October 2012

Final Report on the Owens Lake Groundwater Evaluation Project

Department of Water and Power, City of Los Angeles, Founded 1781

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BUILDING A BETTER WORLD

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LIST OF ACRONYMS AND ABBREVIATIONS

AF	Acre-feet
AF/yr	Acre-feet per year
Basin	Owens Lake Basin
BMP	Best Management Practice
BRP	Blue Ribbon Panel
CDWR	California Department of Water Resources
CEQA	California Environmental Quality Act
cfs	Cubic feet per second
DCM	Dust control measure
DRI	Desert Research Institute
DWP-x	OLGEP monitoring well site designation
EDYS	Ecological Dynamics Simulation Model
EIR	Environmental Impact Report
ET	Evapotranspiration
fbgs	Feet below ground surface
fmsl	Feet above mean sea level
ft^2/day	Square feet per day
GBUAPCD	Great Basin Unified Air Pollution Control District
GMS	Groundwater Modeling System
gpm	Gallons per minute
HSLA	High strength low alloy
ICWD	Inyo County Water Department
in/yr	Inches per year
J	Concentration above method detection limit and below reporting limit
K	Hydraulic conductivity
LAA	Los Angeles Aqueduct
LADWP	Los Angeles Department of Water and Power
LORP	Lower Owens River Project
mg/L	Milligrams per liter
MODFLOW	Modular, three-dimensional finite-difference groundwater flow model
MWH	MWH America's, Inc.
ND	Not detected
Neponset	Neponset Geophysical Corporation

NTU	Nephelometric turbidity units
OLGEP	Owens Lake Groundwater Evaluation Project
OLSAC	Owens Lake Soda Ash Company (Now Rio Tinto Mining)
Partner Agencies	Great Basin Unified Air Pollution Control District, Inyo County Water Department, and California State Lands Commission
Q	Flow
s	Drawdown
SP	Spontaneous potential
T	Transmissivity
TDS	Total dissolved solids
TM	Technical Memorandum
uS/cm	MicroSiemens per centimeter
˚ C	Degrees Celsius

EXECUTIVE SUMMARY

The Los Angeles Department of Water and Power (LADWP) is implementing a dust mitigation program to reduce emissions of fine particulates from the dry Owens Lake bed. The water delivery system for dust control measures supplies approximately 43 square miles of management area, and the amount of water supplied has been increasing steadily since inception of the dust mitigation program. **Figure ES-1** plots water use by year from 2001 through present, showing increasing water use through time that reflects the development and phased implementation of dust control measures. Total water use in 2012 is expected to be approximately 95,000 acre-feet.

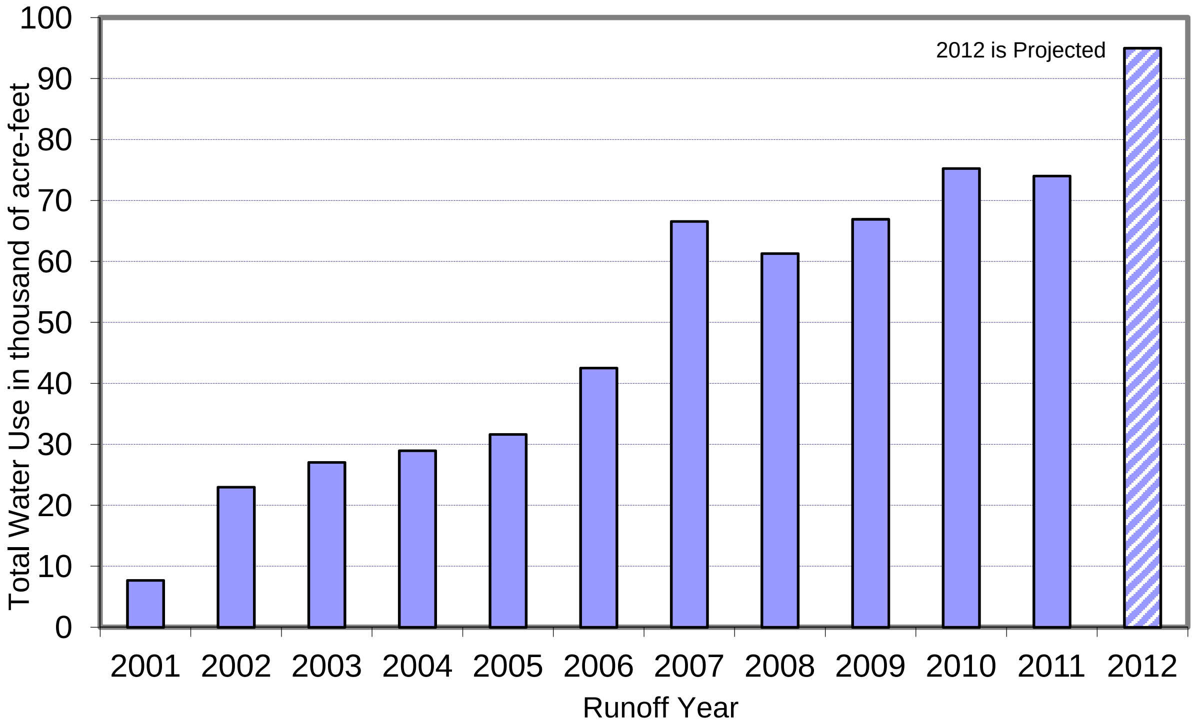


Figure ES-1

Water Use by Year for Dust Control Measures

With the goal of continuing dust control measures on Owens Lake while conserving potable water, the LADWP has evaluated the use of groundwater under Owens Lake to supply a portion of the water demand for dust suppression. LADWP contracted with MWH under Agreement 47830 to conduct the Owens Lake Groundwater Evaluation Project (OLGEP). The project consisted of 10 primary tasks:

1 – Compilation of Existing Data

2 – Data Evaluation and Identification of Data Gaps

3 – Assist in the Collection of Field Data

4 – Update Hydrologic Conceptual Model

5 – Numerical Groundwater Model Update and Development

6 – Model Simulations and Alternatives Analysis

7 – Develop and Implement a Public Outreach Plan

8 – Blue Ribbon Panel Participation and Final Report

9 - Evaluation of Geophysical Data and Isotope Sampling and Analysis of Groundwater and Surface Discharge Areas

10 - Additional Groundwater Model Improvements, Calibration, and Groundwater Pumping Simulation

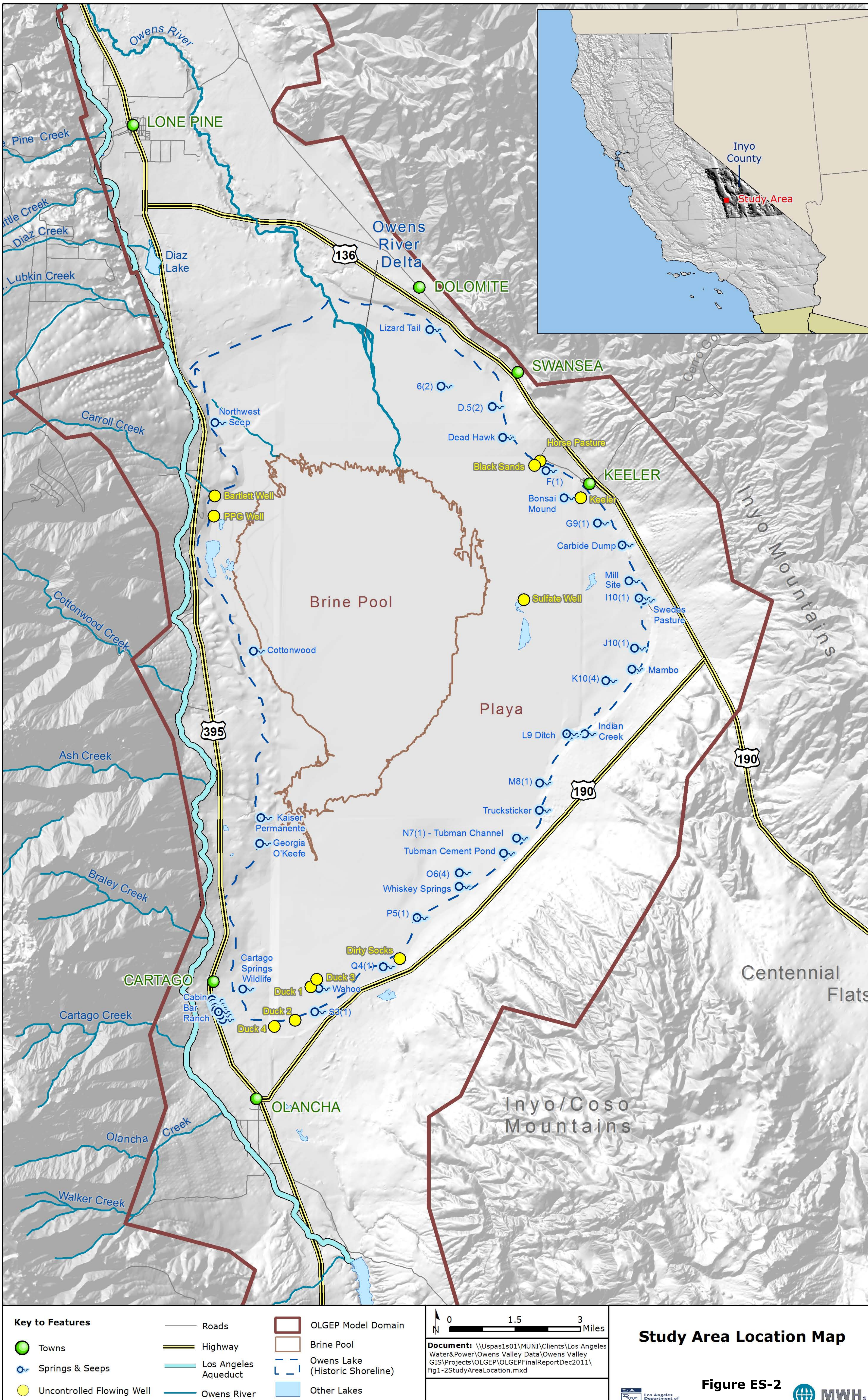
The OLGEP project was supplemented by a public outreach program that included mailing of fact sheets, three public meetings, an educational outreach program, and meetings with targeted stakeholders. An expert Blue Ribbon Panel, composed of experts in groundwater modeling and ecology, brought experience from the U.S. Geological Survey, academia, and private industry to the project. The panel was consulted at key points during the project.

This final report on the OLGEP provides a narrative of the OLGEP study along with a summary of key findings and study conclusions. All deliverables produced under the OLGEP are provided as appendices. This final report also provides recommendations and a framework for implementation of a proposed groundwater development program. These recommendations address the following:

- Exploratory development of groundwater production wells
- Actions to manage effects on the environment
- Design considerations
- Implementation schedule and project phasing
- Overview of monitoring objectives, rationale for the number and locations of monitoring points, and monitoring frequency

Study Area

The study area is the Owens Lake area and underlying groundwater basin, located in Inyo County, CA. This area is the southern portion of the Owens Lake Basin and extends from the Alabama Hills in the north southward to Owens Lake, as shown on the study area location map (**Figure ES-2**).



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Study Area Location Map

Figure ES-2

Los Angeles Department of Water & Power

MWH

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A summary of the key tasks completed, findings, and recommendations of the OLGEP is provided herein.

Hydrogeologic Conceptual Model

MWH conducted extensive data compilation and review of existing groundwater models for the study area. Existing data was used to develop a preliminary conceptual model based on the voluminous body of work conducted on or around the lake in the last century. The preliminary conceptual model summarized what was known about the hydrostratigraphy and geologic structure, depositional history, water budget, groundwater gradients, and private or commercial entities that may be affected by changes in groundwater or surface water in the vicinity of the lake. Most significantly, the preliminary conceptual model identified data gaps relevant to future development of a numerical groundwater model, and provided recommendations and strategies for resolving these data gaps during the OLGEP field investigation and well drilling program.

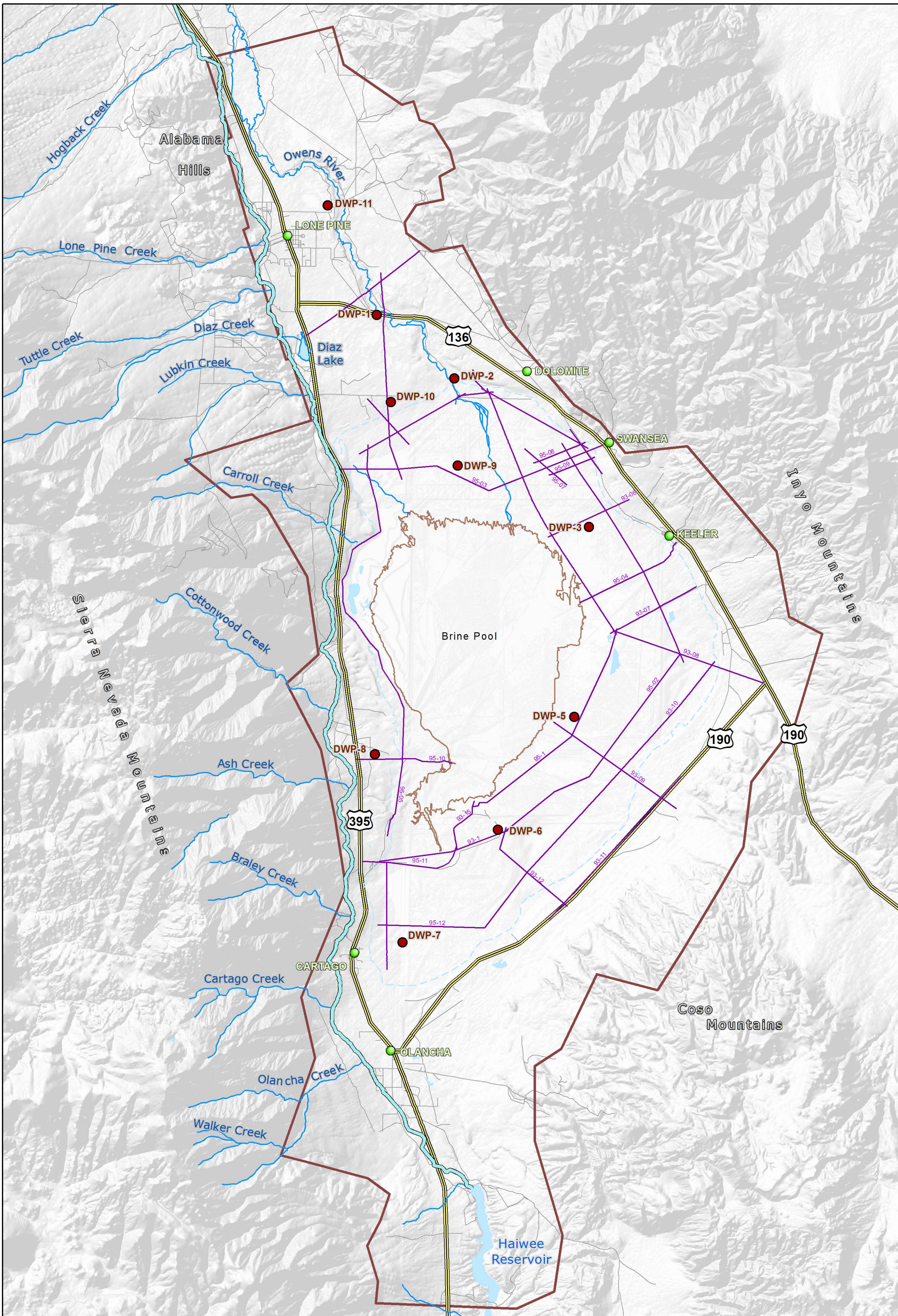
Multi-level monitoring wells were designed and installed at ten strategic locations in the vicinity of Owens Lake to fill data gaps identified by the preliminary conceptual model. These sites were designated DWP-1 through DWP-10 (**Figure ES-3**). At each site, a borehole was advanced to a depth of approximately 1,500 feet below ground surface, and then based on geophysical and lithologic data from the borehole, monitoring wells were constructed at various depths. Following well installation, aquifer testing and water quality sampling was conducted. Results of this work supported development of an updated conceptual model.

A geophysical study was conducted that utilized a combination of seismic interpretation, borehole lithologic and geophysical data, and surface geologic mapping to interpret the structural geology, depositional history, and hydrostratigrapy of the OLGEP study area. Results of this work fed directly into the updated conceptual model and numerical groundwater model.

An isotope study was conducted that included sampling of groundwater and surface discharge areas for the purpose of determining the source region of groundwater recharge and the age of the water. Results of the study were used to support the conceptual model development.

MWH's updated hydrogeologic conceptual model was based primarily on the following:

- Newly-acquired data from the OLGEP drilling and monitoring well installation program
- Detailed interpretation of surface seismic data, used in conjunction with new drilling data
- Results and lessons learned from LADWP/MWH groundwater modeling efforts in wellfields north of the study area
- Detailed review and re-analysis of the water budget
- Detailed review of available data on springs and seeps for the purposes of characterizing the nature and source of spring flow



Towns
OLGEP Test Well
Seismic Line (Neponset, 1997)
Highways
Roads
Aqueduct
Owens River
OLGEP Study Area
Other Water Bodies
Owens Lake (Historic Shoreline)

N
0 1.5 3 Miles

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Study Area Location Map Showing the Location of Seismic Lines and New OLGEP wells

Figure ES-3

Los Angeles Department of Water & Power

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The new data, combined with re-analysis of existing data, dramatically improved the hydrogeologic conceptual model for the study area by better defining the hydrostratigraphy, updating the location of key faults, improving estimates on the location and amounts of groundwater recharge, characterizing the interaction between groundwater and surface water, and evaluating sensitive resources such as springs, artesian wells, and local wells. Key elements of the updated conceptual model are summarized below:

Stratigraphy
Previous work identified four deep confined aquifers comprised of sands and silty sands, separated by low permeability clay units of variable thickness. OLGEP work was successful in filling critical stratigraphic data gaps, including:

- **Elevation of Top and Bottom of Each Confined Aquifer**. Prior to the OLGEP study, the complex stratigraphy of the deep aquifers made correlation of lithologic and geophysical logs challenging, and sometimes inconsistent with the surface geophysical interpretations. The results of the OLGEP identified the tops and bottoms of each aquifer unit, which facilitated generation of 3-dimensional surfaces of each unit.
- **Previously-Unidentified Deep Confined Aquifer Below Aquifer 4**. Deeper drilling allowed for identification of a previously unidentified deep confined aquifer (generally deeper than 1,000 feet) that is interpreted to represent flood plain deposits deposited prior to the existence of Owens Lake.

Five aquifer units are named from shallowest to deepest as Aquifers 1 through 5. The following observations can be made regarding the individual aquifers:

- **Aquifer 1** is the shallowest aquifer, characterized by a lithology of relatively well-sorted coarse sands and gravels in the Owens River delta area. Overall, the resistivity observed in this aquifer is characteristically very high, suggesting an absence of clay or silt material and a subaerial depositional environment. However, beneath the lake, this stratigraphic sequence transitions to lacustrine clays.
- **Aquifer 2** consists of relatively coarse material in the delta, but tends to have declining resistivity (higher percentage of fine material) with depth. The sequence transitions to lacustrine clays in the southern part of the lake in a pattern similar to Aquifer 1.
- **Aquifers 3 and 4** also consist of relatively coarse material in the delta, but tend to have declining resistivity (higher percentage of fine material) with depth. Again, beneath the lake, these stratigraphic sequences contain increasing amounts of fine material.
- **Aquifer 5** is a stratigraphic sequence that has a characteristic geophysical and lithologic signature. It is composed of silty sand with interbedded sands and occasional clay. The resistivity of this aquifer is relatively uniform. This aquifer is interpreted to be the result of a flood plain or braided stream depositional environment, deposited before the formation of Owens Lake. The bottom of Aquifer 5 is deeper than 1,500 feet over most of the area, except in the eastern portion of the Basin, where it is underlain by bedrock at relatively shallow depths.

Three-dimensional surfaces for these sequences were developed that directly applied to the numerical model layering used in the groundwater model.

Depositional Environment
Comparison of the stratigraphic sequences to lithologic logging allowed for identification of several transgressive and regressive events that occurred during the infilling of the Owens Lake Basin. Evidence of a pre-lake period of deposition of flood plain or braided stream deposits, then the first evidence of the lake being formed, followed by at least four regressive events where lake levels dropped (separated by transgressive events) was documented.

Structural Geology
A number of fault zones were mapped in planar and cross-sectional view, providing new knowledge on the location and approximate displacement of key faults. This, in turn, allowed for more accurate modeling of groundwater flow as well as accounting for fault-related impacts, which is a significant improvement over previous modeling efforts that did not incorporate the effect of faulting.

Depth to Bedrock
Characterization of the bedrock boundary and basin geometry was improved by evaluation of seismic and drilling data, whereby relatively shallow bedrock was found underlying the east side of the Basin, and this bedrock surface was not identified in previous work. On the northeast and southeast margins, the Basin is terminated structurally by bedrock highs causing thinning or pinching-out of the mapped sequences. On the west, the sequences coarsen and lacustrine deposits are absent.

Variation of Groundwater Head at Depth
The installation of zone-specific screened intervals in new monitoring wells allowed for detailed evaluation of vertical gradients throughout most of the study area. Artesian heads of up to nearly 60 feet above ground surface were observed. The highest heads are observed in Aquifers 1, 3, and 5.

Groundwater Budget
Re-analysis of the groundwater budget for the OLGEP study area, in combination with new data suggests that the overall inflow and outflow for the Basin is in the range of 45,000 to 67,500 acre-feet per year. The total inflow/outflow is similar to what was estimated in previous studies; however, new data and re-interpretation of existing data served to refine the locations of recharge and discharge that was particularly useful for development of the groundwater model. New data showed conclusively that the Basin is a closed basin with no outflow to the south, even in deeper sediments.

Surface Water/Groundwater Interaction
A review of the stratigraphy and groundwater flow patterns demonstrated evidence that the surface water on Owens Lake is hydraulically disconnected from groundwater underlying the lake. This is the primary reason why the Lower Owens River Project (LORP) and dust control measures projects have little effect on the deep groundwater system. In the case of the LORP, the Lower Owens River was a gaining reach prior to the initiation of the LORP project, thereby prohibiting infiltration of added surface water during the LORP project. In the case of dust control measures (DCMs), the presence of thick sequences of impermeable clays underlying the DCMs effectively isolate them from the main groundwater body.

Groundwater Quality

Analysis of groundwater samples from new monitoring wells allowed for evaluation of the 3-dimensional configuration of salinity and other specific constituents under the lake bed. Both salinity and arsenic concentrations decrease with depth and tend to be higher under the eastern portion of the lake where sediments have been exposed to evaporation.

OLGEP Groundwater Model

The updated conceptual model formed the basis for development of the OLGEP numerical groundwater model. Initially, necessary groundwater model attributes and functionality were defined, followed by a review of available groundwater modeling software. This review resulted in the selection of MODFLOW-2000 as the most appropriate software to be used. The model was calibrated using existing data and available aquifer test results. The east and west boundaries of the model domain are governed by bedrock boundaries. The model has 12 model layers based on hydrostratigraphic interpretations. A uniform cell dimension of 500 feet is used, and grid spacing is consistent with previous models constructed in the Owens Valley. The total steady-state calibrated inflow and outflow to the model domain is approximately 56,740 AF/yr, which fits with the conceptual model's water budget.

Simulation of Alternatives

MWH utilized the OLGEP numerical groundwater model to evaluate various groundwater development alternatives and the associated influence on environmental elements. Results of this work provided the foundation for selecting the potential alternative for the project. The potential alternative is a groundwater pumping alternative that meets pre-determined criteria. It was used to optimize well locations, develop protocols for pumping and monitoring, and provide recommendations on new well locations and use of existing facilities and infrastructure.

Recommendations for a Groundwater Development Program

Groundwater modeling at Owens Lake has shown that approximately 9,000 to 15,000 acre-feet per year (AF/yr) of groundwater development at Owens Lake can be environmentally sustainable, depending on what criteria for springflow is used. It is recommended that at least 9 new monitoring wells be installed on the margins of the lake that will serve to monitor flow to the springs surrounding the lake. These wells should be installed as soon as possible in order to begin collecting baseline groundwater level data. Two new test wells as part of California Environmental Quality Act (CEQA) related activities are recommended to evaluate the hydrologic characteristics of the Owens Valley Fault. Additional recommended data collection activities include pump testing, focused isotope sampling, and installation of stream gauging stations. The current monitoring program should be reviewed and modified if necessary to increase efficiency of data collection.

A phased implementation and adaptive management approach is recommended that develops new hydrogeologic information and modifies groundwater development plans accordingly, as information becomes available. The recommended initial phase of the implementation plan involves groundwater development at a rate of approximately 7,000 AF/yr, and 3 years of monitoring, before implementing additional groundwater development. The recommended project implementation steps are shown in the flowchart in **Figure ES-4**. Phase I production and monitoring well locations are shown on **Figure ES-5**.

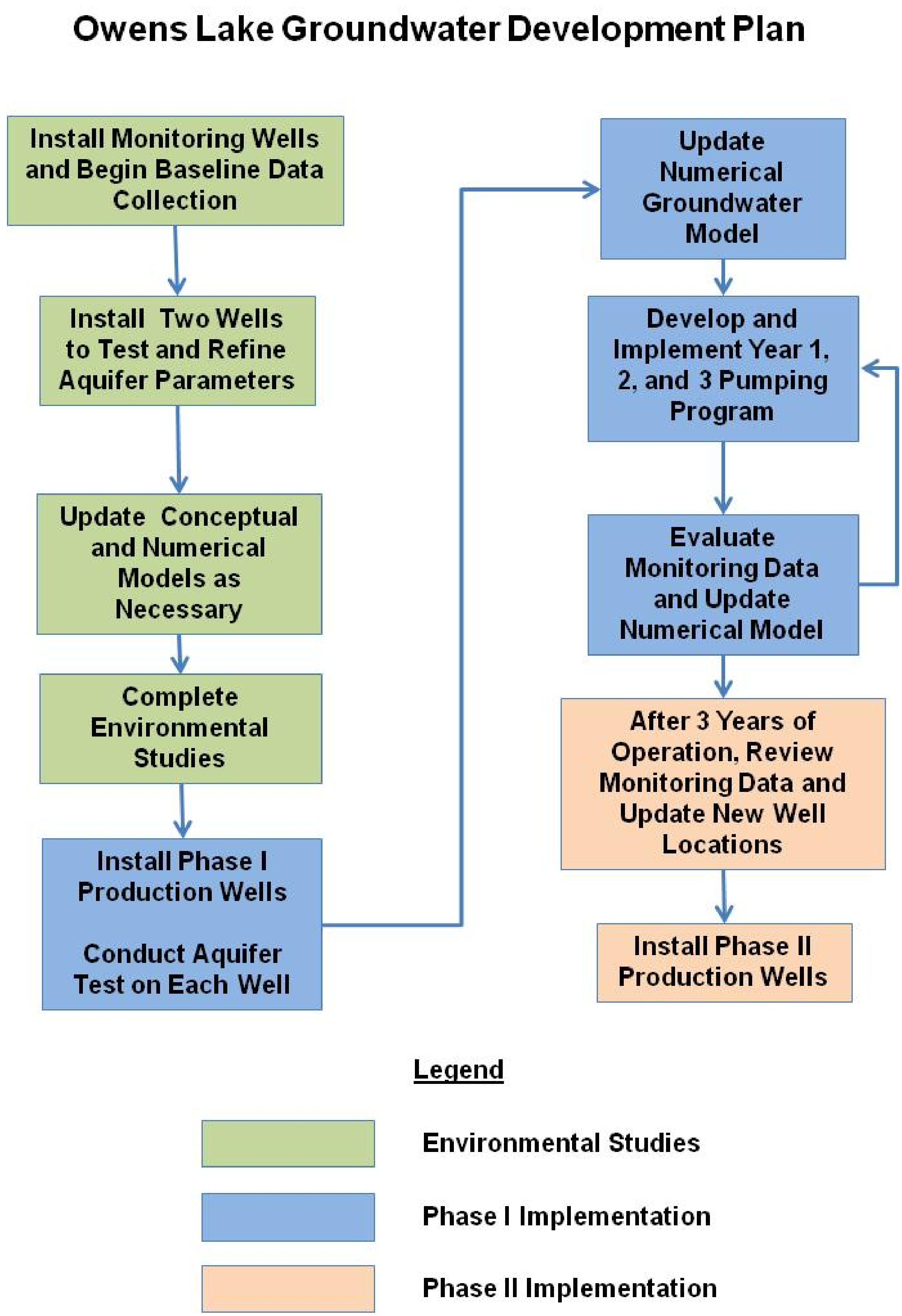
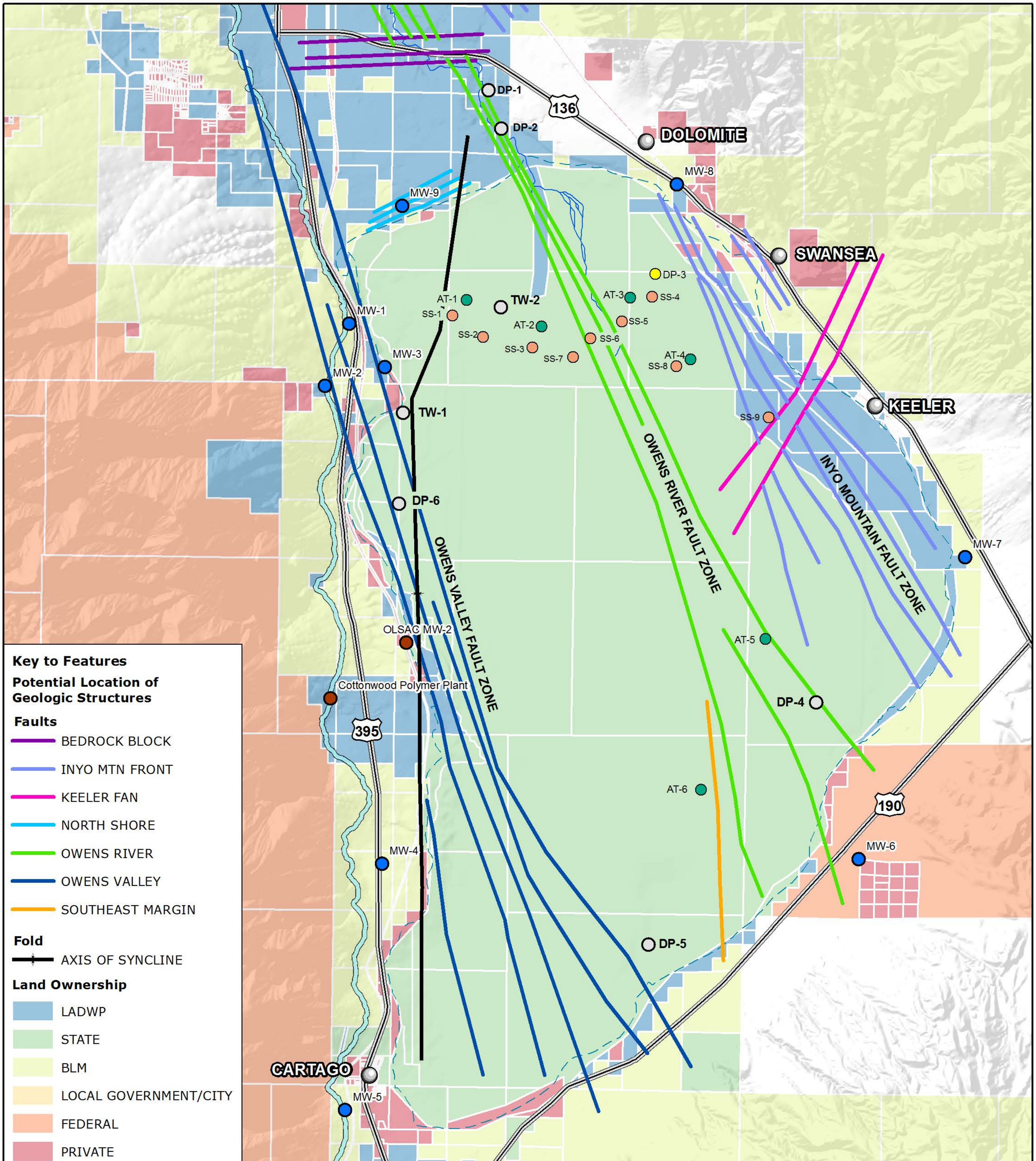


Figure ES-4
Flowchart Showing Project Implementation Using Adaptive Management Strategy



Town	
Highways	
Los Angeles Aqueduct	
Owens River	
Owens Lake (Historic Shoreline)	

Alternative Well Locations

- Testing Well
- Deep Well
- Artesian Well
- Sand Sheet Well
- Existing Monitoring Well
- Proposed Monitoring Well

N

0 1.5 3 Miles

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Phase I Production and Monitoring Well Locations

Figure ES-5

MWH.

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1.0 INTRODUCTION

With the goal of continuing dust mitigation measures on Owens Lake while conserving potable water, the City of Los Angeles Department of Water and Power (LADWP) is evaluating the use of groundwater under Owens Lake to supply a portion of the water demand for dust suppression. LADWP contracted with MWH Americas, Inc. (MWH) under Agreement 47830 to conduct the Owens Lake Groundwater Evaluation Project (OLGEP). The project consisted of the following primary tasks:

1 – Compilation of Existing Data

2 – Data Evaluation and Identification of Data Gaps

3 – Assist in the Collection of Field Data

4 – Update Hydrologic Conceptual Model

5 – Numerical Groundwater Model Update and Development

6 – Model Simulations and Alternatives Analysis

7 – Develop and Implement a Public Outreach Plan

8 –Blue Ribbon Panel Participation and Final Report

9.1 - Evaluation of Geophysical Data

9.2 - Isotope Sampling and Analysis of Groundwater and Surface Discharge Areas

10 - Additional Groundwater Model Improvements, Calibration, and Groundwater Pumping Simulation

This report represents the final report on the OLGEP and serves as the deliverable for Task 8. The document provides a narrative of the OLGEP study along with a summary of key findings, study conclusions, and recommendations by task. Detailed information reported in previous technical memoranda is included as appendices.

Figure 1-1 is a diagram showing the interrelationships among the OLGEP tasks as well as deliverables affiliated with each task. **Table 1-1** is a listing of each task and deliverable or product, showing the task number, deliverable type, deliverable name, date, and its appendix location. The first six tasks were generally sequential, while tasks 7 and 8 had periodic activity throughout the project. Exceptions to the sequential nature of OLGEP tasks were:

- Public outreach (Task 7) was conducted throughout the duration of the project.
- Blue Ribbon Panel support (Task 8) was solicited at key decision points during the project.
- Evaluation of Geophysical Data (Task 9) was conducted just prior to the completion of Task 4, and results directly fed into the updated conceptual model (Task 4) and numerical groundwater model (Tasks 5 and 10).
- Both the Isotope Study (Task 9.2) and the Groundwater Model Improvement, Calibration, and Simulation (Task 10) were done after elements of Task 6, with final results feeding back into Task 6.

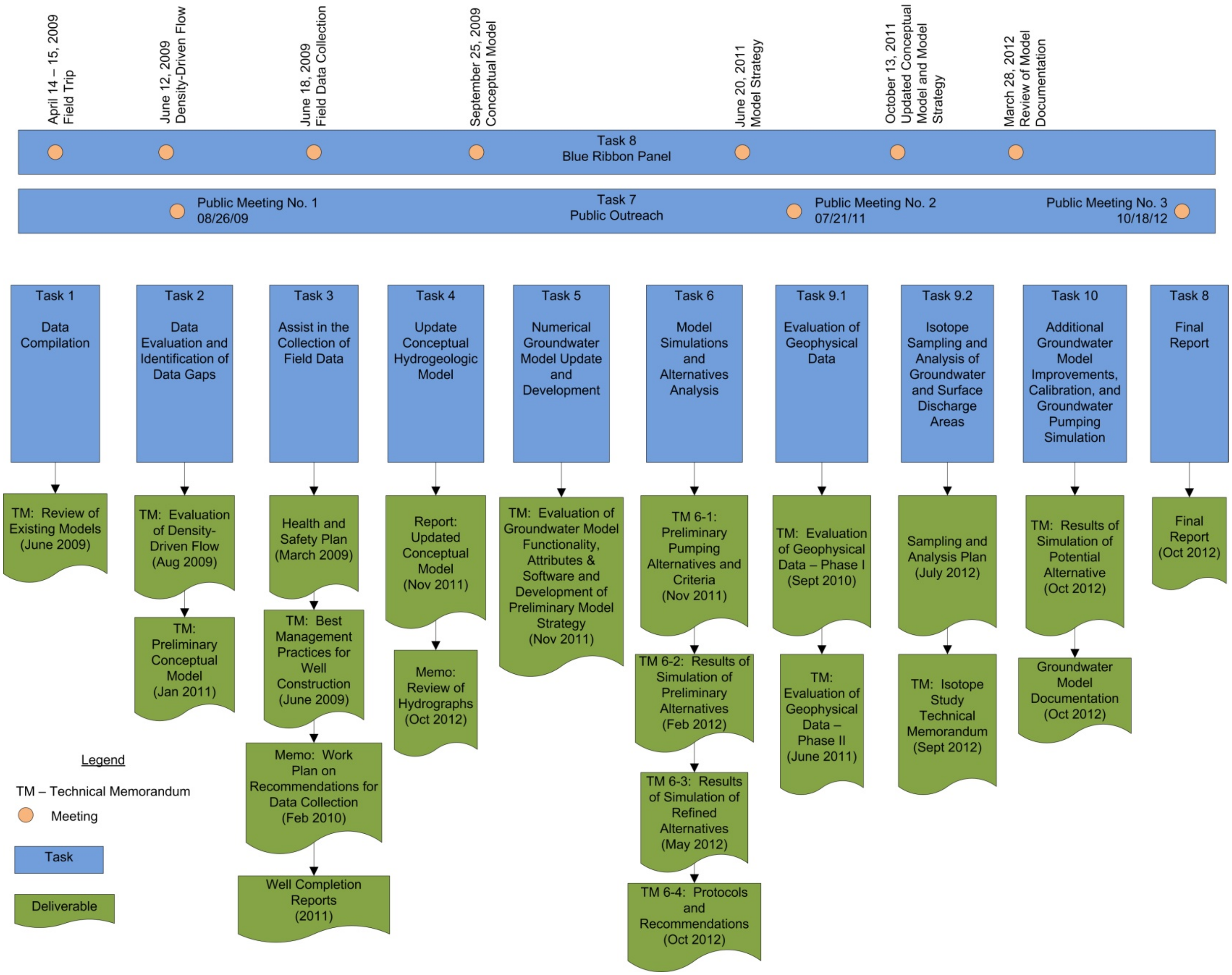


Figure 1-1
Tasks and Deliverables in the OLGEP Study

Table 1-1
Summary of OLGEP Deliverables and Products

Task	Deliverable Type	Name	Date	Appendix
1	Technical Memorandum	Review of Existing Models	Jun-09	A
2	Technical Memorandum	Evaluation of Density-Driven Flow	Aug-09	B
	Technical Memorandum	Preliminary Conceptual Model Addendum (Summary of Recent Video Logs)	Jan-11 Oct-12	C
3	Technical Memorandum	Best Management Practices for Construction on Owens Lake	Jun-09	D
	Memorandum	Work Plan: Recommendations for Modifications to Data Collection	Feb-10	E
	Health and Safety Plan	OLGEP Health and Safety Plan	Mar-09	F
	Well Completion Report	Compilation of Well Completion Reports for DWP-1 to DWP-3 and DWP-5 to DWP-11	2011	G
4	Report Technical Memorandum	Updated Conceptual Model Addendum (Technical Memorandum: OLGEP Water Level and Flowing Well Evaluation)	Nov-11 Oct-12	H
5	Technical Memorandum	Evaluation of Groundwater Model Functionality, Attributes & Software and Development of Preliminary Model Strategy	Nov-11	I
	Technical Memorandum	Groundwater Model Documentation	Oct-12	J
	Model	Preliminary OLGEP Numerical Groundwater Model	Feb-12	---
6	Technical Memorandum	TM 6-1: Preliminary Pumping Alternatives and Criteria	Nov-11	K
	Technical Memorandum	TM 6-2: Results of Simultion of Preliminary Alternatives	Feb-12	L
	Technical Memorandum	TM 6-3: Summary of Previous Pumping Alternatives and Concepts for Continued Work on the Refined Alternative	May-12	M
	Technical Memorandum	TM 6-4: Protocols and Recommendations	Oct-12	N
7	Public Outreach Plan	Public Outreach Plan	May-09	O
	Mailing List	Mailing List	May-09 to Jan-12	
	Memorandum	Educational Outreach Plan	Aug-10	
	Memorandum	Educational Outreach Safety Plan	Dec-10	
	Memorandum	Educational Outreach Documentation	Mar-11	
	Fact Sheet	Fact Sheets	2009 - 2011	
	Presentation and Notes	Public Meeting No. 1	Aug-09	
	Presentation and Notes	Public Meeting No. 2	Jul-11	
	Presentation and Notes	Public Meeting No. 3	Oct-12	
	Meeting Notes	Stakeholder Meeting Notes	2009 - 2011	
8	Report	Final Report	Jan-10	---
	Meeting Notes	Blue Ribbon Panel Documentation	2009 - 2011	P
9.1	Technical Memorandum	Evaluation of Geophysical Data - Phase I	Sep-10	Q
	Technical Memorandum	Evaluation of Geophysical Data - Phase II	Jun-11	R
9.2	Sampling and Analysis Plan	Isotope Study Sampling and Analysis Plan	Jul-12	S
	Technical Memorandum	Owens Lake Isotope Study	Sep-12	T
10	Technical Memorandum	TM 10.1: Results of Simulation of the Potential Alternative	Oct-12	U
	Technical Memorandum	TM 10.2: Groundwater Model Documentation	Oct-12	J
	Model	Improved/"Final" OLGEP Numerical Groundwater Model	Aug-12	---

This final report provides recommendations and a framework for implementation of a proposed groundwater development program, presented in Section 4. These recommendations address the following:

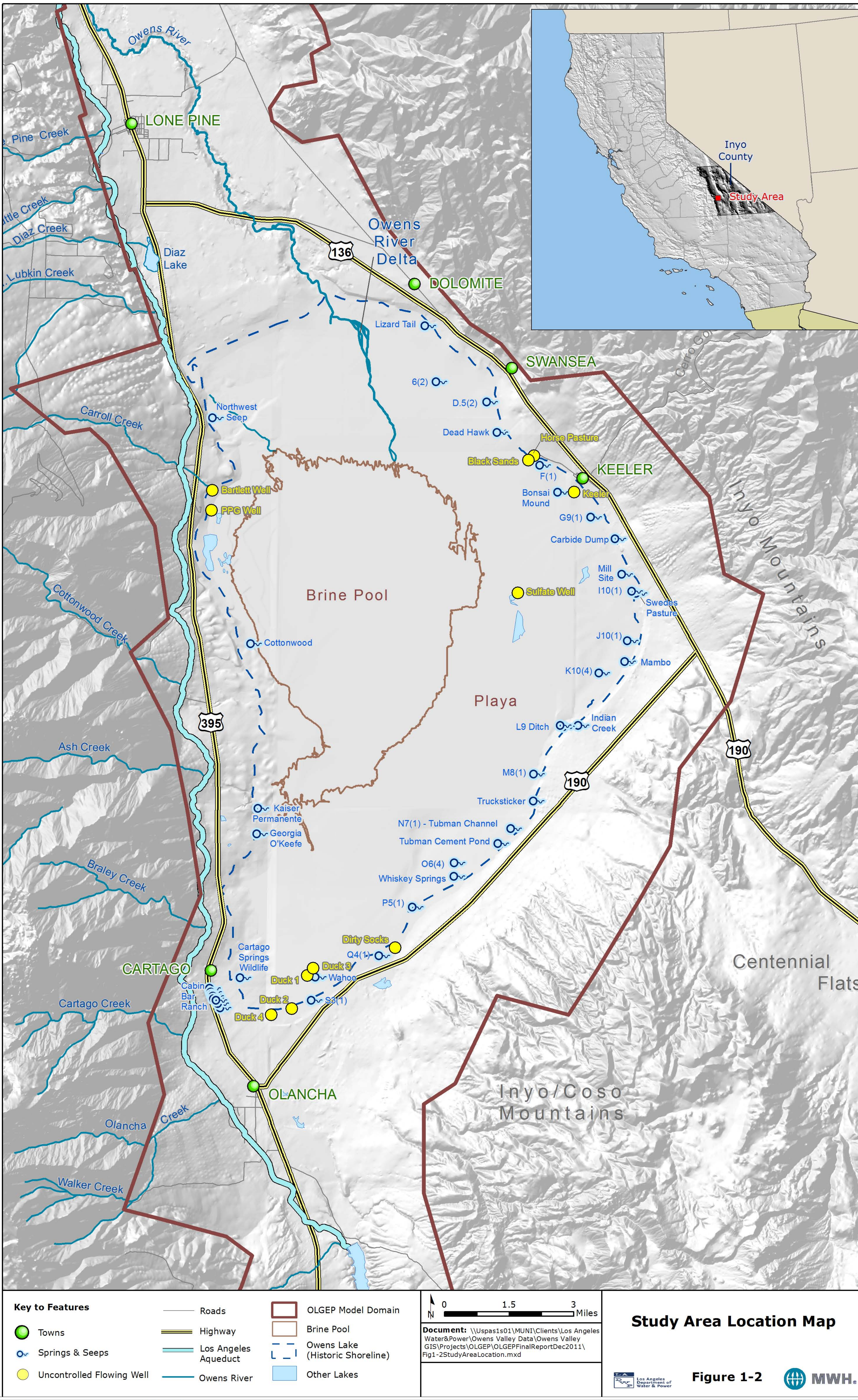
- Exploratory development of groundwater production wells
- Actions to manage effects on the environment
- Design considerations
- Implementation schedule and project phasing
- Overview of monitoring objectives, rationale for the number and locations of monitoring points, and monitoring frequency

1.1 Description of Study Area

The study area is the Owens Lake area and underlying groundwater basin, located in Inyo County, CA. This area is the southern portion of the Owens Lake Basin (Basin) and extends from the Alabama Hills in the north southward to Owens Lake, as shown on the study area location map (**Figure 1-2**). Physiographic boundaries include the Eastern Sierra Nevada Mountains to the west and the Inyo and Coso Mountains to the east, with the bedrock/alluvial contact forming the study area boundary; the Alabama Hills to the north; and a topographic divide at Haiwee Reservoir to the south. Overlying communities include the towns of Lone Pine, Cartago, Olancha, and Keeler.

Climate. The study area climate is greatly influenced by the Sierra Nevada Mountains to the west. Precipitation is derived chiefly from moisture-laden air masses that originate over the Pacific Ocean and move eastward. Because of the orographic effect of the Sierra Nevada, a rain shadow is present east of the crest of the mountains. Precipitation on the valley floor is appreciably less than that west of the crest. Average precipitation ranges from more than 30 inches/year (in/yr) at the crest of the Sierra Nevada, to about 7 to 14 in/yr in the Inyo Mountains, to approximately 5 in/yr on the valley floor. Consequently, the climate in the Owens Valley is semiarid to arid and is characterized by low precipitation, abundant sunshine, frequent winds, moderate to low humidity, and high potential evapotranspiration.

Geomorphology. The Owens Valley is viewed as the western edge of the Basin and Range Physiographic Province, with the Sierra Nevada being the western boundary. This Province typically consists of linear, roughly parallel, north–south mountain ranges separated by down-dropped valleys, most of which are closed drainage basins. A number of faults exist in the study area that are generally high-angle faults with displacement spread across multiple fault strands.



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Study Area Location Map

Los Angeles Department of Water & Power

Figure 1-2

MWH.

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Hydrology. Prior to the construction of the Los Angeles Aqueduct (LAA), water that flowed from the mountains was transported by tributary streams to the Owens River in the Owens Valley, and then south to the Owens Lake, the natural terminus of the drainage system. The study area is a closed groundwater basin with no outflow to the south. The Brine Pool is the lowest topographic area of Owens Lake and contains the remnant portion of Owens Lake waters. It is defined by the U.S. Army Corps of Engineers as that portion of the lake bed lower in elevation than the ordinary high water mark of 3,553.55 feet above mean sea level (fmsl). Water depths within the brine pool range from zero to several feet depending on the location and the time of year.

Seeps, Springs, and Wetland Areas. A series of natural springs, seeps, and associated wetlands are located along the historic shoreline and form a discontinuous narrow band encircling the lake area (see **Figure 1-2**). In addition, there are multiple uncontrolled deep-sourced flowing wells (also shown on **Figure 1-2**) that have created wetland areas.

Hydrogeology and Groundwater Flow. Alluvial, fluvial and lacustrine deposits, consisting of interbedded gravel, sand, silt, and clay, predominate in the study area. Aquifers typically exhibit flowing artesian conditions when penetrated by wells located at lower elevations near Owens Lake. Where wells of different depths are present, the hydraulic gradient is typically upward, and discharging to the lake bed. Horizontal groundwater flow is typically toward the center of the lake.

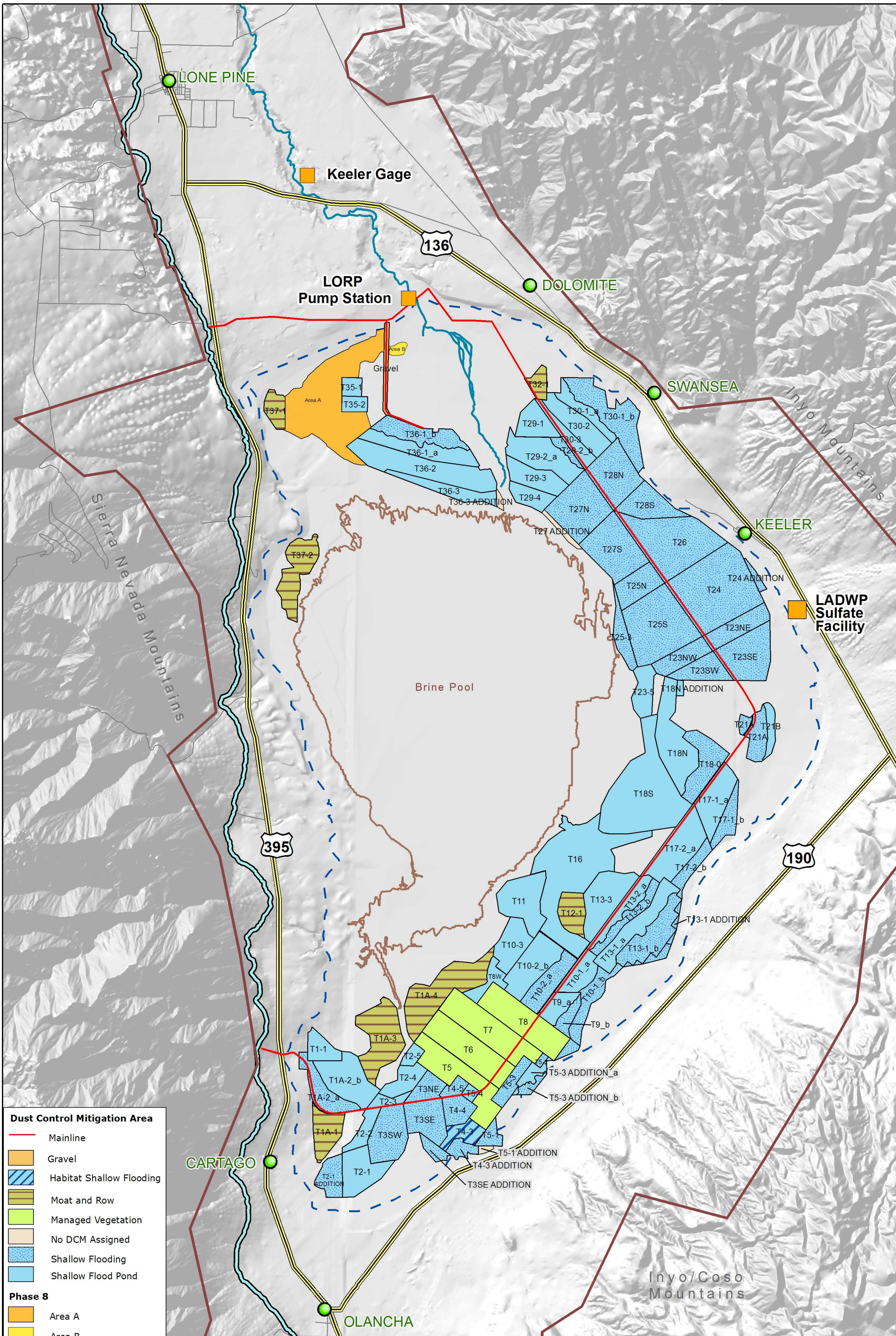
Other Key Features. Two key features in the study area include dust control measures (DCM's) for dust mitigation and the Lower Owens River Project (LORP), as described below.

<u>DCMs</u>. LADWP is implementing a dust mitigation program to reduce emissions of fine particulates from the dry Owens Lake bed. Implementation of the project has been done in multiple phases. Dust management areas are supplied from a 28-mile long pipeline (termed the main line, that supplies water from the LAA 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 1-3**. The LORP pump back station also supplies the mainline. 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)
- Moat and row management areas (2,400 acres)

<u>LORP</u>. LORP is a large-scale habitat restoration project that includes:

- Restoration of the Lower Owens River by providing flows to the river to enhance fish, wetland, and riparian habitats
- Creation of new wetlands through seasonal flooding at the Blackrock Waterfowl Habitat Area (located outside of the LORP area midway between the towns of Aberdeen and Independence) as well as off-river lakes and ponds
- Release of flows to the Delta Habitat Area to maintain and enhance wetlands
- Modification of grazing practices on LADWP leases adjacent to the river



Key to Features

- Towns
- LORP Pump Back Station
- Roads
- Highway
- Los Angeles Aqueduct
- Owens River
- OLGEP Model Domain
- Brine Pool
- Owens Lake (Historic Shoreline)
- Other Lakes

N 0 1 2 Miles

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Map Showing Dust Control Measures and Elements of LORP

Figure 1-3

Los Angeles Department of Water & Power

MWH.

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Key elements of LORP are shown on **Figure 1-3**. The river intake structure, which was completed in 1913 and is located north of Independence, formerly diverted all of the Lower Owens River flows to the LAA. As part of the LORP, a consistent supply of water is released to the Lower Owens River from the intake to provide a continuous and year-round baseflow of approximately 40 cubic feet per second (cfs) from the river intake to the pump station (located approximately 4.5 river miles upstream of the Owens River Delta). In addition, higher flows of up to approximately 200 cfs (“seasonal habitat flows”) are released from the River Intake in late May or early June (to provide hydrologic conditions similar to natural flood flows). LADWP’s Keeler gauge, located just upstream of the State Route 136 crossing, is the only existing flow monitoring station on the river downstream of the river Intake. Downstream of the river intake, surface water is either re-captured at the pump back station and sent to the LAA or DCMs; or water is released to the delta, whereby a certain amount travels through the brine pool transition area and into the brine pool.

1.2 Organization of Report

This report is organized in the following manner:

- **Section 1** includes an introduction to the report, defines the study area, and summarizes the report's organization.
- **Section 2** is a brief narrative of the overall OLGEP study.
- **Section 3** summarizes key findings, conclusions, and recommendations on a task-by-task basis. This section also identifies and references deliverables produced by each task.
- **Section 4** provides recommendations and a framework for implementation of a proposed groundwater development program.
- **Section 5** is a compilation of literature cited.

2.0 PROJECT NARRATIVE

LADWP is implementing a dust mitigation program to reduce emissions of fine particulates from the dry Owens Lake bed. Implementation of the project has been done in phases (Phases I - V and Phase 7) beginning in 2001 up to present. The water delivery system for DCMs supplies a total of 27,600 acres (approximately 43 square miles) of management area. The amount of water supplied to DCMs has been increasing steadily since inception of the dust mitigation program. **Figure 2-1** plots water use by year from 2001 through present, whereby initial water use in 2001 was less than 10,000 acre-feet (AF). Water use in 2012 (Runoff Year 2012-13 ends on March 31, 2013) is expected to be approximately 95,000 acre-feet. Increasing water use through time reflects the development and implementation of DCMs in phases.

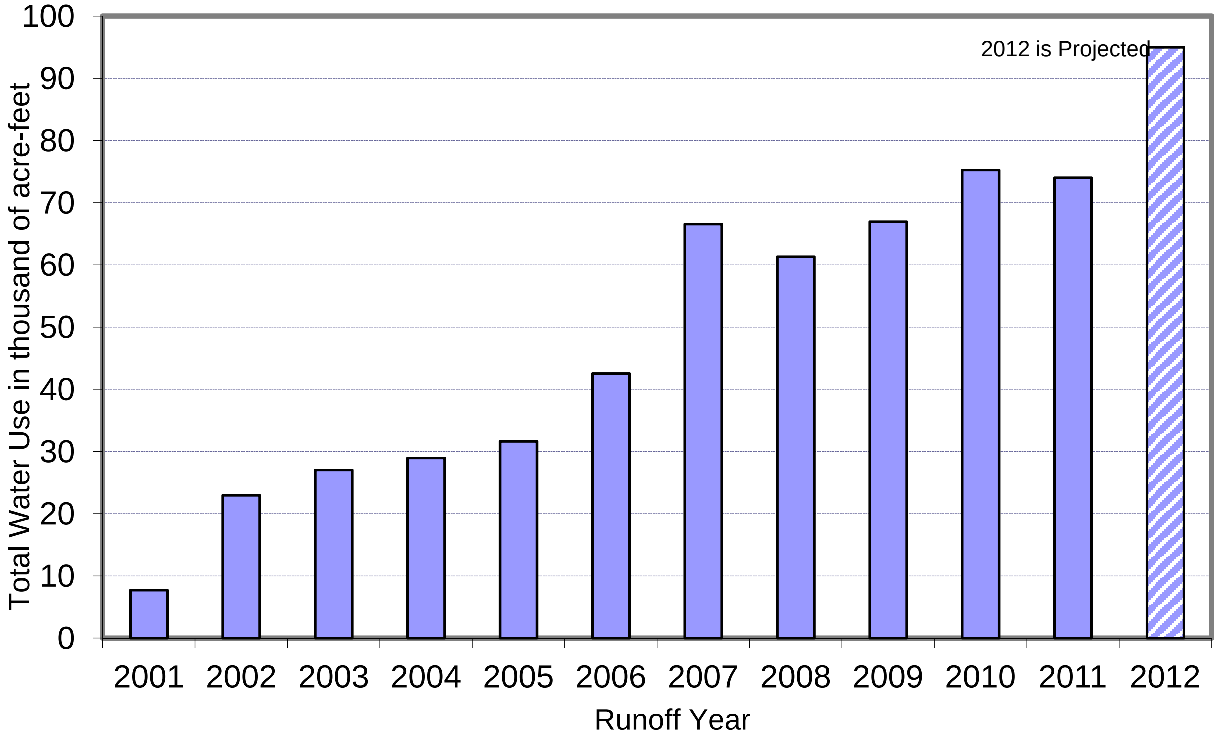


Figure 2-1
Water Use by Year for Dust Control Measures

With the goal of continuing dust control activities while conserving potable water, the LADWP and MWH conducted the OLGEP to evaluate groundwater under Owens Lake for supplying water to a portion of the dust suppression activities.

In **Task 1**, MWH conducted extensive data compilation and a review of existing groundwater models for the study area.

In **Task 2**, existing data was used to develop a preliminary conceptual model for the study area based on the voluminous body of work conducted on or around the lake in the last century. The preliminary conceptual model described what was known initially about the hydrostratigraphy and geologic structure, depositional history, water budget, groundwater gradients, and private or commercial entities that may be affected by changes in groundwater or surface water in the vicinity of the lake. The preliminary conceptual model also summarized environmental issues to be considered in future phases of work. Most significantly, the preliminary conceptual model identified data gaps relevant to future development of a numerical groundwater model, and provided recommendations and strategies for resolving these data gaps during the field investigation and well drilling program.

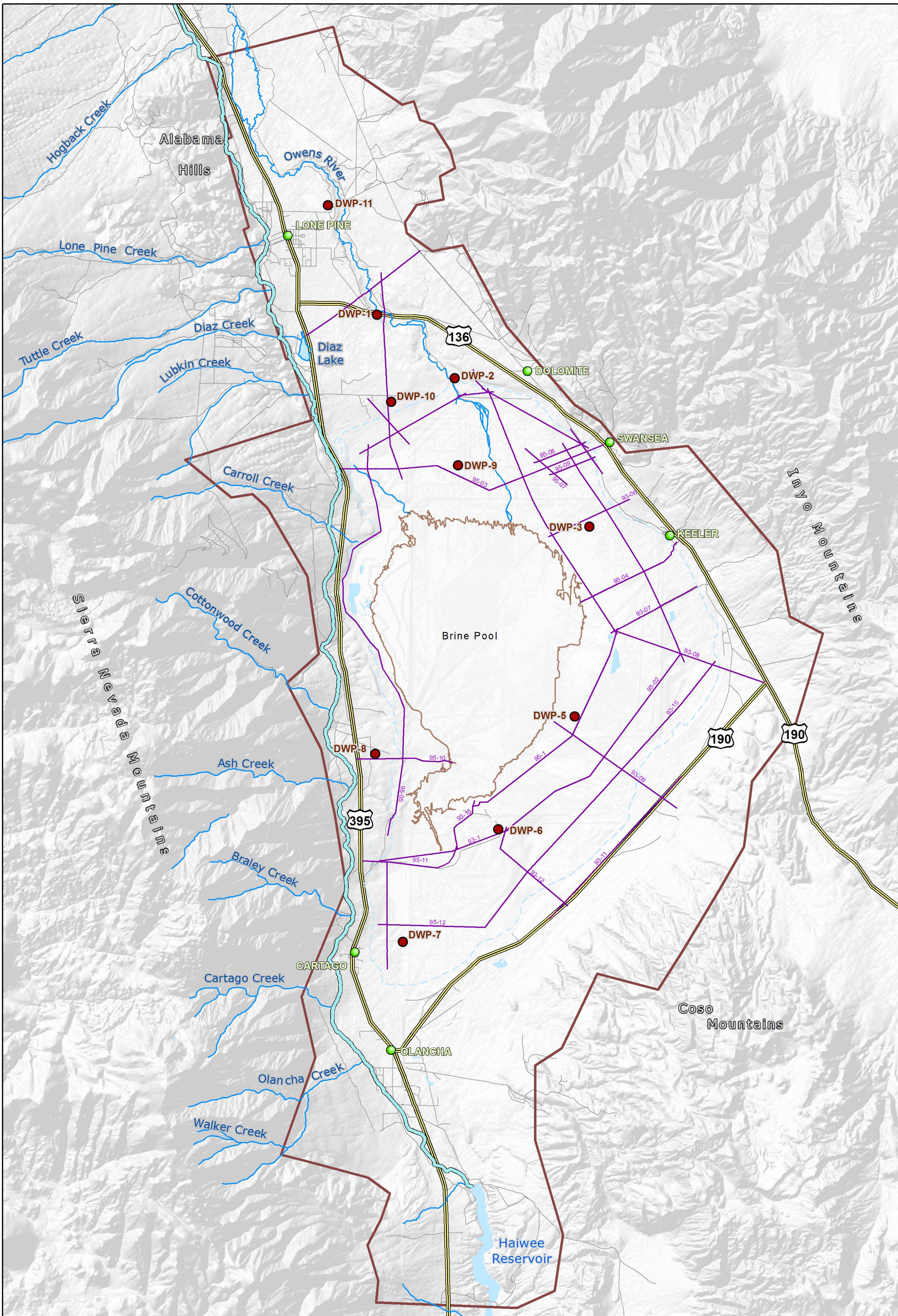
Task 3 represented the field investigation and well drilling program for the study. Initial work plans and a health and safety plan were developed to guide the field program. Construction of monitoring wells occurred at ten sites in the vicinity of Owens Lake and at strategic locations to fill data gaps identified in Task 2 (**Figure 2-2**). These sites were designated DWP-1 through DWP-10. A deep borehole to a depth of approximately 1,500 feet below ground surface (fbgs) was drilled initially at each site. Based on geophysical and lithologic data from the first borehole, monitoring wells were then constructed at various depths. Finally, aquifer testing and water quality sampling was conducted.

The geophysical study conducted as **Task 9.1** followed Task 3 and preceded Task 4. During the data collection phase, it was noted that a large quantity of seismic data had been collected at Owens Lake by Neponset Geophysical Corporation and Aquila Geosciences, Inc. (Neponset, 1997; 1999) along designated seismic lines shown on **Figure 2-2**. This task utilized a combination of seismic interpretation along existing seismic lines, borehole lithologic and geophysical data, and surface geologic mapping to interpret the structural geology, depositional history, and hydrostratigrapy of the OLGEP study area. In turn, results of this work fed directly into the updated conceptual model as well as the layering strategy and estimation of hydraulic parameters for the numerical groundwater model.

The primary focus of **Task 4** was the development of an updated conceptual model for the study area utilizing the data collected in Tasks 3 and 9.1. The updated conceptual model was based primarily on the following:

- Newly-acquired data from the OLGEP Task 3 drilling and monitoring well installation program
- Detailed interpretation of surface seismic data evaluated under Task 9.1, used in conjunction with new drilling data
- Results and lessons learned from LADWP/MWH groundwater modeling efforts in the northern portion of the study area commonly called the “Southern Model” (MWH, 2011b)
- Detailed review and re-analysis of the water budget
- Detailed review of available data on springs and seeps for the purposes of characterizing the nature and source of spring flow

The new data, combined with re-analysis of existing data, dramatically improved the hydrogeologic conceptual model for the OLGEP study area by better defining the hydrostratigraphy, updating the location of key faults, improving estimates on the location and amounts of groundwater recharge, characterizing the interaction between groundwater and surface water, and evaluating sensitive resources such as springs, seeps, and local wells.



Towns

OLGEP Test Well

Seismic Line (Neponset, 1997)

Highways

Roads

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 LADWP\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\OLGEPFinalReportDec2011\Fig_2-2_Wells_SeismicLines.mxd

Study Area Location Map Showing the Location of Seismic Lines and New OLGEP wells

Los Angeles Department of Water & Power

Figure 2-2

MWH

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

Task 5 utilized the much-improved conceptual model to develop a numerical groundwater model for the study area. Initially, necessary groundwater model attributes and functionality were defined, followed by a review of available groundwater modeling software. This review resulted in the selection of MODFLOW-2000 (Harbaugh and others, 2000) as the most appropriate software to be used. Rationale for this recommendation included the fact that MODFLOW:

- Contains all of the functionality required for the project
- Has a source code that is very well documented
- Has sustained rigorous U.S. Geological Survey and academic peer review
- Has a long history of successful development and use
- Is the most widely-used model today
- Will continue to be the subject of new development and improvement
- Has a wide range of functionality that could be added when sufficient data becomes available and/or the need is identified including: density driven flow, estimation of subsidence, and contaminant transport capabilities
- Has been applied successfully previously in the Owens Valley and is well known by LADWP and OLGEP Partner Agencies (including Great Basin Unified Air Pollution Control District, Inyo County Water Department, and the California State Lands Commission)

The model was calibrated using existing data and available pump test results. New pump test data became available following the completion of **Task 5**. Improvements were made to the groundwater model based on input from the Blue Ribbon Panel, and the model was calibrated to new pump test data under **Task 10**. The groundwater model ultimately was completed under **Task 10** and used to conduct alternative analysis and simulation to identify the potential alternative.

Task 6 included identification, simulation, and analysis of pumping alternatives using the numerical groundwater flow model for the OLGEP study area. The scenarios consisted of a preliminary set of alternatives followed by a revised set of alternatives. Results of this work provided the foundation for selecting the potential alternative (under **Task 10**). This potential alternative is a groundwater pumping alternative that meets pre-determined criteria. The potential alternative was used to optimize well locations, develop protocols for pumping and monitoring, and provide recommendations on new well locations and use of existing facilities and infrastructure. Results of this final effort were documented in a TM under **Task 6**.

The isotope study was conducted as **Task 9.2** and included sampling of groundwater and surface discharge areas for cations and anions, stable isotopes, radiocarbon, tritium, and/or noble gas. The purpose of this study was to (1) determine the source region of groundwater recharge and (2) to determine the age of the water. Results of the study were used to confirm the existing conceptual model and assist in final numerical model calibration and selection of the potential alternative (in **Task 10**).

Task 7 spanned the duration of the project and included a public outreach program aimed at community and stakeholder involvement. The program consisted of the distribution of facts sheets, public meetings, interaction with individual stakeholders, as well as an educational outreach program.

Task 8 included active participation by an expert Blue Ribbon Panel (BRP) at key points during the project. The Blue Ribbon Panel was comprised of experts in groundwater modeling and ecology with experience from the U.S. Geological Survey, academia, and private industry. This Final Report represents the deliverable for **Task 8**.

The following Sections of this report provide a more in-depth review of key technical conclusions and findings associated with the various OLGEP tasks.

3.0 SUMMARY OF MAIN ACTIVITIES, KEY FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This section provides a detailed overview of the project, including a summary of key findings, conclusions, and recommendations by task.

3.1 Compilation of Existing Data

The overall purpose of Task 1 was to compile available and relevant data in the vicinity of Owens Lake. Data sources were primarily LADWP, Great Basin Unified Air Pollution Control District (GBUAPCD), and Inyo County Water Department (ICWD). These agencies provided previous studies by private consulting firms and the Desert Research Institute (DRI). In addition, well logs were obtained from the California Department of Water Resources (CDWR).

MWH developed a database of existing studies and reports pertaining to geology, hydrogeology, hydrology, natural resources, and water quality within the study area. These studies and reports were scanned into Adobe® Acrobat format®. Reports were reviewed in order to create an index of studies and reports (as shown on **Figure 3-1**) that identified how each document was relevant to specific technical areas pertinent to the study such as stratigraphy, geophysics, water quality, water budget, climatic data, groundwater levels, soils, vegetation, aquatic and terrestrial habitats, and special status species. Relevant information on DCMs was compiled (water use amounts, spatial and temporal distribution, physical facilities, and water demand). Similarly, pertinent information on the LORP was compiled, including previous reports, flow data, water quality data, and diversions from LORP to DCMs.

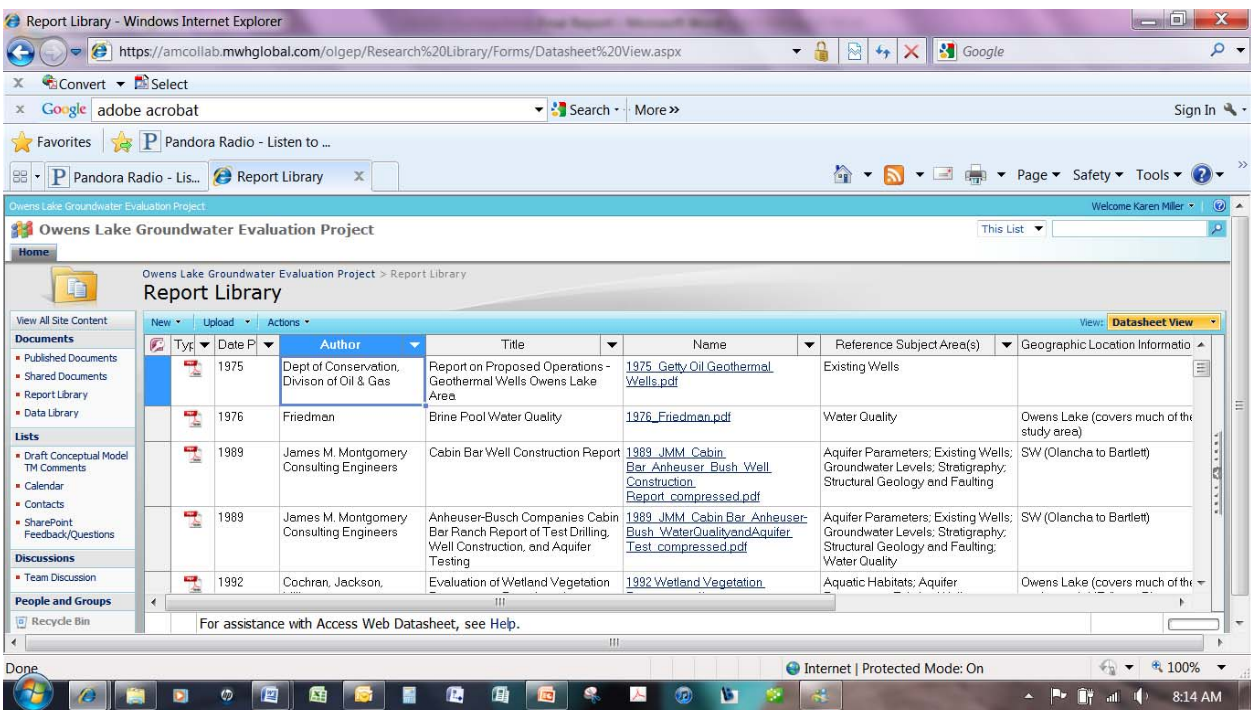


Figure 3-1
Web-Based SharePoint® Site Showing Report Library and Indexing

A web-based and password-protected centralized collaborative data storage/team SharePoint® site was created for the project (**Figure 3-1**). Compiled reports and data were loaded and organized on the site. In addition, all project deliverables were posted to SharePoint®. A ©Google Earth map interface was created, whereby a map of the Owens Lake study area was integrated into the site with linking features to selected data.

This task concluded with a review of currently available groundwater flow models for the Owens Lake study area. Results of this review were described in a Technical Memorandum (TM) entitled, "Review of Existing Models" (MWH, 2009c) included as **Appendix A**. This review found that groundwater models built within the Owens Lake study area included models by:

- United States Geological Survey (Danskin, 1988)
- LADWP (1988)
- Great Basin Unified Air Pollution Control District, in collaboration with the Desert Research Institute and the University of Nevada-Reno (Wirganowicz, 1997 and Schumer, 1997)
- Owens Lake Soda Ash Company (OLSAC) (Woodward-Clyde Consultants, 1993 and Luhdorff and Scalmanini Consulting Engineers, 1994)
- Anheuser-Busch Companies (Montgomery Watson, 1993)
- Camp, Dresser and McKee (CDM, 1999; 2000)

A comparison of these models was conducted alongside a tabulation of model limitations as they relate to specific model attributes. The collective key uncertainties, limitations, and data gaps of these models are listed in bullet format below:

- Existing models did not incorporate findings from the 1999 River Pump Test. Attempts were made to calibrate the CDM model to early results of the large-scale 1999 aquifer test, but could not accurately simulate the effects of the test.
- The hydrogeological structure of the existing models did not fully incorporate findings from the Phase 3 and 4 seismic program performed by Neponset (1997).
- Existing models did not incorporate aquifers below a depth of 1,000 ft.
- Previous models had to incorporate a deep source of groundwater to explain groundwater flow patterns in the system.
- Estimates of flow from the northern Owens Valley into the model domain varied widely (Danskin/U.S. Geological Survey: 10,000 acre-ft/yr, Schumer: 21,500 acre-ft/yr, CDM: 4,200 acre-ft/yr). Sensitivity analysis in the past demonstrated that modeled heads are highly sensitive to the amount of down-valley recharge input into the model.
- No direct measurements of the hydraulic properties of confining clay units had been performed. CDM suggested that the inability of the model to replicate the 1999 pump test results could be in large part due to inaccurate vertical conductances assigned to these confining clay units.
- Previous studies note that there is uncertainty as to whether there is deep underflow out of the southern boundary of the model at Haiwee Reservoir. Previous modelers treated Haiwee Reservoir as a groundwater divide; therefore, representing it as a no-flow boundary.

- Previous conceptual models assumed that the transition zone developed at the interface between the lake and alluvial fans extended vertically down the entire 1,000 feet of sediments near the historic shoreline.
- The role of faults in acting as potential barriers to flow or vertical pathways to flow between aquifers was recognized as important; however, faults were not included in previous modeling efforts.
- Previous models pre-dated implementation of DCMs and the LORP.

The TM concluded that the DRI and CDM models were most relevant to the current study, whereby the CDM model represented an update and refinement of the previous DRI model. MWH recommended that the following key uncertainties, data gaps, and limitations of previous modeling efforts be focused on during the field program and subsequent update of the hydrogeologic and numerical models of the Owens Lake groundwater basin:

- **Water Budget**. Previous modeling efforts noted key uncertainties in components of the water budget, particularly estimates for down-valley flow (Lone Pine recharge) and mountain-block recharge, which are both large components of inflows to the model. MWH recommended that future tasks should therefore focus on further refining these estimates.
- **Stratigraphy and Aquifer Characterization**. There was much uncertainty in the locations and characteristics of confined aquifers, as well as the confining clay units that separate them. It was recommended that future tasks focus on further characterization of the aquifers and confining clay units by evaluating findings from studies performed since the development of the CDM model (e.g. Neponset's Phase 3 and 4 Seismic Analysis), reviewing and incorporating findings from the 1999 River Pump Test, analyzing lithologic borehole data, and locating monitoring wells in strategic locations to fill key data gap areas. An important data gap identified was that the nature of sediments below a depth of 500 feet was largely unknown.
- **Faulting**. Previous groundwater models did not incorporate faults that exist in the Owens Lake groundwater basin, stating that the role of these faults in acting as barriers or conduits to groundwater flow was uncertain. MWH recommended that the role of faults in acting as either a barrier or conduit to groundwater flow should be further evaluated during the update of the conceptual model, and also used as a variable parameter in the groundwater model during the calibration process.

3.2 Data Evaluation, Identification of Data Gaps, and Development of Preliminary Conceptual Model

In Task 2, the voluminous body of data that was collected in Task 1 was reviewed and synthesized to develop a preliminary conceptual model for the study area. In this preliminary conceptual model, data gaps in key areas were identified to develop the Task 3 field investigation program. The Blue Ribbon Panel provided detailed review and comment on the preliminary conceptual model and the topic of density-driven flow. Two deliverables were produced by this task:

- TM on the Evaluation of Density-Driven Flow (MWH, 2009e), located in Appendix B
- TM on the Preliminary Conceptual Model (MWH, 2011a), located in Appendix C

Key findings from these technical memoranda are summarized in the following sections.

3.2.1 Density-Driven Flow

Density-driven flow is a convective process that results from instability in a system created by an imbalance of density in two vertically-adjacent sources of water. Several previous authors had indicated that density-driven flow might play a significant role in groundwater flow in the Owens Lake Basin, and that future modeling efforts should consider the incorporation of density-driven flow capabilities. A review of previous literature revealed several widely-differing viewpoints on the significance that density-driven flow plays in the Owens Lake Basin.

MWH evaluated the impact of density-driven flow to ascertain the need for specialized modeling that considers the incorporation of density-driven flow capabilities. Several preliminary model scenarios were performed utilizing the existing model of Owens Lake developed by CDM (2000) to observe the possible regional impacts of accounting for highly-dense water at the brine pool. Based on the results of modeling coupled with input from the Blue Ribbon Panel, it was concluded that a variety of salt transport processes likely are occurring at Owens Lake, including density-driven flow. Although conditions for density-driven flow may exist on a local scale, it was concluded that density-driven flow is not significant on a regional scale.

At Owens Lake, the high-density water sources are the brine pool and shallow groundwater, whereas the low-density water source is freshwater emanating from nearby mountains and deep surfacing groundwater. There is no source of salinity at the surface other than evaporation. The high salinity in the brine pool results from high rates of evaporation that remove water and leave dissolved salts. In order for density-driven flow to be a constant process, there would need to be a source of salt at the surface to replenish the salts that would be carried downward. In reality, the reverse occurs because salt solids are lost at the surface to wind and erosion. Because of the temporal persistence of the salt crust, it is more likely that groundwater is flowing upward to the salt crust and discharging primarily through evaporation, replenishing the salt concentration at the surface. However, it is probable that localized mixing occurs as a result of density differences in specific regions of the lake, or at certain times. The localized region where fresh recharge water encounters more saline playa waters along the historic shoreline probably results in localized mixing as a result of density differences. This would explain the slightly saline water quality of many of the springs along the historic shoreline.

In consultation with the Blue Ribbon Panel, it was concluded that a variable fluid density groundwater model was not required for building a new OLGEP numerical groundwater model. Modeling of potential density-driven flow would not provide substantial overall value towards achieving the primary objective of the modeling, which was to evaluate regional impacts to groundwater levels due to pumping in deep aquifers.

3.2.2 Preliminary Conceptual Hydrogeologic Model

The preliminary conceptual model was developed initially in a draft TM, after which feedback was received from the Blue Ribbon Panel and Partner Agencies. Review comments were incorporated, and the TM was finalized (MWH, 2011a).

The preliminary conceptual model represented the initial conceptual understanding of the study area and hydrologic system based on the voluminous body of work conducted on or around the lake in the last century, and thereby provided a framework for defining key hydrologic components and their interrelationships. In addition, the preliminary conceptual model formed the context in which data were evaluated and interpreted. Most significantly, the preliminary conceptual model allowed for identification of data gaps in key areas followed by prioritization of Task 3 field work (including monitoring well installation) and selection of methods to fill these data gaps and reduce uncertainty.

The preliminary conceptual hydrogeologic model described in detail what was known initially about the following concepts:

- **Geology, Structure, Depositional History, and Hydrostratigraphy**. The preliminary conceptual model summarized the geologic and structural setting of the study area followed by a review of the depositional history. The initial understanding of the study area's hydrostratigraphy was presented, including a detailed review and analysis of available lithologic logs in the study area. Lithology was categorized and stored in digital form based on its relative permeability. A review of available geophysical data was conducted. The initial understanding of the aquifer system and configuration was presented, including a review of aquifer and aquitard parameters. Finally, the potential for subsidence was considered.

  A master well table that compiles information on every known existing well in the study area was prepared and is included as Table 2-1 in the preliminary conceptual model report (Appendix C). The master well table presents key information for each well (location, type, lithologic and/or geophysical log availability, well construction data, elevation, and water level data). Since this table was completed, LADWP conducted and/or obtained video log information on selected wells. This new information is included as an addendum to the conceptual model report.

  The preliminary conceptual model was largely based on drilling and seismic investigations conducted by the GBUAPCD on the lake bed that led to the interpretation of four aquifers in approximately the upper 1,000 feet of sediments. The area beneath the lake contains extensive valley-fill deposits estimated to range up to 8,000 feet in thickness. The four deep confined aquifers are comprised of sands and silty sands, separated by low permeability clay units of variable thickness. All aquifers typically exhibit flowing artesian conditions when penetrated by wells located at lower elevations near Owens Lake. Where wells of different depths are available, the hydraulic gradient is typically upward, suggesting that the primary groundwater discharge area is the Owens Lakebed.

  The most significant data gaps identified and later addressed by subsequent tasks were:

  - Elevations of tops and bottoms of each aquifer
  - Characterization of deeper confined aquifers.
  - Definition of the bedrock contact
  - Characterization of aquifer and aquitard parameters

- **Groundwater Flow**. The groundwater flow characteristics of the OLGEP study area were reasonably well defined in the preliminary conceptual model based on numerous hydrogeologic studies in localized areas and the preponderance of groundwater elevation data compiled from various sources. The shallow groundwater system was described, including potential impacts of the LORP and DCM projects, springs, and seeps. The deep groundwater system was also described.

Groundwater flow is typically inward toward the center of the lake basin. Based on well locations where there is information on piezometric heads in both deep and shallow aquifer zones, relatively high vertical gradients are observed in the OLGEP study area.

The most significant data gaps identified and later addressed by subsequent tasks were:

- ➢ Although groundwater flow conditions in the vicinity of Owens Lake were reasonably well documented in the shallower system, flow conditions in deeper aquifers were less documented because of the paucity of wells screened only in the deeper zones.
- ➢ The quantification of impacts associated with the LORP and DCM projects required further evaluation.

- **Water Quality**. Available surface and groundwater quality for the OLGEP study area were summarized. In addition, shallow isotope data was reviewed. The quality of groundwater in the study area is highly heterogeneous, and its composition is influenced by multiple past and current hydrogeologic processes. The most significant data gaps identified and later addressed by subsequent tasks were:
  - ➢ Water quality data was more limited in certain portions of the study area (along southern margin and northwest of brine pool)
  - ➢ Additional water quality data with depth was needed
  - ➢ Characterization of water quality by aquifer was needed
  - ➢ Relationship of water quality and spring origin was unknown
- **Water Budget**. A review of the study area's water budget based on that of previous investigators was conducted. Investigators that have developed water budgets for the area include Lopes (1987; 1988), Wirganowicz (1997), Schumer (1997), GBUAPCD (1997) and CDM (1999; 2000). Previous work relative to the water budget was summarized with inflows and outflows described in detail. The relative importance of water budget components was discussed as well as data gaps and uncertainties associated with the water budget.

  The calibrated water balance by CDM (2000) represented the most current understanding for the study area (see **Table 3-1**). Each of these components was described in detail in the preliminary conceptual model report (MWH, 2011a).

  The most significant data gaps identified and later addressed by subsequent tasks were:

  - ➢ Down-valley flow is one of the most significant components of the water budget, and had a relatively high uncertainty.
  - ➢ Mountain block recharge is not known and cannot be measured; therefore, evaluation of CDM's mountain block recharge component, which accounted for 55% of their inflows, was needed.
  - ➢ Calculation of other components (i.e., stream channel recharge) using alternate techniques was desired.
  - ➢ Previous studies identified subsurface flow at the southern end of the Basin as an uncertainty.
  - ➢ Quantification and evaluation of the effects of LORP and DCMs on the water budget was needed.

Table 3-1
Calibrated Water Budget by CDM (2000)

Inflows – AF/yr		Outflows – AF/yr	
Down-Valley Flow	4,184	ET *Playa/Brine Pool Evaporation* *Lone Pine Area* *Seep & Spring*	55,427 *29,242* *6,140* *20,045*
Mountain Block Recharge *Inyo* *Coso* *Sierra Nevada* *Deep*	36,707 *3,959* *7,321* *17,556* *7,871*	Spring and Seep Discharge and Discharge from Flowing Wells	8,318
Stream Channel Recharge *Inyo/Coso Range* *Sierra Nevada Range*	7,489 *1,568* *5,921*	Groundwater Pumped from Wells (includes Lone Pine Pumping)	1,894
Interfluve/Fan Recharge	1,716	Owens River Discharge	1,687
Haiwee Reservoir Subsurface Inflow	3,791		
Centennial Flats Subsurface Inflow	1,095		
Lone Pine Area Recharge	12,342		
Total	**67,324**		**67,326**

- **Summary of Private Entities and Commercial Interests that may be Affected by Changes in Groundwater or Surface Water in the Vicinity of Owens Lake**. A variety of private entities and commercial interests surrounding Owens Lake and the Lone Pine/Owens Lake Delta were identified that may be affected by changes in groundwater or surface water in the study area. These entities include private and municipal well owners, Crystal Geyser Roxane bottled spring water operation, Rio Tinto Mining, and LADWP's dust control operations.
- **Review of Environmental Considerations**. A review of environmental factors that would require consideration prior to developing groundwater supply in the area was conducted. Environmental factors identified included: vegetation, rare plants, birds, mammals, macroinvertebrates, fish, water quality, air quality, cultural resources, and paleontological resources.
- **Recommendations for New Monitoring Wells** were presented, including general design criteria and recommendations for new sites.
- **Recommendations for Aquifer Testing** were presented, including pumping rates, test durations, observation wells, monitoring intervals, monitoring seeps and springs, and prioritization of wells to test.

Most significantly, the preliminary conceptual model summarized the current body of knowledge for the study area and allowed for the identification of data gaps relevant to the development of a numerical groundwater model. The TM provided recommendations and strategies for resolving these data gaps during future phases of this study. These recommendations included:

- Utilize groundwater gradient, geophysical, and water quality data from approximately 30 new monitoring wells to refine the hydrostratigraphy, water budget, and water quality components of the preliminary conceptual model.
- Utilize borehole information from the new wells in conjunction with previous seismic studies to refine the conceptualization of geologic structure.

- Collect core samples from confining layers during installation of the monitoring wells as an aid to evaluate of confining layer properties and potential for subsidence.
- Perform aquifer testing and utilize the new monitoring wells to evaluate the hydraulic properties of aquifers and the role of faults in groundwater flow.
- Refine the water budget based on new information gathered since previous efforts and methods or using alternate techniques.
- Utilize borehole information compiled during this study (that was not used in previous modeling efforts), combined with borehole information from new monitoring wells to develop a three-dimensional representation of hydrogeologic units that can be efficiently transferred to a numerical model.

Recommended locations for new monitoring wells were based on the most significant data gaps identified by previous authors and by MWH during development of the preliminary conceptual model. The decision matrix showing well selection criteria and proposed monitoring wells that was used to guide and plan the Task 3 field program is presented as **Table 3-2**.

3.3 Monitoring Well Installation and Collection of Field Data

The focus of Task 3 was the field investigation and well drilling program, whereby ten new well clusters were installed in the study area (DWP-1 through DWP-3 and DWP-5 through DWP-11). Well locations are shown on **Figure 2-2**, and **Table 3-3** is a master well table for the new wells, showing constructions details and calculated aquifer parameters. Deliverables in Task 3 included field planning documents and a well completion report, as listed below in bullet format.

- TM on Best Management Practices (BMPs) for Construction on Owens Lake (MWH, 2009d; Appendix D). This TM described BMPs for drilling and well construction in adverse conditions known to exist at Owens Lake such as flowing artesian aquifers, unstable soils, lost circulation of drilling fluid, corrosive/brackish water, and large boulders. The TM identified environmental considerations and measures for use during the field program.
- A memorandum that served as an interim work plan was prepared (MWH, 2010a; Appendix E) that served to optimize drilling locations in order to reduce project delays related to permitting with the California State Lands Commission. In addition, the memorandum identified the importance of existing seismic data (along seismic lines shown on **Figure 2-2**) to improve the understanding of hydrostratigraphy in the study area and outlined methods to utilize this data in Task 9.1.
- A field health and safety plan was developed for use during the field program (MWH, 2009a; Appendix F). The plan identified potential adverse conditions along with alternative and recommended treatment, emergency contact information, and hospital route maps.
- After completion of the new monitoring wells, a well completion report for each new well site was prepared. These reports have been compiled into Appendix G (MWH, 2011d).

Table 3-2
Well Siting Decision Matrix Based on the Preliminary Conceptual Hydrogeologic Model

Monitoring Objectives		Well Selection Criteria	Preliminary Monitoring Wells									
To Evaluate Production Potential	To Evaluate Spring Impacts		DWP - 1	DWP - 2	DWP - 3	DWP - 4	DWP - 5	DWP - 6	DWP - 7	DWP - 8	DWP - 9	DWP - 10
X	X	1. Near existing high-capacity wells, so they can be used to see the drawdown impacts while pumping those wells.		X		X	X				X	X
X		2. Where well can use them to resolve the density-driven flow issue (radial pattern from brine pool outward?)					X	X	X			X?
X	X	3. Where water is eventually needed for DCM, with the feeling that this area needs to be characterized, and the wells can eventually be used for monitoring the effects of pumping. A corollary would be near existing conveyance facilities so that water can be moved fast from eventual production wells.					X?	X?	X?		X?	X?
NA	NA	4. Along existing roads where a pad would be easy. What new opportunities exist because of all the DCM road building?			X	X	X	X	X			
NA	NA	5. AWAY from sensitive habitat such as snowy plover.	X	X	X	X	X	X		X		
X	X	6. South of Lone Pine to document potential future drawdown impacts (i.e. a guard well north of lake shore and south of Lone Pine).	X									
X	X	7. North of the Lake, because this is where it is thought that the best production wells will be that can take advantage of LORP flows.	X	X	X							
X		8. Where there is a need for more information on stratigraphy.							X	X	X	X
X		9. On both sides of key faults, so that displacement can be characterized and the degree to which a fault acts as a barrier can be evaluated (if we are able to stress the system in that location).										X?
	X	10. Near sensitive locations (springs, Keeler) where we will be able to document the impact to the most sensitive locations				X						X
X		11. As far out near (or in) the brine pool as possible because there are few wells here and the area is thereby not well characterized.							X			
NA	NA	12. The wells should be located on LADWP land for access purposed. The next order of priority would be State, BLM, Private. (Private least preferred).										
NA	NA	13. Regardless of site chosen, each site must be ground-truthed.										
		14. One or two wells should up on the eastern fans, because the extent of the playa deposits is not known.				X						
X	X	15. One or two wells should be sited from Haiwee north, so that the concept of a closed basin can be tested/field checked.								X		
X		16. "Down-valley" flow is one of the biggest uncertainties in the water budget – more wells needed here to reduce uncertainty.								X		
X	X	17. Near exiting well clusters that may not have deep piezometers (i.e. well in vicinity of River wells, existing wells only penetrate aquifers 1 and 2; need to explore deeper zones. Also Star Trek well is only completed in the upper zone, could add a deeper well here).		X	X	X	X?	X?	X			
		18. "Guard" or early warning monitoring well between Owens Lake and Olancha.								X		

NA - Not Applicable
? - indicates level of uncertainty

Table 3-3
Summary Table of New OLGEP Monitoring Wells

Well Site	Well ID	Location		Well Construction				Aquifer Unit (1-5)	Pumping Rate (gpm)	Static Water Level		Maximum Drawdown (feet)	Specific Capacity (Q/s)	Jacob Straight-Line Method		Theis Recovery Method		Comments (also see Notes 1 - 3)
		UTM Meters North	UTM Meters East	Reference Point (fmsl)	Total Borehole Depth (ft)	Screened Interval (fbgs)	Screen Length (ft)			(fbgs)	Date (mo/yr)			T (ft^2/day)	K (ft/day)	T (ft^2/day)	K (ft/day)	
DWP-1	T890	4048003.8	408870.3	3,666.80	1,500	1,150-1,230	80	5	53	26.0	Oct-10	13.4	4.0	4,317	54	6,602	83	
	T891	4048009.6	408869.6	3,667.19	540	480-520	40	2	52	24.9	Oct-10	11.08	4.7	1,311	33	3,368	84	
	T892	4048015.5	408868.2	3,667.22	390	290-370	80	1	53	27.3	Oct-10	17.4	3.0	850	11	1,188	15	
DWP-2	T893	4045191.3	412319.0	3,599.49	1,530	1,430 - 1,510	80	5	141	Artesian (head = 35 ft)	Apr-10	40.6	3.5	829	10	1,746	22	Variable flow rate (Q) noted
	T894	4045196.0	412325.0	3,599.72	1,270	1,170 - 1,250	80	5	35	Artesian (head = 31 ft)	Apr-10	52.8	0.7	370	5	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		Variable flow rate (Q) noted
	T895	4045200.9	412330.6	3,600.07	960	860 - 940	80	4	135	Artesian (head = 32 ft)	Apr-10	46.4	2.9	1,588	20	4,765	60	Variable flow rate (Q) noted
DWP-3	T899	4038643.9	418254.5	3,572.98	1,003	920-960	40	5	252	Artesian (head = 45 ft)	Jun-10	44.8	5.6	22,235	556	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		Variable flow rate (Q) noted
	T900	4038647.2	418259.9	3,572.95	720	660-700	40	5	247	Artesian (head = 45 ft)	Jun-10	47.1	5.2	9,018	226	3,487	87	Variable flow rate (Q) noted
	T901	4038651.5	418265.1	3,572.87	190	150-170	20	1	141	Artesian (head = 38 ft)	Jun-10	39.3	3.6	8,782	439	1,816	91	Variable flow rate (Q) noted
DWP-5	T914	4030256.9	417580.6	3,566.34	1,500	1,360 - 1,400	40	5	74	Artesian (head = 47 ft)	Apr-11	47.8	1.5	7,878	197	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		
	T915	4030253.2	417575.6	3,566.30	1,088	760 - 800	40	3	112	Artesian (head = 44 ft)	Apr-11	44.1	2.5	4,729	118	1,971	49	
DWP-6	T911	4025254.3	414252	3,564.44	1,500	1,420 - 1,460	40	5	52	Artesian (head = 45 ft)	Apr-11	44.9	1.2	1,835	46	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		
	T912	4025249.3	414248.3	3,564.42	1,080	1,020 - 1,060	40	5	27	Artesian (head = 47 ft)	Apr-11	45.9	0.6	70,703	1,767	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		
	T913	4025259.6	414255.5	3,564.51	312	260 - 300	40	1	6	Artesian (head = 9 ft)	Apr-11	7.6	0.8	244	6	111	3	Variable flow rate (Q) noted
DWP-7	T908	4020292.7	410017.4	3,581.90	1,470	1,360 - 1,400	40	5	58	Artesian (head = 47 ft)	Apr-11	47.0	1.2	27,722	693	Recovery test analysis could not be performed because subsequent pump test interfered with recovery.		
	T909	4020298.7	410017.4	3,581.91	800	740 - 780	40	3	177	Artesian (head =41 ft)	Apr-11	45.4	3.9	3,992	100	1,787	45	Variable flow rate (Q) noted
	T910	4020304.8	410018.6	3,581.50	260	200 - 240	40	1	106	Artesian (head = 28 ft)	Apr-11	28.2	3.8	7,489	187	2,052	51	
DWP-8	T905	4028605.5	408814.5	3,643.60	1,500	1,200-1,260	60	3	56	55.5	Oct-10	21.3	2.6	1,210	20	2,156	36	
	T906	4028605.1	408806.8	3,643.60	530	450-510	60	1	52	59.0	Oct-10	5.5	9.5	7,245	121	18,353	306	Variable flow rate (Q) noted
	T907	4028604.7	408799.6	3,643.48	330	250-310	60	1	52	60.4	Oct-10	5.9	8.8	7,341	122	11,123	185	Variable flow rate (Q) noted
DWP-9	T896	4041347.6	412453.5	3,672.10	1,601	1,280-1,360	80	5	171	Artesian (head = 53 ft)	May-10	53.1	3.2	6,705	84	7,592	95	
	T897	4041340.1	412453.6	3,672.39	880	780-860	80	3	268	Artesian (head = 57 ft)	May-10	51.2	5.2	12,612	158	9,459	118	Variable flow rate (Q) noted
	T898	4041332.4	412453.3	3,672.22	340	240-320	80	1	384	Artesian (head = 48 ft)	May-10	32.3	11.9	13,553	169	12,510	156	
DWP-10	T902	4044157.4	409502.0	3,631.19	1,500	1,290-1,350	60	5	48	0.9	Oct-10	42.3	1.1	968	16	1,653	28	
	T903	4044165.8	409501.7	3,631.30	800	720-780	60	3	57	Artesian (head = 5 ft)	Oct-10	5.8	9.8	6,190	103	12,573	210	Variable flow rate (Q) noted Only 10 minutes of recovery data
	T904	4044174.4	409501.4	3,631.46	380	300-360	60	1	51	0.74	Oct-10	6.1	8.4	3,272	55	7,500	125	
DWP-11	T916	4052838.8	406753.5	3,679.27	1,500	1,220 - 1,260	40	5	59	25.8	May-11	24.5	2.4	912	23	765	19	
	T917	4052842.6	406748.9	3,669.38	990	930 - 970	40	4	69	26.4	Jun-11	34.4	2.0	332	8	2,706	68	Variable flow rate (Q) noted

Notes:
fbgs - feet below ground surface
s - maximum drawdown
Q - pumping rate
gpm - gallons per minutes

1. In general, later recovery data (after the 1st 10 minutes) were used to minimize wellbore effects.
2. The short-term pumping test were conducted using a surface pump in which the pumping rate was not carefully controlled. Therefore, some of the pumping
3. Pumping rates were obtained from either driller's development/pumping records or from totalizer readings at the start and end of a pump test.

Ten new well clusters were installed between April 2010 - April 2011. At each site, a deep borehole to a depth of approximately 1,500 feet below ground surface was drilled. Based on geophysical and lithologic data from the first borehole, monitoring wells were then constructed at various depths.

A well completion report was prepared for each site (see Appendix G; MWH, 2011d) that includes a chronology of major well construction and testing activities, copies of field documentation related to well construction, well development/pump test results, well completion information, analytical water quality data, a lithologic log, geophysical logs, as-built well construction diagrams, and survey data.

In general, the typical well installation consisted of the following:

- Soil cuttings were collected at 10-foot intervals or change in formation, and a lithologic log was prepared by an on-site geologist.
- A total of four soil samples from four different boreholes were selected for geotechnical analysis to characterize properties of confining units and subsidence potential.
- Geophysical logging was conducted. The geophysical log suite consisted of: gamma ray, spontaneous potential, resistivity, sonic velocity, temperature, and caliper logs.
- Based on the lithologic and geophysical logs, selected depth zones in which to install well screens were identified, along with the most appropriate casing materials to be used. Well screen lengths range from 20 - 80 feet.
- The deepest of the casings was completed in the 1,500-foot pilot hole, and the borehole was developed.
- Shallower boreholes were then drilled to the desired depth based on geophysical and lithologic logging, and subsequently developed. Typically, three casings were installed in three separate boreholes, although at some locations, less than three casings were installed.
- Flow testing of each well was conducted while changes in head were monitored in adjacent casings. Aquifer test analyses were applied to these results to estimate aquifer transmissivity (T) and hydraulic conductivity (K).
- Simultaneously, field parameters were monitored, including ph, electrical conductivity, total dissolved solids (TDS), and temperature.
- Water quality samples from all wells were collected near the end of flow testing and submitted to LADWP's water quality laboratory for analysis. Water quality data is summarized in **Table 3-4**.

Table 3-4
Summary of Water Quality Data from New OLGEP Monitoring Wells

Well Site	Well ID	Water Quality																																					
		Temp (˚C)	DO (mg/L)	pH	Specific Conductivity (uS/cm)	Turbidity (NTU)	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Total Chromium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Lead (mg/L)	Lithium (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Molybdenum (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Sodium (mg/L)	Thallium (mg/L)	Vanadium (mg/L)	Zinc (mg/L)	Nitrate (mg/L)	Chloride (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)	TDS (mg/L)	Ammonia (mg/L)	Alkalinity (mg/L)	TOC (mg/L)
DWP-1	T890	26.5	2.90	6.74	2,000	<1	0.006	0.043	0.28	<0.001	3.5	<0.001	0.007	<0.001	0.006	0.012	1.0	100	0.35	0.009	0.055	<0.002	0.007 J	170	<0.002	<0.001	0.01 J	<0.03	211	<0.1	30	1,200	0.5	830	1.4
	T891	20.9	0.88	7.23	1,100	<1	0.004 J	0.033	0.23	<0.001	2	<0.001	0.009	<0.001	0.005 J	0.006	0.79	46	0.32	<0.001	0.022	<0.002	0.007 J	100	<0.002	0.002 J	0.003 J	<0.03	66	<0.1	<0.1	650	4.5	550	2.4
	T892	19	1.24	7.71	540	<1	0.007	0.009 J	0.092	<0.001	0.68	<0.001	0.005 J	<0.001	0.012	0.007	0.32	13	0.16	0.002 J	0.014	<0.002	0.012 J	63	<0.002	<0.001	0.003 J	<0.03	24	<0.1	1.1	330	3.9	250	1.5
DWP-2	T893	23.3	2.77	6.75	1,931	1.13	ND	0.034 J	0.170	ND	3.1	ND	0.013 J	ND	ND	ND	0.84	120	0.16	0.019J	0.036	ND	ND	181	ND	ND	0.025	<0.06	180	<0.06	56	1,200	0.7	804	1.3
	T894	24.4	3.99	6.92	1,139	9.6	ND	0.047 J	0.0172	ND	1.3	0.005 J	ND	ND	ND	ND	0.36	64	0.28	0.027 J	0.024 J	ND	ND	89	ND	ND	0.020	<0.06	100	<0.06	55	700	0.6	400	0.6
	T895	23.4	3.84	6.73	2,002	0.88	ND	0.036 J	0.224	ND	3.6	0.004J	0.0115	ND	ND	ND	0.95	120	0.20	0.007 J	0.041	ND	ND	170	ND	ND	0.020	<0.06	190	<0.06	21	1,200	2.4	870	1.3
DWP-3	T899	26.6	4.65	7.38	1,800	34	0.015	0.067	0.25	<0.001	3.0	<0.001	0.006	0.001 J	<0.001	0.011	0.81	84	0.085	0.023	0.029	<0.002	0.005 J	210	<0.002	0.004 J	0.073	<0.03	100	<0.1	67	1,000	0.6	750	1.1
	T900	23.9	4.98	7.6	1,300	1	0.005 J	0.004 J	0.25	<0.001	1.7	<0.001	0.007	<0.001	0.001 J	0.01	0.68	76	0.054	0.009	0.019	<0.002	0.003 J	100	<0.002	<0.001	0.059	<0.03	91	<0.1	30	750	3.3	550	0.9
	T901	18.2	1.49	9.2	3,000	3	0.012	0.016	0.29	<0.001	13	<0.001	0.017	<0.001	0.15	0.007	0.64	0.62	0.012 J	0.017	0.002 J	<0.002	0.02	730	<0.002	0.094	0.029	<0.03	400	<0.1	95	1,900	8.5	1,100	6.8
DWP-5	T914	36.7	0.86	7.05	4,540	14.1	0.002 J	0.007 J	0.642	<0.001	14.9	<0.001	<0.001	<0.001	0.003 J	0.005 J	1.64	35.5	0.034	0.009	0.007	<0.002	<0.003	1,070	<0.002	<0.001	0.007 J	<0.7	255	<0.7	6.05	2,820	0.7	2,120	5.7
	T915	28.8	0.48	8.11	7,360	1.35	0.002 J	<0.002	0.299	<0.001	24.8	<0.001	<0.001	<0.001	0.007	0.003 J	0.445	5.42	0.011	0.013	<0.001	0.007 J	<0.003	2,020	<0.002	0.007	0.003 J					4,816	16.4	3,084	9.5
DWP-6	T911	42.1	0.67	6.87	10,990	0.79	0.002 J	0.034	0.419	<0.001	36.6	<0.001	<0.001	<0.001	<0.001	0.008	4.83	61.2	0.071	0.004 J	0.007	<0.002	<0.003	2,460	<0.002	0.002 J	0.013	<0.3	2,356	<1.0	59.2	6,490	2.5	2,090	4.2
	T912	33.5	0.49	6.73	6,910	72.9	<0.001	0.003 J	0.987	<0.001	16.8	<0.001	<0.001	<0.001	<0.001	0.005 J	2.35	50.5	0.116	0.022	0.012	<0.002	<0.003	1,530	<0.002	<0.001	0.013	0.21	715	<1.0	12.1	4,208	3.1	2,587	9.1
	T913	21.5	0.06	8.77	28,600	1.52	0.002 J	0.038	0.524	<0.001	203	0.001 J	<0.001	0.001 J	0.008	0.006	1.02	0.857	0.027	0.014	<0.001	0.028	<0.003	9,040	<0.002	0.009	0.002 J	<0.03	4,667	33.6	8.61	20,983	67.2	11,625	22.5
DWP-7	T908	34.5	1.61	7.76	1,486	9.97	0.003 J	0.072	0.182	<0.001	7.59	<0.001	<0.001	<0.001	<0.001	0.005 J	0.219	0.969	0.031	0.047	<0.001	<0.002	<0.003	339	<0.002	0.061	0.004 J	<0.03	32.2	<0.1	52.9	1,007	<0.2	713	1.4
	T909	27.6	0.88	8.78	628	102	<0.001	0.053	0.1	<0.001	1.61	<0.001	0.004 J	0.001 J	0.001 J	0.006	0.056	1.48	0.26	0.011	0.003 J	<0.002	<0.003	140	<0.002	0.008	0.02	0.04	49.9	0.2	31.2	420	1.6	209	1.1
	T910	19.8	1.12	8.2	281	39.6	0.001 J	0.009 J	0.837	<0.001	0.307	<0.001	<0.001	<0.001	0.001 J	0.002 J	0.14	1.31	0.052	<0.001	<0.001	<0.002	<0.003	56.8	<0.002	0.002 J	0.003 J	0.04	5.6	<0.01	9.1	222	1.8	149	0.8
DWP-8	T905	29.3	1.53	8.38	9,950	1	0.009	0.009 J	0.19	<0.001	44	0.001 J	0.014	<0.001	0.01	0.003 J	0.67	1.3	0.007 J	0.08	<0.001	0.004 J	0.012 J	2,500	<0.002	0.062	0.015	<0.03	2,240	1.3	10	5,600	8.1	2,400	4.8
	T906	21.9	1.51	8.57	2,900	<1	0.021	0.5	0.04	<0.001	13	<0.001	0.011	<0.001	0.02	0.002 J	0.69	2.0	0.012 J	0.097	<0.001	<0.002	0.011 J	720	<0.002	0.021	0.005 J	<0.03	429	1.1	100	1,700	1.2	1,100	13
	T907	18.8	1.6	7.96	2,900	1	0.013	0.095	0.024	<0.001	13	<0.001	<0.001	<0.001	0.008	0.002 J	0.39	3.8	0.1	0.11	0.009	<0.002	0.008 J	680	<0.002	<0.001	0.005 J	<0.03	445	<0.1	<1.0	1,700	<0.2	1,000	4.5
DWP-9	T896	21.1		6.37	2,300	17.2	ND	0.012	0.623	ND	3.44	ND	0.002 J	ND	0.012	0.009	1.22	157	0.164	0.004 J	0.055	ND	0.131	203	ND	ND	0.013	<0.03	188	<1	11.3	1,370	5.5	1,031	1.8
	T897	23.9		6.76	1,990	8.86	ND	0.01 J	0.52	ND	3.41	ND	0.002 J	ND	0.02	0.008	1.32	105	0.044	ND	0.027	ND	0.102	225	ND	ND	0.004 J	0.18	142	<1	<1	1,142	15	864	1.9
	T898	22.0		8.46	1,158	2.28	ND	0.012	0.205	ND	1.96	ND	0.011	ND	0.025	0.005 J	0.733	0.386	0.013	0.006	0.002 J	ND	0.106	254	ND	0.015	ND	<0.03	95.8	<1	10	726	4.7	430	2.3
DWP-10	T902	26.2	2.11	6.74	2,400	2	0.006	0.053	0.34	<0.001	4.2	<0.001	<0.001	<0.001	0.002 J	0.011	1.4	140	0.16	0.008	0.049	<0.002	<0.003	220	<0.002	0.002 J	0.007 J	<0.3	220	<0.1	34	1,400	1.1	1100	2.1
	T903	23.2	1.78	6.98	1,800	<1	0.004 J	0.003 J	0.2	<0.001	3.2	<0.001	0.005 J	<0.001	0.004 J	0.013	0.98	82	0.068	<0.001	0.045	<0.002	<0.003	160	<0.002	<0.001	0.003 J	0.3	160	<0.1	<0.1	1,000	1.7	750	1.4
	T904	21.1	2.35	8.07	780	<1	0.005 J	<0.002	0.034	<0.001	1.3	<0.001	0.005 J	<0.001	<0.001	0.005 J	0.34	8.8	0.033	0.002 J	0.003 J	<0.002	0.007 J	140	<0.002	0.006	<0.002	0.3	48	<0.1	1	480	2.4	330	1.4
DWP-11	T916	24.7	1.01	6.57	1,870	0.79	0.0002	0.028	0.21	ND	3.25	0.00002	0.0006	0.0005	0.002	0.00008	0.625	81.9	0.4	0.005	0.006	0.002	0.0006	155	0.0001	0.001	0.004	0.21	169	<1.0	26.1	1,058	0.6	739	1.9
	T917	24.2	1.83	6.64	2,260	1.21	0.0002	0.026	0.26	ND	4.01	0.00006	0.001	0.0008	0.003	0.0002	0.76	104	0.27	0.005	0.007	0.002	0.0003	181	ND	0.0003	0.009	0.23	219	<1.0	19.3	1,266	0.9	903	2.5

Notes:
˚C – degrees Celsius
mg/L – milligrams/liter
uS/cm - microSiemens per centimeter
ND – not detected; below detection limit
NTU - Nephelometric Turbidity Units
J – concentration above method detection limit and below reporting limit

3.4 Evaluation of Geophysical Data

Evaluation of Geophysical Data conducted in Task 9.1 largely followed Task 3, but preceded Task 4. In this task, both seismic and borehole geophysical data were evaluated to refine the study area's hydrostratigraphy and structure. Geophysical data in the study area was identified during the data compilation and evaluation task as having potential to further characterize the study area's hydrostratigraphy and structure. Neponset acquired geophysical data from 1992 through 1997, and data from seismic lines (shown on **Figure 2-2**) was used in conjunction with borehole geophysics from both existing and new OLGEP monitoring wells to refine the hydrostratigaphy and structure of the study area. This work was conducted in two phases, resulting in two TMs as follows:

- TM on the Evaluation of Geophysical Data - Phase I (MWH, 2010c; Appendix Q)
- TM on the Evaluation of Geophysical Data - Phase II (MWH, 2011e; Appendix R)

The purpose of the initial Phase I work was to evaluate the general usefulness and potential methods to incorporate previously-collected seismic geophysical data into the OLGEP for a small segment of the northern portion of the study area. Phase I work demonstrated that the combination of seismic interpretation, borehole lithologic and geophysical data, and surface geologic mapping is a powerful tool for interpretation of the structural geology, depositional history, and hydrostratigrapy of the OLGEP study area, which in turn led to the implementation of full-scale Phase II evaluation for the entire study area (where data existed).

The Phase I TM provides great detail on the concept and background of geophysics, unique nomenclature, a history of the seismic reflection program at Owens Lake, as well as a detailed description of the approach. Key findings from both Phase I and Phase II were instrumental in refining the hydrostratigraphy, depositional history, depth to bedrock, and location of existing faults in the study area. These findings were documented in the two Task 9.1 TM's and subsequently incorporated into the updated Task 4 conceptual model report. Therefore, instead of here, key findings are presented in the next section about the Task 4 updated conceptual model. In addition, the geophysical study was used in combination with lithology to identify the top and bottom elevations of the aquifers for use by the numerical groundwater model.

3.5 Preparation of the Updated Conceptual Model

The focus of Task 4, which involved utilization of the data collected in Tasks 3 and 9.1, was to revise and update the study area conceptual model. This work resulted in the Updated Conceptual Model Report (MWH, 2011f; see Appendix H). The updated conceptual model was based primarily on the following:

- Newly-acquired data from the OLGEP Task 3 drilling and monitoring well installation program conducted in 2010 - 2011
- Detailed interpretation of surface seismic data evaluated under Task 9.1, used in conjunction with new drilling data
- Results and lessons learned from development of a groundwater model in the northern portion of the study area commonly called the “Southern Model” (MWH, 2011b)
- Detailed review and re-analysis of the water budget for the OLGEP study area

- Detailed review of available data on springs and seeps for the purposes of characterizing the nature and source of spring flow

The new data, combined with re-analysis of existing data dramatically improved the hydrogeologic conceptual model for the OLGEP study area by better defining the hydrostratigraphy, updating the location of key faults, improving estimates on the location and amounts of groundwater recharge, characterizing the interaction between groundwater and surface water, and evaluating sensitive resources such as springs, seeps, local wells. This much-improved conceptual model led to improved numerical modeling in subsequent tasks.

The Updated Conceptual Model Report (MWH, 2011f; Appendix H) supplemented information presented in the preliminary conceptual model and summarized the significance of new information and resulting changes to the preliminary conceptual model. Key findings of the revised conceptual model are provided in the following subsections by topic:

- Stratigraphy
- Depositional Environment
- Structural Geology
- Depth to Bedrock
- Variation of Groundwater Head at Depth
- Aquifer Parameters
- Groundwater Budget
- Effects of the LORP and DCMS on the Study Area Water Budget
- Surface Water/Groundwater Interaction
- Groundwater Quality
- Characterization of Springs
- Water Level and Flowing Well Evaluation

3.5.1 Stratigraphy

Previous work identified four deep confined aquifers in the study area comprised of sands and silty sands, separated by low permeability clay units of variable thickness. Detailed analysis of surface seismic data, used in conjunction with borehole geophysical data allowed for the delineation of 10 separate stratigraphic sequences that were traced over most of the OLGEP study area. The field investigation and geophysical evaluation were successful in filling critical stratigraphic data gaps as follows:

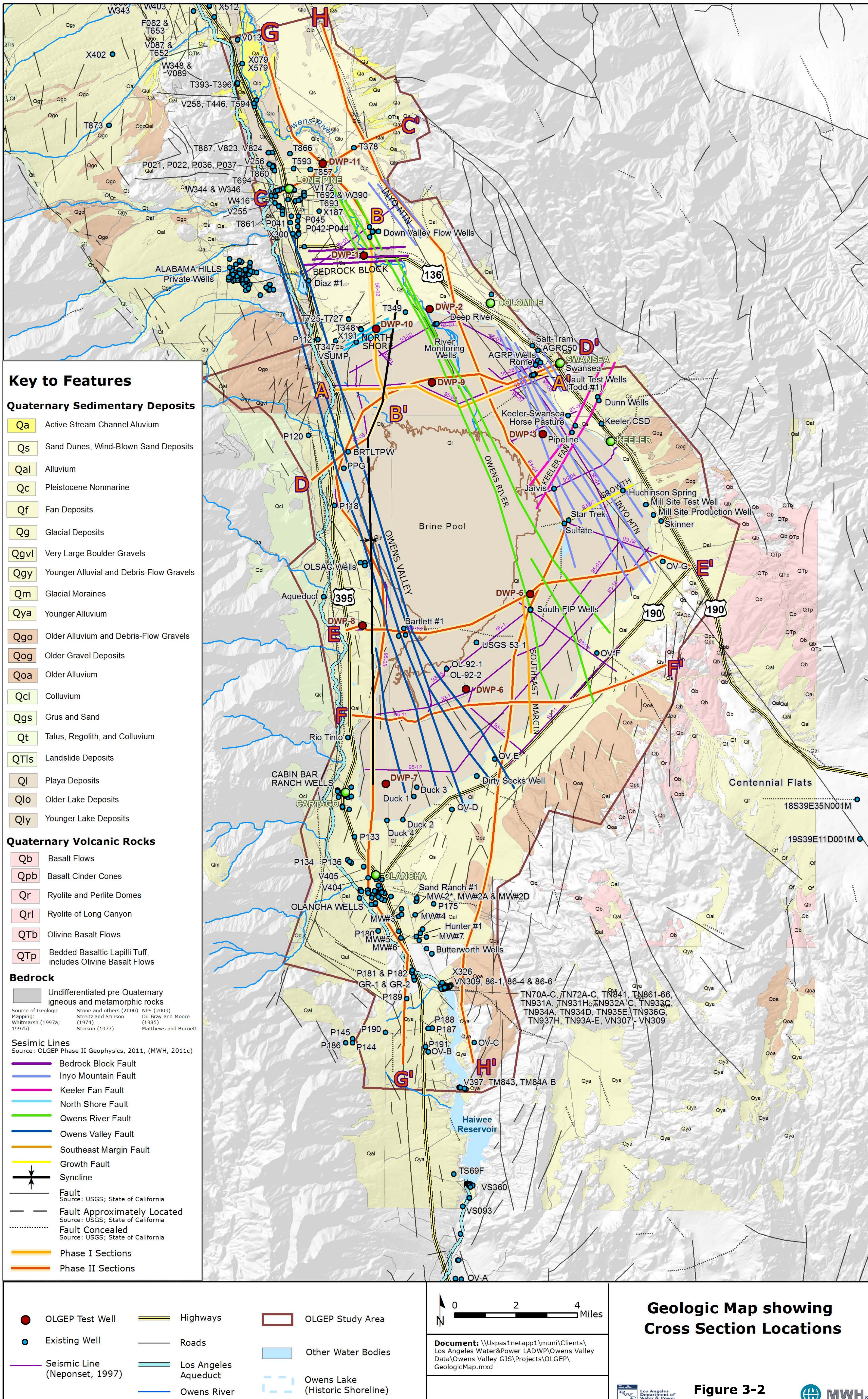
- **Elevation of Top and Bottom of Each Confined Aquifer**. Prior to the OLGEP study, the complex stratigraphy of the deep aquifers made correlation of lithologic and geophysical logs challenging, and sometimes inconsistent with the surface geophysical interpretations. The results of the geophysical evaluation in combination with results of the updated conceptual model work identified the tops and bottoms of each aquifer unit, which in turn facilitated generation of three-dimensional surfaces of each unit throughout much of the study area.

- **Previously-Unidentified Deep Confined Aquifer Below Aquifer 4**. The ten new OLGEP monitoring wells (locations shown on **Figure 2-2**) were drilled to maximum depths of 1,600 feet, whereas previous borehole information was generally limited to less than 1,000 feet. This deeper drilling allowed for identification of a previously unidentified deep confined aquifer (generally deeper than 1,000 feet) that is interpreted to represent flood plain deposits deposited prior to the existence of Owens Lake.
- **Aquifer Characteristics**. The hydrogeologic framework of the study area has evolved with the progression of previous work. This framework was re-interpreted based upon new data from drilling coupled with interpretation of the seismic data.

Eight cross sections were developed as part of the geophysical study to display the interpreted stratigraphy of the groundwater basin. These cross section locations are shown on **Figure 3-2**, atop a geologic map for the study area. There are two sets of cross sections that differ in appearance, whereby cross sections A-A' and B-B' are a direct export from seismic workstation software prepared under Phase I of the geophysics study (see Appendix H). Cross sections C-C' through H-H' were created by transferring the sequence boundaries (elevations) into Groundwater Modeling System (GMS) software to create a solids model. These GMS-generated sections are presented as **Figures 3-3** to **3-8** (Cross Sections C-C' through H–H') to illustrate the nature and extent of the aquifer units in the study area.

Five aquifer units are named from shallowest to deepest as Aquifers 1 though 5. The designation as aquifers is somewhat misleading, because although the stratigraphic sequences correspond to aquifers and aquitards in the delta area, the shallower stratigraphic sequences transition from permeable materials to clay near the center of the lake, and are thus inappropriate to refer to as “aquifers”. This potential for confusion notwithstanding, the designation as aquifers was retained to follow the precedent of previous studies. The following observations can be made regarding the individual aquifers:

- **Aquifer 1** is the shallowest aquifer, characterized by a lithology of relatively well-sorted coarse sands and gravels in the Owens River delta area. Overall, the resistivity observed in this aquifer is characteristically very high, suggesting an absence of clay or silt material and a subaerial depositional environment. However, beneath the lake, this stratigraphic sequence transitions to lacustrine clays.
- **Aquifer 2** consists of relatively coarse material in the delta, but tends to have declining resistivity (higher percentage of fine material) with depth. The sequence transitions to lacustrine clays in the southern part of the lake in a pattern similar to Aquifer 1.
- **Aquifers 3 and 4** also consist of relatively coarse material in the delta, but tend to have declining resistivity (higher percentage of fine material) with depth. Again, beneath the lake, these stratigraphic sequences contain increasing amounts of fine material.
- **Aquifer 5** is a stratigraphic sequence that has a characteristic geophysical and lithologic signature. It is composed of silty sand with interbedded sands and occasional clay. The resistivity of this aquifer is relatively uniform. This aquifer is interpreted to be the result of a flood plain or braided stream depositional environment, deposited before the formation of Owens Lake. The bottom of Aquifer 5 is deeper than 1,500 feet over most of the area, except in the eastern portion of the Basin, where it is underlain by bedrock at relatively shallow depths.



Geologic Map showing Cross Section Locations

Figure 3-2

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

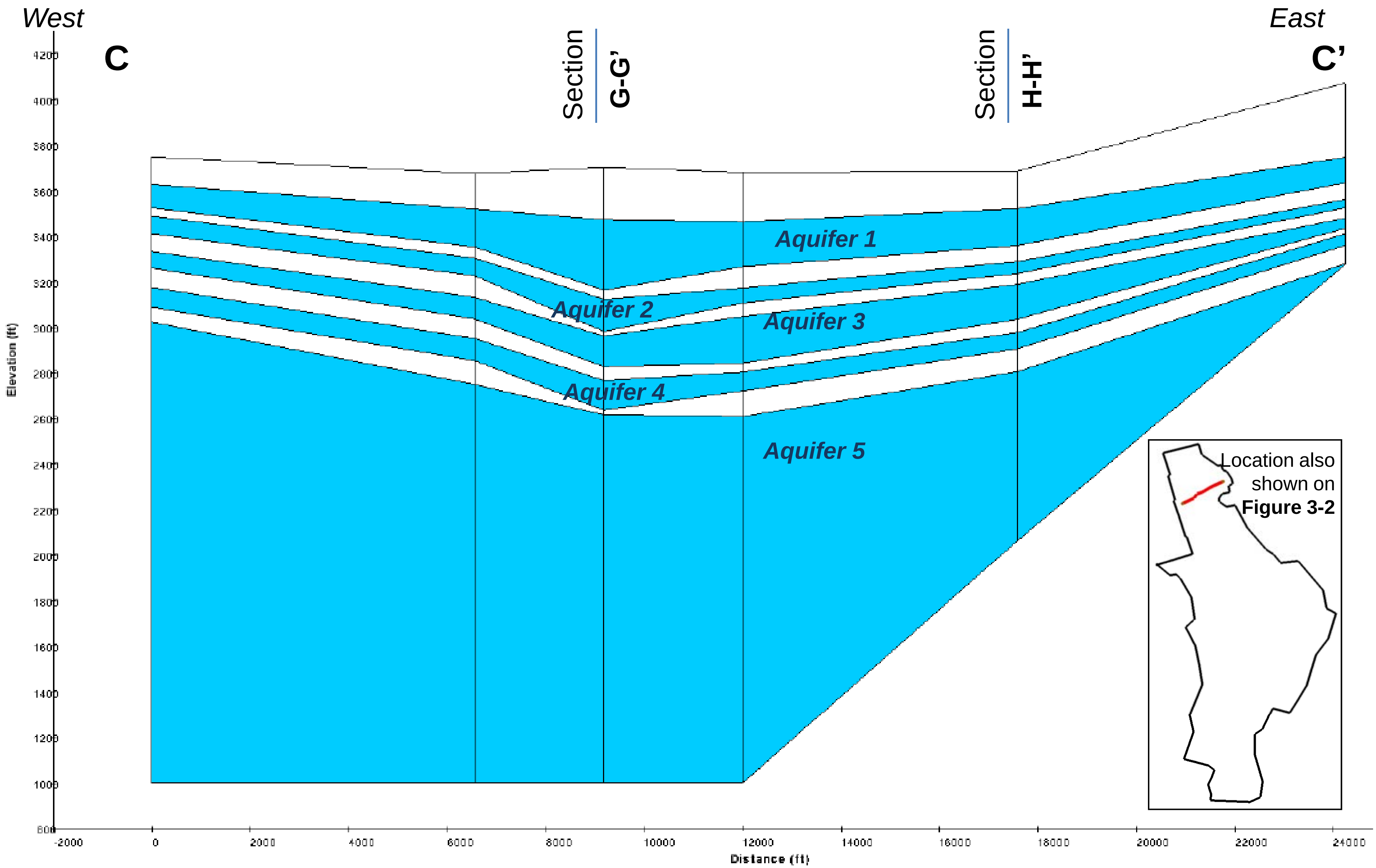


Figure 3-3
Cross Section C-C'

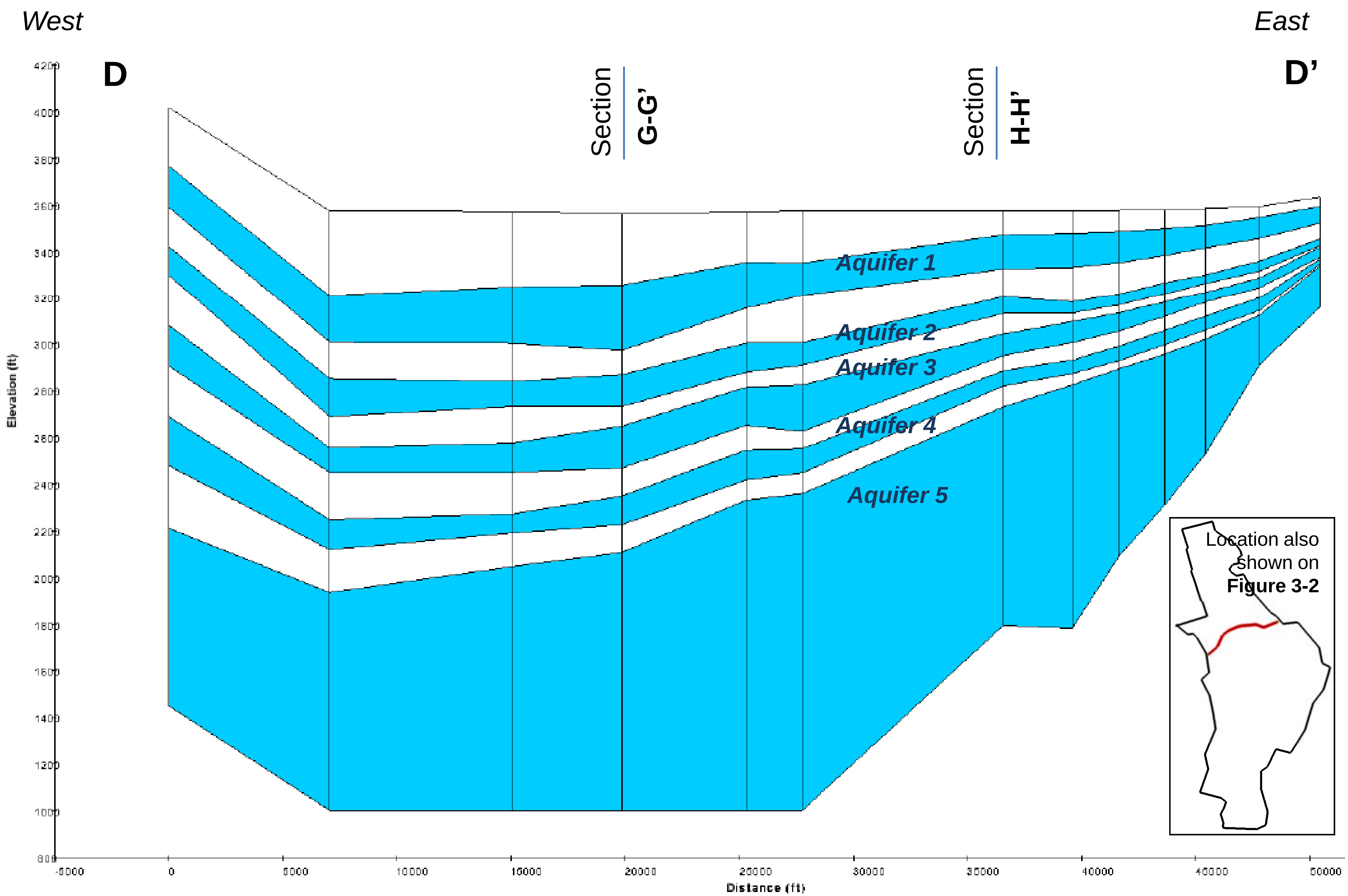


Figure 3-4
Cross Section D-D'

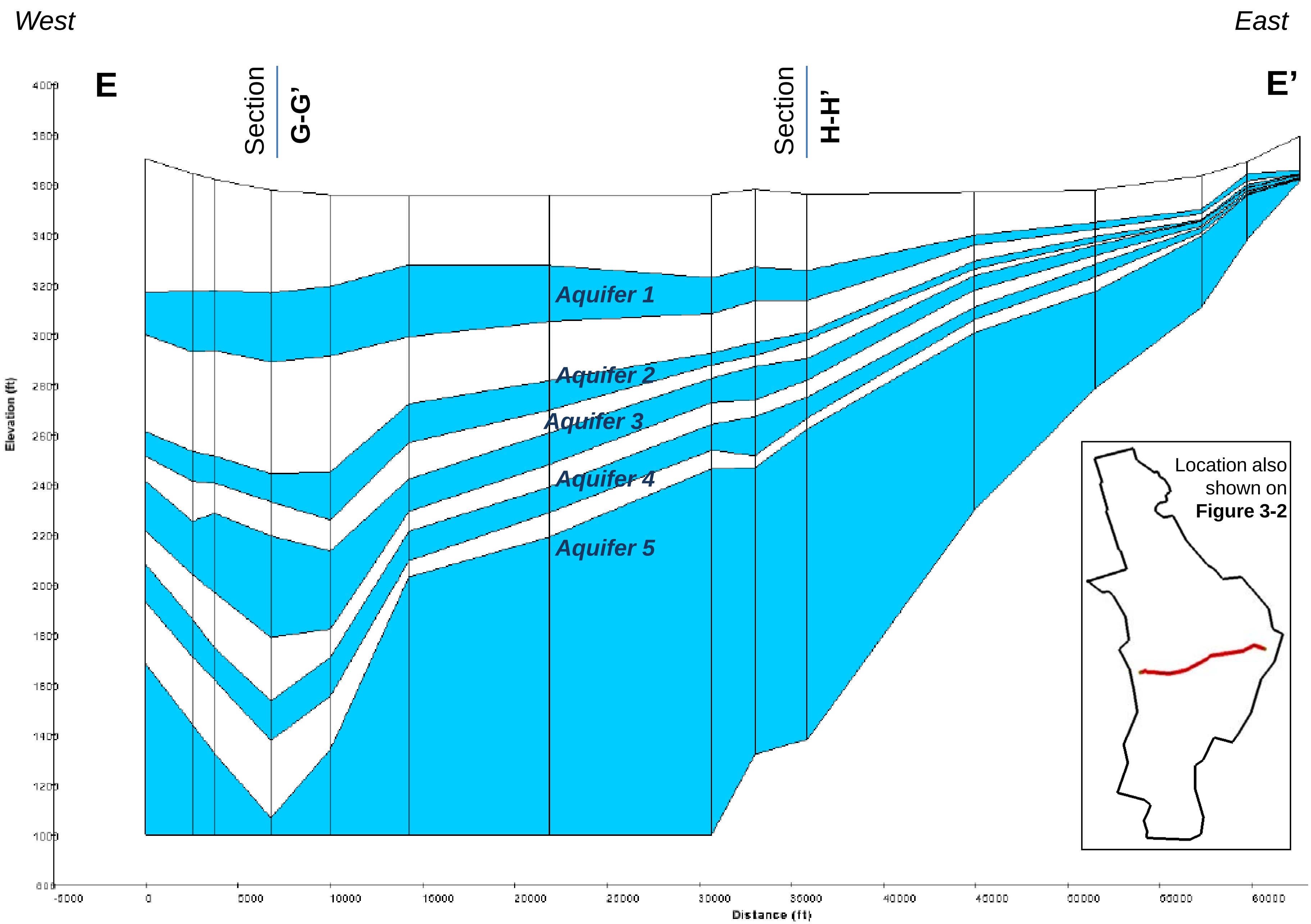


Figure 3-5
Cross Section E-E’

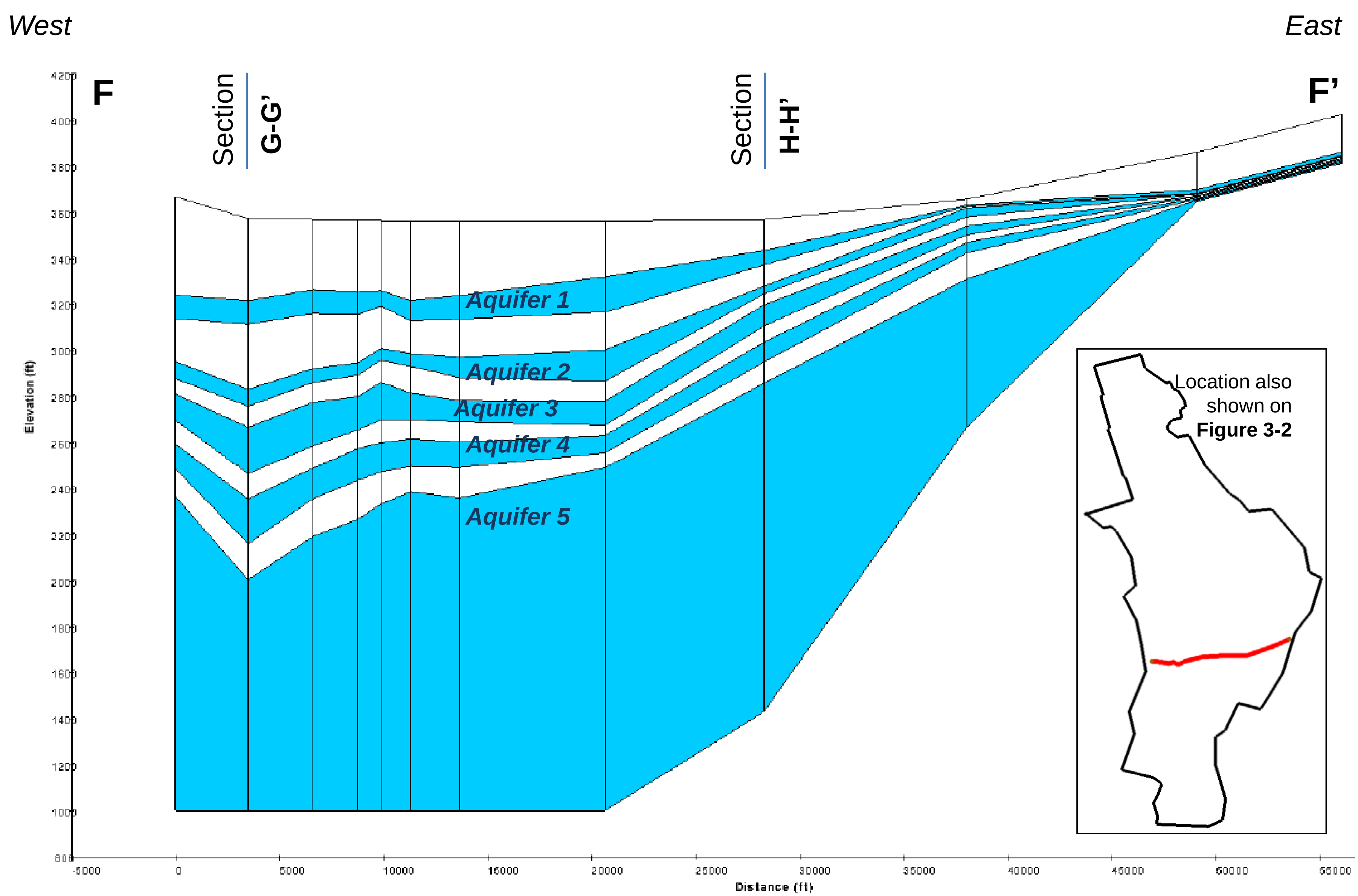


Figure 3-6
Cross Section F-F'

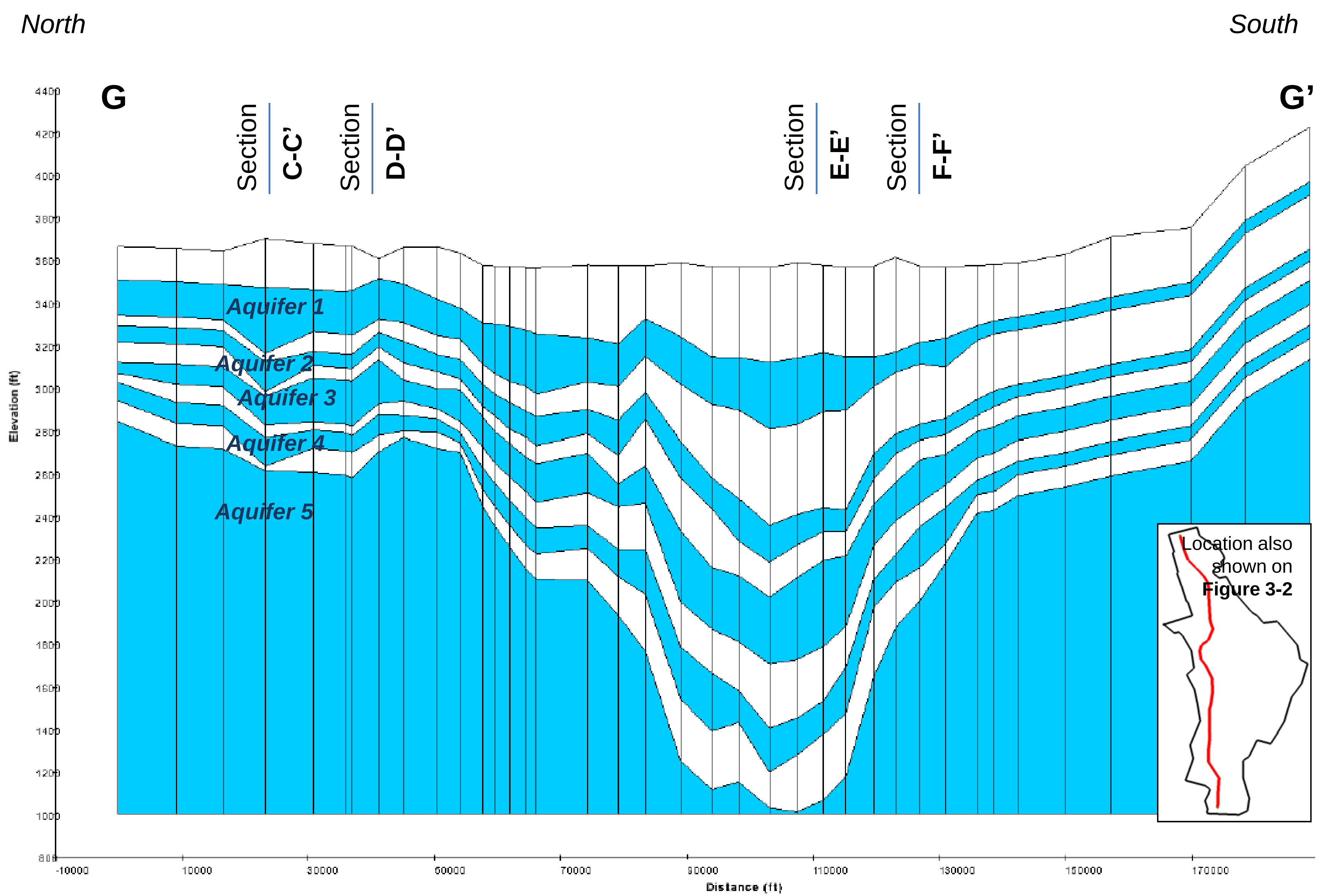


Figure 3-7
Cross Section G–G'

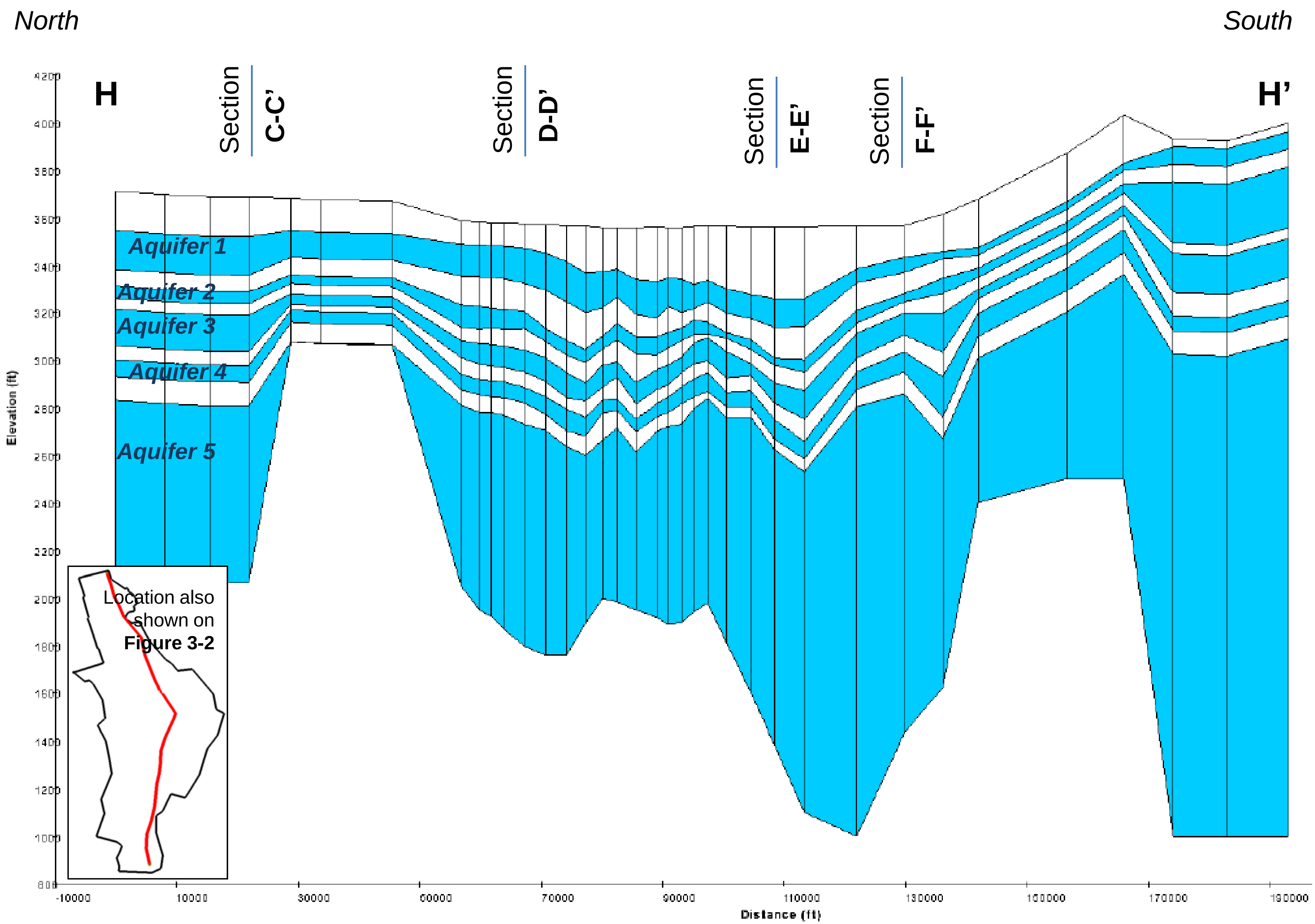


Figure 3-8
Cross Section H-H'

Three-dimensional surfaces for these sequences were developed that directly applied to the numerical model layering used in the groundwater model.

3.5.2 Depositional Environment

Comparison of the stratigraphic sequences to lithologic logging allowed for identification of several transgressive and regressive events that occurred during the infilling of the Owens Lake Basin. The geophysical and lithologic data in the delta area provided evidence of a pre-lake period of deposition of flood plain or braided stream deposits, then the first evidence of the lake being formed, followed by at least four regressive events where lake levels dropped (separated by transgressive events). **Figure 3-9** illustrates the depositional sequence at DWP-9 (location shown on **Figure 3-2**), showing correlation between lithologic observations, resistivity, and interpreted depositional environment. This pattern is remarkably recognizable in many of the boreholes in the study area.

In addition, significant thinning of sedimentary features was identified where lakebed sediments lapped up against bedrock during deposition. A deep synclinal feature was identified in the western portion of the Basin that was the center of deposition of the ancestral Owens Lake.

By combining the well data and seismic data, it was possible to draw insights into the depositional character of the aquifers. It was found that the sequence boundaries tend to correlate with the top or near the top of aquifers, in locations where aquifers were found to exist. In addition, surfaces were also identified that tend to correlate with the base of the aquifers, where aquifers exist.

3.5.3 Structural Geology

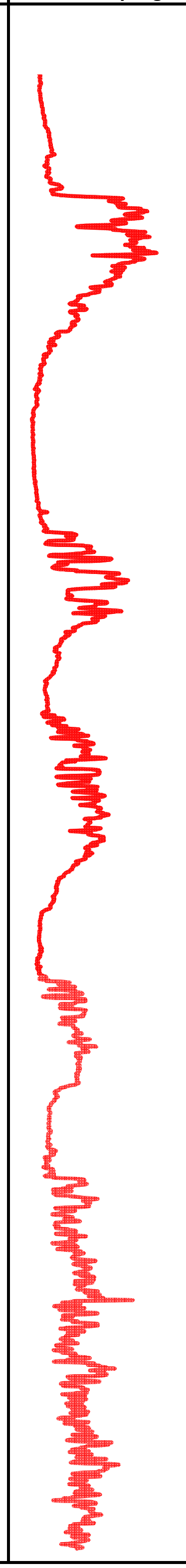
Using the seismic data, a number of fault zones were mapped in the study area in planar and cross-sectional view. The faults are generally high angle with displacement spread across multiple fault strands rather than a single fault plane. This is typical of faulting in strike-slip structural styles. The three largest fault zones are the Owens Valley Fault, Owens River Fault, and the Inyo Mountain Front Fault. These faults are roughly parallel and trend north-northwest to south-southeast. Other faults have strikes intersecting these three large fault zones. Evidence of sufficient vertical offset to juxtapose aquifers and aquitards was found. The most significant faults or fault zones are listed in **Table 3-5** and shown in **Figure 3-2**.

This new knowledge on the location and approximate displacement allowed for more accurate modeling of groundwater flow as well as accounting for fault-related impacts in the calibration process. In turn, there was significant improvement over previous modeling efforts, which did not incorporate the effect of faulting.

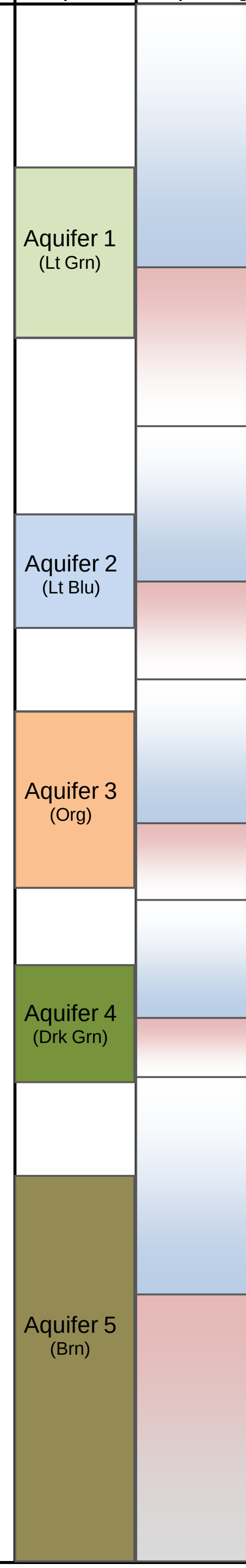
Figure 3-9
Lithology, Resistivity and Interpreted Depositional Environment for DWP-9 (T896)

Depth (ft)	Typical Lithology Interpretation	Interpreted Depositional Environment
25	Silty sand	
50		
75	Grey clay	Deeper lacustrine
100		
125	Silty clay, spongy texture, roots	Delta
150		
175		
200	Black clay with organic odor	Delta
225	Silty sand with gastropod shell fragments	Nearshore lacustrine
250		
275		
300	Sand and gravel	
325	Very well sorted sand	Nearshore beach deposits or dunes
350		
375	Sand with plant fragments	Delta
400	Silty sand with oolites	Nearshore beach deposits
425		
450		
475	Grey silty clay	Deeper lacustrine
500		
525		
550		
575		
600		
625		
650	Silty sand with clay -decayed organic matter	Delta
675		
700		
725	Grey silty clay	Deeper lacustrine
750		
775		
800		
825		
850	Silty sand with gravel	Delta deposits
875		
900		
925	Grey silty sand	Nearshore lacustrine
950		
975		
1000	Grey clay	Deeper lacustrine
1025		
1050		
1075	Sand with traces of plant fragments	Delta deposits
1100		
1125		
1150		
1175	Grey silty clay	Lacustrine
1200		
1225		
1250		
1275		
1300		
1325		Delta/nearshore lacustrine
1350	Silty sand	Braided stream
1375		
1400		
1425	Silty sand with trace of gravel	Braided stream
1450		
1475		
1500		
1525		
1550	Silty sand	Braided stream
1575		

Resistivity Log



Aquifer / Graphic Log



No lake – prior to lake development

Transgressive sequence – lake levels rising, sediments fining upwards

Regressive sequence – lake levels dropping – sediments coarsening upwards

Table 3-5
Summary of Fault Zones

Fault	Description
Owens Valley	Located along the western shoreline of the lakebed.
Owens River	Located along the Owens River, interpreted to transect the lakebed to the southeast shore.
Inyo Mtn Front	Series of faults that roughly parallel the northeastern shore of the lakebed.
Keeler Fan	A northeast/southwest trending fault that appears to originate on the Keeler Fan.
Bedrock Block	East-west oriented faults that appear to originate from bedrock. Interpreted to cause the Owens River Fault to be right-lateral offset (toward the east).
North Shore	East-west oriented fault zone that roughly parallels the northern shore.
Southeast Margin	Faults identified on the seismic lines in the southeast seismic lines. Orientation is unknown because correlation between lines is difficult to establish.
Growth	Growth faults appear to be caused by differential compaction of the underlying sediment pile. Do not appear to originate from bedrock.

Note - The Updated Conceptual Model Report (Appendix H) provides a more detailed description of each fault.

3.5.4 Depth to Bedrock

Characterization of the bedrock boundary and basin geometry was improved by evaluation of seismic and drilling data as illustrated in **Figure 3-10**. Relatively shallow bedrock was found underlying the east side of the Basin, and this bedrock surface was not identified in previous work. Bedrock was not identified on the southwestern and western margin. On the northeast and southeast margins, the Basin is terminated structurally by bedrock highs causing thinning or pinching-out of the mapped sequences. On the west, the sequences coarsen and lacustrine deposits are absent. Bedrock depth on the west side of the Basin can neither be resolved based on the seismic data nor have any boreholes encountered bedrock in this area.

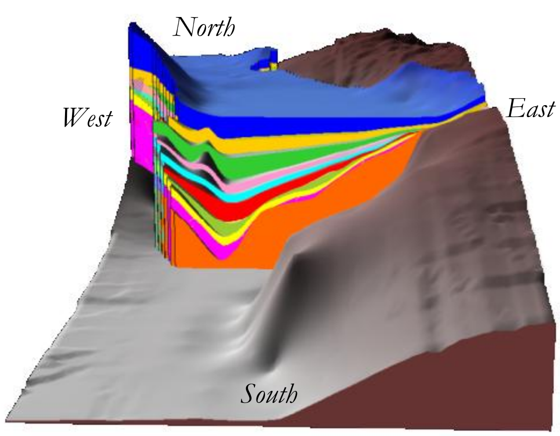


Figure 3-10
Conceptualization of Basin Geometry and Bedrock Boundary
(*view north along eastern margin of the Basin*)

3.5.5 Variation of Groundwater Head at Depth

The installation of zone-specific screened intervals in new monitoring wells allowed for detailed evaluation of vertical gradients throughout most of the study area. This data facilitated calibration of the numerical model to more closely simulate actual conditions.

Static water levels recorded at the time of testing indicate the presence of strong artesian conditions coupled with upward vertical gradients. Strong artesian conditions were found at DWP-2, -3, -5, -6, -7, -9, and -10 as shown on **Figure 3-11**. Artesian heads of up to nearly 60 feet above ground surface were observed. The strongest artesian conditions were observed at DWP-9 located in the north central portion of the Owens Lake. The highest heads are observed in Aquifers 1, 3, and 5.

In addition, contours of equal head at discrete stratigraphic intervals with depth allowed for characterization of flow directions in deeper zones. Of particular significance are deeper water level measurements between DWP-7 and DWP-6, located in the southern portion of the lake. At this location, a northwesterly gradient is observed. This is significant because it fills one of the major data gaps identified in previous work, whereby Johnson and others (1999) suggested that the Basin is not closed and deep outflow south through Haiwee Reservoir is possible. This new deep drilling data confirmed that the Basin is a closed basin with no outflow from the Basin to the south, even in deeper sediments.

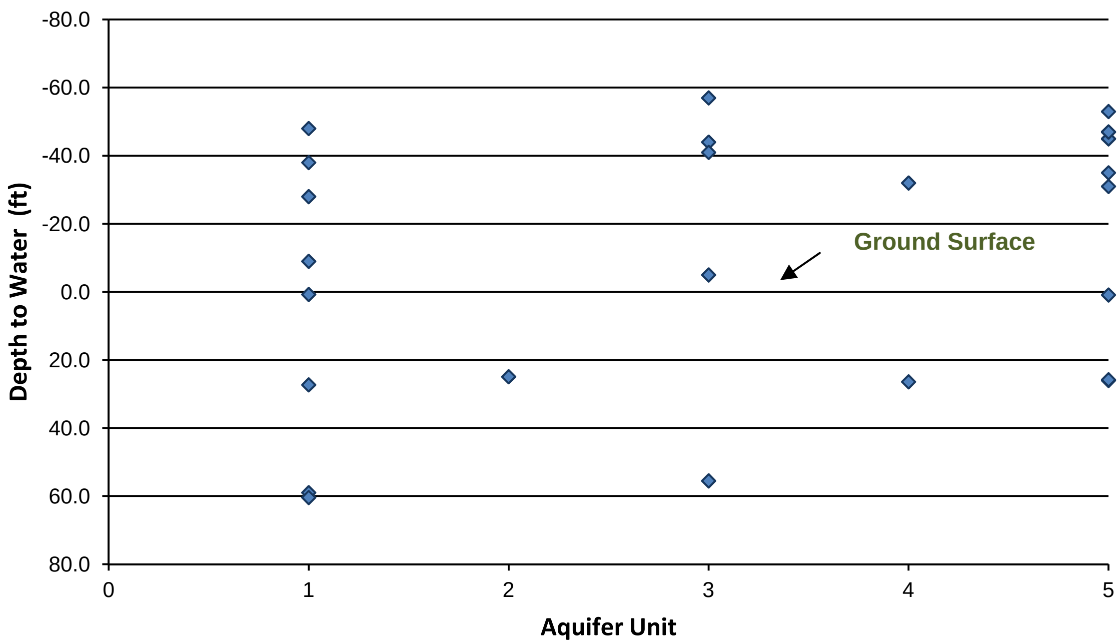


Figure 3-11
Distribution of Hydraulic Head by Aquifer Unit

3.5.6 Aquifer Parameters

Pump testing at each of the new OLGEP monitoring wells allowed for estimation of transmissivity (T) and hydraulic conductivity (K) in discrete aquifer zones as summarized in **Table 3-3**. **Table 3-6** shows the maximum, minimum, average, and median values of T and K using the different analysis methods. In general, the distribution of T and K estimated from the new OLGEP monitoring wells by aquifer unit shows a decreasing trend with depth. The decrease in T and K with depth is consistent with the understanding that compaction and aquifer induration increases with depth.

Table 3-6
Summary of Transmissivity and Hydraulic Conductivity Estimates for OLGEP Monitoring Wells

	Jacob Straight-Line Method		Theis Recovery Method	
	T (ft^2/day)	K (ft/day)	T (ft^2/day)	K (ft/day)
Maximum	70,703	1,767	18,353	306
Minimum	244	5	111	3
Average	8,365	191	5,240	88
Median	4,523	92	3,037	76

3.5.7 Groundwater Budget

Re-analysis of the groundwater budget for the OLGEP study area, in combination with new drilling data suggests that the overall inflow and outflow for the Basin is in the range of 45,000 to 67,500 acre-feet per year (AF/yr). The total inflow/outflow is similar to what was estimated in previous studies; however, new data and re-interpretation of existing data served to refine the locations of recharge and discharge that was particularly useful for development of the groundwater model. **Table 3-7** provides a summary of the recommended range for recharge estimates that was used during construction of the groundwater model.

Table 3-7
Summary of Recharge Estimates

Inflows – AF/yr	
Component	**Recommended Range**
Down-Valley Flow	12,500 - 14,500
Stream Channel Recharge	29,500 - 40,000
Inyo/Coso Range	*5,500*
Sierra Nevada Range (Lone Pine - Lubkin)	*15,750*
Sierra Nevada Range (Carroll to Walker)	*8,000 - 18,500*
Interfluve/Fan Recharge	0-2,000
Haiwee Reservoir Subsurface Inflow	2,000-10,000
Centennial Flats Subsurface Inflow	0 - 1,000
Mountain Block Recharge	0
Total	**44,000-67,500**

Specific attributes of the updated conceptual model groundwater budget are summarized briefly herein.

- Because Owens Lake is a closed basin, there are only two methods by which either groundwater or surface water is believed to leave the Basin: (1) evapotranspiration (ET) or (2) export. Thus, estimation of total export and ET provided a method to “bracket” total estimated surface and groundwater inflows. This approach differed from traditional groundwater budget estimations (and previous work) in which there were attempts to tally outflows from individual wells, springs, and other outflow sources.
- The water budget is an accounting of groundwater recharge (inflow) as it moves into the OLGEP study area and outflows (both groundwater and surface water). The water budget was developed as an long-term average condition without reference to a particular year, as an approximation of 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.
- The purpose of the groundwater budget accounting was to provide guidance and reasonable limits to the groundwater modeling effort. The general strategy was to begin with latest published calibrated groundwater budget developed by CDM (CDM, 2000). Those components that could be improved significantly using either new data that was not previously available to others, or by using what might be regarded as an improved estimation approach were identified.

The following components of the groundwater budget were updated as described briefly herein. The reader is referred to the Updated Conceptual Model Report (Appendix H; MWH, 2011f) for a detailed description of these components.

- **Down-Valley Flow** - Groundwater from the greater Owens Valley to the north of the OLGEP study area flows southward toward Owens Lake, and is termed “down-valley flow”. Down-valley flow is one of the most significant components of the groundwater budget, and historically has had a relatively high uncertainty. This uncertainty was reduced by numerical groundwater modeling work to the north as part of the MWH/LADWP Southern Model (MWH, 2011b), along with the installation of several new wells north of the Owens Lake delta area, which allowed for improved groundwater gradient calculations and evaluation of aquifer transmissivity in this area. The recommended range for the groundwater model was approximately 12,382 - 14,400 AF/yr. These values are higher than the calibrated value used by CDM; however, it is recognized that these estimates include all down-valley flow in the unconsolidated materials (down to bedrock or approximately 8,000 feet), rather than just flow in sediments above 1,000 feet as estimated by CDM.
- **Stream Channel Recharge** - Stream channels are present on alluvial fans surrounding the Owens Lake study area, and the resultant infiltration of water from these streams provides a significant source of groundwater recharge to the study area. Typically,

stream channel recharge is quantified by utilizing accurate gauging data between two points to determine streamflow losses and then developing loss rates for given stream reaches. However, existing data was insufficient to determine the streamflow losses necessary to develop a stream-specific loss rate for each of the creeks flowing into the study area. Given that steam channel losses could not be estimated from gauging data, a variety of other methods were used, including:

- Estimates Based on Previous Modeling Efforts. Estimates based upon numerical modeling utilizing the MWH/LADWP Southern Model (MWH, 2011b) were used for stream recharge occurring in Lone Pine, Tuttle, Diaz, and Lubkin Creeks.
- Estimates Based on Cabin Bar Ranch Water Supply Study. Estimates based upon the approach utilized in the Cabin Bar Ranch studies (James M. Montgomery Engineers, 1990) were developed for Carroll Creek south to Walker Creek. In this method, appropriate runoff coefficients and loss factors were calculated for the Sierra Nevada streams that enabled runoff to be calculated as a function of watershed area and stream losses as a percent of runoff.
- Crippen Method. Estimates based upon the approach developed by Crippen (1965) was used for Inyo/Coso streams along the east side of the study area.
- Estimates Based on Typical Loss Rates. Estimates based on the use of typical loss rates for other gauged streams in the Owens Valley were used. These estimates were applied to Eastern Sierra streams in the study area for comparative purposes.

Table 3-8 summarizes the stream recharge estimates using the techniques described above. Total stream recharge for the OLGEP study area is estimated at 33,329 AF/yr, with a reasonable range of 29,451 to 40,003 AF/yr.

Table 3-8
Summary of Stream Recharge

Location	Streams	Method	Recharge (AF/yr)
E. Sierra	Lone Pine Tuttle Diaz Lubkin	Southern Model	15,756
	Carroll Creek Cottonwood Creek Ash Creek Braley Creek Cartago Creek Olancha Creek Walker Creek	Cabin Bar Ranch	8,136 to 18,688 (Recommended = 12,014)
Inyo/Coso Range	East Side Streams	Crippen	5,559
		Recommended Range	29,451 - 40,003
		Total	33,329

- **Interfluve/Fan Recharge** - Interfluve/fan recharge is surface recharge as a result of deep percolation of precipitation that falls on the land surface outside of defined channels. Precipitation that infiltrates the soil and is not consumed by ET can infiltrate to the alluvial fan surface. Initially, the total interfluve/fan area for the OLGEP area was calculated. Next, MWH used three techniques to estimate the range of interfluve/fan recharge between 0 - 1,910 AF/yr.

- Danskin - Danskin (1988) estimated interfluve/fan recharge to be about 0.1 inches/year. MWH applied this rate and calculated interfluve/fan recharge in the amount of 1,910 AF/yr. .
- Crippen - Using Crippen (1965), MWH estimated interfluve/fan recharge of about 15 AF/yr.
- EDYS - Using EDYS [the Ecological Dynamics Simulation Model developed for the Southern Model area (MWH, 2011b], which is a general ecosystem simulation model), MWH found interfluve/fan recharge to be negligible.

- **Haiwee Subsurface Inflow** - The southern boundary of the study area is defined by the topographic divide separating North and South Haiwee Reservoir. Danskin (1988) assumed that seepage from the reservoir had created a groundwater divide at the south end of the study area. No new additional data were available to refine previous estimates for this inflow component; however, MWH applied Darcy's Law to evaluate the potential range of values. The estimated range using reasonable estimates of gradient and hydraulic conductivity was 2,000 to 10,000 AF/yr
- **Centennial Flats Subsurface Inflow** - Centennial Flats is a basin located to the southeast of the study area (**Figure 3-2**), where previous investigators believe subsurface flow enters the Basin. MWH's evaluation of this inflow component included a review of geologic mapping and well logs that were not available to previous workers. Analysis of this data suggested that subsurface inflow from Centennial Flat may be negligible. A recommended range for the groundwater model was 0 - 1,095 AF/yr (whereby 1,095 AF/yr is the number used by CDM).
- **Mountain Block Recharge** - Mountain block recharge is conceptualized as deep percolating groundwater from fractures in the bedrock surrounding the Basin that discharges to the valley-fill deposits in the subsurface. For the purposes of the updated conceptual model, mountain block recharge was considered negligible.
- **Evapotranspiration/Consumptive Use Zones** - For the purpose of estimating total outflows (excluding export) out of the OLGEP study area, the approach utilized included division of the study area into different “consumptive use” zones based on ET. The footprint of the study area was divided into three major consumptive use zones, with further subsets based upon vegetative cover and depth to water: brine pool, dry lake bed, and areas occurring at elevations above the historic shoreline of Owens Lake. Based upon the delineation of consumptive use zones and associated ET rates, total consumptive use for the study area was estimated at approximately 66,419 AF/yr.
- **Export** - A number of production wells are located in the study area for the purpose of water supply. However, of these wells, the only ones that export groundwater out of the Basin and groundwater system are those operated by Crystal Geyser Roxane. Annual production at the Olancha water bottling facility is between approximately 275 and 325 AF/yr.

  In addition, surface water from four Eastern Sierra streams (Carroll, Cottonwood, Ash, and Braley Creeks) is diverted into the LAA and exported out of the OLGEP study area to Los Angeles. Based upon gauged data, an average of 17,791 AF/yr of water is diverted into the LAA for export to Los Angeles.

- **Owens River** - Surface water from the Owens River flows onto Owens Lake at a historical average rate of 15,000 AF/yr. This surface water flow is believed to provide negligible recharge to the groundwater system because the river is a gaining reach north of the lake. Once this water enters the area within the historic shoreline, thick lacustrine clays isolate this water from the groundwater system. This water then leaves the Basin through ET.

All groundwater in the Owens Lake Basin was assumed to ultimately discharge to the surface, primarily in the form of springs, seeps, or artesian flow near the lake and leave the Basin through ET. The estimated total ET and groundwater export was 66,400 AF/yr plus 300 AF/yr, respectively, or approximately 67,000 AF/yr in total. This total discharge approximates the estimated groundwater recharge summarized in **Table 3-7**. The surface water exports from the LAA were not be considered in this analysis because the water never enters the groundwater system.

By adding the total evapotranspiration estimate (66,400 AF/yr) and Crystal Geyser Roxane groundwater export (300 AF/yr), and then subtracting the Owens River inflow (15,000 AF/yr) amounts to 51,700 AF/yr, which falls about mid-way between the groundwater recharge estimate of 44,000 - 67,500 AF/yr. This balanced well with groundwater recharge estimate of 44,000 to 67,500 AF/yr and completed the quasi-steady-state water budget for the study area.

3.5.8 Effects of the Lower Owens River Project and Dust Control Measures on the Area Water Budget

MWH evaluated the effect of DCMs and LORP on groundwater, wells, and piezometers in the study area. Detailed analysis of hydrographs for pre- and post LORP and DCM time periods indicated that both of these projects have negligible effects on groundwater in storage or flow patterns in the study area. The ultimate fate of large quantities of water used on the DCM projects is either evaporation in place or subsequent evaporation in the brine pool. LORP may be increasing the degree of fresh water mounding in the sandy shallow delta aquifer to a small extent. However, the change in gradient is minimal, and there does not appear to be a significant change in gradient when looking at pre- and post-LORP conditions. Water passing through the LORP can be accounted for in two ways:

- Water sent to the delta and/or brine pool is isolated from the deeper groundwater body by lakebed clays, and eventually is consumed by evaporation or transpiration by plants
- Water is re-captured for other uses (i.e., sent to LAA or applied to DCMs)

Although some of the lower reaches of LORP were dry before the project began, groundwater was at or near the surface, indicating that water from the LORP could not substantially change the groundwater regime. This led to the conclusion that the majority of surface water added to the LORP has no significant effect on groundwater storage or flow patterns in deeper aquifers.

3.5.9 Surface Water/Groundwater Interaction

Based upon a review of the stratigraphy and groundwater flow patterns, there is evidence that the surface water on Owens Lake is hydraulically disconnected from groundwater underlying the lake. This is the primary reason why the LORP and DCM projects have little effect on the deep groundwater system. In the case of the LORP, the Lower Owens River was a gaining reach prior to the initiation of the LORP project, thereby prohibiting infiltration of added surface water during the LORP project. In the case of DCMs, the presence of thick sequences of impermeable clays underlying the DCMs effectively isolate them from the main groundwater body.

3.5.10 Groundwater Quality

Analysis of groundwater samples from new monitoring wells completed at a variety of depths allowed for evaluation of the 3-dimensional configuration of salinity and other specific constituents under the lake bed. Both salinity and arsenic concentrations decrease with depth and tend to be higher under the eastern portion of the lake where sediments have been exposed to evaporation.

3.5.11 Characterization of Springs

A detailed comparison of spring flow to precipitation and runoff; classification of each spring's physical characteristics; evaluation of spring locations relative to structural and depositional features; and characterization of spring water quality was conducted. The purpose of this effort was to define the source water for each spring as either "shallow" or "deep" groundwater. As a result, this review allowed for a preliminary identification of the source groundwater by spring. However, it was subsequently determined that the monitoring point for springs is commonly located at some distance from the spring discharge area, thereby impeding efforts to draw conclusions on spring sourcing. Conclusions relative to the source of spring flow were utilized with caution because in many cases, the distance between the spring source and the point at which various water quality parameters were collected is not known.

3.5.12 Water Level and Flowing Well Evaluation

An analysis was conducted to utilize the most recent groundwater monitoring data available and to evaluate the seasonality of groundwater levels and artesian flow in the Owens Lake area. The purpose of the analysis was to fit this most recent data with the conceptual model for the study area and to integrate findings into the groundwater model. Specifically, the following evaluation and analyses were conducted to help identify the influence of external parameters, such as pumping and precipitation, on groundwater elevations within the OLGEP aquifers:

1. Statistical analyses were performed on water level data.
2. Hydrographs were constructed using recent water levels measurement for study area wells.
3. Water levels were evaluated for seasonality and or other potentially-influential parameters.
4. Water level measurements by aquifer unit (model layer) were evaluated against groundwater pumping at nearby production wells.
5. Data from flowing wells was evaluated for seasonality and other potentially-influential parameters.

This evaluation was documented in a TM (MWH, 2012f) as an addendum to the Updated Conceptual Model Report. Pertinent findings include:

- Water level fluctuation generally decreases with depth.

- Variations in water levels for aquifer units 4 and 5 (model layers 9 and deeper) are minimal.
- Generally, wells located near the Owens River Delta are structurally isolated, and display the greatest influence of pumping from nearby production wells.
- While discharge from flowing wells in the OLGEP study area is far more constant than discharge from the various seeps and springs, the data shows some variability of flow. This flow variability has a vague pattern of seasonality in some wells and random in others, and the vague pattern of seasonality could be the result of multiple influences.

The analysis concluded that there is no reproducible or consistent seasonal pattern to deep groundwater levels or flow rates in artesian wells. These findings improved the understanding of the deep groundwater system and was complementary to the conceptual model for the study area. Furthermore, this analysis reinforced the particular concept that the deeper aquifers in the OLGEP area are isolated and not influenced by seasonal factors.

3.6 Development of the Numerical Groundwater Model

The updated conceptual model formed the basis for development of the numerical groundwater model for OLGEP. Initially, reviewed groundwater model functionality, attributes, and software (MWH, 2011g; see Appendix I). This TM also provided a preliminary model strategy, and Blue Ribbon Panel input was provided. Required model functionality identified included the ability of the groundwater model to simulate:

- Spring flow
- Variable groundwater flow direction at various depth horizons
- Effects of existing and proposed groundwater pumping
- Effects on local wells
- Evapotranspiration
- Vertical gradients between aquifers
- Results of pump tests (regional-scale representation)
- Hydraulic effects of faults

MWH then evaluated three groundwater modeling source code options in order to identify the one with the greatest applicability to the OLGEP study area and project objectives. The Modular 3-Dimensional Finite Difference Model (MODFLOW) was the selected source code for this project because MODFLOW-2000:

- Contains all of the functionality required for the project
- Has a source code that is very well documented
- Has sustained rigorous U.S. Geological Survey and academic peer review
- Has a long history of successful development and use
- Is the most widely-used model today
- Will continue to be the subject of new development and improvement

- Has a wide range of functionality that could be added when sufficient data becomes available and/or the need is identified including: density-driven flow, estimation of subsidence, and contaminant transport capabilities
- Has been applied successfully previously in the Owens Valley and is well known by LADWP and OLGEP Partner Agencies

An initial groundwater model was completed in February 2012, after which a suite of improvements to the model were identified by the model working group (LADWP, MWH, Partner Agencies, Blue Ribbon Panel). In addition, aquifer testing was conducted by LADWP over a roughly 10-month period from October 2011 - May 2012. Data from these tests became available subsequent to development of the initial model. As a result, Task 10 was conceived to incorporate model improvements and to calibrate the model to newly-available pump test data described below:

- The **Fault Test Site** production well T5 was tested from October 24, 2011 to November 22, 2011 at an average flow rate of 250 gallons per minute (gpm).
- The **Deep River Site** production well was tested from December 14, 2011 to January 17, 2012 at an average flow rate of 1,335 gpm.
- The **Shallow River Site** was tested from February 23, 2012 to March 26, 2012 at an average flow rate of 2,133 gpm.
- The **SFIP** (South Flood Irrigation Project) well was tested from June 18, 2012 to July 2, 2012 at an average flow rate of 1,000 gpm.

The improved groundwater model was completed in August 2012 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, model area is approximately 13 miles wide. The east and west boundaries of the model domain are governed by bedrock boundaries. The model has 12 model layers based on hydrostratigraphic interpretations as presented in the Updated Conceptual Model (MWH, 2011f; Appendix H). A uniform cell dimension of 500 feet is used, whereby this size represents a reasonable tradeoff between computational time and model accuracy. This grid spacing is also consistent with previous models constructed in the Owens Valley.

Complete documentation of the OLGEP numerical groundwater model was prepared (Appendix J, MWH, 2012a). Notable findings from the model development and calibration process include:

- Based on lithology and geophysical survey, the model was built based on the five identified aquifers. In general, sediments become finer to the south and toward the center of the lake. High hydraulic conductivity values are assigned in the north delta area and the coalescing alluvial fans on the east and west margins of the Basin.
- Review of shallow borings in the delta area suggests that a relatively large vertical anisotropy could be applied to the model where sediments are highly stratified. The model is sensitive to the vertical anisotropy.
- The model is sensitive to fault conductance, and the extent to which the Owens Valley Fault acts as a groundwater barrier has a very large influence on the effects of groundwater pumping.

- The MODFLOW evapotranspiration (ET) and Drain packages successfully simulate discharge on the playa. The value of drain conductance corresponds to the cell size and vertical hydraulic conductivity. Drain conductivity values that are too high can cause model instability.
- When the model is used to simulate shallow flooding for DCMs, minimal head change was observed in deep layers. The same is true for simulation of the LORP project. This appears to confirm field observations that the DCM and LORP projects have little effect on the deeper groundwater system. This is primarily because of the presence of thick, relatively impermeable lacustrine clays below the DCM and LORP projects, combined with the existing upward vertical gradient.
- Hydrographs at Down Valley Flow Sites, which show an apparent seasonal variation in groundwater level, actually represent the combined effect of seasonal pumping at W390, W344, W346, and the two River Site Production Wells.
- Simulation of this historical pumping and more recent pumping tests at River Site, Fault Test Site, and SFIP Production wells has improved the model calibration, especially characterization of fault conductance and vertical anisotropy values. This highlights the importance of pump tests to improve the predictive capacity of the numerical model.
- The Brine Pool can be simulated by Constant Head MODFLOW package or a combination of Drain and ET packages. Either method produces similar results. Simulation of a seasonally larger or smaller Brine Pool using the Constant Head package has little effect on deeper aquifers. This is because the Brine Pool is largely isolated from the deeper system by the lakebed clays.
- The total steady-state calibrated inflow and outflow to the model domain is approximately 56,740 AF/yr.

3.7 Groundwater Model Simulation, Alternatives Analysis, and Identification of a Potential Alternative

Simulation and analysis of alternative pumping scenarios using the numerical groundwater flow model for the OLGEP study area were conducted under Tasks 6 and 10. The scenarios consisted of a preliminary set of alternatives followed by a revised set of alternatives using the preliminary groundwater model. Results of this work was then used to optimize well locations and conduct additional simulations using the improved groundwater model to select the potential alternative. MWH developed protocols for pumping and monitoring, and provided recommendations on new well locations and use of existing facilities and infrastructure. Deliverables associated with this work are shown in chronological order:

- TM 6-1: Preliminary Pumping Alternatives and Criteria - This TM described the preliminary pumping alternatives and proposed criteria (MWH, 2011h; Appendix K).
- TM 6-2: Results of Simulation of Preliminary Alternatives - This TM summarized the simulation of the preliminary pumping alternatives, including modeled impacts (MWH, 2012b; Appendix L).
- TM 6-3: Summary of Previous Pumping Alternatives and Concepts for Continued Work on the Refined Alternative - This TM utilized the results of previous pumping alternatives (TM 6-2) to develop concepts for future model simulations and identification of a potential alternative (completed in Task 10) (MWH, 2012c; Appendix M).

- Task 401.1.10 TM: Results of Simulation of the Potential Alternative - This work and associated TM was done under Task 10 using the improved groundwater model. The TM (MWH, 2012d; Appendix U) describes the development of the potential alternative, including a discussion of its model-calculated impact on groundwater discharge zone flow, the water budget, relationships between zone discharge and hydraulic head, as well as recommendations for new monitoring well locations.
- TM 6-4: Protocols and Recommendations - This TM summarizes protocols for pumping and monitoring, recommendations for new production well locations, and recommendations for use of existing and proposed facilities (MWH, 2012e; Appendix N).

Using the initial OLGEP model, MWH conducted 21 groundwater pumping model simulations that are documented in TM 6-1 and 6-2. Results of this work were used to further conceptualize additional simulations to support development of the potential alternative (TM 6-3). Further simulations were conducted during the completion of Task 10, when optimization was conducted in an iterative manner to identify the potential alternative.

An important goal of modeling various groundwater development alternatives is to evaluate the potential impact that groundwater pumping may have on various sensitive elements on and around Owens Lake. Sensitive elements may include: local wells, habitat areas, vegetation, springs, and seeps. Of the sensitive elements that may be adversely affected by groundwater development, it is recognized that springs and seeps are one of the most sensitive environmental elements. Therefore, evaluation of groundwater development alternatives focused on changes in groundwater outflow to springs and seeps. During conceptual and numerical modeling of the study area, it was recognized that groundwater comes to the surface not only in discrete springs, but also in wide zones of surfacing groundwater that form saturated soils, seeps, and wetlands on the margins of Owens Lake. Therefore, in the groundwater model, the margin of Owens Lake was divided into discrete zones, in which the change in groundwater flowing to the surface could be estimated. These zones, shown on Figure 1 of Appendix U, and are based on a Habitat Suitability Index model being created for the Owens Lake under separate studies. The most sensitive areas have been distinguished as *"highly sensitive"* in order to maintain sensitive habitat. This designation is based on the potential presence of a sensitive springsnail. For each of these highly-sensitive areas, the maximum decrease in discharge was set at 10 percent. For the remaining sensitive areas in the study area, the maximum decrease in discharge was set at 70 percent. Highly-sensitive locations include:

- Northwest Seep
- Cottonwood Marsh
- Ash Creek
- Cartago Springs
- Crystal Geyser

Development of maximum decrease percentages in discharge limits has been an ongoing, collaborative effort among stakeholders, including LADWP, Inyo County Water Department, the Owens Lake Master Planning group, and Dr. Donald Sada of the Desert Research Institute in Reno, Nevada. For modeling purposes, the maximum decreases in groundwater discharge are utilized as optimization constraints.

Twenty (20) different iterative simulations were conducted in an effort to maximize pumping amounts while satisfying discharge constraints (percent of discharge decrease at groundwater discharge zones). The results of the optimization became the potential alternative. The relationship of this simulated optimized solution to project implementation recommendations is presented in Section 4. As discussed in Section 4, the potential alternative is a representative alternative to be implemented using adaptive management strategies and concepts; it is based on model results. In order to minimize impacts, pumping should be implemented in a phased approach complemented by monitoring to determine actual measurable impacts.

Key findings of model simulations performed to optimize the potential alternative include:

- The model is relatively insensitive to the role of the Owens Valley Fault during steady-state calibration, meaning that a reasonable calibration can be achieved by modeling the fault as a groundwater barrier, or not as a barrier at all. However, when regionally-significant groundwater pumping is simulated, the results are entirely different if the fault is simulated as a barrier, or not. This highlights the importance of pump testing in the vicinity of the Owens Valley Fault and throughout the study area.
- Pumping simulations indicate that when regionally-significant pumping occurs, higher drawdown occurs with time on the margins of the Basin than near the lake. This is because of the higher vertical hydraulic conductivity values on the alluvial fans surrounding the lake.
- The majority of water in the first few years of pumping comes from decreases in storage in the aquifers, and not declines in groundwater discharge.
- Within the model, the Northwest Seep is one of the most sensitive discharge areas, with a discharge decrease constraint of no more than 10 percent. Because this zone is located east of the Owens Valley Fault (barrier), and is believed to be underlain by permeable alluvial deposits with a relatively high vertical conductivity, it is the first sensitive discharge area to be affected by pumping wells located east of the Owens Valley Fault.

3.8 Public Outreach

Public outreach for the OLGEP consisted of the following elements as shown on **Figure 3-12**:

- Public Outreach Plan
- Development of a stakeholder mailing list
- Educational outreach
- Fact sheets and public meeting notices
- Public meetings
- Meetings with key stakeholders

All public outreach deliverables are located in Appendix O and described below.

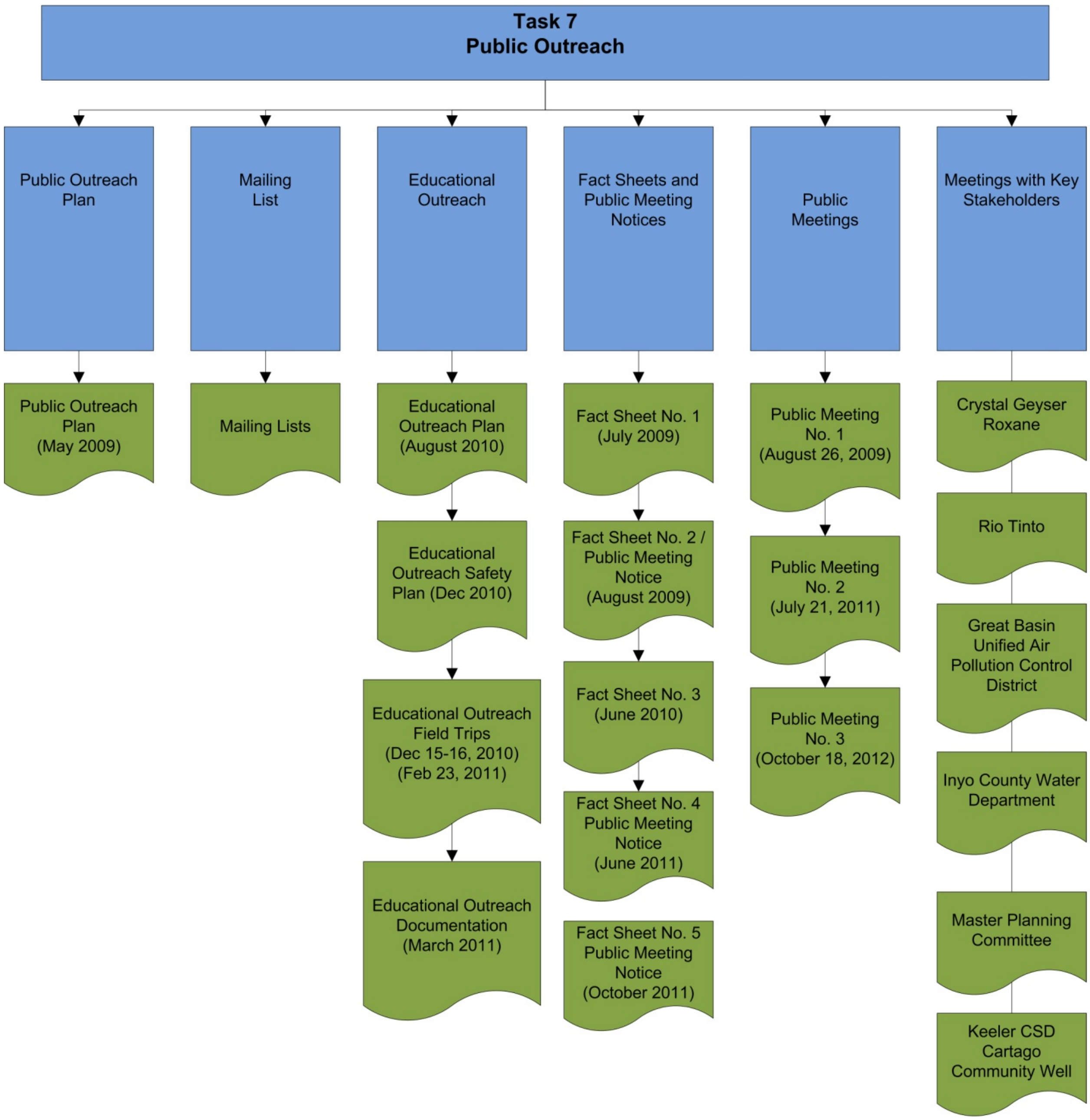


Figure 3-12
Summary of Public Outreach Program for the OLGEP

3.8.1 Public Outreach Plan

Public outreach was an integral part of the OLGEP. Outreach required an appreciation for the small, tight-knit and environmentally-conscious nature of the Owens Valley community. To this end, early and meaningful communication with a varied group of stakeholders, including regulatory agencies, landowners, groundwater users, environmental organizations, and interested members of the public, was needed.

A public outreach plan was prepared at the outset of the OLGEP project in coordination with LADWP (MWH, 2009b; Appendix O). The purpose of the outreach plan was to provide the project with a roadmap for public outreach. The outreach plan contained a preliminary schedule for meetings, identified the key links between technical milestones and outreach activities, suggested methods of communication, and clearly identified outreach roles and responsibilities.

Objectives of the outreach plan were to:

- Identify and proactively include all interested and affected governments, agencies, tribal organizations, land use and environmental organizations, and members of the public
- Provide multiple forums for stakeholder involvement
- Encourage stakeholder input on all aspects of the project, well before key decision points
- Receive and understand information about stakeholder's values and interests
- Incorporate comments/feedback received into the OLGEP process and key decisions
- Communicate information in a timely and understandable fashion
- Obtain consensus on a realistic conceptual model, as well as a reliable numerical groundwater model that accurately reflects the complexities of the study area
- Establish and maintain credibility of the project planners with agencies, organizations, and the public by conducting all activities in an open and transparent manner

Implementation of the outreach plan required coordination with LADWP's Project Manager as well as LADWP public relations group in Bishop and Los Angeles. Activities outlined in the outreach plan were conducted in parallel with technical activities and utilized appropriate tools to clearly communicate information to a variety of audience members.

3.8.2 Mailing List

An initial mailing list (Appendix O) was prepared for distribution of fact sheets and public meeting notices via US Mail. LADWP took responsibility for maintaining and updating the mailing list during project implementation.

3.8.3 Educational Outreach

Scientific evaluation of Owens Lake conditions provided an opportunity for educational outreach. One of the best environments for earth sciences education is located in the field. MWH facilitated educational opportunities within the local community for school children in cooperation with the LADWP. The educational outreach program consisted of both a classroom-type presentation and a field tour.

An educational outreach program plan was prepared in coordination with LADWP public outreach staff (MWH, 2010b; Appendix O). The purpose of the plan was to outline the field trip, including its purpose and goal, an agenda of specific sites to visit in the study area, as well as field trip logistics. The plan was approved by LADWP in August 2010, followed by development of a field trip safety plan (MWH, 2010d; Appendix O) and coordination with LADWP's Sulfate

Facility staff. The safety plan included a field trip agenda, logistics, contact information for key individuals, field safety information, as well as hospital routes and emergency phone numbers.

Two field trips were led by Tom Brooks of Lone Pine, CA and Victor Harris with MWH:

- Field Trip No. 1 took place on December 15 - 16, 2010 for Lone Pine High School junior and senior science classes.
- Field Trip No. 2 took place on February 23, 2011 for a career-focused group of students enrolled as either part-time or full-time students at Cerro Coso Community College.

Field Trip No. 1 consisted of the following stops:

- **Sulfate Road Facility** - provided an opportunity to visit the SCADA control room at LADWP's Sulfate Road facility
- **Sulfate Road Facility Well** - discussed basic well construction and implementation
- **Sulfate Flowing Well** - an existing artesian flowing well on the lakebed, at which artesian flows, geothermal effects (warm water), and wetland monitoring was discussed
- **T-9 Site** - this site provided a focus on dust mitigation, and provided examples of all existing dust mitigation methods
- **DWP-7 Drilling Site** - watched drilling rig “trip” out of the well (reached total depth that morning) and reviewed soil cutting samples
- **Kaiser Permenente Spring** - this site provided an example of natural springs and tufa deposits

Field Trip No. 2 consisted of the following stops:

- **Sulfate Road Facility Presentations** - presentations were made by a number of professionals from LADWP that focused on safety, environmental compliance, biological resources, and engineering
- **LADWP Tour of the Sulfate Road Facility** - tour included the shops and the SCADA control room
- **Sulfate Road Facility Well** - discussed basic well construction and implementation
- **Sulfate Flowing Well** - an existing artesian flowing well on the lakebed, at which artesian flows, geothermal effects (warm water), and wetland monitoring were discussed
- **DWP-6** - observed drilling and soil cutting samples as well as mud condition/viscosity testing
- **T-9 Site** - this site provided a focus on dust mitigation
- **T-1 Site** - this site afforded a look at well distribution and sand separators
- **Kaiser Permenente Spring** - this site provided an example of natural springs and tufa deposits

The field trips were later documented in a memorandum to LADWP (MWH, 2011c; Appendix O).

3.8.4 Fact Sheet and Public Meeting Notices

Fact Sheets were prepared to update regulatory agencies, organizations, and the public on project milestones (Appendix O). Fact sheets consisted of one-page color documents with text and supporting graphics. These materials were printed and mailed by LADWP.

- **Fact Sheet No. 1**. The first fact sheet was published in July 2009 and discussed the preliminary hydrogeologic conceptual model for the OLGEP study area. It also included a schedule showing the OLGEP process.
- **Fact Sheet No. 2**. The second fact sheet was a public meeting announcement for the August 26, 2009 public meeting.
- **Fact Sheet No. 3**. The third fact sheet was published in June 2010. Drilling and monitoring well installation formed the focus of this fact sheet. It also included a conceptual monitoring well diagram, sample geophysical log, and a photo of the well completion at DWP-2.
- **Fact Sheet No. 4**. The forth fact sheet was a public meeting announcement for the July 21, 2011 public meeting.
- **Fact Sheet No. 5**. The final fact sheet was a public meeting announcement for the third public meeting.

3.8.5 Public Meetings

Three public meetings were conducted to disseminate information to the local community and stakeholders (see Appendix O). Meetings were held in Lone Pine at Statham Hall. These meetings were open to the large audience of stakeholders, including agency and organization representatives, as well as the general public. The format of the meetings included introduction of project participants, approximately 20 to 30 minutes of presentation by technical staff, opportunity for oral comments/questions by meeting attendees, and subsequent informal discussions with LADWP and consultant staff. Meeting documentation, including a summary of comments/questions received were documented.

- **Public Meeting No. 1** was held on August 26, 2009. The preliminary conceptual model, planned data collection activities, and the numerical model were reviewed. In addition to the goals of the project, an overall schedule for OLGEP was presented. The presentation, summary of meeting attendees, comments/questions, and meeting documentation is included in Appendix O.
- **Public Meeting No. 2** was held on July 21, 2011. A summary of the field investigation program was presented, including key findings and updates to the study area conceptual model. Finally, next steps, including a discussion of numerical modeling, were summarized. The presentation, summary of meeting attendees, comments/questions, and meeting documentation is included in Appendix O.
- **Public Meeting No. 3** was held on October 18, 2012. A summary of work conducted since the last public meeting was presented. The results of the isotope study were presented along with groundwater model simulation results. Concepts for project implementation were discussed, along with planned next steps in the project. The presentation, summary of meeting attendees, comments/questions, and meeting documentation is included in Appendix O.

3.8.6 Meetings with Key Stakeholders

Meetings with key stakeholders were held to gather data and facilitate one-on-one discussion.

- **Crystal Geyser Roxane**. MWH had a series of informal discussions with Crystal Geyser Roxane to ascertain groundwater pumping and available data. A conference call was held on January 22, 2010 (see Appendix O), after which information on the Cabin Bar Ranch was exchanged at MWH's offices in Arcadia, California.
- **Rio Tinto**. MWH met with Rio Tinto in Lone Pine on July 21, 2011 (see Appendix O). The purpose of the meeting was to review Rio Tinto's hard copy data and reports that relate to the OLGEP study area. Reports and monitoring data were gathered for use by the study. MWH subsequently converted hardcopy information into digital form and returned both the hardcopy reports and electronic data to Rio Tinto. MWH also sampled the Rio Tinto domestic supply well and transmitted the results to Rio Tinto.
- **Great Basin Unified Air Pollution Control District**. GBUAPCD actively was involved throughout the OLGEP. GBUAPCD led the initial field trip, provided data throughout the project, attended public meetings, and was an active Partner Agency, including both a role in Blue Ribbon Panel meetings as well as technical meetings with MWH and LADWP.
- **Inyo County Water Department**. ICWD was an active participant and Partner Agency in the OLGEP, attending meetings and participating in technical discussion. ICWD also participated in meetings regarding potential pumping criteria with the Master Planning Committee.
- **Master Planning Committee**. The Owens Lake Master Planning Committee consists of members that represent the following interest groups: Agriculture/Ranchers, Air Quality, Community, Economic/Local Business, Energy/Solar, Environmental (Bird and Native Plants), Governmental (County, State & Tribal), Open Space, Landowners, Public Access, Public Trust, Recreation and Water. They are working collaboratively to develop a Master Plan for the Owens Lakebed. The Master Plan will be a document that identifies a vision, broadly-supported goals, objectives, actions, and projects to enhance the Owens Lakebed, including dust mitigation, habitat and wildlife, water efficiency, renewable energy resources, and economic interests. MWH's primary interface with the group centered on informing the group about the OLGEP project, and rationale for pumping criteria and monitoring methods. MWH retained Dr. Donald Sada to assist in development flow rate criteria and monitoring methods for seeps and springs to allow evaluation of various pumping regimes. He also evaluated the sensitivity of potentially impacted seeps and springs.
- **Keeler Community Services District and Cartago Community Wells**. During field sampling events, MWH met with representatives responsible for both of these community wells. MWH explained the purpose of the OLGEP project and sampled both wells, after which results were transmitted to both entities.

3.9 Blue Ribbon Panel Participation in the OLGEP

The Blue Ribbon Panel was a crucial component of the project that provided expert opinion and guidance at key decision points. A world-renowned team of specialists in hydrogeology, groundwater modeling, and ecology was assembled. The panel provided credibility to the technical work and was called upon to assist with technical input and solutions. The Blue

Ribbon Panel consisted of a chair person and five experts as shown in the Blue Ribbon Panel organization chart on **Figure 3-13**. All Blue Ribbon Panel documentation has been compiled and is included in Appendix P.

The Blue Ribbon Panel was introduced to the project by a kick-off meeting and field tour in April 2009. Meeting participants visited and viewed monitoring sites, flowing wells, dust control measures, the LORP pump back station, and other points of interest. Blue Ribbon Panel participation was then solicited throughout the project. A summary of Blue Ribbon Panel meetings is provided in **Table 3-9**, and meeting documentation is provided in Appendix O. Although the last formal Blue Ribbon Panel meeting was held in March 2012, technical input from selected members of the panel continued informally via email during model calibration and alternatives analysis.

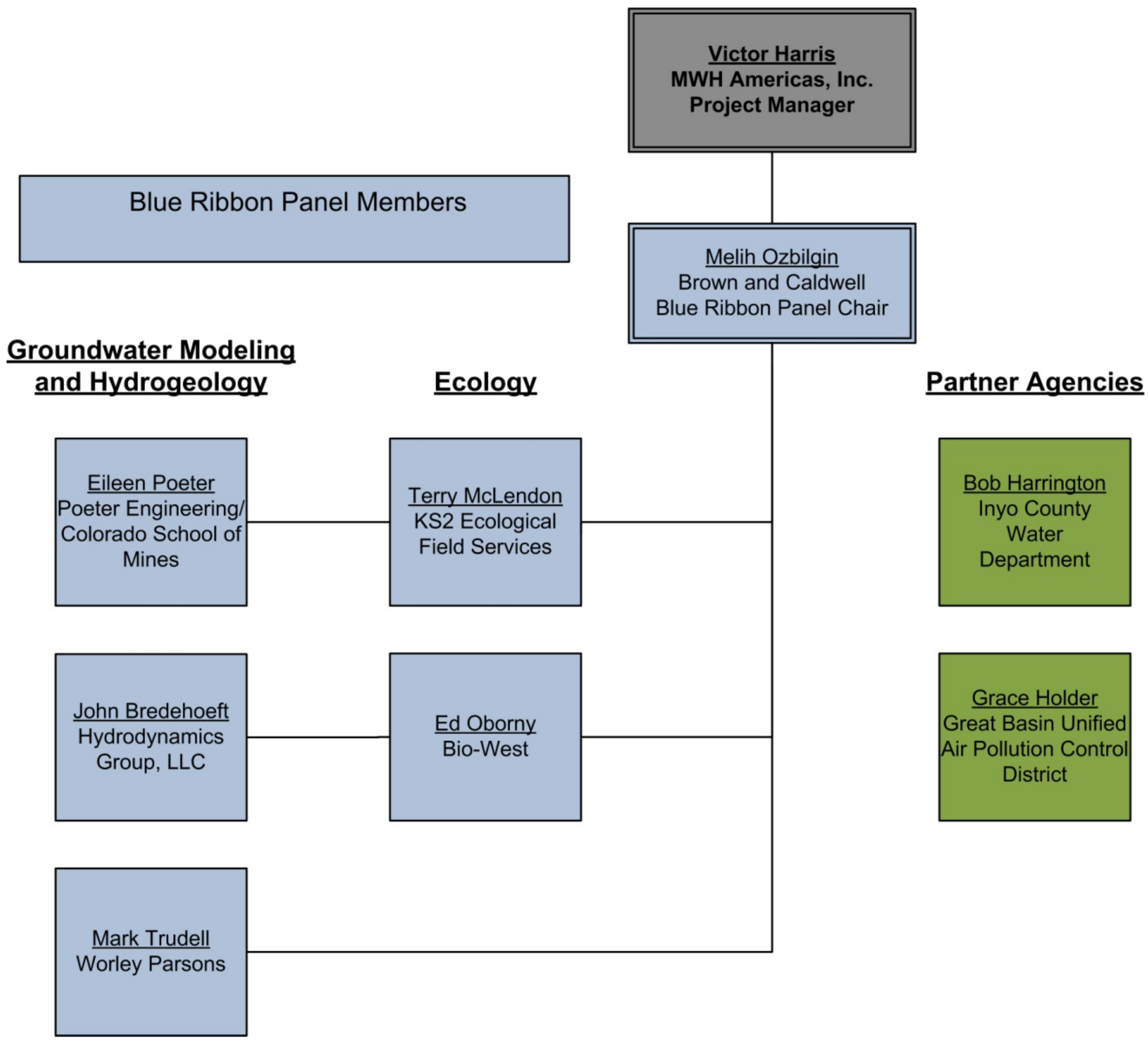


Figure 3-13
Blue Ribbon Panel Organization Chart

Table 3-9
Summary of Blue Ribbon Panel Participation

Meeting Date	Topic Discussed	Description
April 14 - 15, 2009	Kick-Off Meeting and Field Tour	The kick-off meeting and field tour was a 2-day event. Participants were given a tour of the study area followed by a technical meeting at LADWP's Sulfate Facility
June 12, 2009	Density-Driven Flow	The concept of density-driven flow was discussed. It was determined that from a scientific perspective, density-driven flow is interesting, but it does not change the overall hydrology of the system and therefore did not alter the OLGEP model strategy.
June 18, 2009	Monitoring Sites and Field Data Collection	The purpose of this call was to review the proposed well location rationale, after which the Blue Ribbon Panel provided feedback on refining certain locations.
September 25, 2009	Preliminary Conceptual Model, Water Budget, Preliminary Modeling, and Initial Model Strategy	The purpose of this meeting was to review the preliminary conceptual model, discuss the water budget for the study area, present results of preliminary modeling using CDM's model, and to review and receive feedback on the initial groundwater model strategy.
June 20, 2011	OLGEP Status Update and Model Strategy	Implementation of the field program in associated with delays due to permitting issues resulted in limited participation by the Blue Ribbon Panel in 2010 - early 2011. The purpose of this call was to bring the Blue Ribbon Panel back up to speed on the project and to review the groundwater model strategy in more detail. Key decision points on the modeling effort were flagged for discussion.
October 13, 2011	Updated Conceptual Model and Model Strategy	The purpose of this meeting was to review key issues in the updated conceptual model and obtain consensus on how they affect the groundwater model strategy.
March 28, 2012	Review of Model Documentation	The purpose of this meeting receive comments on the preliminary groundwater model documentation and to discuss a suite of model-related questions posed to the Blue Ribbon Panel.

Note: Meeting documentation and handouts is provided in Appendix O.

Blue Ribbon Panel members are described herein:

Dr. Melih Ozbilgin, a Vice President with Brown and Caldwell, has 30 years of hands-on technical experience working on groundwater and water resources projects. Melih has a PhD in Civil and Environmental Engineering, an MS in Civil and Environmental Engineering as well as Community Planning, and a BS in Architecture. In collaboration with LADWP, he developed the 1992 San Fernando Groundwater Basin flow model still in practical use today. He has also provided expert witness testimony in a variety of groundwater modeling cases.

Dr. Terry McLendon, with KS2 Ecological Field Services, LLC, has more than 35 years of research and consulting experience in plant ecology, restoration of disturbed lands, ecological modeling, ecological risk assessment, range and land management, watershed dynamics, and statistical ecology. Terry has PhD in Range Ecology & Statistics, an MS in Range Science, and a BS in Range Management. He is the originator and co-developer of the EDYS ecological model, has served as expert witness in litigation support relative to effects of hazardous materials on plants and animals, and has provided testimony to regulatory agencies both nationally and internationally. Dr. McLendon's areas of expertise include ecological modeling, design of water-balance covers for mined-land reclamation, secondary ecological succession, ecological risk assessment, and vegetation sampling. In the research projects that Dr. McLendon has led, he has investigated ecological factors controlling plant succession, simulation modeling of ecological systems, multivariate statistical classification of vegetation, restoration of disturbed lands, linkages between plant and soil microbial communities, invasion dynamics of non-native plants, and ecology of shrublands and grasslands. He was a key participant in the Owens Valley Natural Resources Management Program for LADWP on topics that address the interaction of vegetation, groundwater, precipitations, and other factors such as precipitation, grazing, and ecological succession.

Dr. John Bredehoeft, founder of the Hydrodynamics Group, is a nationally-recognized expert in hydrogeology and water resources and has more than 35 years of experience. John has both a PhD and MS in Geology, along with a BS in Geological Engineering. He worked at the U.S. Geological Survey for 32 years and also managed the national water research program. He is a world-class expert in the field of sustainable dynamic groundwater basin yield. At present, John provides specialized water expertise to various projects.

Dr. Eileen Poeter, Co-Director of the International Ground Water Modeling Center (IGWMC) at the Colorado School of Mines and owner of Poeter Engineering, has 35 years of experience. Eileen has a PhD in Engineering Science, an MS in Engineering, and a BS in Geology. Her primary responsibility is for managing and guiding the IGWMC in its mission to stimulate the appropriate use of simulation models and related computer-based support technology in the management and protection of groundwater resources. Dr. Poeter brings a unique perspective to selection of appropriate modeling techniques, with particular expertise in inverse modeling, parameter estimation, and density driven flow. Through her position at Poeter Engineering, Eileen provides specialized water and modeling expertise to various projects.

Ed Oborny, a Principal Biologist with Bio West, provides specialized expertise in aquatic biology and has 20 years of experience. Ed has an MS in Wildlife and Fisheries Science as well as a BS in Wildlife Biology. He was a principal biologist for a comprehensive spring evaluation focusing on unique ecosystems and endemic species in the Basin and Range province for the Southern Nevada Water Authority and has performed similar studies on spring-fed habitats of the Edwards Aquifer system in Texas.

Dr. Mark Trudell, a Principal with Worley Parsons Group, has 29 years of experience in groundwater resources management, contaminant hydrogeology, contaminated site remediation, numerical modeling, and aqueous geochemistry. Mark has a PhD from the Waterloo Centre for Groundwater Research, an MS in Earth Sciences, and a BS in Geology. He is also a licensed Professional Geologist and Certified Hydrogeologist. Mark has considerable experience in groundwater development and management, modeling of contaminated and uncontaminated sites, and remediation of petroleum hydrocarbons and wood-preserving compounds. He has conducted groundwater resource evaluations for industrial groundwater supply or groundwater management for five world-scale oils and developments in northern Alberta Canada, including groundwater injection studies at four of the facilities. In addition, Mark has managed numerous environmental projects involving multi-disciplinary activities.

3.10 Development of the Final Report

Development of the Final Report on the OLGEP was scoped in Task 8. This document represents the Final Report and the Task 8 deliverable.

4.0 RECOMMENDATIONS FOR A GROUNDWATER DEVELOPMENT PROGRAM

Groundwater modeling at Owens Lake has shown that approximately 9,000 to 15,000 acre-feet per year (AF/yr) of groundwater development at Owens Lake can be environmentally sustainable, depending on what criteria for springflow is used. It is recommended that at least 9 new monitoring wells be installed on the margins of the lake that will serve to monitor flow to the springs surrounding the lake. These wells should be installed as soon as possible in order to begin collecting baseline groundwater level data. Two new test wells as part of California Environmental Quality Act (CEQA) related activities are recommended to evaluate the hydrologic characteristics of the Owens Valley Fault. Additional recommended data collection activities include pump testing, focused isotope sampling, and installation of stream gauging stations. The current monitoring program should be reviewed and modified if necessary to increase efficiency of data collection.

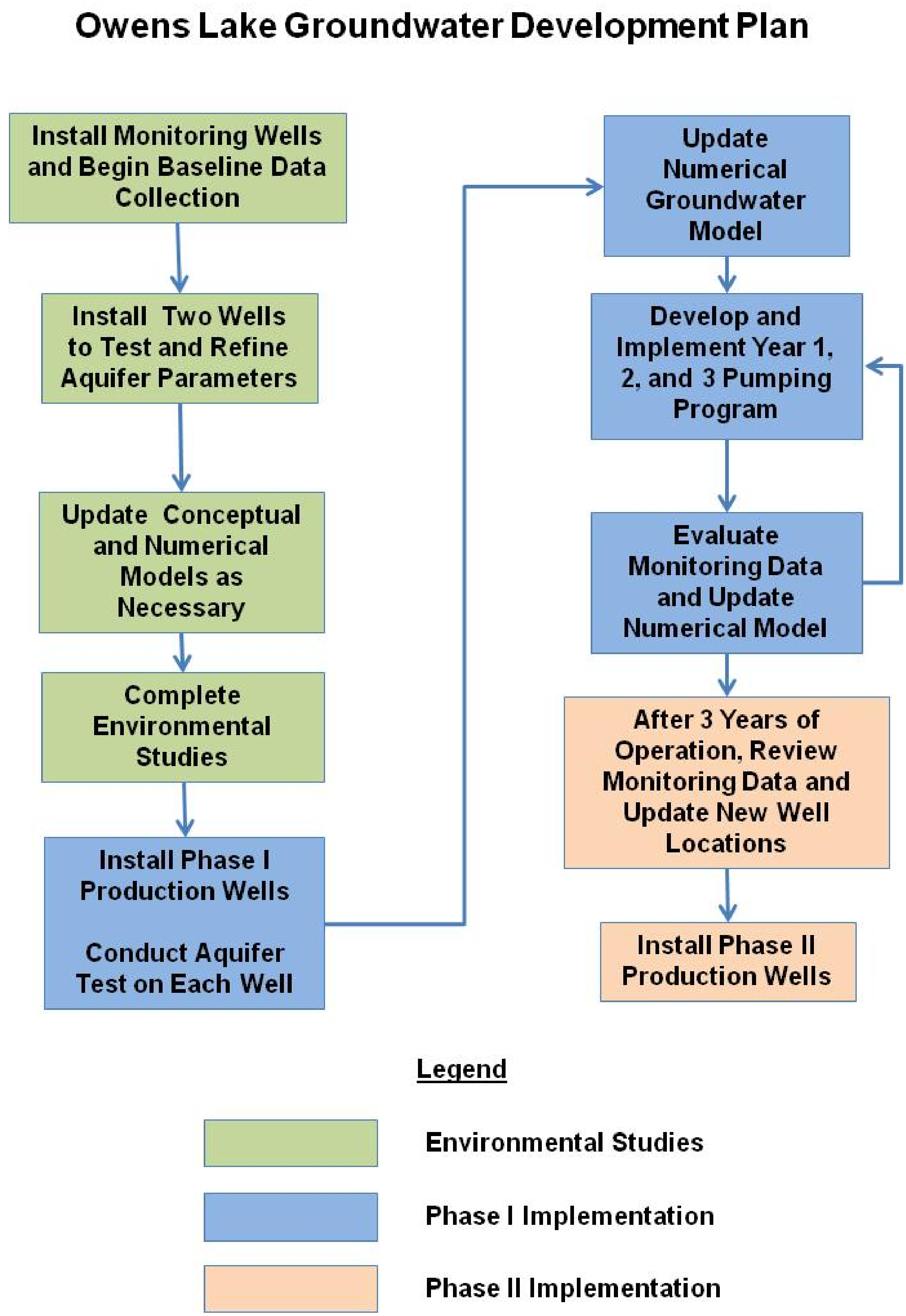
A phased implementation and adaptive management approach is recommended that develops new hydrogeologic information and modifies groundwater development plans accordingly, as information becomes available. The recommended initial phase of the implementation plan involves groundwater development at a rate of approximately 7,000 AF/yr, and 3 years of monitoring, before implementing additional groundwater development.

4.1 Pumping Criteria and Maximum Pumping Amount

Pumping from aquifers in the vicinity of Owens Lake can result in changes in groundwater in storage and decreased groundwater discharge to the surface. The maximum amount of environmentally-sustainable groundwater development in the OLGEP study area is dependent on the amount of change in storage and groundwater discharge that can be allowed in order to maintain habitat value and avoid impacts that cannot be managed. Draft pumping criteria were presented initially in TM 6-1 (MWH, 2011h), and included consideration of potential impacts such as effects on local wells, springs, artesian wells, subsidence, the Lower Owens River Project, and dust emission.

Development of pumping criteria is an ongoing, collaborative effort among the stakeholders, including LADWP, Habitat Group of the Owens Lake Master Planning group, Inyo County, and Great Basin Unified Air Pollution Control District. Although the pumping criteria are currently under revision by LADWP and other stakeholders, a consistent theme is that the most sensitive environmental elements that may be affected by groundwater development are the springs and artesian wells on the west side of Owens Lake. These areas are particularly sensitive because they form habitat for aquatic mollusk species such as springsnails. Whereas spring habitat on the east side of Owens Lake are in part anthropogenic and can be reproduced elsewhere on Owens Lake, it is thought that certain springs on the west side of the lake cannot be reproduced, and are unique because of the nature of relatively high-volume, long-standing continuous flow and excellent water quality.

During conceptual and numerical modeling of the study area, it was recognized that groundwater comes to the surface not only in discrete springs, but also in wide zones of surfacing groundwater that form saturated soils, seeps, and wetlands on the margins of Owens Lake. Therefore, for the purposes of the groundwater model, the margin of Owens Lake was divided into discrete habitat zones, in which the change in groundwater flowing to the surface could be simulated using the model.



Flow Chart showing Project Implementation Using Adaptive Management Strategy

The maximum amount of groundwater pumping has been evaluated using the OLGEP groundwater model, with a variety of discharge constraints for springs (e.g., habitat zones) and several varying assumptions regarding key aquifer parameters. Discharge constraints for sensitive western springs (or habitat zones) has ranged from a 10 to 20 percent decrease in flow, while the discharge constraint for other less sensitive springs has been up to a 70 percent decrease in flow. A key assumption regarding aquifer parameters is the extent to which the Owens Valley Fault acts as a groundwater barrier. The Owens Valley Fault has been modeled both as a relatively incomplete and relatively complete barrier to groundwater flow. These various model simulations suggest that a range of maximum allowable pumping should be considered, rather than one single unchanging amount. The model scenarios do, however, serve to bracket the potential pumping amount in the range of 9,000 to 15,000 AF/yr (MWH, 2012b; MWH, 2012c; MWH, 2012d).

4.2 Recommended Implementation Strategy

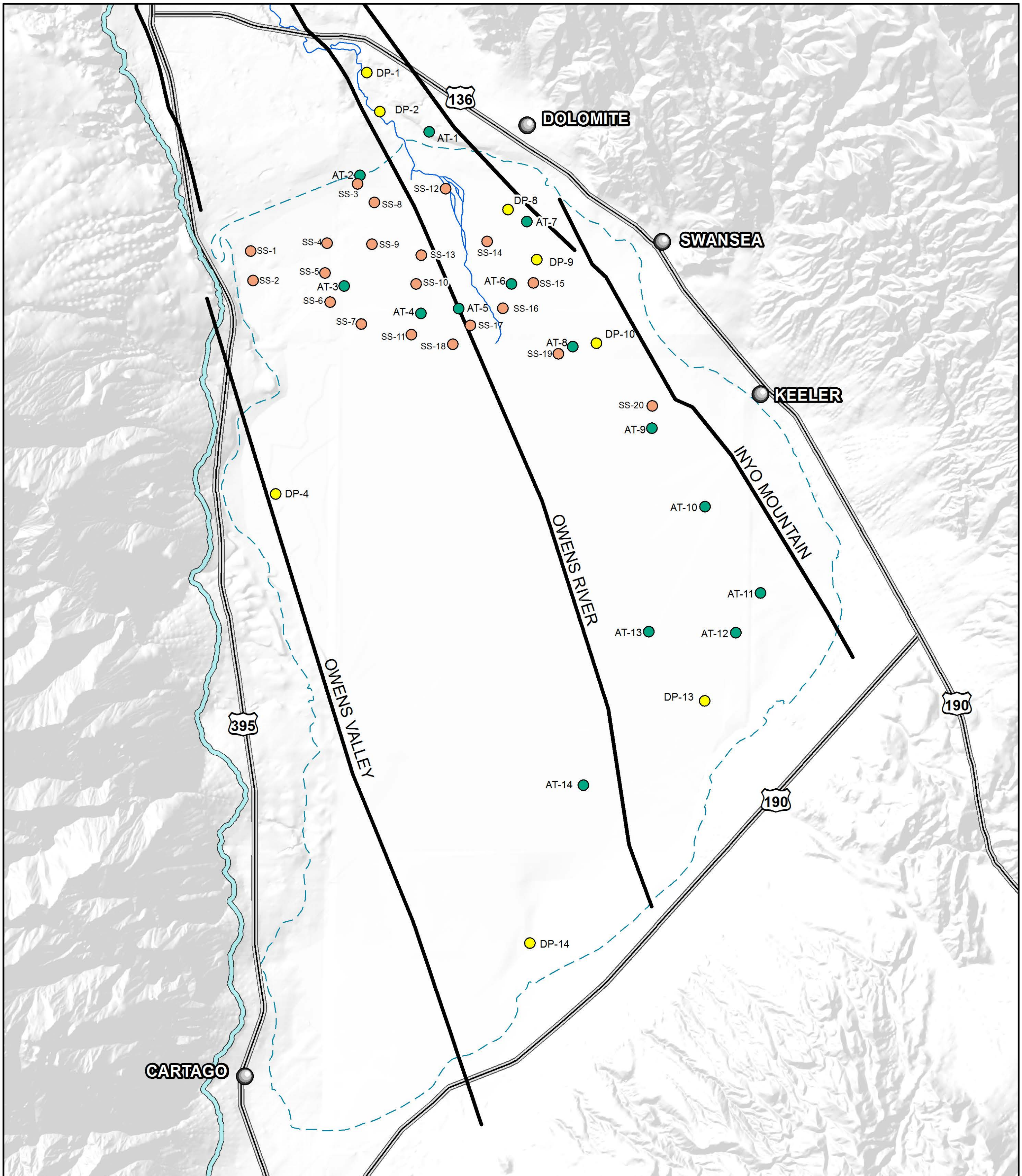
A potential alternative (or model simulation) for groundwater development was presented in the Task 401.1.10 TM (MWH, 2012d). The terminology of "potential alternative" is used in lieu of “preferred” or “selected” alternative in recognition that although the groundwater model used for alternative analysis is based on the most up-to-date knowledge of the hydrogeology and hydrology of Owens Lake, there are still uncertainties regarding the exact response of the groundwater system to pumping. The exact number of wells and total amount of sustainable groundwater pumping will be dependent on several variables that are unknown at this time, including:

- Refinement of aquifer parameter estimations, such as the extent to which the Owens Valley Fault acts as a barrier and storage coefficient,
- Actual production capacity of new wells in various aquifers, and
- Pumping criteria to protect environmental resources around Owens Lake.

4.3 Recommendations for New Well Locations

Potential or simulated well locations for production of groundwater for dust control measures are shown on **Figure 4-1**. Also shown on **Figure 4-1** are selected geologic structures that are important to the project's implementation. Three distinct well designs were simulated, as summarized in **Table 4-1**.

The potential production well locations were developed by an iterative trial-and-error optimization of pumping rates, locations, and depths using groundwater discharge constraints to springs as described in the Task 401.1.10 TM (MWH, 2012d). **Table 4-2** lists the simulated potential well locations, along with well coordinates and simulated pumping rates.



Key to Features

Town

Highways

Los Angeles Aqueduct

Owens River

Modeled fault Location

Alternative Well Locations

Deep Well

Artesian Well

Sand Sheet Well

Owens Lake (Historic Shoreline)

N

0 1.5 3 Miles

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Modeled Well Locations

Los Angeles Department of Water & Power

Figure 4-1

MWH

This map has been designed to print size 8.5" by 11".

Table 4-1
Recommended Types of Wells

Type of Well	Typical Capacity (gpm)	Typical Depth (feet)	Typical Diameter (inches)	Description
Shallow	50	30	6	Designed to capture shallow groundwater that otherwise would evaporate in the brine pool
Artesian	150	700	12	Wells flow initially on their own under artesian pressure, may be equipped with pumps at a later date
Deep	500	1,500	12	Deep completion designed to minimize shallow impacts

4.4 Recommendations For Phased Implementation

Experience in the Owens Lake area has shown that aquifer testing is the best method to accurately determine aquifer parameters that control the response of the system. For this reason, a phased implementation approach and adaptive management strategy is proposed for groundwater development at Owens Lake. The concept of this adaptive management strategy is that pumping would commence at a rate less than the lower end of the range of sustainable pumping determined by the groundwater model, and the effects of pumping would be carefully monitored. Based on what is learned during that monitoring, pumping amounts and timing would be adjusted upwards or downwards, if necessary, to ensure protection of sensitive resources. This conservative approach not only protects the value of sensitive resources, but also allows for improvement of understanding of the groundwater system as pumping occurs. An adaptive management strategy will provide feedback that allows managers to incorporate information as it is learned. Furthermore, this strategy will test current assumptions and knowledge by implementing conservative pumping rates, monitoring relevant parameters, analyzing outcomes, and using this feedback information to plan future pumping programs.

Groundwater model simulations suggest that between 9,000 and 15,000 AF/yr may be extracted from aquifers surrounding the lake, depending on what key assumptions are made for aquifer parameters and what criteria for maximum change in springflow is used. As a conservative measure, it is recommended that the initial implementation (Phase I) involve a maximum pumping amount of approximately 7,000 AF extracted in one year (approximately 2,000 AF less than the modeled potential alternative). In addition, it is recommended that the monitoring data be used to reassess the program after 3 years (7 years less than the modeled potential alternative). Depending on conditions observed during pumping of these wells, additional wells may be added at a later date. The recommended Phase I wells are listed in **Table 4-3**. With two exceptions, these wells consist of a subset of the wells contained in **Table 4-2**.

Table 4-2
Modeled Potential Alternative Well Locations [1]

Group	Well ID	No. of Wells	Simulated Pumping Rate (gpm)	Group Pumping Rate (gpm)	Total (AF/6 mos.)	Model Layers Screened	Aquifers Pumped
Shallow Sand Sheet Production Well	SS-1	20	50	1,000	807	1	Shallow
	SS-2						
	SS-3						
	SS-4						
	SS-5						
	SS-6						
	SS-7						
	SS-8						
	SS-9						
	SS-10						
	SS-11						
	SS-12						
	SS-13						
	SS-14						
	SS-15						
	SS-16						
	SS-17						
	SS-18						
	SS-19						
	SS-20						
Artesian Flowing Wells[2]	AT-1	14	145	2,030	1,689	7	3
	AT-2						
	AT-3						
	AT-4						
	AT-5						
	AT-6						
	AT-7						
	AT-8						
	AT-9						
	AT-10						
	AT-11						
	AT-12						
	AT-13						
	AT-14						
Deep Pumping Wells	DP-1	5	1,200	6,000	4,839	9, 11, 12	4, 5
	DP-2						
	DP-8						
	DP-9						
	DP-10						
	DP-4	1	140	140	113	11, 12	5
	DP-13	1	480	480	387	11, 12	5
	DP-14	1	1,200	1,200	968	11, 12	5
	Total:	**42**		**10,850**	**8,803**		

1, MWH, 2012c. TM: Results of Simulation of a Potential Alternative. October.

2. Flowing well, no pumping will occur. Total discharge depends on hydraulic head over time.

Table 4-3
Recommended Phase I Wells

Group	Previous Well ID [2]	Phase I Well ID	No. of Wells	Nominal Capacity (gpm)	Group Capacity (gpm)	Total (AF/6 mos.)
Shallow Sand Sheet Production Wells	SS-6	SS-1	9	50	450	363
	SS-7	SS-2				
	SS-11	SS-3				
	SS-15	SS-4				
	SS-16	SS-5				
	SS-17	SS-6				
	SS-18	SS-7				
	SS-19	SS-8				
	SS-20	SS-9				
Artesian Flowing Wells [2]	AT-3	AT-1	6	150	900	726
	AT-4	AT-2				
	AT-6	AT-3				
	AT-8	AT-4				
	AT-13	AT-5				
	AT-14	AT-6				
Deep Pumping Wells	none	DP-1	6	1,200	7,200	5,807
	none	DP-2				
	DP-9	DP-3				
	DP-4	DP-4				
	DP-13	DP-5				
	DP-14	DP-6				
Testing Wells	none	TW-1	2	TBD	TBD	TBD
	none	TW-2				
	Total:		**23**		**8,550**	**6,896**

1. Well location identifier used in previous modeling TM (MWH, 2012c).

2. Flowing well, total discharge depends on hydraulic head over time.

The two exceptions regarding well placement are testing wells (TWs) designated TW-1 and TW-2, shown on **Figure 4-2**. These two wells are described on **Table 4-3** and **Figure 4-2**, and are located specifically to verify the extent to which faults and synclinal structures control groundwater flow. Pump testing in the vicinity of faults is required to reduce uncertainty regarding the extent to which the Owens Valley Fault acts as a groundwater barrier. This limited or temporary aquifer testing for the purposes of improving the conceptual and numerical model of the area should be conducted for a duration of at least one month. Depending on the outcome of this testing, the wells may be used in the future for dust control activities. It is further recommended that TW-1 and TW-2 be constructed as part of permitting activities associated with CEQA before project implementation.

The wells shown on **Figure 4-2** and listed in **Table 4-3** are designed to test the productive capacity of the target aquifers at a diverse set of locations. Based on what is learned during construction and testing of these wells, it is recommended that the groundwater model be refined in accordance with utilizing new data, and then used to locate optimal sites for additional production wells.

4.5 Recommended Well Construction Methods, Design and Appurtenant Equipment for Phase I Wells

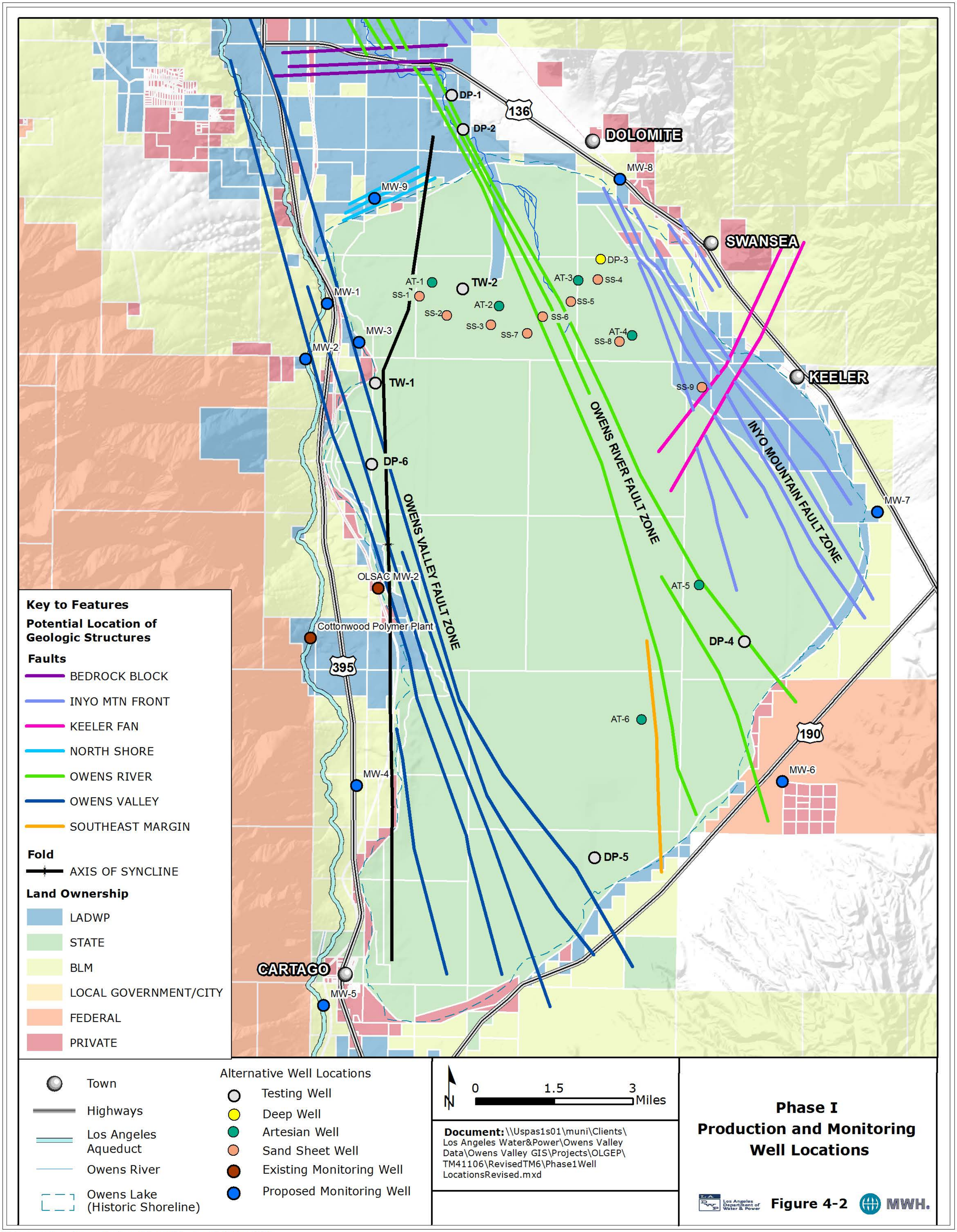
The following sections contain recommendations for well design, appurtenant equipment, and operation of the three types of well designs recommended for groundwater development.

4.5.1 Shallow Wells

The shallow sand sheet wells are designed to extract shallow water from the sand sheet area that is located in the northern portion of the lake in the delta area (MWH, 2012d). The wells are intended to be shallow, inexpensive, and have a relatively low pumping rate. The recommended well diameter for the shallow wells is 6 inches. Maximum depth of these wells is estimated at 30 feet. Because the wells are shallow and have a relatively low design flow rate, PVC casing and screen materials can be used. Drilling methods could include auger methods or percussion/casing hammer methods, which would minimize development efforts because they do not involve drilling mud.

The shallow sand sheet wells listed in **Table 4-3** have been sited directly adjacent to dust control areas that currently require water, which would eliminate or minimize the need for extensive conveyance facilities. Anecdotal information obtained during construction of dust control facilities in the sand sheet area suggests that artesian conditions may exist in this area; but regardless, groundwater is expected to be shallow.

Given shallow groundwater depths, it may be possible to equip the wells with smaller surface pumps that would draft the water from the well. If this is the case, semi-rigid 2- to 4-inch hoses could be used to convey the water to its destination. If drafting is not possible, then submersible pumps are recommended. The production rates of individual wells and the practicality of any particular pump design should be based on individual testing of each well.



Phase I Production and Monitoring Well Locations

Figure 4-2

This map has been designed to print size 8.5'' by 11''.

4.5.2 Artesian Wells

Artesian wells are designed to intercept groundwater in Aquifer 3, which has relatively high artesian pressures. The recommended drilling method for these wells is the direct rotary method. Because of the anticipated artesian conditions, best management practices for drilling on the lake should be followed (MWH, 2009d). The recommended well diameter for the artesian wells is 12 inches. Although a smaller diameter would result in similar artesian flow, a 12-inch design is recommended so that aquifer testing of the wells can be accomplished and future pumping of these wells could be accommodated if needed. The top of the artesian wells should be fitted with control and relief valves to allow for control of artesian flow.

Because of the potentially-corrosive environment of the Owens Lake study area, the recommended material for exposed casing and screen of the artesian wells is stainless steel. Mild or high-strength low-alloy steel could be used in portions of the wells that are encased in cement grout. Louvered screen, similar to Roscoe Moss “Super Flo” shutter screen, is recommended because of its superior durability relative to wire-wrapped screen and relatively high open area.

The exact depth of the screen for the artesian wells should be based on a suite of geophysical logs run in a smaller diameter pilot hole. The recommended geophysical suite consists of gamma ray, spontaneous potential (SP), short and long resistivity, guard resistivity, sonic velocity, temperature, and caliper logs. Minimum pilot-hole depth for well AT-1 should be 1,100 feet, 950 feet for AT-2, and 700 feet for wells AT-3 through AT-6 (**Table 4-3**).

Similar to the shallow sand sheet wells, the Phase I artesian wells have been located adjacent to areas of water demand for dust control measures. Therefore, the need for conveyance facilities should be minimal. Semi-rigid pipe such as 4-inch diameter HDPE pipe should be ideal for conveyance of water to dust control areas with minimal friction loss. Use of small diameter pipe on the surface would allow for the pipe to be moved to convey water to the needed areas.

4.5.3 Deep Wells

Deep wells should be designed similar to artesian wells, except that they would extract groundwater from deeper Aquifers 4 and 5, which are also under artesian pressure. The recommended drilling method for these wells is the direct rotary method, and best management practices should be used (MWH, 2009d).

The initial recommended diameter, materials, and geophysical logging of the deep wells is the same as that for the artesian wells, except that the deep wells would be deeper, with longer screened sections. Pilot holes for the deep wells should be completed to a minimum depth of 1,800 feet. The drilling specifications should include the option to construct 16-inch wells if initial well (s) indicate that the aquifer is highly productive.

These wells should also be fitted with control and relief valves similar to artesian wells. A major difference between the artesian and deep wells is that the deep wells are designed to be equipped with pumps in Phase I. Flow rates are anticipated to be 1,000 to 1,500 gallons per minute; however, this rate is subject to some uncertainty because of the exploratory nature of these wells. Pumps should be designed based on pump testing information after the well is constructed, and could consist of vertical turbine pumps or submersible pumps. A major design consideration will be the artesian pressure associated with these wells, and the corresponding need to prevent uncontrolled leakage around the pump. The artesian nature of the wells may favor the use of submersible pumps that can be sealed in the well casing.

The deep wells also have been located adjacent to water demand areas for dust control measures, so the water can be utilized very near the well locations. If water needs to be transported, then 8-inch diameter HDPE pipe is recommended. The pipe diameter may vary depending on the eventual production capacity of each well. Two exceptions are deep wells DP-1 and DP-2, which are located adjacent to the Owens River. In this case, water produced from the wells can be transported to the dust control areas via the Owens River and Lower Owens River Pump Station, where conveyance piping already exists.

4.6 Recommendations for Protocols and Monitoring

This section discusses monitoring protocols associated with groundwater pumping in the Owens Lake study area.

4.6.1 Monitoring Locations

The springs that surround Owens Lake are considered to be the most sensitive environmental elements in the study area. The most sensitive springs are located on the west side of the lake, where consistent, high-volume flow and good water quality have created wetlands with a high habitat value. Monitoring of flow from these springs is critical to understand the relationship between pumping and springflow, and ultimately the relationship between pumping and groundwater dependent habitat.

Unfortunately, the groundwater flow to the majority of springs in the study area cannot be measured directly. With the exception of flow from abandoned artesian wells, locations where surface flow can be measured directly are heavily influenced by factors other than springflow, including evapotranspiration and precipitation. However, results of the model simulations have shown that there are direct relationships between groundwater elevations in the shallow aquifers and springflow. This provides a practical means to estimate changes in springflow, without measuring the flow directly.

The groundwater model has been useful for determining optimal locations for monitoring changes in groundwater levels and changes in groundwater discharge (MWH, 2012d). Monitoring at existing and new locations is proposed in order to establish baseline (before pumping) conditions and to collect data to understand the system's response to pumping.

Each new monitoring location was established based on the following criteria (in order of importance):

- The monitoring location is a source area (up gradient) of groundwater flow to a sensitive discharge zones,
- The monitoring location is expected to incur significant drawdown as a result of the potential alternative, and
- LADWP land ownership is preferred, and that the site is accessible by existing road (s).

It is recommended that LADWP continue existing monitoring at or near the lake, which includes monitoring at selected springs, existing monitoring wells, and all uncontrolled artesian wells, although the monitoring frequency and monitoring locations should be reviewed and modified as discuss below. **Figure 4-2** shows the locations of nine (9) new monitoring well locations that were selected based on the criteria listed above (MWH, 2012d). Each new monitoring well is assumed to penetrate at least 20 feet beneath the current water table. The majority of monitoring locations are at higher elevations on the alluvial fans where drawdown is expected to be the greatest. However, additional monitoring wells were added to evaluate the influence of the Owens Valley Fault. Monitoring wells are suggested on both sides of the fault zone to evaluate the extent to which the fault zone acts as a groundwater barrier. These monitoring wells should be constructed of 4-inch high strength low alloy (HSLA) steel, and could be installed rapidly using sonic drilling methods.

In addition to the installation of new monitoring wells, it is recommended that the existing monitoring program, which consists of measuring flow at all abandoned artesian wells on the lake, as well as selected spring locations and existing wells, be continued. It is recommended that the list of existing wells be expanded to include the LADWP Cottonwood Polymer Plant well and the OLSAC MW-2 monitoring well, currently owned by Rio Tinto Mining (if permission to monitor the well is granted by Rio Tinto). As noted below, it is recommended that the existing monitoring program be reviewed and potentially revised based on historical data and anticipated needs.

4.6.2 Monitoring Triggers

The groundwater model provides a means to correlate flow to springs with change in groundwater elevations, as described in previous Technical Memorandum 401.1.10 (MWH, 2012d). Management triggers involving a specific decrease in groundwater discharge to a particular discharge zone can be related to decreases in groundwater elevations at monitoring points. Once the management criteria or discharge constraint for springflow is finalized, the management trigger for decreases in groundwater elevation can be derived easily. Because the management triggers for groundwater elevation changes are based on the groundwater model, these management triggers should be updated as the groundwater model is updated, which is all part of an adaptive management strategy.

4.7 Recommendations for Future Study

The flowchart provided on page 4-2 illustrates the recommended project implementation and future study. The adaptive management strategy (also captured in this flowchart) involves continuous updating of the conceptual and numerical model as new information becomes available. Each new well constructed should be tested using temporary pumping equipment for the purposes of designing an efficient permanent pump. Once a permanent pump is installed, a one-month pump test should be conducted on each well while drawdown in surrounding wells is monitored. This data will provide critical information on aquifer parameters and the role of faults in groundwater flow. For artesian wells, pump testing for a duration of 1 month is also recommended using a temporary pump.

Once the pump test data is available, the groundwater model should be recalibrated using the pump test information, and new groundwater elevation/spring discharge relationships should be generated. Groundwater pumping using all of the newly-installed wells should then commence for a period of three years. This data should again be used to update the numerical model, which would be the basis for the planning of additional wells and future phases of the project and associated pumping.

Additional studies identified that would improve the understanding of the Owens Lake groundwater system are summarized below:

- Design and install additional monitoring wells (other than the nine identified previously) on the alluvial fans on the margins of the lake as a means to improve recharge estimates and understand the role of faults as barriers to groundwater flow.
- Design and install base-of-mountain and lake boundary flow gauging stations at selected drainages as needed on the eastern and western side of Owens Lake to improve recharge estimates.
- Building on the success of the isotope study in identifying source areas and ages of groundwater, conduct additional sampling of stable and radioactive isotopes, particularly near areas of sensitive springs on the west side of the lake.
- Conduct a review of the current monitoring practices on or near the lake, and modify monitoring locations and frequency based on the historic data set. Integrate this monitoring program with recommended new water quality monitoring at OLGEP monitoring wells and planned production wells.
- Conduct additional model simulations to evaluate how potential climate change or drought periods may influence the effects of pumping.
- Conduct additional model runs to evaluate the sensitivity of model output to various assumptions and parameters.
- Initiate studies related to CEQA, including scoping of an Environmental Impact Report (EIR), development of project alternatives, and necessary special studies.

5.0 LITERATURE CITED

Camp, Dresser, and McKee (CDM). 2000. Technical Memorandum on the Evaluation Results of LADWP 1999-2001 Pumping Proposal Owens Lake Groundwater Evaluation. June.

———. 1999. Technical Memorandum on the Conceptual Model Development Owens Lake Groundwater Evaluation. September.

Crippen, J.R. 1965. Natural Water Loss and Recoverable Water in Mountain Basins of Southern California. U.S. Geological Survey Professional Paper 417-E, 24 pp.

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-H. U.S. Geological Survey, Denver, Colorado, 175 p.

Danskin, W. R. 1988. Preliminary Evaluation of the Hydrogeologic System in Owens Valley, California, USGS Water Resources Investigation 88-4003.

Great Basin Unified Air Pollution Control District (GBUAPCD). 1997. Owens Valley PM10 Planning Area Demonstration of Attainment SIP Final Environmental Impact Report.

———. 2009. Owens Lake Shallow Hydrology Monitoring Data and Chemistry, 1992 - 2004. February.

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.

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

Johnson, K, J. Eliason, G. Maddox, and T. Brooks. 1999. Characterization of the Owens Lake Basin Hydrology System, Inyo County, California. Summary Report for the Great Basin Unified Air Pollution Control District. June.

Lopes. 1987. Hydrology and Water Budget of the Owens Lake, California. Thesis, University of Nevada, Reno.

Lopes, T.M. 1988. Hydrology and Water Budget of Owens Lake, California. Water Resources Center, Desert Research Institute, DRI Pub No. 41107. Reno, Nevada.

Los Angeles Department of Water and Power. 1988. Development of a Mathematical Groundwater Flow Model of the Owens Lake Basin Area, California. Unpublished.

Luhdorff and Scalmanini Consulting Engineers. 1994. OLSAC Ground-Water Model: Recalibration and Simulation of Pumping Impacts. Prepared for the Owens Lake Soda Ash Company.

Montgomery Watson. 1993. Revised Draft Environmental Impact Report for the Anheuser-Busch Companies Los Angeles Brewery Water Supply Study Vol. II- Technical Appendices. Prepared for Anheuser-Busch.

MWH. 2012a. OLGEP Groundwater Model Documentation. October.

———. 2012b. TM 6-2: Results of Simulation of Preliminary Alternatives. February.

———. 2012c. TM 6-3: Summary of Previous Pumping Alternatives and Concepts for Continued Work on the Refined Alternative. May.

———. 2012d. TM: Results of Simulation of the Potential Alternative. October.

———. 2012e. TM 6-4: Protocols and Recommendations. October.

———. 2012f. TM: OLGEP Water Level and Flowing Well Evaluation. October.

———. 2011a. Owens Lake Groundwater Evaluation Project - Preliminary Hydrogeologic Conceptual Model. January.

———. 2011b. Southern Model - Model Documentation Report. February.

———. 2011c. Educational Outreach Program Documentation. March.

———. 2011d. Owens Lake Groundwater Evaluation Project - Well Completion Reports for DWP-1, -2, -3, -5, -6, -7, -8, -9, -10, and -11. March - July.

———. 2011e. Owens Lake Groundwater Evaluation Project - Evaluation of Geophysical Data for Incorporation into the OLGEP Phase II. June.

———. 2011f. Updated Conceptual Model Report. November.

———. 2011g. Evaluation of Groundwater Model Functionality, Attributes & Software and Development of Preliminary Model Strategy. November.

———. 2011h. TM 6-1: Preliminary Pumping Alternatives and Criteria. November.

———. 2010a. Work Plan: Recommendations for Modifications to Data Collection. February.

———. 2010b. Educational Outreach Program Plan. August.

———. 2010c. Owens Lake Groundwater Evaluation Project - Evaluation of Geophysical Data for Incorporation into the OLGEP Phase I. September.

———. 2010d. Educational Outreach Safety Plan. December.

———. 2009a. OLGEP Health and Safety Plan. March.

———. 2009b. Public Outreach Plan. May.

———. 2009c. TM - Review of Existing Models. June.

———. 2009d. TM - Best Management Practices for Construction on Owens Lake. June.

———. 2009e. TM - Evaluation of Density Driven Flow. August.

Neponset Geophysical Corporation (Neponset). 1999. Characterization of the Owens Lake Basin Hydrology System. For Great Basin Unified Air Pollution Control District. Inyo County, California.

———. 1997. Final Report, Phase 3 and 4 Seismic Program. For GBUAPCD. Owens Lake, Inyo County. California.

Schumer, R. 1997. Extension and Refinement of the Owens Lake Groundwater Basin Numerical Simulation. Thesis, University of Nevada, Reno.

Wirganowicz, M. 1997. Numerical Simulation of the Owens Lake Groundwater Basin, Owens Lake, California. Thesis. University of Nevada, Reno.

Woodward Clyde Consultants. 1993. Hydrologic Evaluation of Proposed Owens Lake Soda Ash Company Pumping Near Cottonwood Springs. Prepared for the Inyo County Water Department.

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