductivity and the length of perforated well screen within the layer.
2. No response in other monitoring wells hence very close monitoring wells were used for calibration guidance.

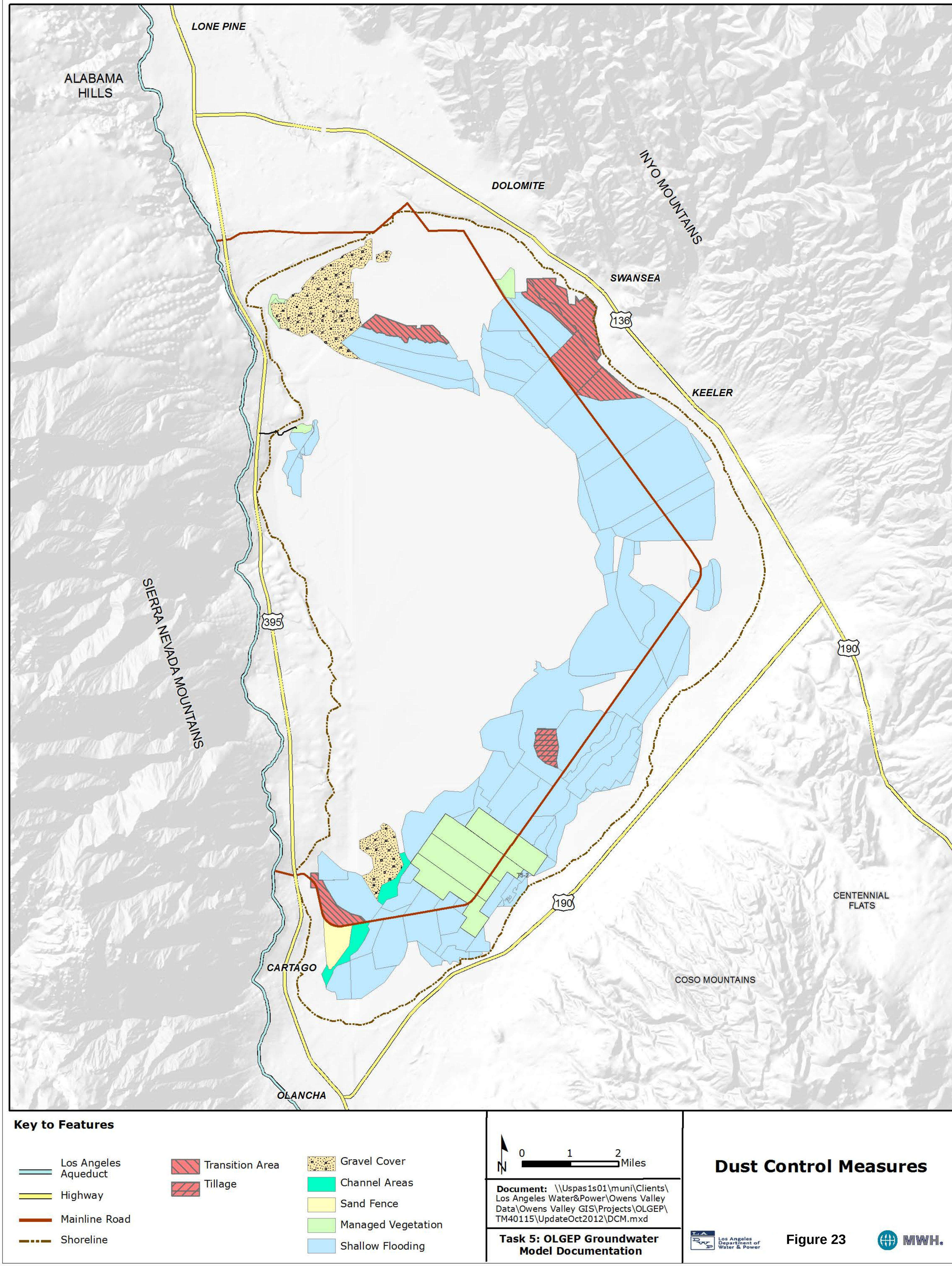
5.0 Modeling of the Dust Control Measures (DCM)

LADWP has implemented a dust mitigation program to reduce emissions of fine particulates from the dry Owens Lake bed. Implementation of the project has been in multiple phases. Dust management areas are supplied from a 28-mile long pipeline, termed the main line, which supplies water from the Los Angeles Aqueduct via two spill gates (Lubkin and Cartago) to the lake bed. There are 37 turnouts along the mainline to deliver water to areas of the lake bed for dust control. Key facilities and management areas are shown on **Figure 22**. The LORP pump back station also supplies the main line. The water delivery system for DCMs supplies a total of 27,600 acres (approximately 43 square miles) of management area, consisting of shallow flood areas (22,900 acres), managed vegetation areas (2,300 acres), and moat and row management areas (2,400 acres).

There are different types of DCMs, this model simulated the shallow flood DCMs. Shallow flood can range from overland flow to surface water pooling. Each model cell overlain by a shallow flood DCM in layer 1 was initially assigned a constant head at the shallow flooding water level in layer 1. The recharge package was applied to simulate DCM shallow flooding operation based on 2007 to 2008 water budget data provided by LADWP (**Table 12**). The two year average for the periods from April to September and October to March is 30,826 and 11,021 acre-feet, respectively. Total area of the shallow flooding pond from T1 through T36 is 18,557 acres. Recharge rate applied to the model was 0.00910 and 0.00325 ft/day for stress periods from April to September and from October to March, respectively, for a total of 30,818 and 11,006 acre-feet.

Table 12
Summary of DCM Water Usage in 2007 and 2008

Month	Water Use (AF)		
	2007	2008	Average
Jan	1320	239	780
Feb	1168	983	1,076
Mar	2330	2,445	2,388
Apr	2974	4,086	3,530
May	4528	8,221	6,374
Jun	5439	7,620	6,529
Jul	2824	1,823	2,324
Aug	2397	8,000	5,199
Sep	5062	8,682	6,872
Oct	2695	5,337	4,016
Nov	1152	2,408	1,780
Dec	830	1,135	982



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Task 5: OLGEP Groundwater Model Documentation

Dust Control Measures

Figure 23

A review of hydrographs suggests that DCMs are locally influencing water levels in the very shallow piezometers on the lake bed (MWH, 2011c). This review concluded that the effect of DCMs on groundwater appears to be limited to thin sand layers on the surface of the lake, and DCMs have no apparent effect on deeper aquifer zones. The presence of strong upward vertical gradients and artesian conditions would prohibit water from DCMs migrating downward into deeper aquifers. Listed in **Table 13** are wells with their pre-DCM measured and simulated water level as well as post-DCM simulated water levels. The simulated results are consistent with the observed conditions and the conceptual understanding that the combination of vertical gradients and artesian conditions suggests that water from DCMs is not affecting gradients or the amount of groundwater in storage in deeper aquifers. This is also consistent with the fact that the DCMs are underlain by a large thickness of relatively impermeable clays which effectively isolate them from the deeper groundwater system.

Table 13
Observed and Simulated Water Levels With and Without DCM Conditions

Well	Model Layer	No-DCM Measured Water Level				With-DCM Measured Water Level				No-DCM Simulated Water Level	With-DCM Simulated Water Level	Difference in Simulated Water Level
		Maximum	Minimum	Average	Period	Maximum	Minimum	Average	Period			
T348	1	3,638	3,632	3,637	12/14/71-10/13/99	3,635	3,630	3,634	4/7/00-1/7/09	3,630	3,630	0
T349	1	3,597	3,590	3,596	12/14/71-12/12/99	3,597	3,596	3,597	1/10/00-1/16/09	3,592	3,592	0
T378	1	3,646	3,643	3,645	8/31/73-10/14/99	3,646	3,646	3,646	4/10/00-10/30/08	3,645	3,645	0
Mill Site Upper	2	3,610	3,608	3,608	12/27/95-12/31/99	3,609	3,609	3,609	1/1/00-1/6/09	3,613	3,613	0
T907	2					3,582	3,581	3,581	1/31/11-7/18/11	3,592	3,592	0
River Site Upper	3	3,637	3,589	3,623	1/27/92-12/16/99	3,629	3,589	3,626	1/15/00-12/9/06	3,627	3,627	0
DVF East Upper	3	3,642	3,638	3,641	6/10/97-12/12/99	3,642	3,637	3,640	2/18/00-9/5/08	3,642	3,641	-1
Keeler Swansea Upper	3	3,614	3,613	3,614	9/28/95-12/1/99	3,614	3,613	3,614	1/30/00-1/3/07	3,612	3,612	0
FTS West Shallow – T2	3	3,619	3,617	3,618	4/14/99-12/8/99	3,620	3,616	3,618	1/7/00-1/20/09	3,622	3,622	0
T892	3					3,641	3,636	3,638	6/15/10-5/1/12	3,641	3,641	0
T901	3					3,612	3,609	3,610	8/11/10-4/30/12	3,616	3,616	0
T913	3					3,574	3,574	3,574	4/6/11-7/20/11	3,576	3,577	1
T910	3					3,609			2/8/2011	3,616	3,617	1
T898	3					3,620	3,612	3,618	6/29/10-4/30/12	3,617	3,617	0
T906	3					3,584	3,582	3,583	1/31/11-7/18/11	3,593	3,593	0
T904	3					3,630	3,622	3,628	1/27/2011-5/1/12	3,626	3,626	0
DVF East Middle	5	3,644	3,640	3,643	6/10/97-12/12/99	3,644	3,640	3,643	2/18/00-9/5/08	3,638	3,638	0
River Site Lower	5	3,636	3,590	3,624	2/1/92-12/4/99	3,635	3,596	3,632	1/3/00-11/27/06	3,628	3,628	0
FTS East Deep - T3	5	3,623	3,617	3,622	4/1/99-12/25/99	3,627	3,622	3,624	1/24/00-1/20/09	3,622	3,622	0
Keeler Swansea Lower	5	3,615	3,614	3,614	9/28/95-12/1/99	3,615	3,614	3,614	1/30/00-3/7/07	3,614	3,614	0
T891	5					3,642	3,640	3,642	6/15/10-5/1/12	3,636	3,636	0
T905	5					3,586	3,585	3,585	1/31/11-7/18/11	3,594	3,594	0
DVF East Lower	7	3,644	3,641	3,643	6/10/97-12/11/99	3,645	3,641	3,644	2/7/00-9/4/08	3,638	3,638	0
SFIP MW	7	3,612	3,599	3,607	10/16/95-12/7/99	3,613	3,596	3,610	1/31/00-6/17/08	3,608	3,608	0
OL-92-2	7	3,611	3,606	3,607	6/1/94-11/9/99	3,608	3,605	3,607	7/17/00-5/26/07	3,606	3,607	1
T915	7					3,610	3,610	3,610	4/25/11-7/20/11	3,608	3,608	0
T909	7					3,626	3,623	3,625	4/25/11-8/25/11	3,620	3,620	0
T897	7					3,629	3,628	3,629	6/29/10-4/30/12	3,623	3,623	0
Mill Site Lower	8	3,610	3,609	3,609	12/27/95-12/19/99	3,609	3,609	3,609	1/18/00-2/5/08	3,615	3,615	0
Star Trek	9	3,619	3,618	3,619	5/14/96-12/23/99	3,620	3,618	3,619	1/22/00-1/2/08	3,614	3,614	0
T895	9					3,632	3,631	3,632	4/21/10-4/30/12	3,629	3,629	0

All elevation measurements are in feet mean sea level

6.0 Unique Characteristics of the OLGEP Model

During development and calibration of the OLGEP model, a number of unique characteristics of the model became apparent. The most significant of these characteristics is summarized below.

- The calibrated steady-state total water budget for the OLGEP groundwater model is approximately 57,000 AF/yr.
- Based on lithology and geophysical survey observed in deeper wells, the model was built based on the five identified aquifers. Generally, grain size becomes finer to the south and to the center of the Owens Lake. High hydraulic conductivity values are assigned in the north delta area and the peripheral coalescing alluvial fans.
- Review of shallow borings in the delta area suggests a large range of vertical anisotropy could be applied to the model. The model is sensitive to the vertical anisotropy.
- Evapotranspiration (ET) is the primary mechanism for discharge of water from the Owens Lake Basin. Significant ET occurs at wetlands surrounding the margins of the lake and on the lakebed itself. These areas are modeled as drains with an elevation equivalent to the land surface elevation (for surface expression) and ET. Use of the drain package mimics the action of groundwater rising to the surface, whereby the elevation of the water table is controlled by the land surface and can go no higher as water leaves the system. Using both the ET and drain packages, as opposed to just one, significantly improved model stability. The ET package is also utilized in the Lone Pine area based on ET rates determined in the Southern Model (MWH, 2010).
- Shallow sediments on or near Owens Lake are highly heterogeneous, with sheets of sand a few inches to several feet thick bounded by lakebed clays above and below them. Several small springs are present where small-scale irregularities in the sediments allow groundwater to leak to the surface. The very shallow stratigraphy and small spring features generally cannot be reproduced well using a regional model such as OLGEP because the cell dimensions are much larger than these features.
- The model is very sensitive to the storage coefficient of deeper layers. During transient simulations that involve pumping, almost all water is derived from storage.
- Based on OLGEP drilling data, confining clay layers were identified that extend as far north to the location of DWP-11 northeast of Lone Pine. This new information was incorporated into the numerical model and was found to have a significant effect on simulating high artesian heads in deeper layers at the lake.
- Review of hydrographs, aerial photos, and a sensitivity analysis indicate that the Brine Pool operates as a separate system and does not influence deep groundwater levels. A sensitivity analysis evaluated the impacts of changing the Brine Pool cells in the OLGEP model from constant head boundaries to the Drain and Evapotranspiration (ET) package boundary condition (similar to the Owens Lake Playa). This model configuration represented a full Brine Pool and a dry Brine Pool. The difference in water levels between the two simulations in any layer of the model is 0.2 feet.
- The Owens Valley, Owens River, and Inyo Mountain Front fault zones were assigned properties such that they act as a barrier to flow. This is based on pump test results at the River Site for the Owens River and Inyo Mountain Front fault zones. This pump test clearly indicated these

faults zones did not transmit pressure changes as a result of pumping the River Site Well. The Owens Valley Fault zone was also assigned properties that made the fault act as a barrier to flow. The low conductance for the zone was based on pump test results and an isotope study (MWH, 2012a). The pump test Well 416W, south of Lone Pine, clearly indicated that the fault in that area acts as a barrier to flow (MWH, 2010). An isotope study was conducted to determine the source region of Owens Lake groundwater recharge and determine the age of the groundwater. The results of this study indicated that relatively young water that drains from the Sierra Nevada does not recharge Owens Lake. Owens Lake is recharged via down-valley flow. One reasonable explanation is that the Owens Valley Fault zone acts as a barrier preventing recharge to the lake from the Sierra Nevada. For each of these fault systems there is still uncertainty associated with the calibrated parameters. The steady-state model performs well whether the Owens Valley fault is present or not, indicating it is a non unique solution.

7.0 Conclusion and Recommendations

The groundwater model for the OLGEP project represents a valuable tool for simulation of variety of future climate or pumping scenarios which may alter the groundwater regime in the vicinity of the lake. The model incorporates concepts regarding the conceptual model of the hydrogeology of the area that were derived from new field evidence combined with detailed analysis of previously existing data (MWH 2011c, 2012).

A key benefit of the groundwater model is that it provides an understanding of the extent to which various model input parameters control the output of the model. In other words, it allows identification of the sensitivity of the model outcomes to input parameters such as hydraulic conductivity, storage coefficient, and boundary conditions. This is important because it helps define where the most significant uncertainty exists with regard to the groundwater regime, and guides future efforts to reduce uncertainty and improve the accuracy of the model.

Although the model represents great improvement in understanding the groundwater system in the vicinity of Owens Lake, and can be utilized for a variety of purposes now, it is recommended that the model be improved continuously, as new information becomes available. Collection of new information should be focused in areas where the model is particularly sensitive. **Table 14** summarizes some of the most significant findings of model calibration and simulation runs, along with recommended methods to reduce uncertainty in the model.

Table 14
Recommendations for Collection of Field Data Based on Modeling Observations

Finding	Recommendation
Changes in groundwater discharge to the surface as a result of pumping are correlated to changes in shallow groundwater levels occurring up gradient (generally away from the center of the lake on alluvial fans) from the discharge area.	Install shallow monitoring wells up gradient of the most sensitive groundwater discharge locations and collect baseline data before groundwater pumping begins. As pumping occurs, observe correlation between water levels in monitoring wells and changes in groundwater discharge or habitat.
The extent to which the numerous faults in the area act as barriers to groundwater flow is extremely important, as evidenced by the River Site and Fault Test Site pump tests. Similar test data is not available for the sensitive areas in the western portion of the study area, and is particularly important in the northwestern portion.	1. Conduct pump tests near the northwestern portion of the lake, where faults influence sensitive springs. 2. Install new monitoring wells on both sides of the Owens Valley fault in the northwestern portion of the study area. 3. As new production wells are constructed, perform pumping tests to evaluate the role of faults on water levels. 4. As groundwater development occurs, carefully observe water level changes on either side of faults.
Based on the current conceptual model, flow at the Northwest Seep groundwater discharge zone is most sensitive to groundwater pumping. This is a result of the Owens Valley Fault zone, the exact location and extent of which is not certain.	Conduct focused isotope sampling in the northwest portion of the study area in the vicinity of the Owens Valley Fault and Northwest Seep.
The water budget of the area and estimated groundwater discharge at important habitat areas are sensitive to the amount of recharge occurring on the alluvial fans surrounding the lake, as well as the amount of recharge from Haiwee Reservoir and the Alabama Hills area.	1. If they are not currently present, install base-of-mountain and valley floor gauging stations at Tuttle, Diaz, Lubkin, Carroll, Cottonwood, Ash, Braley, Cartago, and Olancha Creeks such that loss between gauging stations can be calculated. 2. Install additional monitoring wells south of the Alabama Hills and north of Haiwee Reservoir to calculate groundwater gradients.
The shallow groundwater system on Owens Lake (generally lake ward of the historic shoreline) is largely isolated from the deeper groundwater system due to the existence of thick relatively impermeable clay deposits under the lake. Continuation of measurement of numerous piezometers existing on the lake may not be cost effective.	Conduct a review of the existing monitoring network and evaluate the necessity of monitoring existing locations based on historic observations and the revised conceptual model. Decrease monitoring locations or frequency if warranted at existing locations, and recommend new monitoring as required where existing data is lacking (generally the west side of the lake).

As with any numerical model, this model is a generalization of field conditions. The conceptual model prepared for the Owens Lake groundwater system is a simplification of the physical system. Simplification is required because the physical system is much more complicated than can be simulated, and because information on the geology and hydrology is insufficient to develop a precise description of the physical system. The model is well calibrated given the data available and can be used with confidence to guide groundwater management. Simulation results from the model should be used as a guideline in conjunction with field measurements in an adaptive management of pumping, and the model should be continuously updated as new information becomes available.

8.0 REFERENCES

Anderson, M. P. and Woessner, W. W., 1992. Applied Groundwater Modeling. Academic Press, San Diego.

Danskin, W. R., 1998. Evaluation of the Hydrologic System and Selected Water-Management Alternatives in the Owens Valley, California. U.S. Geological Survey Water-Supply Paper 2370.

Freeze R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 604 p.

Harbaugh, A. W., E. W. Banta, M. C. Hill, and M. G. McDonald, 2000. MODFLOW-2000, U.S. Geological Survey Modular Ground-Water Model, User Guide to Modularization Concepts and the Ground-Water Flow Process. U.S. Geological Survey Open-File Report 00-92.

Hollett, K.J., Danskin, W.R., McCaffrey, W.F., and Walti, C.L., 1991. Geology and water resources of Owens Valley, California, U.S. Geological Survey water-supply paper; 2370-B, Hydrology and soil-water-plant relations in the Owens Valley, California. 77p.

JMM Consulting Engineers, Inc. (JMM), 1990. Environmental Impact Report/Environmental Assessment for the Anheuser-Busch Companies Los Angeles Brewery Water Supply Study. November.

LADWP, 2012. Task Order 401.1.10 - Perform Groundwater Model Improvements, Calibration, and Groundwater Pumping Simulation. June.

LADWP, 2009. OLGEP Task Authorization - Task 401.1.5 Numerical Groundwater Model Update and Development.

MWH, 2010. Southern Groundwater Model Calibration Documentation, Tasks A.2.6 and A.2.1, April.

MWH, 2011a. Evaluation of Geophysical Data for Incorporation into the OLGEP - Task 401.1.9-II. June.

MWH, 2011b. Technical Memorandum – Evaluation Groundwater Model Functionality, Attributes & Software and Development of Preliminary Model Strategy for OLGEP - Task 401.1.5. November.

MWH, 2011c. Updated Conceptual Model Report - Task 401.1.4. November.

MWH, 2012a. TM - Owens Lake Isotope Study. September.

MWH, 2012b. Technical Memorandum: OLGEP Water Level and Flowing Well Evaluation. October.

Pakiser, L.C., Kane, M.F., and Jackson, W.H., 1964, Structural geology and volcanism of Owens Valley region, California—A geophysical study: U.S. Geological Survey Professional Paper 438, 65 p.

Tyler S.W., S. Kranz, M.B. Parlange, J. Albertson, G.G. Katul, G.F. Cochran, B.A. Lyles, and G. Holder., 1997. Estimation of Groundwater Evaporation and Salt Flux from Owens Lake, California, USA, Journal of Hydrology 200 (1997) 110-135.