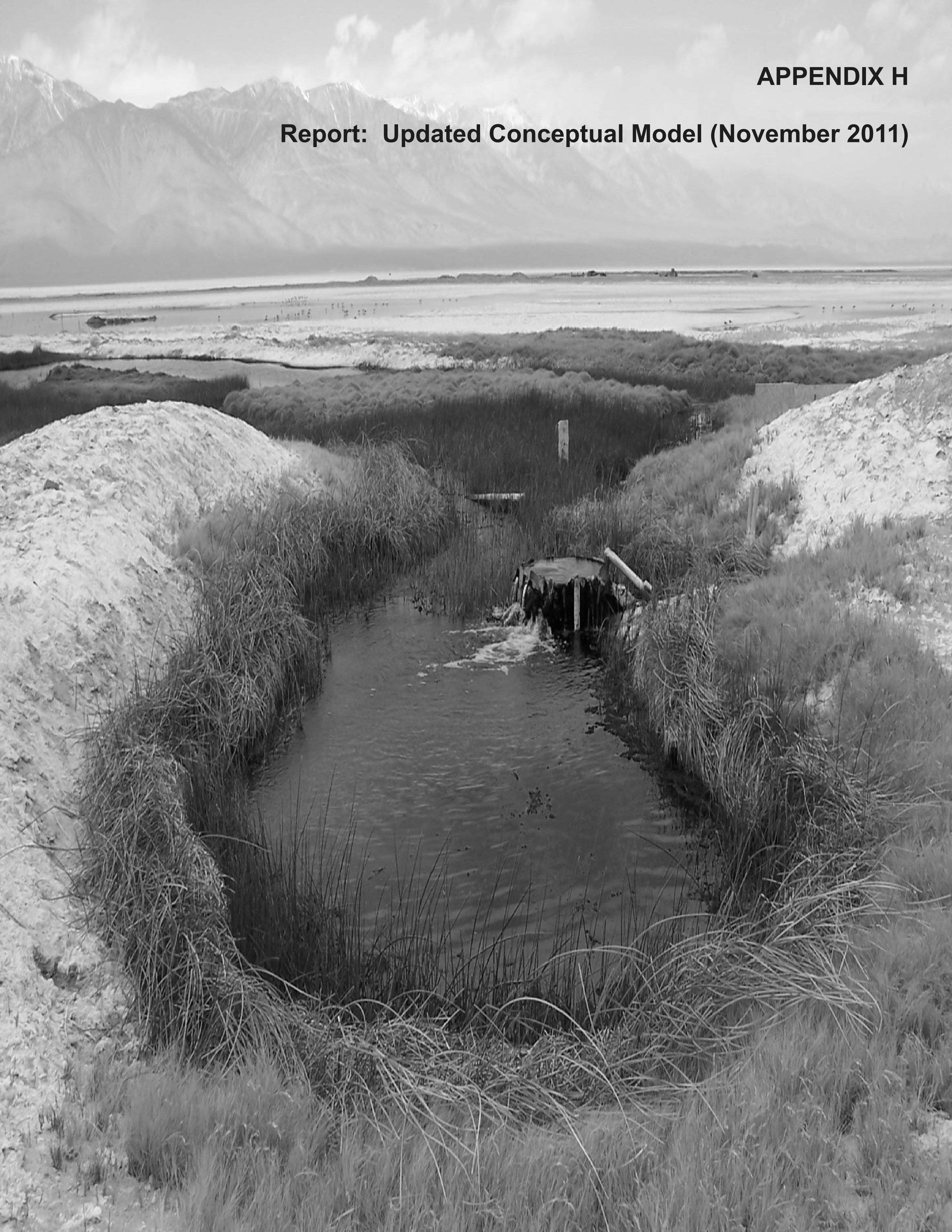
APPENDIX H

Report: Updated Conceptual Model (November 2011)



Owens Lake Groundwater Evaluation Project

Updated Conceptual Model Report - FINAL

November 2011

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LIST OF ACRONYMS AND ABBEVIATIONS

AF	Acre-feet
AF/yr	Acre-feet per year
Basin	Owens Lake Basin
cfs	Cubic feet per second
DCM	Dust Control Measure
DRI	Desert Research Institute
DVFT	Down Valley Flow Test Site
DWP-x	OLGEP monitoring well site designation
ET	Evapotranspiration
fbgs	Feet below ground surface
fmsl	Feet above mean sea level
GBUAPCD	Great Basin Unified Air Pollution Control District
GIS	Geographic Information System
GMS	Groundwater Modeling System
gpm	Gallons per minute
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
LPN	Lakewide Piezometer Network
mg/L	Milligrams per liter
MODFLOW	Modular, Three-Dimensional Finite-Difference Groundwater Flow Model
MWH	Montgomery Watson Harza
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)
Q	Flow
s	Drawdown
SFIP	South Flood Irrigation Project
T	Transmissivity
TDS	Total Dissolved Solids
uS/cm	MicroSiemens per centimeter
UTM	Universal Transverse Mercator
˚ C	Degrees Celsius

EXECUTIVE SUMMARY

Under Agreement 47830 with the Los Angeles Department of Water and Power (LADWP), MWH Americas, Inc. (MWH) has been tasked with completing the Owens Lake Groundwater Evaluation Project (OLGEP). The project began in March 2009, and consists of nine 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

7 – Develop and Implement a Public Outreach Plan

8 – Project Meetings and Final Report

9 - Evaluation of Geophysical Data

Tasks 1, 2, 3, and 9 have been completed. Task 2 consisted of compiling a preliminary conceptual hydrogeologic model based on existing data, and identifying gaps in existing data. Task 3 and 9 were designed to fill existing data gaps identified in Task 2.

The focus of this TM is Task 4, which involves utilizing the data collected in Tasks 3 and 9 to revise and update the conceptual model, and is the subject of this Technical Memorandum (TM). The updated conceptual model is based primarily on the following:

- Newly-acquired data from the OLGEP Task 3 drilling and monitoring well installation program conducted in 2010 through 2011
- Detailed interpretation of surface seismic data evaluated under Task 9, 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"
- 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 has 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 is expected to lead in turn to improved numerical modeling in subsequent tasks.

This TM does supplements information presented in the preliminary conceptual model and summarizes the significance of new information and resulting changes to the preliminary conceptual model. Key findings of the revised conceptual model include:

Stratigraphy. Detailed analysis of surface seismic data, used in conjunction with borehole geophysical data allowed for the delineation of 10 separate stratigraphic sequences that have been traced over most of the OLGEP study area. Three-dimensional surfaces for these sequences were developed that are directly applicable to numerical model layering.

Depositional Environment. Comparison of the stratigraphic sequences to lithologic logging has allowed for identification of several transgressive and regressive events occurring during the infilling of the Owens Lake Basin. Significant thinning of sedimentary features has been identified where lakebed sediments lapped up against bedrock during deposition. A deep synclinal feature has been identified in the western portion of the basin that was the center of deposition of the ancestral Owens Lake.

Structural Geology. Several major fault zones have been identified both in planar and cross-sectional view. Estimation of displacement along these faults evident in the seismic data will allow for relative estimation of the extent to which these faults affect groundwater flow. These features were not accounted for in previous groundwater modeling. In addition, post-depositional folding of beds has been identified and mapped.

Bedrock Depth. The depth to bedrock in the eastern portion of the Basin has been mapped based on the combination of drilling and seismic data. This bedrock surface was not identified in previous work.

Variation of Groundwater Head at Depth. The installation of zone-specific screened intervals in new monitoring wells allows for detailed evaluation of vertical gradients throughout most of the study area. This data will allow for calibration of the numerical model to more closely simulate actual conditions. In addition, contours of equal head at discrete stratigraphic intervals with depth has allowed for characterization of flow directions in deeper zones. This information confirms that the basin is a closed basin with no outflow from the basin to the south, even in deeper sediments.

Aquifer Parameters. Pump testing at each of the new OLGEP monitoring wells allowed for estimation of transmissivity and hydraulic conductivity in discrete aquifer zones. Selected core sampling of aquitard materials at depth will allow for more accurate parameterization during subsequent groundwater modeling.

Previously Unidentified Deep Aquifer. The drilling program for the OLGEP project was conducted to maximum depths of 1,600 feet, whereas previous borehole information is generally limited to less than 1,000 feet. This deeper drilling has allowed for identification of previously unidentified deep aquifer (generally deeper than 1,000 feet) that is interpreted to represent flood plain deposits deposited prior to the existence of Owens Lake.

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 in the basin is in the range of 45,000 to 67,500 acre-ft per year. The total inflow/outflow is similar to what was estimated in previous studies; however, new evidence is presented on the refined locations of recharge and discharge based on new data and re-interpretation of existing data, which in turn will be particularly useful for development of the groundwater model.

Effects of the Lower Owens River Project (LORP) and Dust Control Measures (DCMs) on Study Area Water Budget. Detailed analysis hydrographs of pre- and post LORP and DCM time periods indicate 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.

Surface Water/Groundwater Interaction. Based on 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.

Groundwater Quality. Analysis of groundwater samples from new monitoring wells completed at a variety of depths in the OLGEP study area allow 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.

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 that create the springs as either "shallow" or "deep."

1.0 Introduction

Under Agreement 47830 with the Los Angeles Department of Water and Power (LADWP), MWH Americas, Inc. (MWH) is conducting Task 4 – Update Hydrological Conceptual Model for the Owens Lake Groundwater Evaluation Project (OLGEP). This updated conceptual model is based primarily on the following:

- Newly-acquired data from the OLGEP Task 3 field program conducted in 2010-11,
- Results and cross sections developed as part of the OLGEP Task 9 "Evaluation of Geophysical Data for Incorporation into the OLGEP",
- Results and lessons learned from development of a groundwater model in the northern portion of the study area commonly called the “Southern Model”,
- Detailed review and re-analysis of the water budget for the OLGEP study area, and
- Detailed review of available data on springs and seeps for the purposes of characterizing the nature and source of spring flow.

This report describes how the understanding of stratigraphy, structural geology, groundwater conditions, and sensitive resources in the OLGEP study area, as shown on **Figures 1** and **2**, has been improved as a result of the field work, geophysical evaluation, and subsequent analysis. This work does not repeat work conducted to develop the preliminary hydrogeologic conceptual model under Task 2 efforts (MWH, 2011a); rather, it focuses on the significance of Task 3 field efforts and Task 9 geophysical analysis in updating the conceptual model. This report represents the deliverable for Task 4.

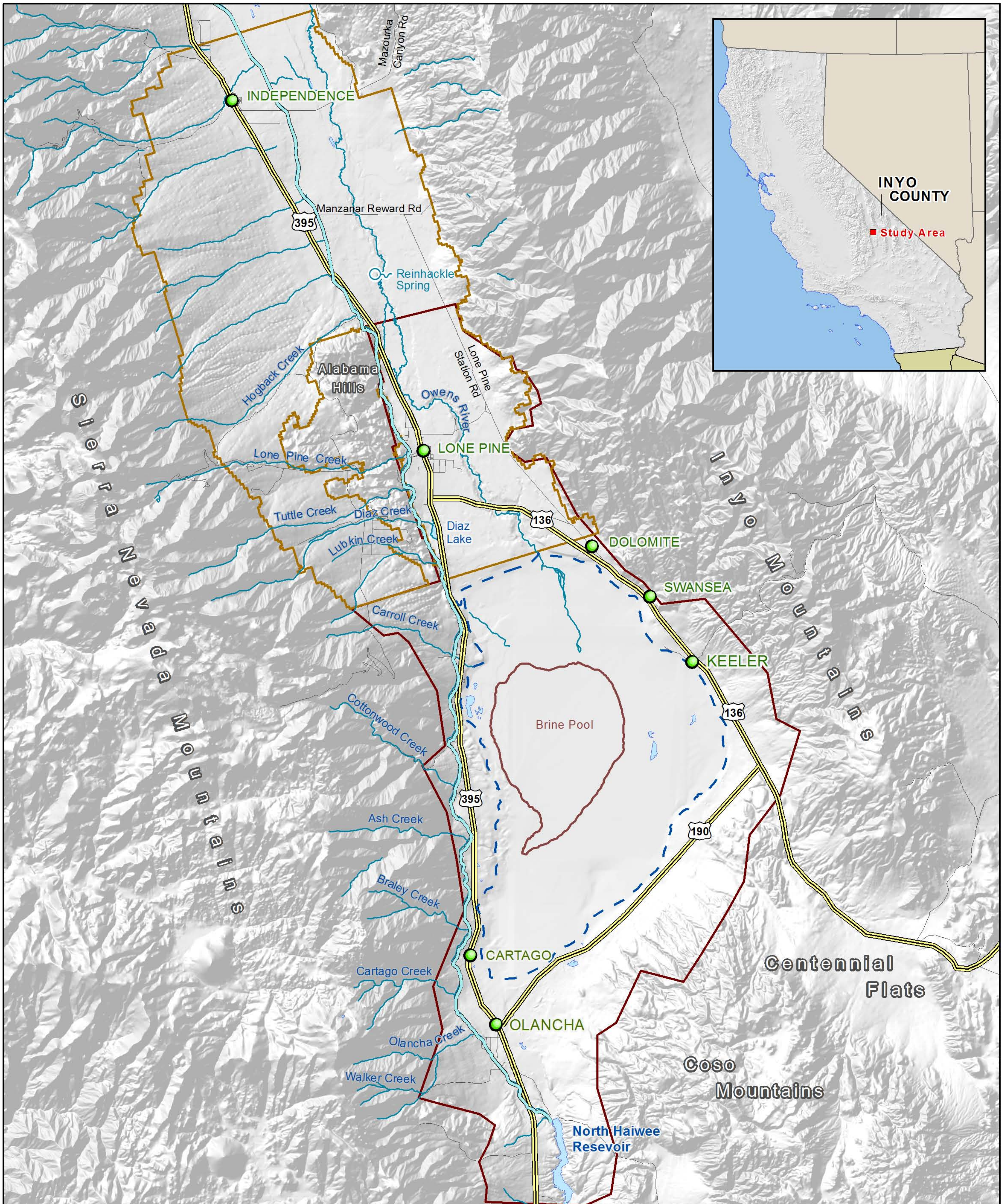
2.0 Summary of Recent Work

This section provides a summary of the field program and provides details on new data collected. In addition, this section describes the geophysical evaluation and interpretation.

2.1 Well Installation Field Program

A primary mechanism to address data gaps identified in the preliminary conceptual model (MWH, 2011a) was the installation and testing of groundwater monitoring wells. New monitoring wells were completed at ten (10) sites in OLGEP study area as shown on **Figure 2**. New monitoring wells provide valuable information on the hydrostratigraphy, structure, and water quality of the aquifers underlying the OLGEP study area. In addition, the new monitoring wells will serve as future observation points for both future aquifer testing and monitoring of the effects of potential future groundwater production.

A consistent theme of previous studies in the OLGEP area is that a lack of information on the hydrostratigraphy of deep sediments has hindered the understanding of deep aquifer flow, and potential interaction of deep and shallow aquifers. Similarly, the water quality and piezometric head of specific individual aquifers has often been cited as a data gap. Therefore, monitoring wells were completed at each site with multiple casings in dedicated boreholes in specific aquifers (including deep aquifers). Well completion reports which detail the as-built configurations of the monitoring wells, lithologic and geophysical logs, pump testing, and groundwater quality are provided in MWH (2011b).



Key to Features

- Towns
- Aqueduct
- Highways
- Roads
- Rivers and Streams
- Owens Lake (Historic Shoreline)
- Southern Model Domain
- OLGEP Study Area

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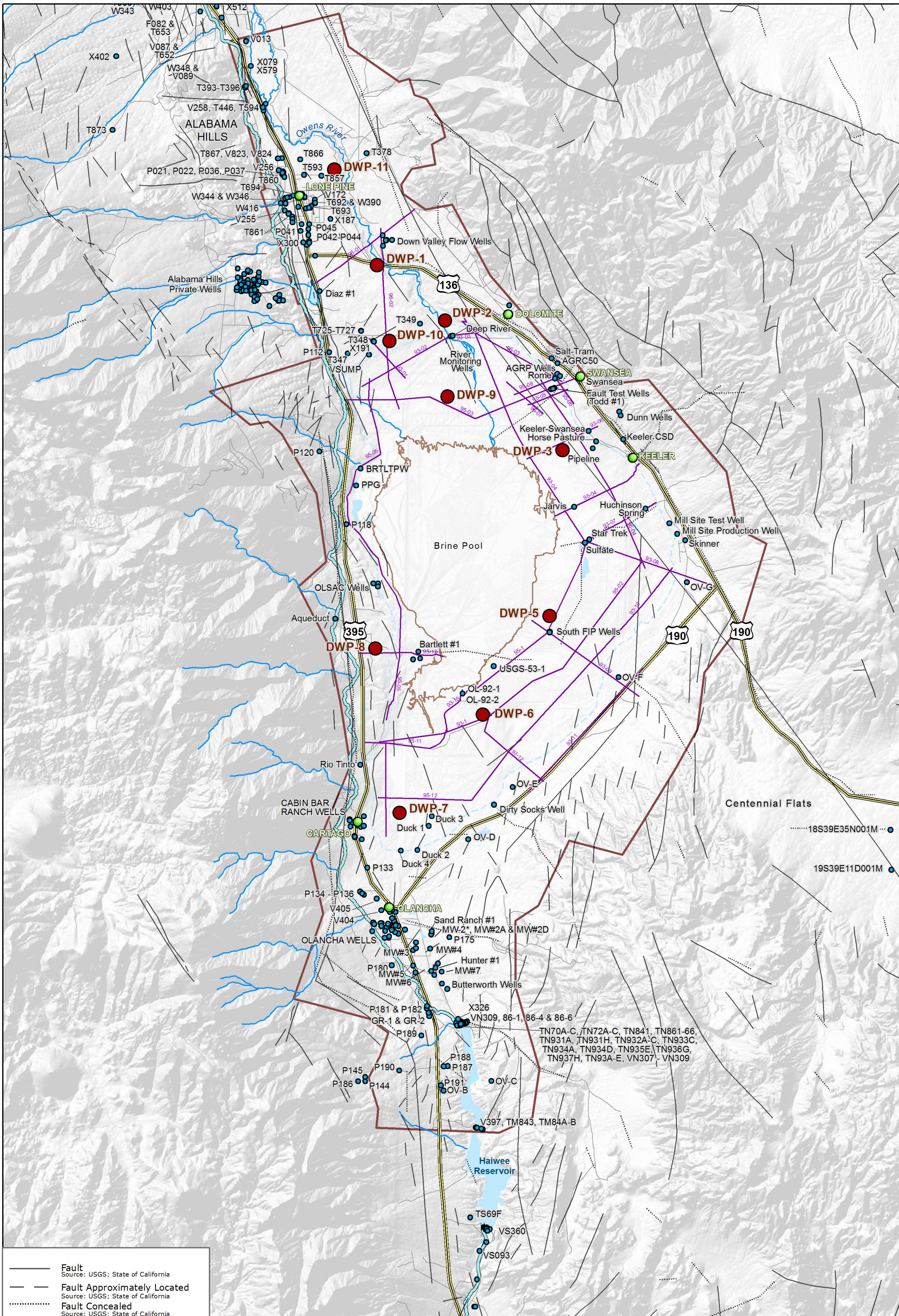
Conceptual Model for Owens Lake Groundwater Evaluation Project

Study Area Location Map

Figure 1

Los Angeles Department of Water & Power

MWH



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

0 2 4 Miles

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Study Area Map Showing the Location of Seismic Lines and Wells

Los Angeles Department of Water & Power

Figure 2

MWH

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

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

- After setup and installation of conductor casing, a borehole was drilled to approximately 1,500 feet below ground surface.
- 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 (4) soil samples from four (4) 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.
- A well completion report was prepared for each well and are compiled collectively in MWH (2011b).

Detailed information on well completion can be found in the well completion reports. A summary table for the newly-installed OLGEP wells is provided as **Table 1**, and includes the pertinent following information:

- Well Site (i.e., DWP-1)
- Well Identification
- Location (latitude and longitude)
- Well Construction:
  - Reference Point
  - Total Depth
  - Screened Interval
  - Screen Length

Table 1
Master Well Table for 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	3,572.10	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	3,572.39	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	3,572.22	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				1,500	1,220 - 1,260	40	5	59	25.8	May-11	24.5	2.4	912	23	765	19	
	T917				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.

- Aquifer Unit
- Pumping Rate
- Static Water Level
- Maximum Drawdown
- Specific Capacity
- Estimates of Transmissivity
- Estimates of Hydraulic Conductivity

Subsequent to the field installation program, a quarterly groundwater level monitoring program was designed and implemented by LADWP staff.

2.2 Evaluation of Geophysical Data for Incorporation into OLGEP

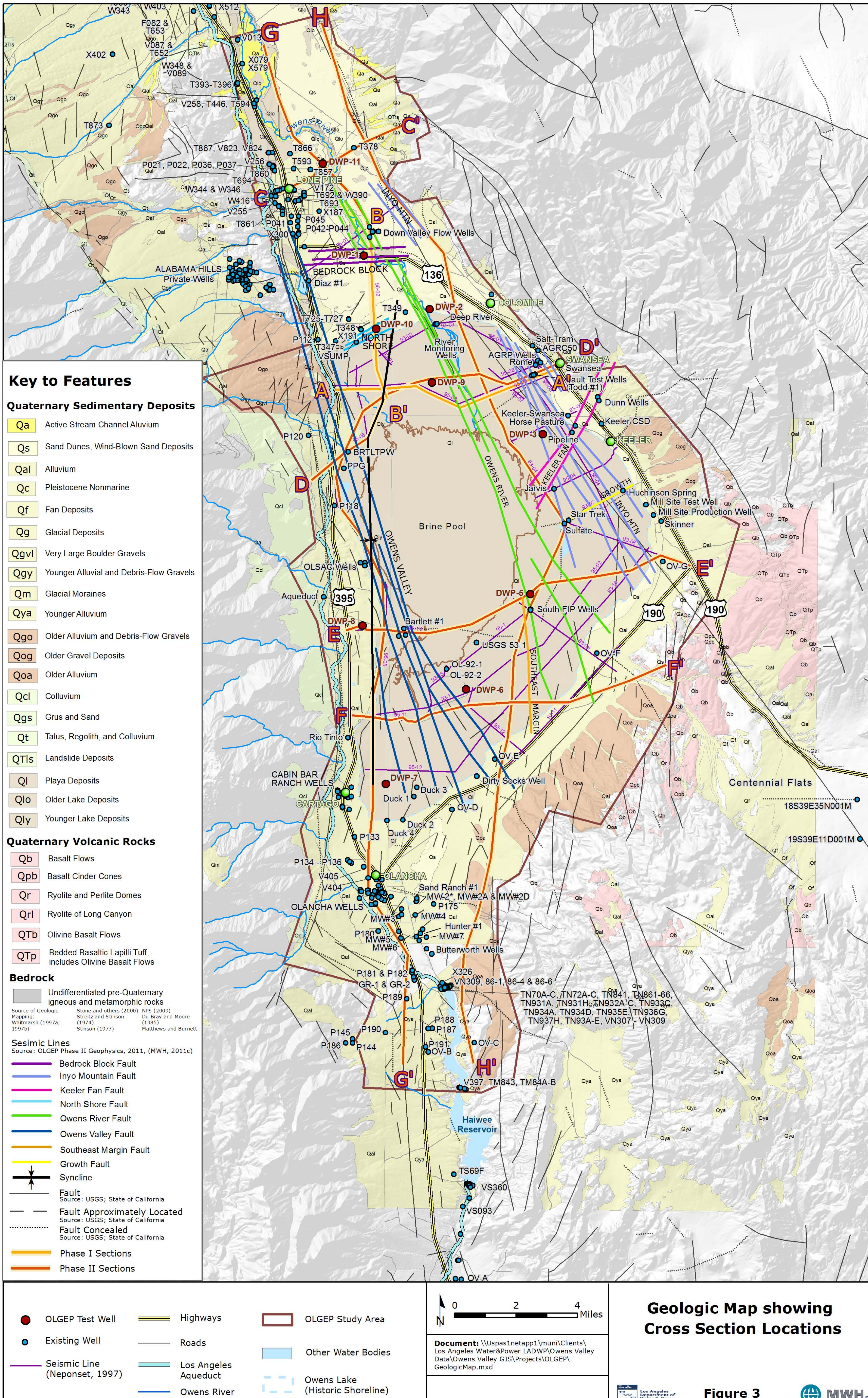
As part of Task 401.1.9, MWH conducted an evaluation of geophysical data for incorporation into the OLGEP as described in MWH (2011c). Seismic reflection data at Owens Lake were acquired by Neponset Geophysical Corporation and Aquila Geosciences, Inc. at Owens Lake for GBUAPCD (Neponset, 1997; 1999). A total of about 120 line-miles of data were collected in the period of 1992 through 1997. The location of seismic lines is shown on **Figure 2**. The objective of the seismic reflection program was to develop an understanding of the geologic history of the Owens Lake sedimentary basin.

Under Task 401.1.9, the seismic data was combined with geophysical logs from existing study area wells and new OLGEP wells to create a fully integrated body of geophysics for the study area for analysis and interpretation. Products produced by this study included multiple seismic sections at locations shown on **Figure 3**. The geophysical study was implemented in two phases, whereby Phase I produced cross sections A-A' and B-B' and Phase II produced cross sections C-C' though H-H'. The tops and bottoms of each stratigraphic unit was identified. In addition, three-dimensional surfaces of key geologic horizons over the entire study area were generated for use by the numerical groundwater model. The detailed approach and findings of this work is documented in MWH (2011c).

The geophysical work demonstrated that the combination of seismic data 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. Interpretation of the data lead to several important conclusions regarding the hydrogeologic conceptual model of the OLGEP study area. These findings are discussed in the following sections on stratigraphy and structural geology.

3.0 Stratigraphy

This section provides an interpretation of depositional history followed by an updated interpretation of the hydrostratigraphy.



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Geologic Map showing Cross Section Locations

Los Angeles Department of Water & Power

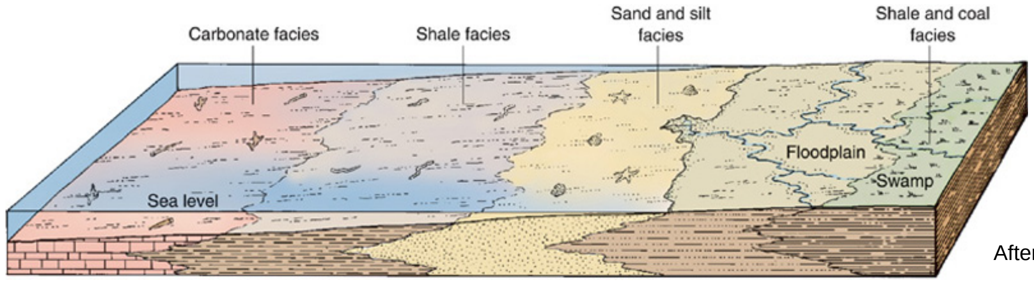
Figure 3

MWH

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

3.1 Depositional History

The combination of interpretation of seismic reflection data, borehole geophysical data, lithologic logs, and geologic maps results in a relatively vivid picture of the depositional history of the Owens Lake Basin (Basin). To interpret the history of deposition, it is helpful to evaluate sedimentary facies that are currently present at the lake. Understanding the depositional history of the OLGEP study area will greatly improve numerical model parameterization model calibration. **Figure 4** is a schematic representation of typical facies present in along an ocean shoreline. Facies present at Owens Lake are similar to those shown in **Figure 4**, except that muds, silts, and organic deposits are found in place of carbonates, shale, or coal, respectively.



After Levin, 2005

Figure 4
Schematic Representation of Typical Facies Present along an Ocean Shoreline

Note that at any particular time period, sediments become finer toward the depositional center, which is generally assumed to be the center of the lake. In the nearshore submerged environment, benthic organisms such as gastropods may be found. In the beach environments, sediments are well sorted and may contain oolites due to wave and wind action. In the floodplain or delta subaerial environment, extensive organic material may be present due to shallow fresh groundwater and sunlight. Further landward, fluvial deposits and bajadas may exist that interfinger with the lacustrine deposits.

As the lake level changes through time, the deposition of sediments is altered as the shoreline moves laterally. **Figure 5** depicts the deposition of sediments as the lake level rises, or "transgresses". As the water level rises and deposition is continuous, sediments are deposited in a fining-upward sequence, and a sequence that represents a successively deeper depositional environment. If the lake level drops (or regresses), the reverse is true, whereby a coarsening upward sequence is found. Deposition follows the receding waters, creating progradational deposits, i.e.- the delta is extending progressively further into the lake because water level is either static or retreating.

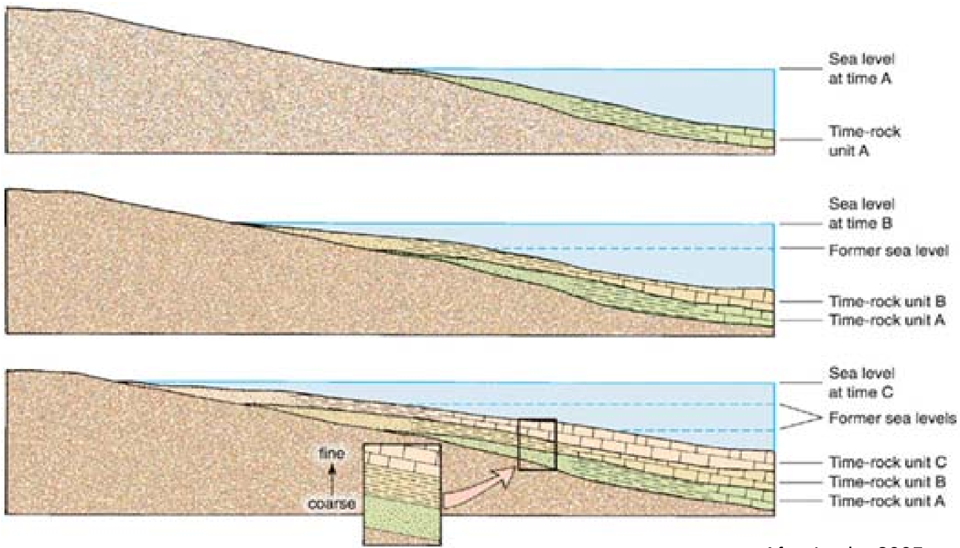


Figure 5
Schematic Showing the Deposition of Sediments as Lake Level Transgresses

Accommodation space is a term used to describe the volume available for sediment deposition. To a first approximation, the volume of Owens Lake at any given water level would be the accommodation space. The accommodation space will vary due to changes in lake level due to runoff and/or tectonic activity which affects the lake level relative to the existing sediments. Changes in accommodation space can be a complex interaction of infilling sediments, climactic changes, and tectonic movement. The depositional patterns reflect this interaction.

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 cannot be resolved based the seismic data nor have any boreholes encountered in wells on the west side of the basin.

Combining the well data and seismic data, 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. By combining the seismic and well data, it is possible to draw insights into the depositional character of the aquifers.

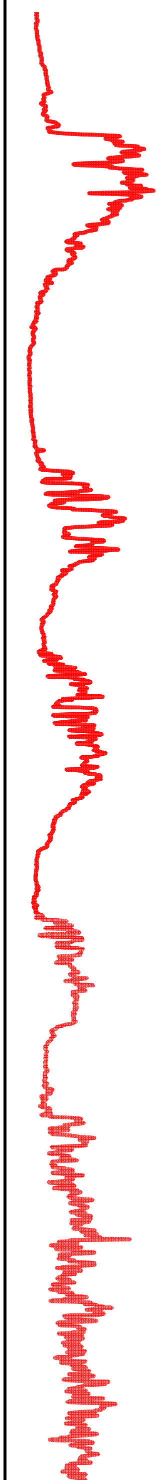
The geophysical and lithologic data in the delta area provides evidence of a pre-lake period of deposition of flood plain or braided stream deposits, then the first evidence of the lake being formed, followed by at least four regressive events where lake levels dropped (separated by transgressive events). **Figure 6** illustrates the depositional sequence at DWP-9, showing correlation between lithologic observations, resistivity, and interpreted depositional environment. This pattern is remarkably recognizable in many of the boreholes in the study area.

Figure 6

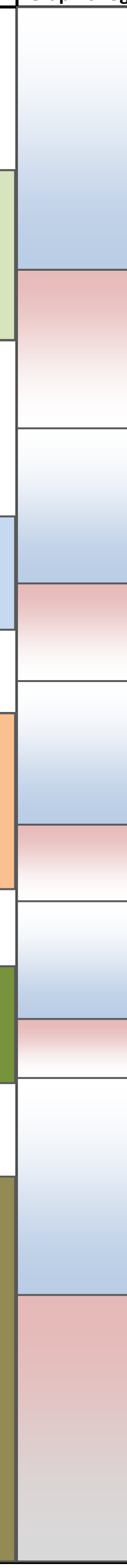
Lithology, Resistivity and Interpreted Depositional Environment for DWP-9 (T896)

Depth (ft)	Typical Lithology Interpretation	Interpreted Depositional Environment	Aquifer
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			Aquifer 1 (Lt Grn)
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			Aquifer 2 (Lt Blu)
625			
650	Silty sand with clay -decayed organic matter	Delta	
675			
700			
725	Grey silty clay	Deeper lacustrine	
750			
775			
800			
825			Aquifer 3 (Org)
850	Silty sand with gravel	Delta deposits	
875			
900			
925	Grey silty sand	Nearshore lacustrine	
950			
975			
1000	Grey clay	Deeper lacustrine	
1025			
1050			Aquifer 4 (Drk Grn)
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			Aquifer 5 (Brn)
1400			
1425	Silty sand with trace of gravel	Braided stream	
1450			
1475			
1500			
1525			
1550	Silty sand	Braided stream	
1575			

Resistivity Log



Graphic Log



- No lake – prior to lake development
- Transgressive sequence – lake levels rising, sediments fining upwards
- Regressive sequence – lake levels dropping – sediments coarsening upwards

While seismic data provides evidence of depositional environment and patterns, the seismic data does not directly provide meaningful information on differing hydraulic properties. This information comes primarily from borehole geophysical logs and lithologic logs based on drilling cuttings. The primary value of the seismic data is to provide a means to correlate the various sequences from well to well and to provide information in three dimensions where drilling data is absent.

3.2 Updated Interpretation of Hydrostratigraphy

Whereas sedimentary facies previously discussed are a result of the depositional environment in which the sediment was deposited, hydrostratigraphy refers primarily to the hydraulic properties of the sediments, such as hydraulic conductivity and storage coefficient. It is the hydrostratigraphy that is of most interest in groundwater modeling because it is the hydraulic characteristics of the sediments that will control groundwater flow. However, because in many cases the depositional environment has a strong influence on hydraulic characteristics, the various sedimentary facies discussed previously translate well into hydraulic properties. For example, deeper lacustrine deposits of clay have very low hydraulic conductivity resulting in an aquitard, whereas beach deposits or delta deposits may have relatively high hydraulic conductivity, resulting in a potentially productive aquifer.

It is important to note that stratigraphic sequences are not universally synonymous with aquifers or aquitards. A stratigraphic sequence is a depositional episode in which all source material (ranging from coarse to fine material) is deposited depending on the depositional facies. Assuming water supply is not limited, material is laterally distributed based on the energy, or velocity of the water or wind. A stratigraphic sequence will contain the full range of sediment size from coarse to fine. The lateral and vertical distribution of the layers will be genetically linked by the depositional processes in place at the time of deposition, and the lithology at any specific location cannot be determined from the seismic data alone. Borehole lithologic or geophysical data are required to identify lithology and lithologic trends within each sequence.

This section provides a summary of the updated hydrostratigraphy of the study area. As described in the preliminary hydrogeologic conceptual model (MWH, 2011a), previous work identified four (4) deep confined aquifers in the Owens River delta area comprised of sands and silty sands, separated by low permeability clay units of variable thickness. The field investigation and geophysical evaluation were successful in filling critical data gaps as follows:

- **Elevation of Top and Bottom of Each Confined Aquifer**. Previous to the geophysical data interpretation, the complex stratigraphy of the deep aquifers has made correlation of lithologic and geophysical logs challenging, and sometimes inconsistent with the surface geophysical interpretations. OLGEP work has identified the tops and bottoms of each aquifer unit which facilitates generation of three-dimensional surfaces of each unit throughout much of the study area.

- **Deeper Confined Aquifer below Aquifer 4**. There has been relatively little exploration below a depth of 1,000 feet. The OLGEP monitoring wells were drilled to 1,500 and identified a fifth deep confined aquifer.

- **Aquifer Characteristics**. The hydrogeologic framework of the study area has evolved with the progression of previous work. This framework has been re-interpreted based upon new data from drilling coupled with a interpretation seismic data.

Eight cross sections were developed as part of the geophysical study to display the interpreted stratigraphy of the Basin. These cross section locations are shown on **Figure 3**. Cross sections are presented as **Figures 7** to **14** (Cross Sections A-A' through H–H'). 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. 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.

Five (5) 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”. The following observations can be made:

- Aquifer 1 is the shallowest aquifer, characterized by a lithology of relatively well-sorted coarse sands and gravels in the 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 of the aquifer. 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 of the aquifer. 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.

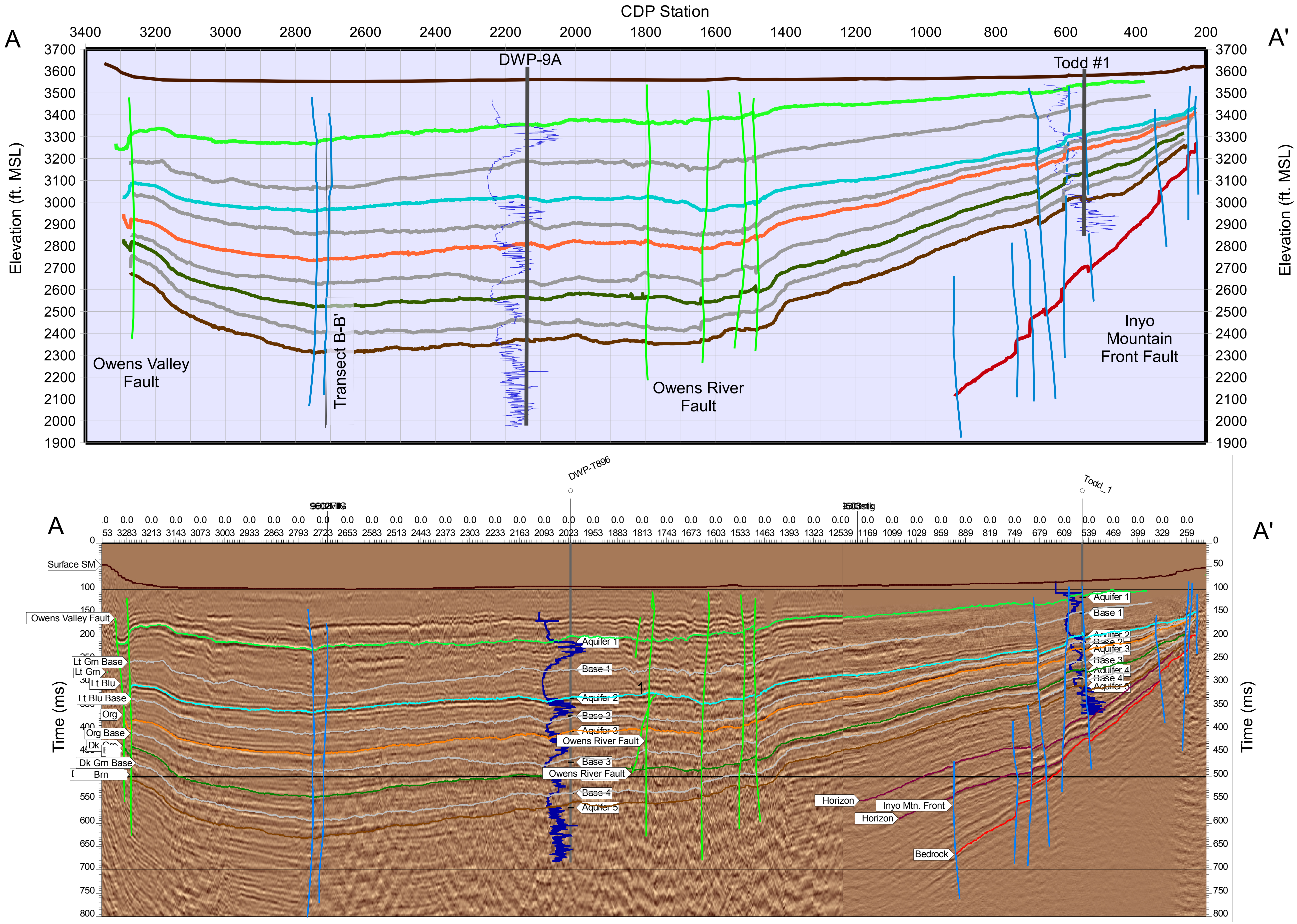


Figure 7: Cross Section A-A' interpreted depth section (top) and migrated time section (bottom). Sequence boundaries are shown in colors, and clays are shown in gray. Bedrock is shown in red. Wells are shown with guard logs overlaid in blue.

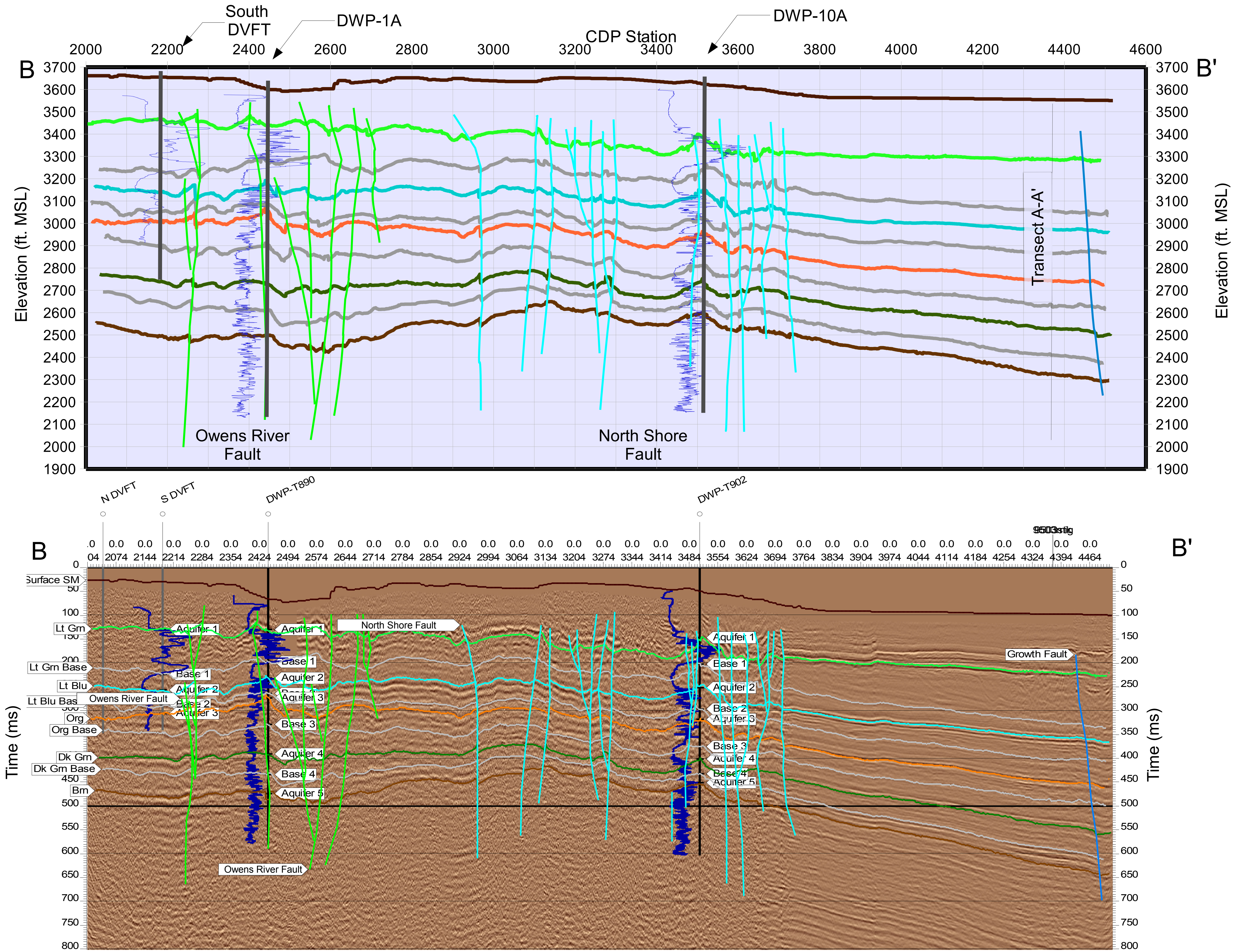


Figure 8: Cross Section B-B' interpreted depth section (top) and migrated time section (bottom). Sequence boundaries are shown in colors, and clays are shown in gray. Wells are shown with electric logs overlaid in blue. Guard logs are displayed at DWP-1A and DWP-10A. South DVFT is a 64-in electric log.

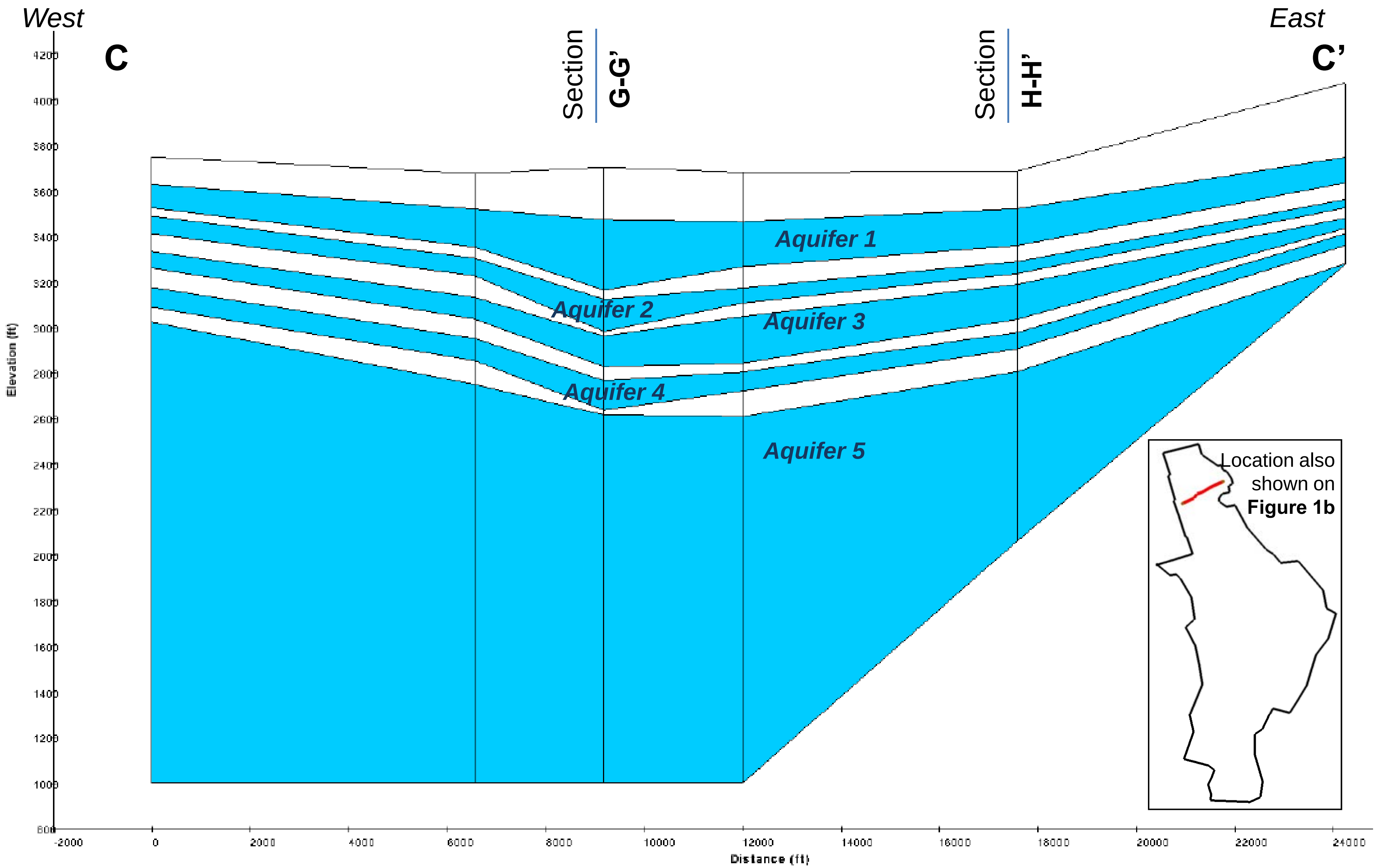


Figure 9
Cross Section C-C'

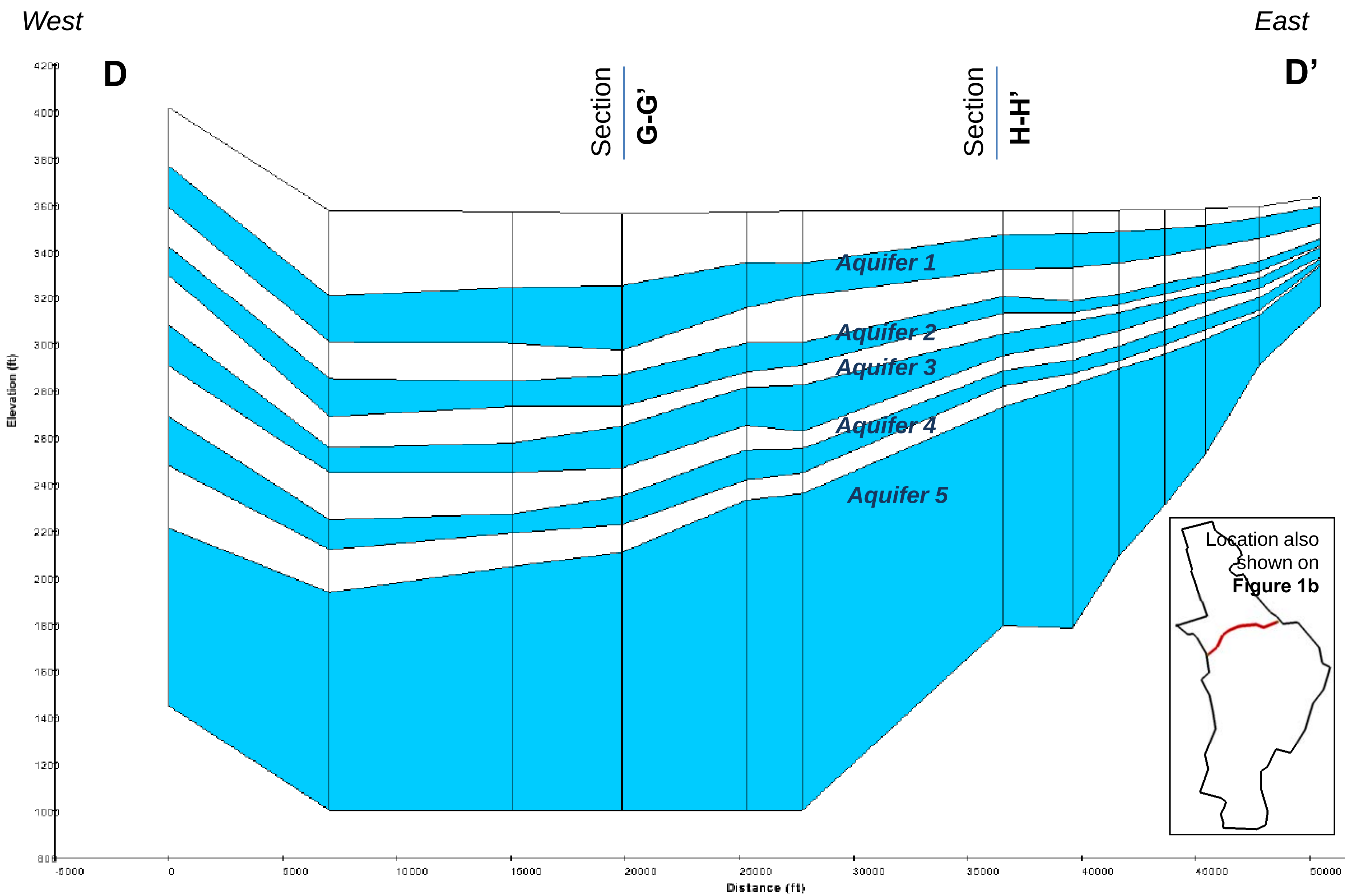


Figure 10
Cross Section D-D'

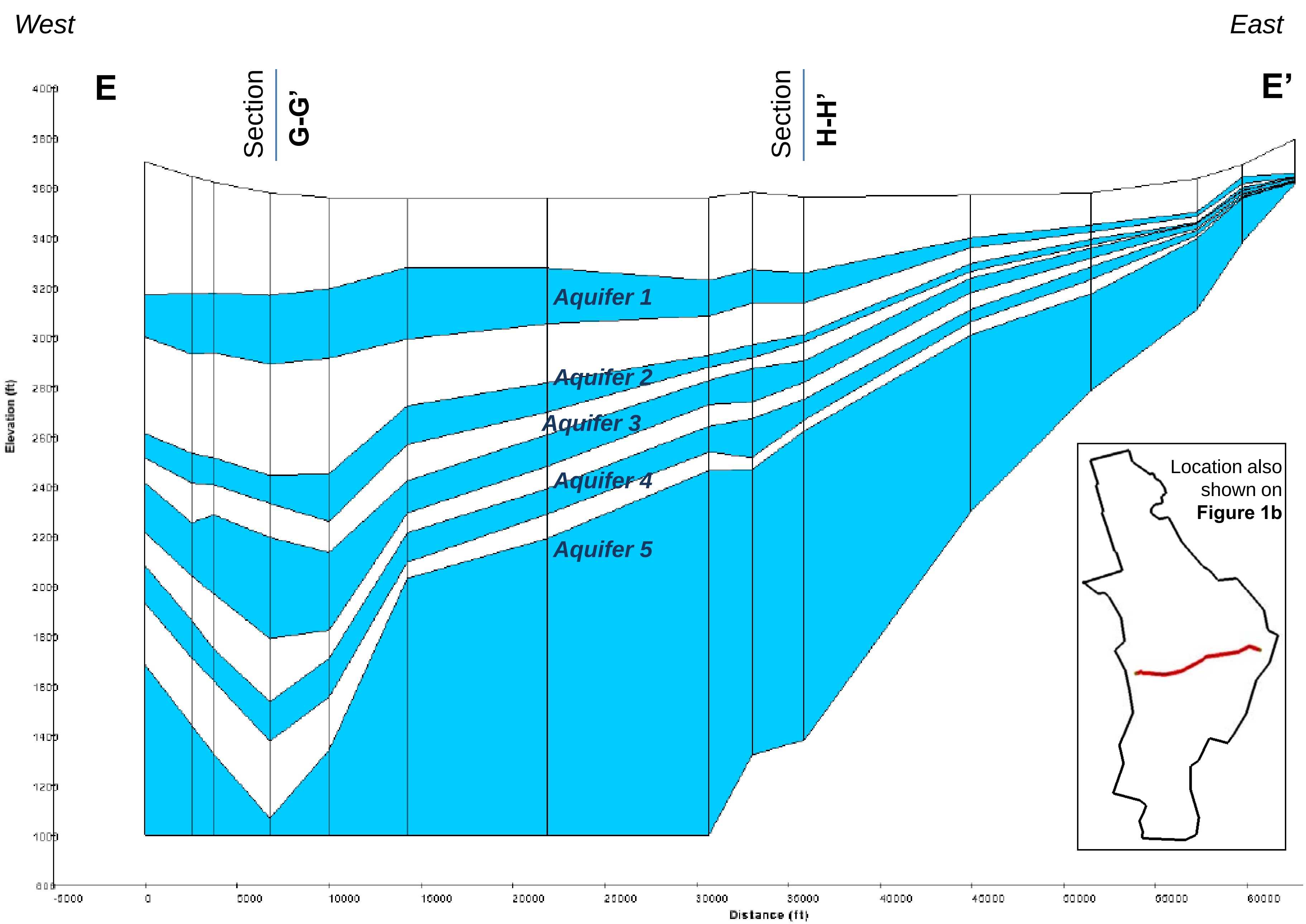


Figure 11
Cross Section E-E'

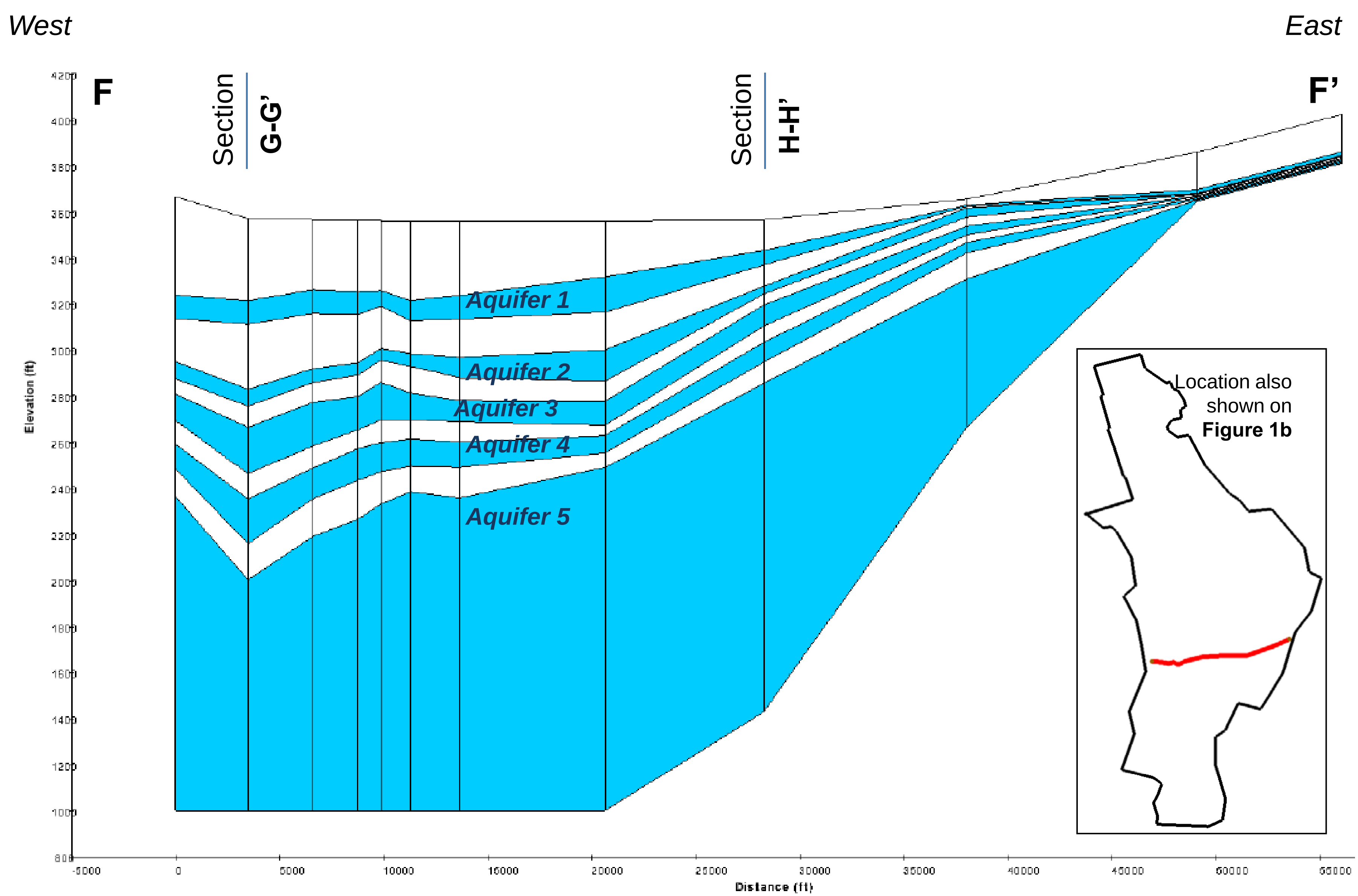


Figure 12
Cross Section F-F’

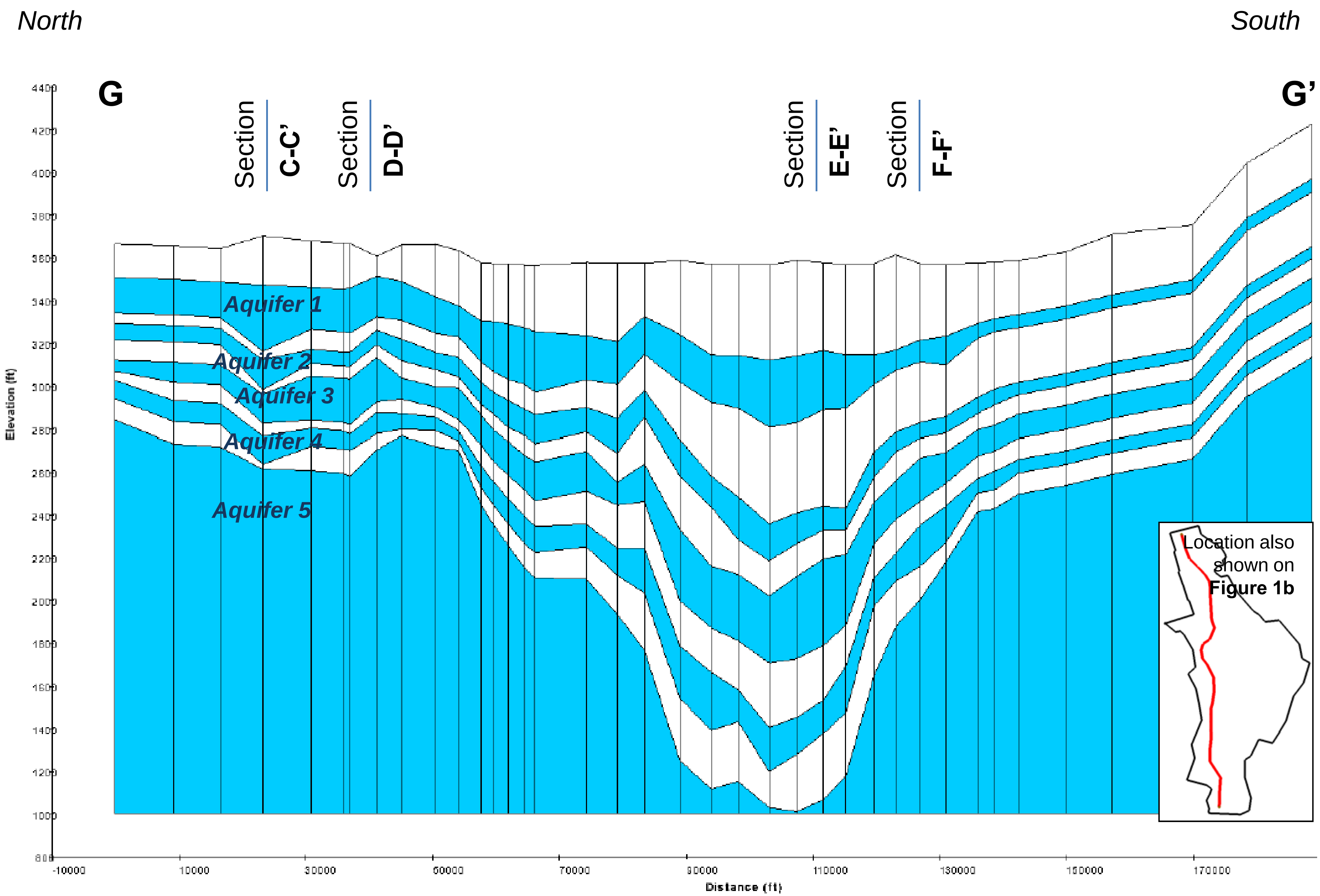


Figure 13
Cross Section G–G’

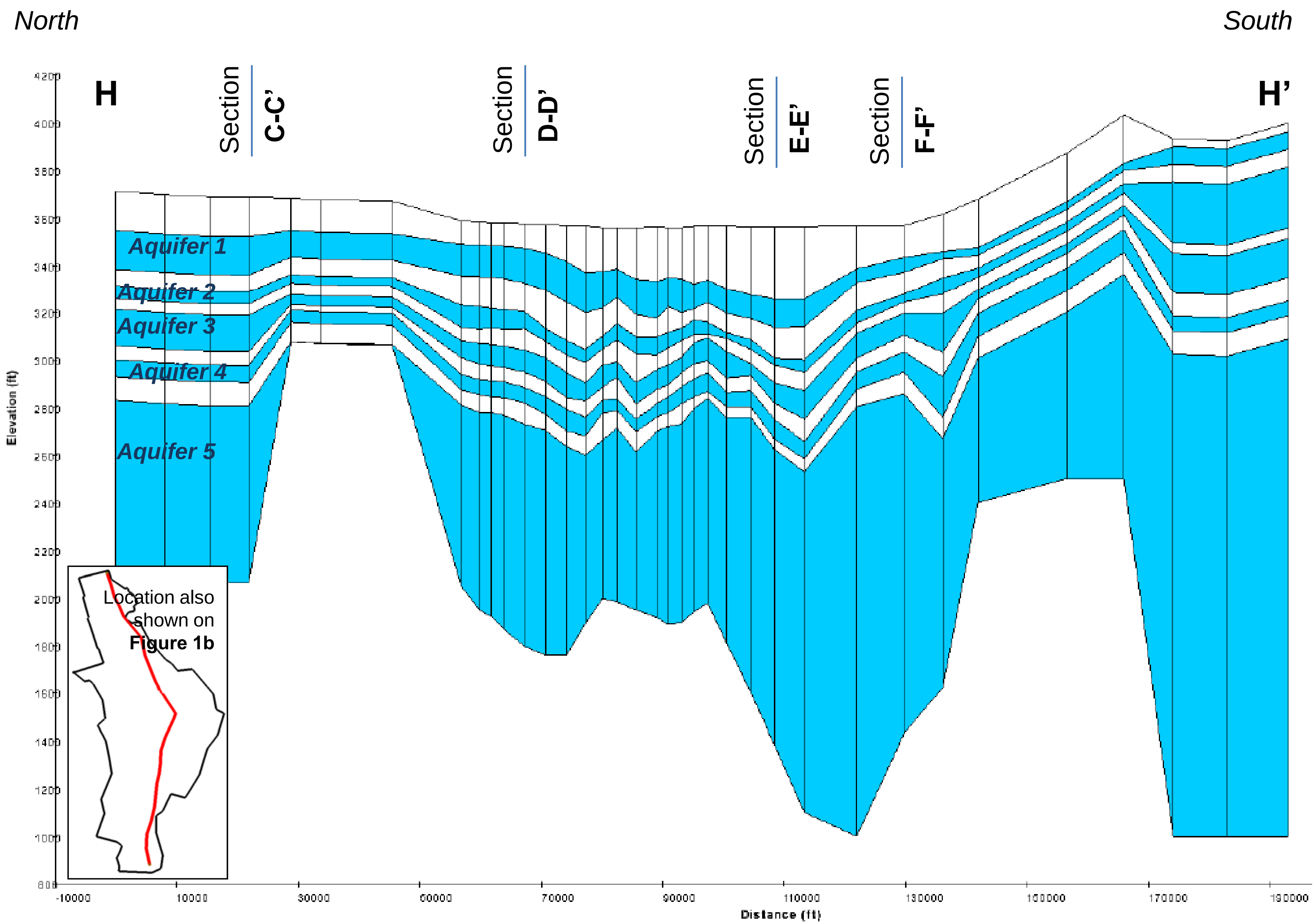


Figure 14
Cross Section H-H'

The stratigraphic units are not expected to have the same hydraulic properties or lithology laterally across the study area. Thus, they do not necessarily represent the same hydraulic properties from point to point. Even though the seismic reflections are relatively consistent, the hydraulic properties and lithology are not. Nevertheless, the correlation of sequence boundaries to lithologic and borehole geophysical data shows a strong *relative* correlation of expected hydraulic conductivity.

Because the stratigraphic sequences reflect the structure of the basin very well, they represent an obvious method to develop numerical model layering. Results of this work will directly contribute to the layering strategy to be used by the numerical model.

4.0 Structural Geology

A key benefit of the geophysical data review was the ability to map subsurface faults in the study area. This section describes the structural geology based on the results of the geophysical evaluation. Information presented is an updated interpretation to that presented in Neponset (1997;1999) and MWH (2011a).

Owens Lake is located in a strike-slip pull-apart basin, and the faulting tends to be high angle (Johnson and others, 1999). Vertical displacement along these faults was estimated from the depth sections created under the Task 401.1.9 Geophysics work. In a strike-slip basin, faults may be hydraulically significant but may not have significant vertical offset. These faults and fractures can play a significant role in groundwater flow, which has not been incorporated into previous models. Geophysics was used to identify diffraction patterns that occur at faults, and then the locations of the faults were mapped.

Sequence boundaries are either an unconformity or correlative conformity that occurs at a change in the depositional regime. Therefore, a sequence boundary marks a horizon of uniform time. The five horizons that correlate to the top of the aquifer units are considered to be sequence boundaries. The sequence boundaries and base horizons provide a series of marker horizons that allow mapping of the basin geometry and structure.

The displacement observed across faults indicates faulting was syn-depositional (e.g., deposition occurred contemporaneously with structural displacement). The deepest part of the Basin is located near the Bartlett #1 Well on the west margin of the Basin. Johnson and others (1999) identified the Owens Lake as a right-lateral strike-slip pull-apart basin with the greatest accommodation space forming on the west margin. The seismic data shows a double plunging, asymmetric syncline with the north-south trending axis near the western shore of the lakebed (**Figure 3**). The syncline is bounded by faults on the west and east. Faults on the southeast margin appear to be splays of the larger faults terminating against the Coso Mountains.

4.1 Bedrock and Basin Geometry

Characterization of the bedrock boundary and basin geometry was improved by evaluation of seismic and drilling data as shown on **Figure 15**. Relatively shallow bedrock was found underlying the east side of the Basin. The synclinal features seen in the sequence boundaries reflect the form of the underlying bedrock. Bedrock in the western portion of the basin is deeper than can be resolved using the seismic data.

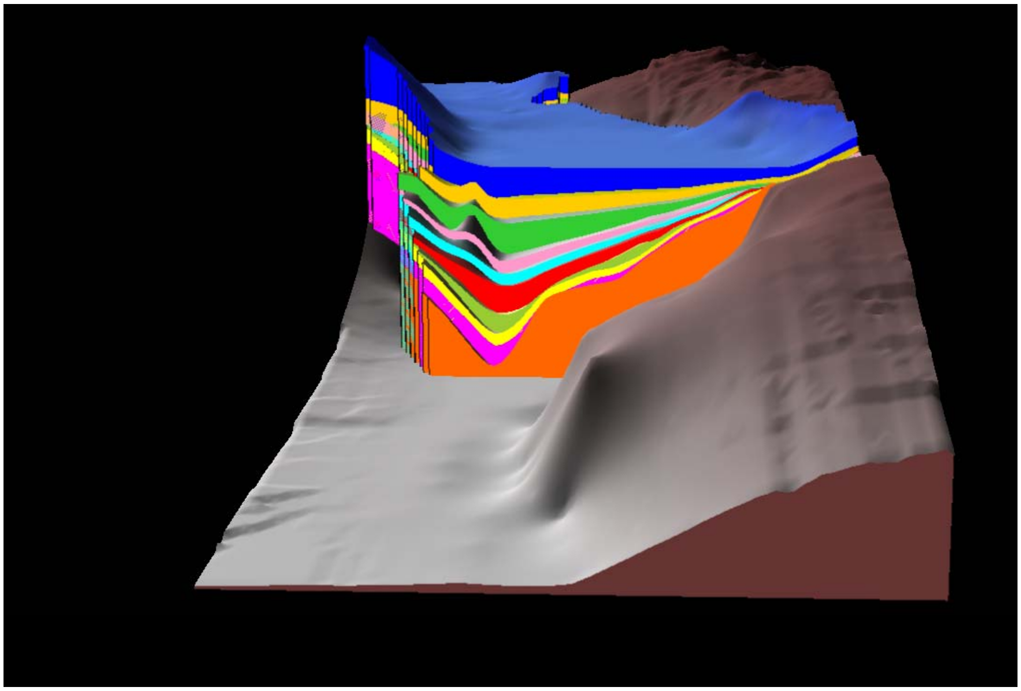


Figure 15
Conceptualization of Basin Geometry and Bedrock Boundary
(*view north along eastern margin of the Basin*)

Bedrock appears on the seismic sections on the northeast and east margins of the seismic coverage. Along the base of the Inyo Mountains, bedrock exhibits seismic reflections typical of sedimentary layering, consistent with the meta-sediments that comprise the Inyo Mountains (**Figure 3**). Bedrock was encountered in LADWP's recently-drilled Sulfate Facility well and at the DWP-3 site, at depths of approximately 526 and 975 feet, respectively. No wells were identified in the study area that penetrate a significant depth into the bedrock. Seismic reflections that show bedrock layering suggest lithologic contrasts exist in the bedrock that could be interpreted as variable depths of bedrock weathering, or the original layering of the now-metamorphosed sediments.

The bedrock surface is locally irregular, and tends to show more relief than the overlying sediments. As bedrock shallows, the mapped hydrostratigraphic sequences drape over bedrock and thin, pinch-out, or truncate against the bedrock.

Bedrock was not identified on the southwestern and western margin. Although bedrock may be evident on the seismic data, the seismic reflections are neither continuous with interpreted bedrock, diagnostically unique to bedrock, nor do any known wells in this area contact bedrock. As a result, the bedrock surface cannot be mapped with confidence on the southeastern or western margin of the Basin.

4.2 Fault Zones and Structural Features

Using the seismic data, a number of fault zones were mapped in the study area. 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 most significant faults or fault zones are listed in **Table 2** and shown in **Figure 3**.

Table 2
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.

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. **Figure 16** shows a close-up example of faulting with sufficient vertical offset to juxtapose aquifers and aquitards. In this figure, a fault near the South DVFT well offsets the aquifer units.

Faults that juxtapose sediments of low and high hydraulic conductivity are potential barriers to groundwater flow. Crushed material and clay gouge along the fault zones may further restrict groundwater flow. Conversely, fracturing and cracking of consolidated sediments may actually act as conduits or preferential pathways to groundwater flow (particularly vertical flow). Although seismic data does not allow for direct interpretation of the hydraulic impact of faults, it does allow for quantification of displacement that is not possible using borehole data alone. It is expected that the degree to which faults act as barriers is related to the degree to which fault displacement places relatively impermeable material adjacent to permeable aquifers. While juxtaposed aquifers are evident, the degree of juxtaposition generally does not extend laterally along the faults to adjacent seismic lines to the same degree.

Regardless of the hydraulic significance of faults in the Owens Lake area, knowledge of the exact location and approximate displacement will allow for more accurate modeling of groundwater flow as well as accounting for fault-related impacts in the calibration process. This will to result in a very significant improvement of previous modeling efforts, which did not incorporate the effect of faulting. The following sections provide a description of each major fault zone shown on **Figure 3**.

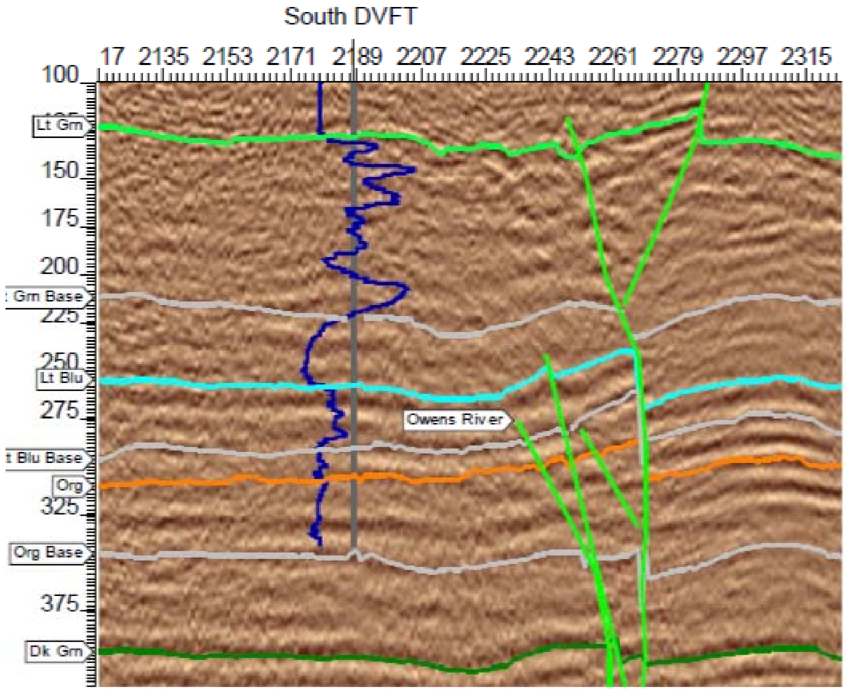


Figure 16
High-Angle Fault Downthrown to the South Showing Aquifer Juxtaposition

4.2.1.1 Owens Valley Fault

The Owens Valley Fault is a major fault zone along the western margin of the lakebed. Horizons are not continuous within the fault zone, implying extensive deformation. The fault is high angle with extensive deformation within the fault zone. At the south end of the lakebed the fault appears to splay, becoming a group of individual fault strands with stratigraphic definition still clearly evident within the fault zone.

4.2.1.2 Owens River Fault

This fault is located along the channel of the Owens River in the north and extending across the lakebed toward the southeast shore. At the northern part of the seismic coverage, the fault appears to be offset in a right-lateral sense by bedrock block faults. The Owens River Fault is interpreted to cross the lakebed and for the fault strands to splay at the southern end of the zone.

4.2.1.3 Inyo Mountain Front Fault

Located parallel to the northeast shore, the Inyo Mountain Front Fault Zone consists of a network of high-angle faults that appear to originate from bedrock. The bedrock faults propagate upwards into the overlying sediments. The general trend is that the individual faults are downthrown to the west. The bedrock rise and faulting creates a complex interaction of structural displacement with stratigraphic sequences thinning toward the east. Horizons may pinch out or may truncate against bedrock or faults.

4.2.1.4 North Shore Fault Zone

A fault zone was identified along the northern shore of the lakebed, termed the North Shore Fault (MWH, 2011c). The sediments are disrupted by faulting, but the seismic reflections are sufficiently continuous to allow mapping sequence boundaries across the fault zone.

4.2.1.5 Bedrock Block Faults

Located north of the North Shore Fault Zone, the bedrock block faults appear to strike east-west, sub parallel to the North Shore Fault. The fault zone appears to cause a right-lateral displacement in the Owens River Fault, which is reflected in the channel of the Owens River. The Bedrock Block faults may cause a similar right-lateral offset for the Inyo Mountain Front fault zone. The nature of the intersection of this fault with the Owens Valley fault is not evident in the seismic data due to lack of coverage.

4.2.1.6 Keeler Fan Fault

The Keeler Fan Fault appears to originate on the Keeler Fan with a northeast-southwest strike. The fault appears to be associated with a local bedrock depression, or perhaps a paleo-channel. The fault appears to splay, getting wider toward the southwest. The seismic data does not cover the area where the Keeler Fan and Owens River Fault zones are interpreted to intersect. As a result, the nature of that fault intersection is not known.

4.2.1.7 Southeast Margin Faults

In general, this group of faults describes a series of faults that do not appear to have consistent strike or displacement sense. The faults may actually be related to the termination of the Owens Valley and/or Owens River faults; however, the line-to-line correlation is not clear. As a result, this group of faults is better described as a category of unassigned faults rather than an identified fault system.

5.0 Aquifer Characteristics

Aquifer characteristics derived from the new OLGEP monitoring wells are summarized herein, including a discussion of aquifer parameters and characterization of groundwater gradients.

5.1 Aquifer Parameters

Short-term pumping tests having duration of approximately two hours were conducted at the new OLGEP monitoring wells. Water level data was recorded using transducers for desktop analysis and evaluation of aquifer parameters.

Unfortunately, the testing was conducted using a surface pump in which the pumping rate was variable. Therefore, some of the pumping test data is erratic and does not fit classical pumping test theory. As a result, estimates of transmissivity (T) and hydraulic conductivity (K) are regarded as relative or approximate measures of aquifer parameters only. Furthermore, pumping rates were obtained from either driller's development/pumping logs or from totalizer readings at the start and end of a pump test. As a result, the flow rate used in the analysis is a gross average and does not reflect variations in pumping rate. In general, later recovery data (after the initial 10 minutes) were used to minimize wellbore effects.

Transmissivity and hydraulic conductivity estimates using two analysis methods, Jacob Straight-Line Method and Theis Recovery Method, are summarized in **Table 1**. This table also shows the aquifer unit associated with the screened interval for each well. **Table 3** shows the maximum, minimum, average, and median values of T and K using the different analysis methods.

Table 3
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

The distribution of T and K estimated from the new OLGEP monitoring wells by aquifer unit is plotted on **Figures 17** and **18**, respectively. In general, T and K show a decreasing trend with depth, with the exception of Aquifer 5, which has a few anomalous high values of T and K. These values should be regarded with caution and may be an artifact of testing limitations. The decrease in T and K with depth is consistent with the understanding that compaction and aquifer induration increases with depth.

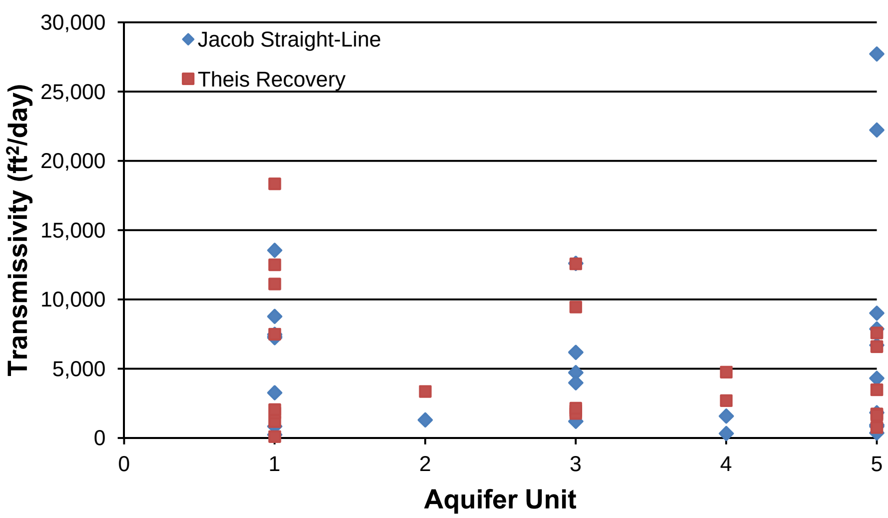


Figure 17
Distribution of Transmissivity by Aquifer Unit

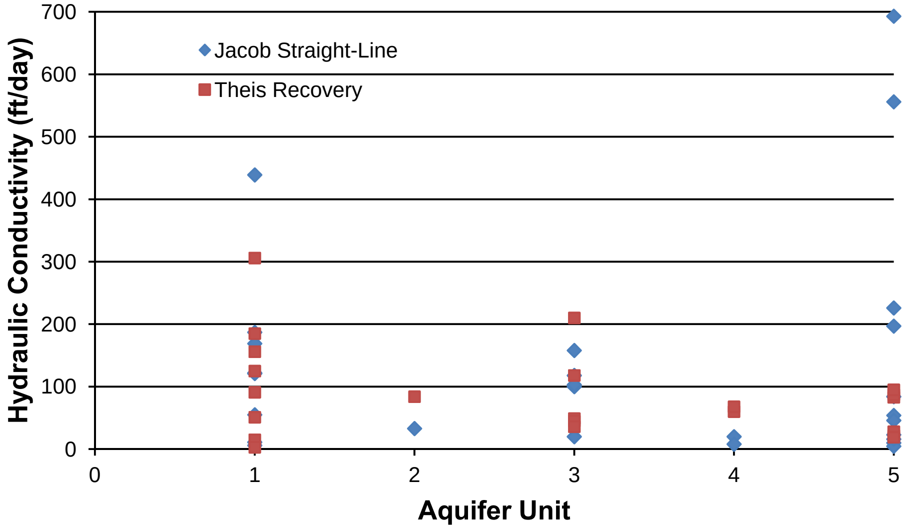


Figure 18
Distribution of Hydraulic Conductivity by Aquifer Unit

5.2 Groundwater Elevations

Static water levels recorded at the time of testing indicates 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 **Table 1**. The distribution of hydraulic head by aquifer unit is shown on **Figure 19**.

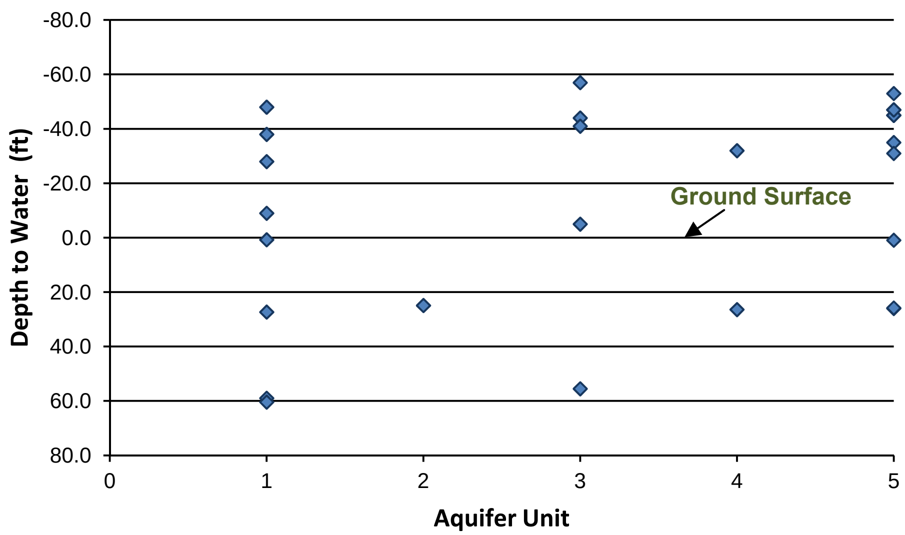


Figure 19
Distribution of Hydraulic Head by Aquifer Unit

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 aquifer units 1, 3, and 5.

Quarterly monitoring has been initiated at the new OLGEP wells. Recent monitoring indicates similar conditions to that observed at the time of well installation. In the future, quarterly monitoring will allow LADWP hydrographers to evaluate changes in head over time.

Based on the water level measurements in the new OLGEP wells, piezometric contour maps for each aquifer unit were developed. These contour maps are provided in **Appendix A**. Water level data from the new OLGEP monitoring wells was used in combination with GBUAPCD data. Head corrections were made based on the temperature and salinity of each well as described in **Appendix A** .

The piezometric contours shown in **Appendix A** must be interpreted with caution because large distances between data points mean that a variety of interpretations are possible. However, it does seem clear that while shallow groundwater flow directions seem to be consistently toward the brine pool (MWH, 2011a), deeper groundwater tends to flow to an area southeast of the brine pool.

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 (Johnson and others, 1999). Johnson and others (1999) suggested that the basin is not closed and deep outflow south through Haiwee Reservoir is possible. The new deep drilling data confirms a northerly component of flow in the deep aquifer and suggests that the basin is indeed a closed or terminal basin.

6.0 Water Budget

A groundwater budget, as it applies to a modeled groundwater body, is the quantification of the recharge (inflow) and discharge (outflow). A typical groundwater outflow budget includes components such as groundwater pumping, subsurface outflow, artesian flow, spring flow, and evapotranspiration.

In the case of Owens Lake Basin, detailed data on outflow from the groundwater system is not available. For example, private groundwater pumping from most wells is not gauged, and the amount of pumped water from those wells that returns to the aquifer through deep percolation is a further unknown. Additionally, although flow is monitored in several springs and artesian wells near the lake, they represent only a fraction of the flow from springs and seeps that exist near the lake.

An evaluation of topography in combination with shallow and deep groundwater gradients indicate that Owens Lake is a closed or terminal basin, in which there is no surface or subsurface outflow. Therefore, 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 provides a method to “bracket” or provide a check on total estimated surface and groundwater inflows. This approach differs from traditional groundwater budget estimations (and previous work) in which there have been attempts to tally outflows from individual wells, springs, and other outflow sources.

For the OLGEP study area (shown on **Figure 2**), 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 is developed as an long-term average condition without reference to a particular year, as an approximation of a steady-state condition. There is no true "steady state", but the water budget attempts to balance annual average historic inflows and outflows to/from the OLGEP study area.

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 water budget accounting discussed herein is not to conclusively apply fixed numbers to the groundwater model, but to provide guidance and reasonable limits to the groundwater modeling effort. The general strategy to developing an updated groundwater budget for the OLGEP study area was to begin with latest published calibrated groundwater budget developed by CDM (CDM, 2000) as listed in **Table 4**. 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. Previous groundwater budget estimates by other investigators are described in detail in the preliminary hydrogeologic conceptual model (MWH, 2011a).

Table 4
Calibrated Water Balance by CDM (2000)

Inflows – AF/yr		**Outflows – AF/yr**	
Down-valley flow	4,184	ET	55,427
		Playa/Brine Pool Evaporation	*29,242*
		Lone Pine Area	*6,140*
		Seep & Spring	*20,045*
Mountain Block Recharge	36,707	Spring and Seep Discharge and Discharge from Flowing Wells	8,318
Inyo	*3,959*		
Coso	*7,321*		
Sierra Nevada	*17,556*		
Deep	*7,871*		
Stream Channel Recharge	7,489	Groundwater Pumped from Wells (includes Lone Pine Pumping)	1,894
Inyo/Coso Range	*1,568*		
Sierra Nevada Range	*5,921*		
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**	Total	**67,326**

The groundwater recharge (inflow) and outflow components used in the updated water budget for the OLGEP study area are listed below and quantified individually in the following subsections.

<u>GROUNDWATER RECHARGE</u>

- Down-Valley Flow
- Stream Channel Recharge
- Interfluve/Fan Recharge
- Haiwee Reservoir Subsurface Inflow
- Centennial Flats Subsurface Inflow
- Mountain Block Recharge

<u>OUTFLOWS</u>

- Evapotranspiration
- Export

Notable features to the updated groundwater budget include:

- One area of confusion is a term that previous investigators have referred to as "Lone Pine Recharge", which is recharge occurring in and around the Lone Pine area without reference to the type of recharge (e.g. stream infiltration or precipitation). MWH has abandoned use of this term and included inflow and outflow in this area within the calculation of the typical groundwater budget components.
- Because of the extreme topography between the adjacent mountains and the valley floor, precipitation rates falling over the study area vary over small areas as summarized in the preliminary conceptual model (MWH, 2011a). Regardless of the precipitation volume estimated, it is assumed that all precipitation falling on the playa evaporates before it can recharge the groundwater system. Other precipitation is assumed to enter the basin either through stream channel recharge and/or interfluve/fan recharge. As a result, there is not an explicit component of precipitation in the groundwater budget.
- Danskin (1998) provided a brief description of the hydrologic setting for Haiwee Reservoir and assumed that the seepage from the reservoir had created a groundwater divide, which in turn resulting in a no flow boundary for groundwater. Similar to previous groundwater budgets, it is assumed that there is zero flow out of the Basin, to the south.
- Owens Lake is a closed or terminal basin, in which there are only two methods by which water leaves the basin: evapotranspiration or export. Therefore, as a method to “bracket”, or provide a check on total estimated inflows, MWH estimated the total evapotranspiration and export from the basin. This differs from traditional groundwater budget estimations (and previous work) in which there were attempts to tally outflows from individual wells, springs, and other outflow sources.

It should be noted that because many of the groundwater budget estimates are products of land area inflow/outflow rates, the estimated value has a high number of significant digits. In order to prohibit propagating uncertainty due to rounding individual values, the number of significant digits has not been lowered, but this should not be construed as implying accuracy or certainty of the estimates.

Over the last ten years since CDM's (2000) groundwater budget, surface water conditions in the OLGEP study area have changed significantly with the initiation of dust control measures (DCMs) and the Lower Owens River Project (LORP). LADWP is implementing a dust mitigation program to reduce emissions of fine particulates from the dry Owens Lakebed. These DCMs include nearly 23,000 acres of shallow flooding within the study area. The LORP includes restoration of the Lower Owens River by providing stream flow to over 60 miles of river to enhance fish, wetland, and riparian habitats. The potential effects on the groundwater system and groundwater budget as a result of DCMS and the LORP are discussed in this section as well.

The following subsections present the water budget, including a detailed evaluation of each groundwater recharge and outflow component. This analysis is then followed by a summary of the water budget for what is assumed to be steady-state conditions prior to the LORP and DCM projects. The section concludes with an evaluation of the potential effects of DCMS and LORP on the water budget.

6.1 Groundwater Recharge

The following section provides more detail on the quantity of the groundwater recharge components to the OLGEP study area.

6.1.1 Down-Valley Flow

Groundwater from the greater Owens Valley to the north of the OLGEP study area flows southward toward Owens Lake. This inflow component is termed “down-valley flow” and encompasses all groundwater flowing south into the northern portion of the study area. Down-valley flow is one of the most significant components of the groundwater budget, and historically has had a relatively high uncertainty. This uncertainty has been reduced by numerical groundwater modeling work to the north as part of the MWH/LADWP Southern Model, the boundary of which is shown on **Figure 1** (MWH, 2011e), along with the installation of several new wells north of the Owens Lake delta area, which have allowed for improved groundwater gradient calculations and evaluation of aquifer transmissivity in this area.

The down-valley flow component includes both deep and shallow flow through the unconsolidated deposits overlying (and bordered by) bedrock materials on the west, east, and below the unconsolidated deposits. Previous investigators primarily estimated down-valley flow at the site of the Down Valley Flow Test (DFVT) wells (**Figure 2**). Various investigations have proposed different estimates for this flow ranging from approximately 5,000 to 21,000 AF/yr. Most recently, CDM (1999) used newer data at the time from the GBUAPCD DVFT site, in combination with groundwater gradients, hydraulic conductivities, cross sections, water level data, and the results of a short-term aquifer test. Their calibrated model calculated down-valley flow to be 4,184 AF/yr for the upper 1,000 feet only (CDM, 2000).

The OLGEP study area boundary is larger than that of previous workers, such as Schumer (1997) and Wirganowicz (1997) and is located at the northern extent of the Alabama Hills. As a result, the DVFT site is approximately 7 miles south of the OLGEP study area northern boundary. MWH used new tools and data to calculate down-valley flow in two different ways:

- Estimated down-valley flow across the northern and northwestern boundaries of the OLGEP study area boundary using results of numerical groundwater modeling to the north, as part of the Southern Model (MWH, 2011e).
- Calculated down-valley flow at the DVFT site using Darcy's Law to not only be consistent with previous work done at this locale, but also to incorporate the results of new data from OLGEP monitoring wells.

6.1.1.1 Down-Valley Flow Based on Numerical Modeling to the North

An estimate of down-valley flow from the north into the OLGEP study area was made using the numerical groundwater model developed by MWH and LADWP, termed the Southern Model (MWH, 2011e). The boundaries of the Southern Model and OLGEP study area are shown together on **Figure 1**, whereby there is an overlap area between the north end of the Alabama Hills and the north side of the Owens Lake historic shoreline. The Southern Model was used to create a localized water budget and to calculate inflow into the OLGEP study area. Not only does groundwater flow across the northern OLGEP study area, but there is also a component of inflow to the southeast emanating from the Alabama Hills. The estimated inflow into the OLGEP study area at its northern boundary is 11,169 AF/yr, and the average flow into the study area from the Alabama Hills is 1,214 AF/yr, for a combined amount of 12,382 AF/yr. This number has been adopted as an initial estimate of down-valley flow.

6.1.1.2 Darcy's Law Calculation of Down-Valley Flow at the Down-Valley Flow Test Site

Estimates of down-valley-flow at the DVFT site were calculated using Darcy's Law, in conjunction with new information from OLGEP monitoring wells combined with previous data. The purpose of this calculation at the DVFT site was to not only be consistent with previous work done at this locale, but also to incorporate the results of new data from OLGEP monitoring wells. Results of this calculation were then cross checked against flow at this point within the Southern Model. The location of the DVFT site along with the locations of nearby wells is shown on **Figure 20**.

The U.S. Geological Survey (Pakiser and others, 1964; Hollett and others, 1991) reported that the DVFT area is bounded on both sides by faults, and valley fill is present to a depth of approximately 8,000 fbgs. Utilizing new information from OLGEP monitoring well construction, two new cross sections were developed, with locations shown on **Figure 20**.

- A north-south cross section, as presented in **Figure 21**, showing the use of lithology and geophysics to correlate aquifer units.
- An east-west cross section, as presented on **Figure 22**, showing seismic data overlain by the delineation of aquifer units.

Table 5 lists the five aquifer units identified in these cross sections and previously discussed under "Stratigraphy", along with the approximate depth and thickness of each zone. The new OLGEP wells at sites DWP-1, DWP-9, and DWP-10 allow for the consideration and quantification of deeper flow. Based upon a review of U.S. Geological Survey gravity surveys (Pakiser and others, 1964), it is inferred that valley fill is present to a depth of approximately 8,000 feet (**Figure 22**).

Key to Features

- Production Well
- Observation Well
- Town
- Section Line
- Los Angeles Aqueduct
- Owens Lake (Historic Shoreline)

N
0 0.25 0.5 Miles

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Down-Valley Flow Analysis Location Map

Los Angeles Department of Water & Power

Figure 20

MWH.

Figure 21
North-South Lithology Correlation among DWP-11, the DVFT Site, DWP-1, DWP-10 and DWP-9

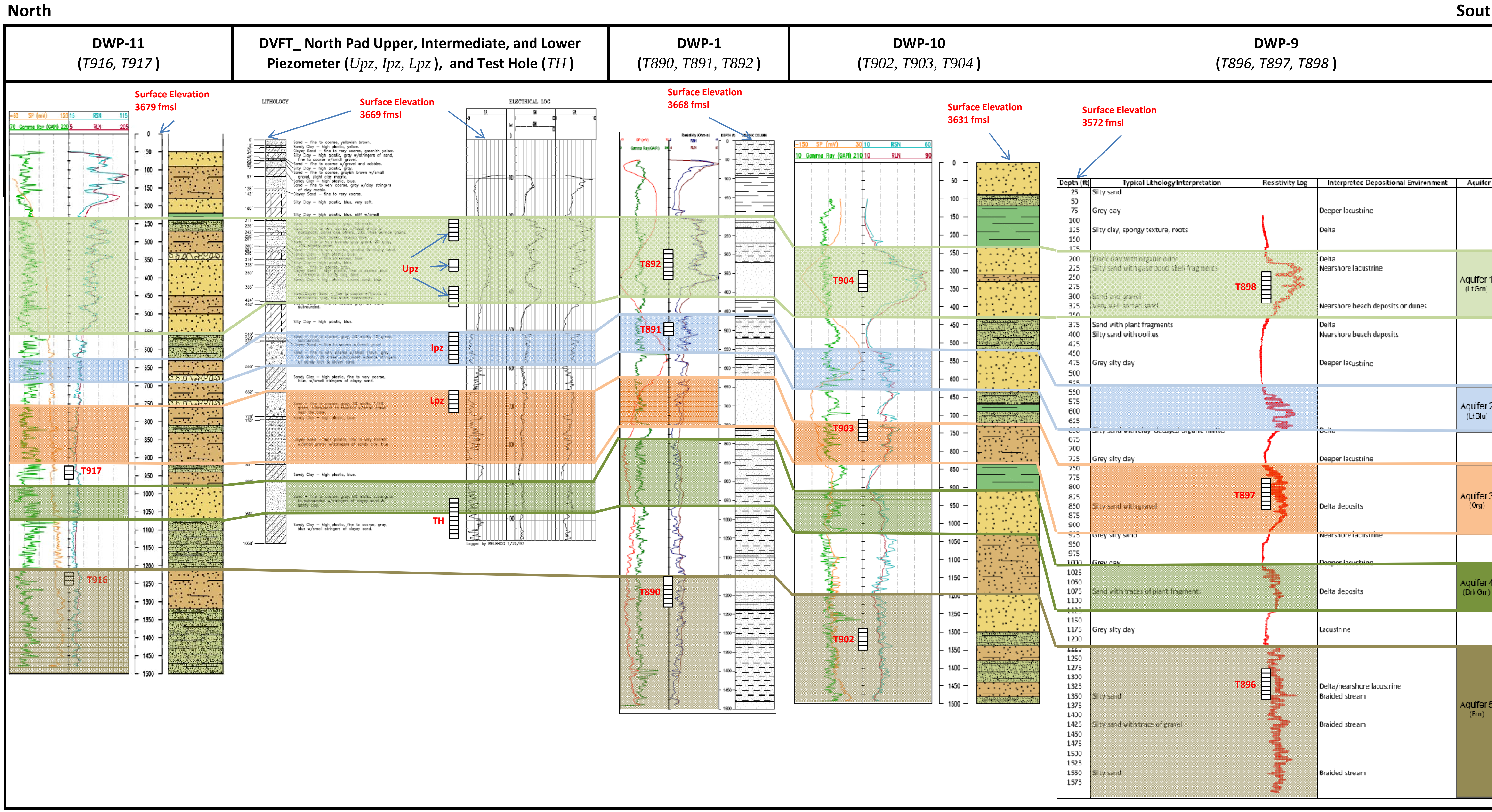


Figure 22 East-West Cross Section through the DVFT Site

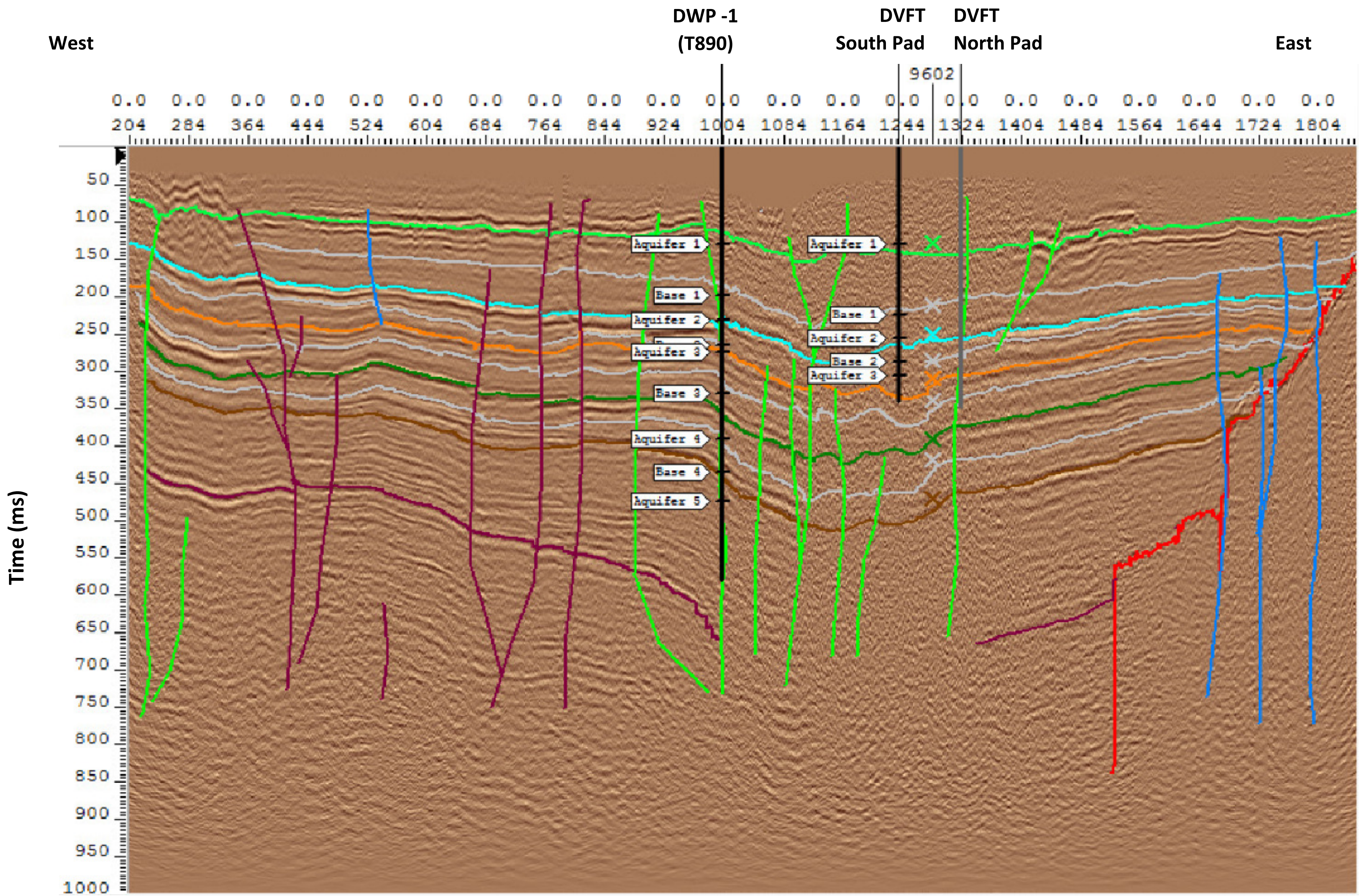


Table 5
Summary of Aquifers at the Down Valley Flow Test Site

Aquifer Unit	Approximate Top Depth (fbgs)	Approximate Bottom Depth (fbgs)	Aquifer Thickness (ft)
1	190	380	190
2	460	560	100
3	580	750	170
4	780	970	190
5	1,100	2,000	900
Deeper Valley Fill	2,000	8,000	6,000

6.1.1.2.1 Application of Darcy's Law

Darcy's Law was applied to estimate down-valley flow as follows:

$$Q = K_h \cdot i \cdot A$$

Where:

Q = the estimated flow in AF/yr across the east-west section shown on **Figure 22.**
K_h = the horizontal hydraulic conductivity in ft/day
i = the unitless hydraulic gradient, measured in a north-south direction
A =is the cross section area of the aquifer zones.

Table 6 summarizes well depth and/or screened intervals, horizontal hydraulic conductivity (K_h), water levels, and hydraulic gradient (i), by aquifer zones utilized for the calculation of down-valley flow. Horizontal hydraulic conductivity values (K_h) were obtained from pump test analyses on the OLGEP wells as documented in the well completion reports (MWH, 2011b). For wells T892, T904, T898, T891, T903, T897, T890, T902, and T896, only one static water level measurement each was available for analysis. No static water level data were available for the two production wells, W390 and W416. LADWP and/or GBUAPCD have maintained continuous water level measurements at wells T378, T348, T692, DVFT Site North Pad Upper Piezometer, DVFT Site North Pad Intermediate Piezometer, DVFT Site North Pad Lower Piezometer, River Site Upper Piezometer, and River Site Lower Piezometer.

Representative hydraulic conductivities were compiled as shown on **Table 6**. Static water level data was used to estimate the hydraulic gradient by correlating water levels within the same aquifer between wells. In Aquifer 1, more than three water level data points were used for the estimation, resulting in a range of hydraulic gradient values. There was insufficient data to directly calculate the hydraulic gradient for Aquifer 4, as a result, the value used for Aquifer 4 represents an average of the values in Aquifer 3 and Aquifer 5.

Little variation in aquifer thickness occurs along the East-West cross section (**Figure 22),** allowing each aquifer to be represented as a rectangular shape. In this analysis, the cross-sectional area of each aquifer zone was calculated by taking the product of the aquifer thickness (**Table 5**) and the cross section width, which is fixed at 25,000 ft (**Figure 22**).

Table 6
Down-Valley Flow Monitoring Well Data

Aquifer	Well ID	Depth/Screened Interval (fbgs)	Horizontal Hydraulic Conductivity (ft/day)	Hydraulic Gradient (unitless)
1	T378	27		Roughly parallel to the Owens River at values from 1.9E-3 to 3.8 E-3
	T348	20		
	T692	23		
	DVFT Upper	212 - 272	76 - 83[1]	
	River Site Upper	170 - 190 200 - 220	66 - 117[2]	
	W390	120 - 500	18 - 19	
	W416	100 - 150	47 - 157[4]	
	T892	290 - 370	11 - 15[5]	From T892 directed to T898 at 7.9E-4
	T904	300 to 360	55 - 125	
	T898	240 to 320	156 - 169[5]	
2	DVFT Intermediate	512 to 592		Roughly parallel to the Owens River at a value of 4.9E-4
	T891	480 to 520	33 - 84 [5]	
	River Site Lower	485 - 505	30 - 146[2]	
	W390	120 - 500	18 - 19	
	W416	200 - 490	47 - 157[4]	
3	DVFT Lower	662 - 722	158 - 219[1]	Roughly parallel to the Owens River at a value of 5.3E-4
	T903	720 to 780	103 - 210	
	T897	780 to 860	118 - 158[5]	
4	DVFS_TH	938 to 1038		In average 5.8E-4
5	T916	1,220 to 1,260	19 - 23[5]	South-South-West at a value of 6.7E-4
	T890	1,150 to 1,230	54 - 83[5]	
	T902	1,290 to 1,350	16 - 28	
	T896	1,280 to 1,360	84 - 95[5]	

Notes:
[1] Schumer (1997), Sierra GeoSciences (1999)
[2] Sierra GeoSciences (1999); Jacobson and Others (1990, 1992); CDM (1999)
[3] MWH (2003)
[4] Jorat, S. (2002)
[6] GBUAPCD and LADWP Water Level Record

6.1.1.2.2 Estimated Subsurface Down-Valley Flow

Using new data from the OLGEP, MWH applied Darcy's Law to refine and re-calculate down-valley flow at the DVFT site by aquifer unit as summarized in **Table 7**. A summation of these values suggests that down-valley flow at the DVFT location is estimated to be 13,407 AF/yr. This estimate includes the valley fill from below the five aquifers identified to a depth of 8,000 feet. The same hydraulic gradient used in Aquifer 5 was used to estimate flow in the deeper valley-fill sediments.

Table 7
Subsurface Flux Estimate at Down Valley Flow Test Site

Aquifer	Cross sectional Area (ft^2)	Typical Horizontal Hydraulic Conductivity (ft/day)	Typical Hydraulic Gradient (-)	Estimated Flux (AF/yr)
1	4,750,000	60	2.3×10^{-3}	5,493
2	2,500,000	50	4.9×10^{-4}	513
3	4,250,000	100	5.3×10^{-4}	2,350
4	4,750,000	40	6.6×10^{-4}	1,051
5	22,500,000	25	6.7×10^{-4}	3,158
Deep Unit	150,000,000	1	6.7×10^{-4}	842
			Total	**13,407**

This result was then compared to a model simulation using the Southern Model (MWH, 2011e). Simulation of the overlapping Southern Model at this specific DVFT locations indicates a flow through the same cross section of approximately 14,400 AF/yr. The two values compare favorably.

6.1.1.3 Summary of Down-Valley Flow

Based on numerical modeling to the north, down-valley flow into the OLGEP study area is calculated to be 12,382 AF/yr. An alternative calculation of down-valley flow at the location of the DVFT site was conducted for comparative purpose with previous work and to include results of new data. Down-valley flow at this location is estimated to be 13,407 AF/yr. This result was compared to flow through the same area using the Southern Model, which calculated flow at this location to be 14,400 AF/yr. The recommended range for the groundwater model is 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.

6.1.2 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.

Previous work by CDM (2000) separated stream recharge into three (3) components:

- Stream recharge in the Lone Pine area was lumped into "Lone Pine area recharge",
- Eastern Sierra stream recharge for Carroll Creek south to Walker Creek was estimated based on the work of Mihevc (1997). Mihevc (1997) estimated losses by assuming that stream loss to the groundwater system was equal to stream flow at the mountain front

minus stream flow at the foot of the alluvial fans and then using a combination of monitoring records and synthetic hydrographs.

- Inyo/Coso stream recharge was estimated using the Maxey-Eakin method based on work done by Conway (1997), Wirganowicz (1997), and Schumer (1997)].

CDM estimated that stream recharge is 7,489 AF/yr (1,568 AF/yr from the east and 5,921 AF/yr from the west); however, this number does not include Lone Pine area stream recharge.

MWH subdivided the study area streams (**Figure 1**) into:

- Sierra Nevada Streams. These streams are located in the western portion of the study area and sourced in the Sierra Nevada range. Eleven major streams occur on the western side of the study area and recharge water to the groundwater system. From north to south, these streams are summarized in **Table 8**.
- Inyo and Coso Streams. These streams are located in the eastern and southern portions of the study area and sourced in the Inyo and Coso ranges and tend to be ephemeral in nature, flowing only in response to high precipitation events. Additionally, these streams lack streamflow gauging data.

Table 8
Summary of Eastern Sierra Nevada Study Area Streams

Stream Name	Gauged (Y/N)
Lone Pine Creek	Y
Tuttle Creek	Y
Diaz Creek	Y
Lubkin Creek	Y
Carroll Creek	N
Cottonwood Creek	Y
Ash Creek	Y
Braley Creek	Y
Cartago Creek	N
Olancha Creek	N
Walker Creek	N

The majority of recharge contributed by these streams occurs on the alluvial fans. Relative to the Eastern Sierra streams, the majority of flow from Braley Creek, Ash Creek, Cottonwood Creek, and Carroll Creek is diverted into the Los Angeles Aqueduct (LAA), while the majority of streamflow from Walker, Olancha, and Cartago Creeks is diverted for agricultural use prior to terminating in the Owens Lake playa.

6.1.2.1 Approach

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. Gauging data is available for seven (7) of the streams along the Eastern Sierra as summarized in **Table 8**, and one (the drainage from Centennial Flats has intermittent gauge data for two of the last 20 years) of the Inyo/Coso streams; however, “base of mountain” and downstream gauging exists only for Cottonwood Creek, and these data are complicated by diversions occurring along the creek. Therefore, in most cases, the existing data is 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 potential methods were investigated. These methods include:

- **Estimates Based on Previous Modeling Efforts**. Estimates based upon numerical modeling utilizing the MWH/LADWP Southern Model (MWH, 2011e) for those streams occurring in the OLGEP/Southern Model overlap area (Lone Pine, Tuttle, Diaz, and Lubkin Creeks) (**Figure 1**),
- **Estimates Based on Cabin Bar Ranch Water Supply Study**. Estimates based upon the approach utilized in the Cabin Bar Ranch studies (JMM, 1990) for Eastern Sierra streams outside of the Southern Model domain (Carroll Creek south to Walker Creek),
- **Crippen Method (eastern Owens Lake)**. Estimates based upon the approach developed by Crippen (1965) for Inyo/Coso streams along the east side of the study area, and
- **Estimates Based on Typical Loss Rates**. Estimates based on use of typical loss rates for other gauged streams in the Owens Valley. These estimates were applied to Eastern Sierra streams in the study area for comparative purposes.

Each of these methods and their application to specific streams in the study area is discussed herein.

6.1.2.1.1 Estimates Based On Previous Modeling Efforts

The Southern Model (MWH, 2011e) includes a portion of the northern part of the OLGEP study area as shown on **Figure 1**. For the streams located within this overlap area (Lone Pine, Tuttle, Diaz, and Lubkin) as shown on **Figure 1**, data from the Southern Model numerical groundwater model was utilized to estimate stream recharge. Stream recharge occurring within the overlap area is estimated at 15,756 AF/yr.

6.1.2.1.2 Estimates Based on Cabin Bar Ranch Water Supply Study

Stream recharge rates for the seven (7) Sierra Nevada streams in the study area draining into Owens Lake (those from Carroll Creek south to Walker Creek as shown on **Figure 1**) were calculated based upon findings from a groundwater supply study for the Cabin Bar Ranch area located near Cartago (JMM, 1990). As part of this study, an assessment of previous methodologies for quantifying stream recharge in the Owens Lake area, such as Lee (1912), Lopes (1987; 1988), and others was made.

A critical component of any method to estimate stream recharge is estimating total runoff from the drainage area at the apex of the respective alluvial fan. The methods reviewed by JMM (1990) differed significantly in calculating both runoff at the apex of alluvial fans and calculating the percentage of runoff that infiltrates the stream channel and recharges the aquifer. Examination of the alternate methods determined that an average annual runoff coefficient (RC) could be calculated by the following equations:

Total Runoff (AF) / Watershed Area (acres) = Runoff Coefficient

Or

Net Runoff (AF) / (1 – Loss Factor) = Total Runoff (AF),

whereby, utilizing an appropriate loss factor representing the fraction of total runoff lost to infiltration, the runoff coefficient can be determined for a given stream.

By using a 32% loss factor, JMM (1990) estimated runoff coefficients for Ash and Braley Creeks. These findings allowed JMM (1990) to determine appropriate runoff coefficients and loss factors for the Sierra Nevada streams, which in turn, enabled runoff to be calculated as a function of watershed area and stream losses as a percent of runoff. The resultant range of recommended values for the runoff coefficients and loss factors are listed in **Table 9**.

Table 9
Range of Runoff Coefficients and Loss Factors per Cabin Bar Ranch Water Supply Study
(*from JMM, 1990*)

	Recommended	High	Low
Runoff Coefficient (AF/yr)	0.45	0.70	.040
Loss Factor (%)	0.42	0.42	0.32

MWH used GIS mapping tools to calculate drainage areas by stream. The runoff and recharge for these drainages were calculated by applying the recommended range of runoff coefficients and loss factors per JMM (1990) shown in **Table 9**. The results of this analysis are presented in **Table 10**. This table shows that the estimated recharge from Eastern Sierra streams using the recommended values from **Table 9** is 12,014 AF/yr, and the reasonable range of Eastern Sierra stream recharge using the high and low values from **Table 9** is 8,136 to 18,688 AF/yr.

Table 10
Summary of Stream Recharge Using the Cabin Bar Ranch Approach

Drainage Name	Area (acres)	Recommended (see Table 9)		Low Range (see Table 9)		High Range (see Table 9)	
		Runoff (AF/yr)	Recharge (AF/yr)	Runoff (AF/yr)	Recharge (AF/yr)	Runoff (AF/yr)	Recharge (AF/yr)
Carroll Creek	5,833	2,625	1,102	2,333	747	4,083	1,715
Cottonwood Creek	27,027	12,162	5,108	10,811	3,459	18,919	7,946
Ash Creek	8,617	3,878	1,629	3,447	1,103	6,032	2,533
Braley Creek Cartago Creek Olancha/Walker Ck.	18,877	8,495	3,568	7,551	2,416	13,214	5,550
Unnamed Drainage	3,211	1,445	607	1,284	411	2,248	944
Total	63,565	28,604	12,014	25,426	8,136	44,496	18,688

6.1.2.1.3 Crippen Method (Eastern Owens Lake)

Crippen (1965) developed a method to estimate the average annual water loss and recoverable water in mountain basins of southern California, whereby:

Recoverable Water = Precipitation – ET

Or

Recoverable Water = Surface Runoff + Groundwater Recharge

In mountain-front areas, “recoverable water” is equivalent to surface runoff and groundwater recharge. According to Lee (1912), groundwater recharge is negligible in the mountain area (above the mouth of canyon), suggesting this is a reasonable approach for calculating runoff.

The procedure for applying the Crippen method to the study area included:

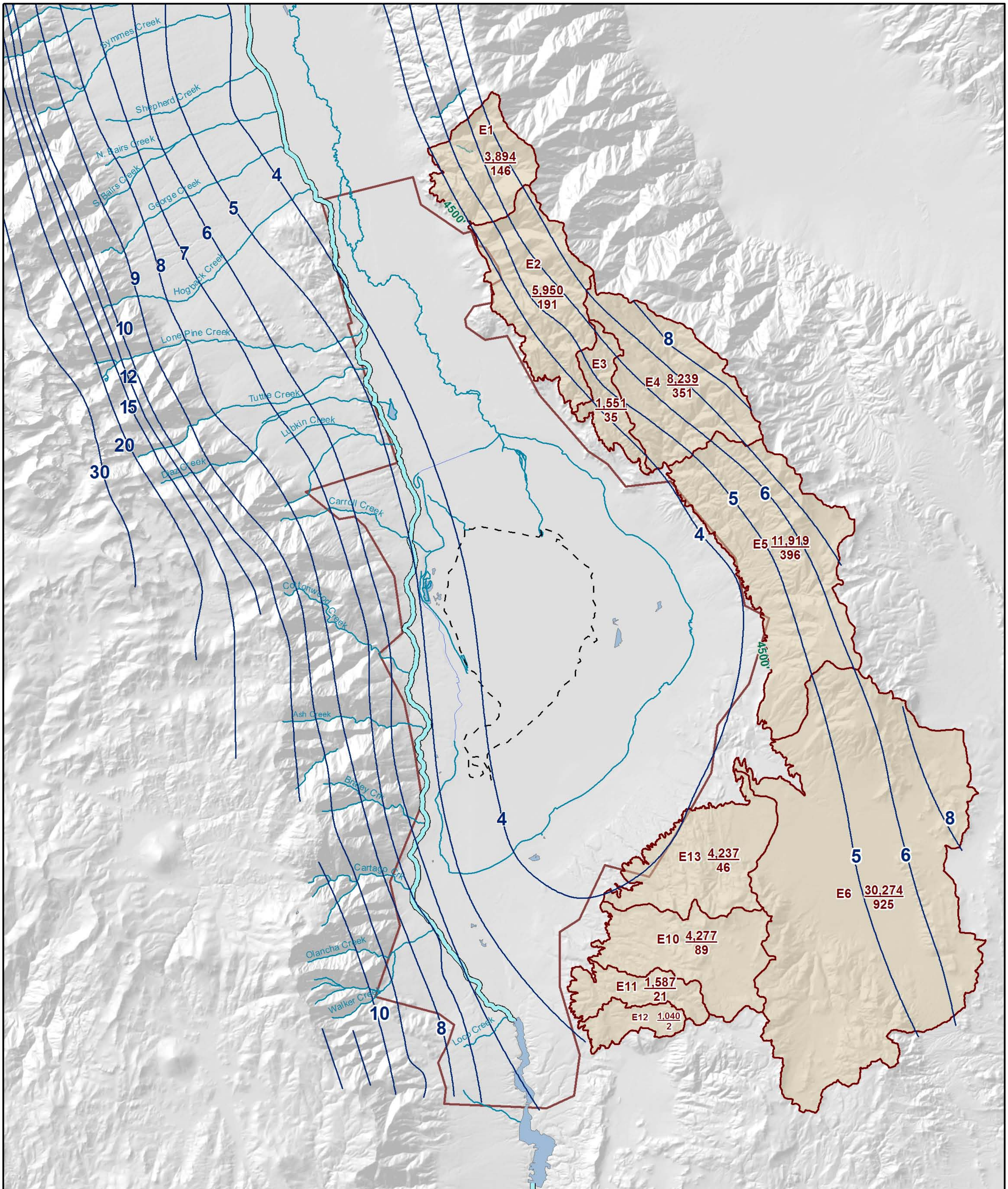
- Zones of altitude were established using topographic maps, and the area of each zone was calculated using ArcView® software GIS measuring tools.
- The long-term mean annual precipitation, *P*, for each altitude zone was determined using estimated isohyets developed by Danskin (1998; Figure 7).
- In combination, these values were used to derive the contribution of the various drainages of the Inyo and Coso Ranges within the study area.

The Crippen method was applied to the east and southeast side streams of the OLGEP study area. **Figure 23** shows the contributing drainage basins on the eastern and southern side of Owens Lake, along with estimated isohyets from Danskin (1998). Also represented next to the area labels are the total precipitation values (top) and total recharge values (bottom).

Along the eastern and southern portions of the study area (Inyo/Coso), areas E1 through E13 represent individual drainages bounded by their respective watershed boundaries and the 4,500 foot contour line along the Inyo and Coso Mountain front. The mountainous bedrock/alluvial fan boundary occurs at approximately 4,500 fmsl and is significant because all precipitation at elevations less than 4,500 ft is assumed to evaporate or transpire.

Table 11 summarizes the estimated stream channel recharge, area, and precipitation for the Inyo/Coso drainages. The estimated annual recharge for these drainages as calculated by the Crippen method is 5,559 AF/yr.

The Crippen method was not applied on the western slopes because it produced runoff estimates that were lower than values gauged at the LAA, meaning that it was not a reasonable method for estimating streamflow at the apex of alluvial fans in the Owens Lake area.



Key to Features

—8— Isohyets (Inches)

Los Angeles Aqueduct

Rivers and Streams

OLGEP Study Area Boundary

Brine Pool

Watershed — Total Precipitation (AFY) / Estimated Recharge (AFY)

Recharge estimation is based on the methods of Crippen (1965). Isohyets after Danskin (1998).

N
0 1.5 3 Miles

Document: \\uspas1netapp1\MUNI\Clients\Los Angeles Water&Power LADWP\Owens Valley Data\Owens Valley GIS\ConceptModel0711\EastSideDrainages.mxd

Delineation of East Side Drainages for Estimation of Stream Recharge Using Crippen

LA DWP Los Angeles Department of Water & Power

Figure 23

MWH.

Table 11
Summary of Inyo/Coso Stream Recharge

Inyo and Coso Stream Recharge			
Area ID	**Area (acres)**	**Precipitation (AF/yr)**	**Recharge (AF/yr)**
E1	7,948	3,894	365
E2	13,455	5,950	478
E3	4,015	1,551	88
E4	14,648	8,239	878
E5	24,938	11,919	990
E6	65,065	30,274	2,314
E10	11,695	4,277	223
E11	4,474	1,587	53
E12	2,834	1,040	55
E13	11,946	4,237	115
Total	**161,018**	**72,968**	**5,559**

6.1.2.1.4 Estimate Based on Typical Loss Rates

The stream length of the creeks in the southern Owens Valley between the alluvial fan apex and the LAA are as follows (Mihevc, 1997):

- Carroll 19,500
- Cottonwood 7,900
- Ash 4,000
- Braley 3,000
- Cartago 6,000
- Olancha 11,485
- Walker 16,400

The total channel length is 68,285 feet for these streams. If a representative stream loss value could be determined, the recharge from these streams could be estimated.

The U.S. Geological Survey has reported average stream loss for nine creeks in the Owens Valley (Hollett and others, 1991) for the period of 1935 to 1984 as acre-feet per year per foot of stream channel as shown below:

Creek	Avg. Stream Loss
Taboose	0.125
Goodale	0.086
Sawmill	0.221
Oak	0.356
Independence	0.235
Symmes	0.077
Shepherd	0.12
Bairs	0.061
George	0.124

By assuming that these stream loss coefficients are reasonable for the southern Sierra Nevada creeks (Carroll to Walker) and using a total length of 68,285 feet, then this results in recharge of 4,200, 10,700, 24,300 AF/yr if the minimum, average, and maximum values for U.S. Geological Survey stream loss coefficients are used, respectively. This method indicates recharge values that are consistent with the method used at the Cabin Bar Ranch but span a wider range. For this reason, the method used at the Cabin Bar Ranch is recommended as a starting point for recharge from the southern Eastern Sierra study area streams during modeling efforts.

6.1.2.2 Summary of Stream Recharge

Table 12 summarizes the stream recharge estimates using the previously described techniques for the entire OLGEP study area. 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.

6.1.3 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 evapotranspiration can infiltrate to the alluvial fan surface. Within the OLGEP study area, alluvial fans exist along the base of the Sierra Nevada Range at an approximate elevation between 6,000 and 3,600 fmsl, whereby 3,600 fmsl represents the historic shoreline of Owens Lake. Alluvial fans at the base of the Inyo and Coso Mountains tend to occur at elevations between 4,500 feet and 3,600 fmsl.

Danskin (1988) estimated this recharge to be about 0.1 inches/year. Wirganowicz (1997) and Schumer (1997) both used Danskin's rate to estimate interfluve/fan recharge. CDM used a similar approach, whereby their calibrated model estimated this component to be 1,716 AF/yr, respectively.

Table 12
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

The total interfluve/fan area for the OLGEP area calculated using GIS mapping tools is 229,182 acres. Application of Danskin's rate indicates that interfluve/fan recharge is 1,910 AF/yr.

The Southern Model (MWH, 2011e) calculates recharge in the interfluve/fan area using input from the Ecological Dynamics Simulation (EDYS) Model developed for the Southern Model area (MWH, 2009a). EDYS is a general ecosystem simulation model that is mechanistically-based and spatially-explicit developed by Terry McLendon and Michael Childress (Childress and McLendon, 1999, Childress and others, 1999a, 1999b). EDYS simulates natural and anthropogenic-induced changes in hydrology, soil, plant, animal, and watershed components across landscapes, at spatial scales ranging from 1 m^2 or less to landscape levels (1,000 km^2 or larger). It is a dynamic model, simulating changes on an hourly (for aquatic) or daily (most terrestrial) basis, over periods ranging from months to centuries.

The maximum recharge rate for the interfluve/fan area in the Southern Model as calculated by EDYS is 1.82×10^{-18} ft/day (per model cell). Application of this rate to the OLGEP model domain indicates that interfluve/fan recharge is negligible.

Previous work by MWH evaluated the application of the Crippen (1965) method to calculate interfluve/fan recharge (MWH, 2009b) and found that Crippen tends to under predict relative to Danskin by about 50%. Crippen (1965) estimates the average annual water loss and recoverable water in mountain basins of southern California, whereby:

$$\textit{Recoverable Water} = \textit{Precipitation} - \textit{ET}$$

Because all precipitation occurring in the interfluve area at elevations less than 6,000 fmsl is assumed to either infiltrate or evapotranspire, Crippen's method of calculating recoverable water can be utilized as a proxy for determining interfluve/fan recharge. For comparative purposes, the Crippen method was applied to the study area (as shown in **Appendix B**. Results indicate that interfluve/fan recharge using Crippen (outside of the Southern Model/OLGEP overlap area) is about 15 AF/yr.

Based on these various estimates, it is concluded that a reasonable range of values for interfluve/fan recharge is 0 to 1,910 AF/yr.

6.1.4 Haiwee Reservoir 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. This concept is confirmed by the observation that groundwater flow in this area is from the reservoir north toward the lake bed (see Figure 17 from MWH, 2011a). Schumer (1997) estimated the inflow to be 2,577 AF/yr by using her groundwater model and specifying a constant head value equal to the water level at Haiwee Reservoir. CDM (2000) refined this value to be 3,791 AF/yr in its calibrated model.

No new additional data are available to refine the estimate for this inflow component. However, MWH applied Darcy's Law to evaluate the potential range of values for this component.

Similar to the estimates of down-valley-flow at the DVFT site, subsurface inflow at Haiwee Reservoir was calculated using Darcy's Law. A cross section was drawn through wells Hunter #1 and MW #5 (Psomas, 1998), whereby well locations are shown on **Figure 2**. Lithology for this area was obtained from Schaer (1981), Psomas (1998), and driller's logs in Olancha-Haiwee area. The most permeable sediments are present at depths from 150 to 200 fbgs (Psomas, 1998). The screened interval in the Hunter #1 well is from 90 to 500 fbgs; all the other wells in this area are generally less than 235 fbgs deep. East of Highway 395, the depth to water has ranged from 12 to 80 fbgs (Psomas, 1998). West of Highway 395, the depth to water has ranged from 2 to 85 fbgs based on driller's logs.

Horizontal hydraulic conductivity (Kh) values were estimated based on extensive pumping tests performed at wells Hunter #1 and Butterworth #4 (Psomas, 1998). The Kh value is 8.4 and 152.1 ft/day in Hunter #1 and Butterworth #4, respectively. Specific capacities recorded in well completion reports for nearby private wells were also used to estimate Kh values, and are estimated to range from 0.43 to 34 ft/day.

A cross section was prepared and the cross sectional area was measured using GIS measuring tools with ArcView® software. Based on groundwater elevation contour maps prepared for the preliminary hydrogeologic conceptual model (Figure 17ab from MWH, 2011a), the hydraulic gradient was estimated.

In the shallow aquifer, the hydraulic gradient is estimated to range from 1.7×10^{-3} to 14.3×10^{-3}, whereas in the deeper aquifer, it ranges from 2.25×10^{-3} to 3.0×10^{-3}. According to Psomas (1998), hydraulic gradient ranges from 2.1×10^{-3} to 11×10^{-3}, which compares favorably to the gradient calculated by MWH.

Using the calculated cross section area, horizontal hydraulic conductivity, and gradient, MWH applied Darcy's Law to estimate subsurface inflow at Haiwee Reservoir. The estimated range using reasonable estimates of gradient and hydraulic conductivity is 2,000 to 10,000 AF/yr. A typical value of 4,600 AF/yr is estimated by applying the typical hydraulic conductivity and hydraulic gradient value. Improved gauging at north Haiwee Reservoir would serve to reduce uncertainty associated with this Basin boundary.

6.1.5 Centennial Flats Subsurface Inflow

Centennial Flats is a basin located to the southeast of the study area (**Figure 2**), where previous investigators believe subsurface flow enters the Basin. However, no direct measurement can be made. Most recently, CDM (2000) estimated that 1,095 AF/yr recharge the Basin as a result of Centennial Flats subsurface inflow.

MWH's evaluation of this inflow component included a review of geologic mapping and well logs that were not available to previous workers (Well information is provided as **Appendix C**). The geologic map shown on **Figure 3** illustrates that the Centennial Flats area, which is immediately underlain by Quaternary surficial deposits, is surrounded by sporadic Quaternary volcanic rocks on the surface. Pre-Quaternary undifferentiated sedimentary, metamorphic, and granitic rocks can be found at to depth.

A monitoring well was drilled for the Bureau of Indian Affairs (State Well No. 19S39E11D001M as shown on **Figure 2**), by the U.S. Geological Survey. The lithologic log indicates that the well penetrated gravel, sand, and silty sand from ground surface to a depth of 408 feet below ground surface (fbgs); clay between the depth of 408 and 510 fbgs; gravelly, sandy silt between 510 and 708 fbgs; and silty clay from 708 and 1,100 fbgs. Screened intervals are 760-780, 820-840, 920-940, 1020-1040, and 1060-1080 fbgs. The surface elevation of the well is 4,860 feet above mean sea level (fmsl). Depth to groundwater was measured at 900 fbgs in March 2007, or at an elevation of 3,960 fmsl.

A second well, State Well No. 18S39E35N001M as shown on **Figure 2**, is constructed to a depth of 702.5 fbgs in a borehole with a total depth of 1,000 fbgs. The surface elevation of the well is 4764.1 fmsl, which is 100 feet lower than Well 19S39E11D001M. Groundwater measurements for this well in December 2005 indicated that this well was dry, suggesting that the elevation of groundwater is at a lower elevation than 4,061.6 fmsl.

The elevation of Owens Lake is approximately 3,600 fmsl; therefore, a 360-foot elevation difference exists between the water level at Well 19S39E11D001M and the Owens Lake. The calculated gradient between Well 19S39E11D001M and the Owens Lake is 0.006 (**Table 13**).

Table 13
Summary of Gradient Between Centennial Flats and Owens Lake

Well	Water Level (fmsl)	Distance to Owens Lake (feet)	Gradient
19S39E11D001M	3,960	~56,950	0.006
18S39E35N001M	>4,061.6	~56,950	<0.008
Owens Lake	3600	Not Applicable	Not Applicable

It is interpreted that groundwater in the Quaternary alluvial fan deposits in Centennial Flats is largely isolated from those in the Owens Lake due to the relatively low gradient and low permeability of surrounding rocks. The existence of faults that act as groundwater barriers could reduce this amount further. This analysis suggests that subsurface inflow into the Basin from Centennial Flat may be negligible. A recommended range for the preliminary groundwater model is 0 - 1,095 AF/yr.

6.1.6 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. The idea of significant deep fracture flow from the eastern Sierra Nevada was proposed in the Indian Wells Valley by Thyne and others (1999) and later debunked by the Indian Wells Valley Cooperative Groundwater Technical Advisory Committee and GTC (2008).

Direct measurement of this term is not possible; therefore, neither Wirganowicz (1997) nor Schumer (1997) attempted to estimate this inflow component. Rather, they estimated mountain block recharge as a residual term in their water budget as 15,800 and 15,845 AF/yr, respectively.

Initially, CDM adopted Schumer's (1997) value of 15,845 AF/yr for mountain block recharge. During model calibration (CDM, 2000), this number was revised to be 36,707 AF/yr. In addition, mountain block recharge was expanded by CDM to include water entering the upper aquifer system from the deeper valley-fill deposits that may originate from either inflow from the north, upward flow, or as recharge from surrounding mountain block areas.

Mountain block recharge was considered negligible in previous groundwater models developed by MWH and LADWP in the northern Owens Valley [Bishop/Laws (MWH, 2011d), Big Pine (MWH, 2004; 2009b), Taboose-Thibaut (MWH, 2006; 2009b), and Southern Model (MWH, 2011e)], all of which are reasonably calibrated and successful models. It is possible that mountain block recharge occurs to some extent, but is within the range of error for stream channel recharge.

For the purposes of the updated conceptual model, mountain block recharge is considered negligible, but it is recognized that this conclusion cannot be confirmed with available data, and the groundwater model may need to include mountain block recharge within reasonable limits if model calibration efforts suggest it is present.

6.2 Outflow

As previously described, a typical groundwater outflow budget would include groundwater pumping, subsurface outflow, artesian flow, spring flow, and evapotranspiration. In the case of Owens Lake Basin, detailed data on outflow from the groundwater system is not available. For example, groundwater pumping from most wells is not gauged, and the amount of pumped water from those wells that returns to the aquifer through deep percolation is a further unknown. And although the flow is monitored in several springs and artesian wells near the lake, they represent only a fraction of the flow from springs and seeps that exist near the lake.

An evaluation of topography in combination with shallow and deep groundwater gradients indicate that Owens Lake is a closed or terminal basin, in which there is no surface or subsurface outflow. Therefore, there are only two methods by which either groundwater or surface water is believed to leave the basin: (1) evapotranspiration or (2) export. Thus, if total export and ET could be estimated, this value could be used as a method to "bracket", or provide a check on total estimated surface and groundwater inflows. This approach differs from traditional water budget estimations (and previous work) in which there is an attempt to tally outflows from individual wells, springs, and other outflow sources.

6.2.1 Evapotranspiration

In previous studies, evapotranspiration (ET) has been identified as the single largest outflow component of the water balance. CDM (2000) estimated that ET accounts for 82% of outflows from the study area as shown on **Figure 24**.

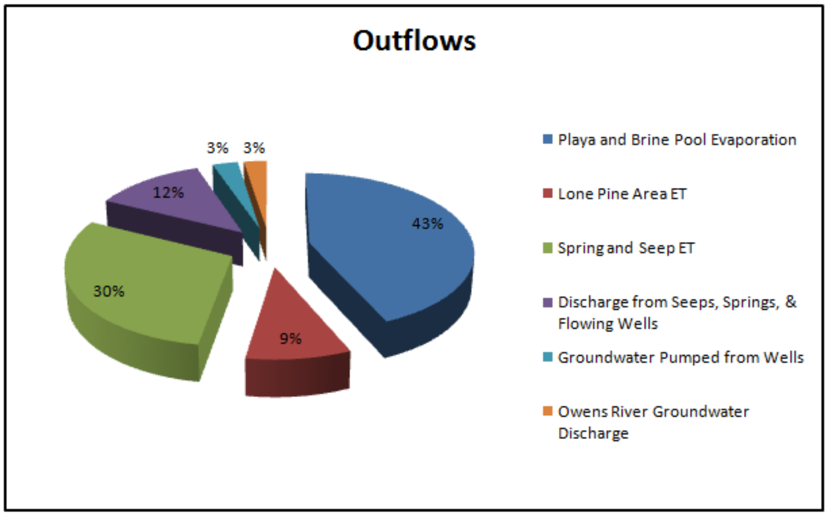


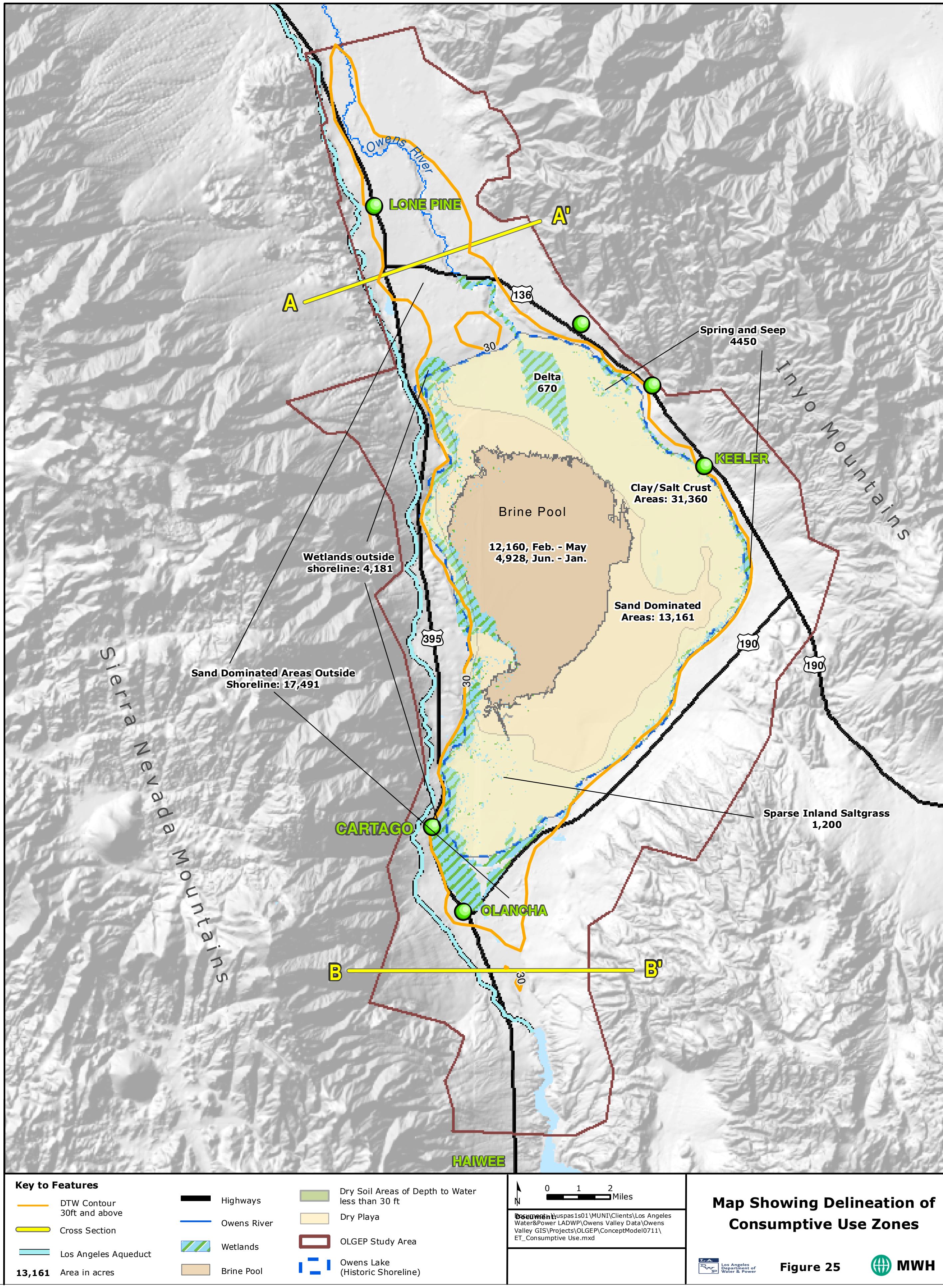
Figure 24
Summary of Outflows from CDM (2000)

For the purpose of estimating total water outflows (excluding export outflows) out of the OLGEP study area, the approach utilized by MWH included division of the study area into different "consumptive use" zones based on ET. This process incorporated domestic and agricultural pumping (because this pumping is for in-basin use only), precipitation, transpiration, evaporation, and discharge from seeps, springs, flowing wells, and the Owens River. The footprint of the study area was divided into three (3) major consumptive use zones, with further subsets based upon vegetative cover and depth to water:

- Brine Pool,
- Dry Lakebed, and
- Areas Occurring at Elevations above the Historic Shoreline of Owens Lake.

6.2.1.1 Consumptive Use Zones

Delineation of consumptive use zones is presented in **Figure 25**. **Table 14** directly corresponds to **Figure 25** and summarizes each consumptive use zone, along with the respective ET rate, and estimated annual consumptive use. It is recognized that these zones are a gross generalization and that actual ET rates may vary greatly within the zones. However, this method is considered a reasonable approach for a basin-wide estimation of total consumptive use.



Map Showing Delineation of Consumptive Use Zones

Figure 25

Los Angeles Department of Water & Power

MWH

Table 14
Summary of the Consumptive Use in the OGLEP Study Area

Zone	Component	Outflow	Area (acres) [6]	Estimated Mean ET Rate (inch/day)	Estimated Annual Volume (AF/yr)	Reference
Brine Pool (3552.6 ft Contour)	Open Water Evaporation	February through May	12,160	0.088	10,701	GBUAPCD (1997) measured rate of 0.088 inch/day from February to May (120 days), area of 19 mile^2. From June to January (245 days), the rate was 0.107 inch/day and an area of 7.7 mile^2. Tyler and others (1997) estimated direct precipitation into the lake by multiplying annual average precipitation of 150 mm and the seasonally adjusted brine area of 50 km^2. This yields $4.5X10^6$ m^3/year (3,648 AF/yr). Subtraction of this amount is the total yearly mean volume of water evaporation from the brine pool .
		June through January	4,928	0.107	10,766	
				Subtotal	17,818	
Dry Lakebed (between 3552.6 and 3600 ft Contour)	Bare Soil Evaporation	Sand-dominated areas represented by the NFIP site	13,161	0.009315	3,729	Unit rate is based on GBUAPCD EIR Version 2 (1997) and Tyler and others (1997), where yearly average evaporation was taken as the arithmetic average of the four seasonal rates for each year. They estimated sand dominated (NFIP) area of 133 km2 (32685 acres) and clay-crust (SFIP) area of 127 km2 (31382 acres). MWH estimates that the total area within the historical shoreline is 70,436 acres. This consists of 19,594 acres of Brine Pool; 44,521 acres of dry playa; and 6,320 acres of wetland. Depth to water within the historical shoreline is less than 30 fbgs.
		Clay/salt crust areas represented by the SFIP site	31,360	0.011260	10,741	
				Subtotal	14,469	
	Evapotranspiration	Spring and Seep areas (Wetland)	4,450	0.096990	13,128	
		Owens River and Delta (Wetland)	670	0.123290	2,513	
		Areas covered by sparse inland saltgrass (Wetland)	1,200	0.032880	1,200	
				Subtotal	16,841	
Between Historical shoreline (3600 ft) and Model Boundary	Bare Soil Evaporation	Sand-dominated areas represented by the NFIP site	17,491	0.009315	4,956	Depth to water less than 30 fbgs between section AA' and BB' outside historical shoreline.
	Evapotranspiration	Wetland outside historical shoreline	4,181	0.096990	12,334	
				Subtotal	17,290	
				Total	66,419	

Notes:

1. Mean annual lake elevation is 3552.60 fmsl and mean annual lake area is 17,700 acres (Lopes, 1988).
2. Minimum evaporation rate of 45 inches per year by Vorster (1985) at Mono Lake.
3. Maximum evaporation rate of 60 inches per year by Lee (1912).
4. Bare soil evaporation from the exposed lakebed was 0.45 inches per year (Lopes, 1988).
5. Range of mean ET rate represents the estimated range of uncertainty of each ET rate based on professional judgment.
6. It is noted that the brine pool's area varies from year to year and season to season, along with the ET rate.

The following is a description of the consumptive use zones.

6.2.1.1.1 Brine Pool

The Brine Pool is defined as the regularly inundated portion of the study area occurring below 3,552.6 feet elevation, and is composed of approximately 17,088 acres. The GBUAPCD EIR (1997) reported that from February through May, free water surface evaporation from the Brine Pool is typically 10,900 AF, whereas during the period from June through January, 10,400 AF of water is lost to evaporation. Additional details regarding Brine Pool evaporation are given in **Table 14**.

6.2.1.1.2 Dry Lakebed

The Dry Lakebed zone is defined as the portion of the study area occurring between 3,552.6 feet and 3,600 feet in elevation, and consists of approximately 50,841 acres. Additionally, the Dry Lakebed zone is subdivided into 5 subsets, based on soil type and/or vegetative cover. These subsets are identified on **Figure 25** and **Table 14**, and a discussion of each subset is provided below.

<u>Bare Soil Evaporation on the Dry Lakebed</u>. The GBUAPCD EIR (1997) evaluated bare soil evaporation on the dry lakebed by soil type. These two soil types are differentiated into sand dominated and clay/salt crust dominated soils, with evaporation rates of 3.4 and 4.11 in/yr respectively. **Table 14** discusses these subsets in more detail, along with estimates of evaporation for each.

<u>Evapotranspiration from Vegetated Areas on the Dry Lakebed</u>. Vegetated areas on the Dry Lakebed were subdivided into three zones, based on findings from the GBUAPCD EIR (1997). These include spring and seep areas, the Owens River and Delta, and areas covered by sparse inland saltgrass. Cumulatively, this subset occupy 6,320 acres of the Dry Lakebed. Listed below are the three vegetated zones and their respective range of evapotranspiration rates:

- Spring and Seep Areas – 24.0 to 46.8 inches/year
- Owens River and Delta – 30.0 to 60.0 inches/year
- Sparse Inland Saltgrass – 8.4 to 15.6 inches/year

<u>Areas Occurring at Elevations above the Historic Shoreline</u>. The zone denoted as "Areas Occurring at Elevations above the Historic Shoreline" is defined as the area between the historic shoreline (3,600 fmsl) and the boundary of the OLGEP study area. This zone is composed of approximately 21,672 acres and is divided into two subsets, based upon vegetative cover.

- Bare Soil Evaporation in Areas above the Historic Shoreline - Areas defined by this subset are characterized by sand-dominated surface soil types and typically have a depth to groundwater of less than 30 feet. Within the OLGEP study area, this zone occurs in the vicinity of Lone Pine and Olancha, and is composed of approximately 17,491 acres. Typical evaporation rates, as measured by the GBUAPCD (1997), are approximately 3.4 inches/year.

- Evapotranspiration from Wetland Areas above the Historic Shoreline - A total of 4,181 acres are defined as wetland areas occurring at elevations above 3,600 feet. For the purpose of quantifying evapotranspiration within this zone, the same range of ET rates (24.0 to 46.8 inches/yr) were utilized as those for spring and seep areas on the Dry Lakebed. Additional details regarding consumptive use calculations for this zone are contained in **Table 14**.

6.2.1.2 Summary of Consumptive Use Results

Table 14 summarizes the results of the consumptive use estimations. Based upon the delineation of consumptive use zones and associated ET rates, total consumptive use for the study area is estimated at approximately 66,419 AF/yr.

6.2.2 Export

6.2.2.1 Groundwater Pumping

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 owned and operated by Crystal Geyser Roxanne (CGR). Recent data collected from Crystal Geyser Roxanne (Jeff Zukin Personal Communication, 2010) indicated that annual production at their Olancha water bottling facility is between approximately 275 and 325 AF/yr.

In the future, CGR is proposing additional groundwater production from the recently-acquired Cabin Bar Ranch area in the amount of 360 AF/yr. This proposed water use is reported in the Project Description recently submitted to Inyo County (Geosyntec Consultants, Personal Communication, 2010).

6.2.2.2 Los Angeles Aqueduct Export

Surface water from four (4) 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. MWH worked with the LADWP staff (Eric Tillemans, personal communication 2011) to obtain historical gauging data for the LAA diversions from these streams. Based upon the gauged data, on average of 17,791 AF/yr of water is diverted into the LAA. **Table 15** summarizes the diversion data by creek, and annual diversion data is included as **Appendix D**.

Table 15
Summary of Los Angeles Aqueduct Diversions

Creek	Period of Record	Average Diversion (AF/yr)
Carroll Creek	1945 – 2010	123
Cottonwood Creek	1992 – 2010	14,250
Ash Creek	1945 – 2010	2,461
Braley Creek	1945 – 2010	957
	Total	**17,791**

6.3 Summary of Estimated Groundwater Recharge

A variety of methods have been used in an attempt improve and/or confirm estimates of groundwater inflow to the study area as described in the previous sections. A summary of this information is provided in **Table 16**. Values are rounded from previous sections.

Table 16
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**

6.4 Reconciliation of Estimated Recharge with Total Outflow

All groundwater in the Owens Lake Basin is 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 evapotranspiration. Because it is a terminal basin, there are believed to be only two ways that water leaves the study area: either through export or evapotranspiration. It is also assumed that prior to the LORP and DCM projects, the estimated total evapotranspiration and groundwater export was 66,400 AF/yr plus 300 AF/yr, respectively, or approximately 67,000 AF/yr in total. This total discharge should approximate the estimated groundwater recharge summarized in **Table 16** after accounting for surface water flows in the Owens River. The surface water exports from the LAA (previously described in Section 6.2.2.2) should not be considered in this analysis because the water never enters the groundwater system.

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 evapotranspiration.

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 balances well with groundwater recharge estimate of 44,000 to 67,500 AF/yr and completes the quasi-steady-state water budget for the study area.

6.5 Effect of Dust Control Measures and the Lower Owens River Project on the Owens Lake Hydrologic Regime

Over the last ten years, surface water conditions in the OLGEP study area have changed significantly with the initiation of DCMs and the LORP. This section provides a summary of both DCMs and the LORP, along with an analysis of their effect on the study area hydrologic regime and groundwater budget discussed in previous sections.

6.5.1 Dust Control Measures

A summary of DCMs and associated water use is largely drawn from input from LADWP staff, CDM (2007), and GBUAPCD (2009). 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 (Phases I - V and Phase 7). 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 26**. The LORP pump back station also supplies the main line. The water delivery system for DCMs supplies a total of 27,600 acres (approximately 43 square miles) of management area, consisting of:

- Shallow flood areas (22,900 acres),
- Managed vegetation areas (2,300 acres), and
- Moat and row management areas (2,400 acres).

The lakebed is divided into 38 management areas, of which the shallow flood and managed vegetation areas are the two DCM types that utilize water for dust control.

<u>Shallow Flood</u>. Shallow flood areas must be operated for dust control from October 15th through June 30th of each year. Two types of shallow flood management areas are operated at the lake bed:

- Shallow flood with laterals, whereby water is spread over the soil surface at minimal depth, and
- Shallow flood using ponds, where the soil surface has been excavated and berms constructed to pond water at depths of less than 1 foot up to about 3 feet.

<u>Managed Vegetation</u>. The managed vegetation area consists of 2,300 acres of saltgrass that has been planted and maintained in the southeast portion of the lake bed at Turnouts T5 through T8. Managed vegetation is irrigated year-round. Compliance requirements are based on maintaining a certain percent of plant cover. Managed vegetation requires about 12 to 15 inches per year of irrigation water.

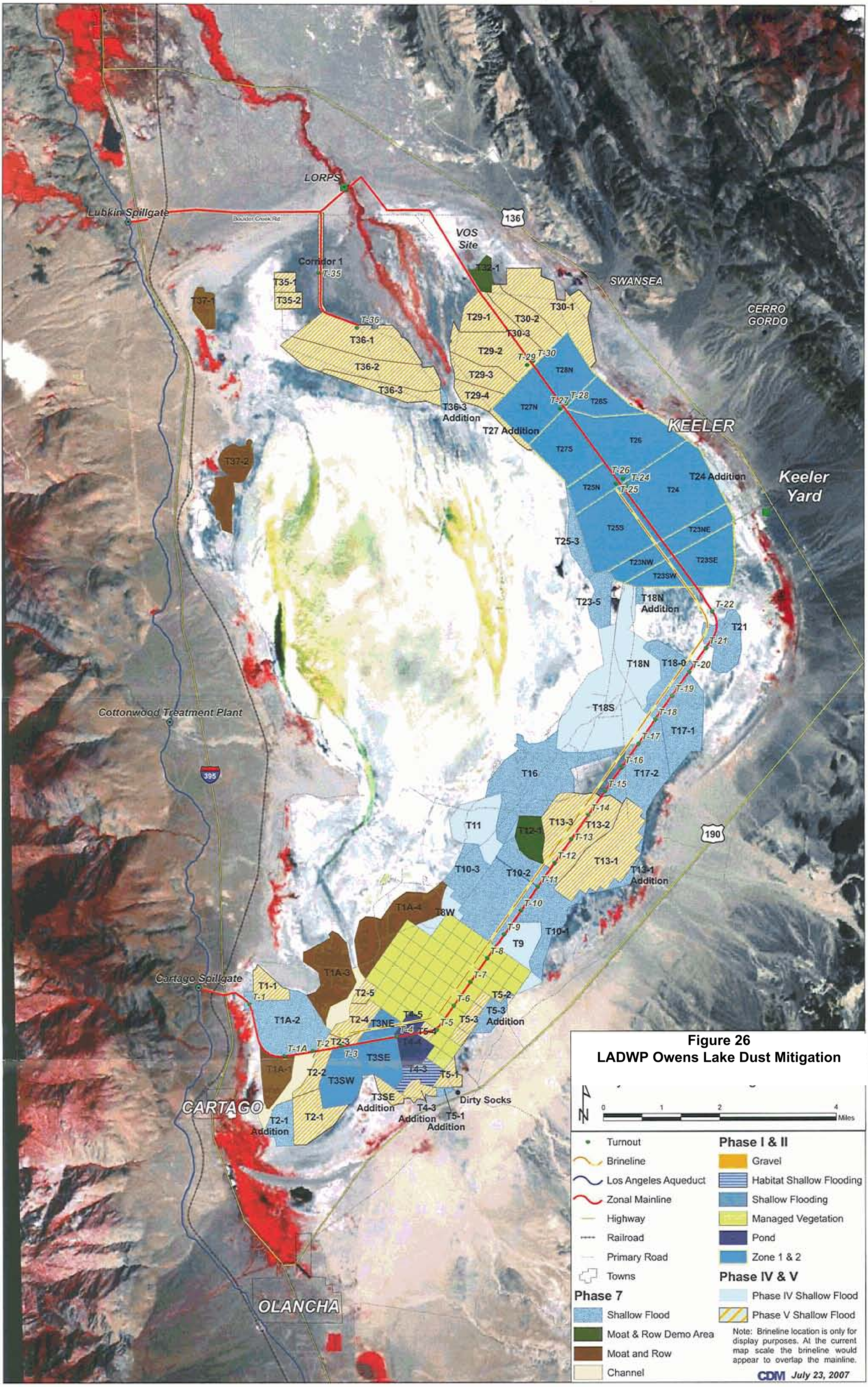


Figure 26
LADWP Owens Lake Dust Mitigation

6.5.1.1 Review of Water Use by Dust Control Measures

The amount of water supplied to DCMs has been increasing steadily since inception of the dust mitigation program. **Figure 27** plots water use by year from 2001 through present, whereby initial water use in 2001 was less than 10,000 acre-feet. Water use in 2011 is expected to be approximately 95,000 acre-feet.

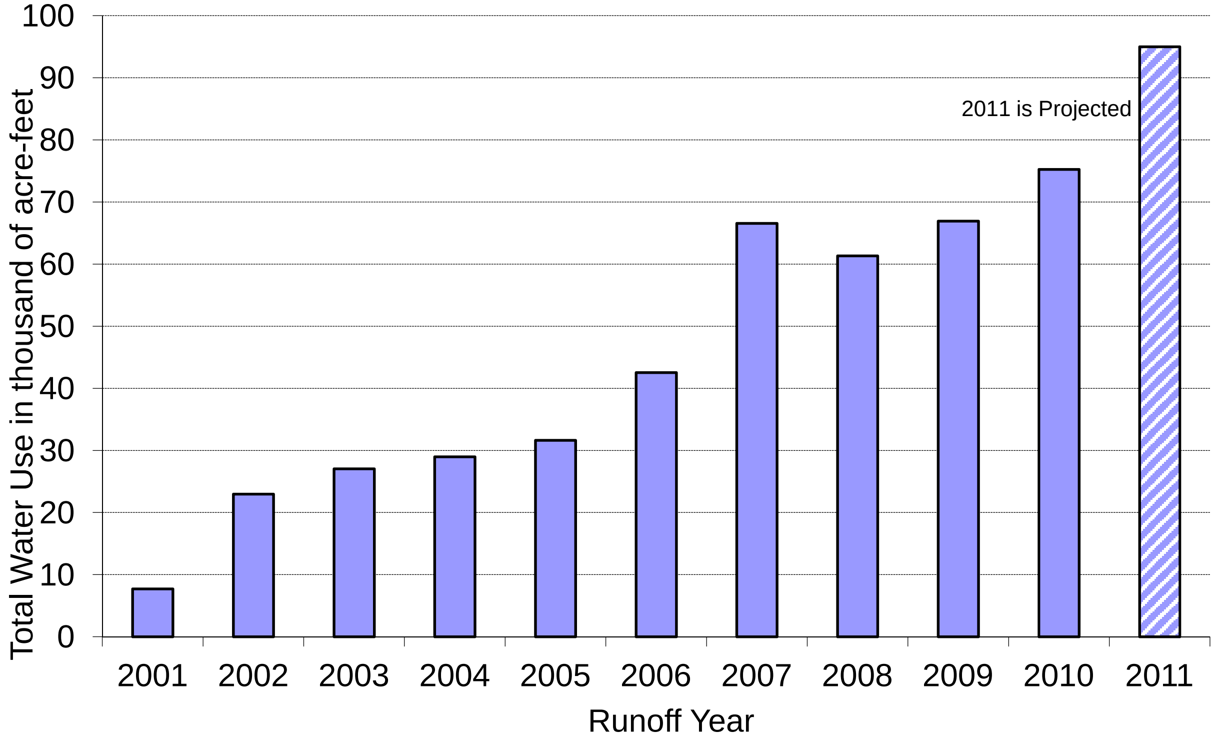


Figure 27
Total Water Use by Year for Dust Control Measures

Water use through time reflects the development and implementation of DCMs in phases as summarized in **Table 17**. Delineation of phases is shown on **Figure 26**. In addition, **Appendix E** pictorially shows development and implementation of DCMs by phase.

Table 17
Summary of Dust Control Mitigation Phases

Phase		Year On-Line	Summary of Construction and Operation Description	
I	Shallow Flooding	2002	11/00 - 11/01	Construction of shallow flood DCM in NW area and North Sand Sheet (NSS).
			11/01	Operation of shallow flooding DCM in NSS begins.
			11/02	Operation of shallow flooding DCM in NW area begins.
	Managed Vegetation Phase I	2002	11/01 - 06/02	Construction of managed vegetation DCM in Dirty Socks/Cartago Creek (South Sand Sheet - SSS) area.
			07/02 - 07/04	Planting of managed vegetation DCM in Dirty Socks/Cartago Creek (SSS) area. Begin operation of site in July 2002. Replanting of isolated areas through 2004.
II	Shallow Flooding	2003	09/02 - 04/03	Construction of shallow flooding DCM in Dirty Socks/Cartago Creek (SSS) area.
			04/03	Operation of shallow flooding DCM in Dirty Socks/Cartago Creek area (SSS) begins.
IV	Shallow Flooding	2005	11/04 - 09/05	Construction of shallow flooding DCM in desiccated clay zone.
			09/05	Operation of shallow flooding DCM in desiccated clay zone begins.
V	Shallow Flooding	2007	11/05 - 11/06	Construction of shallow flooding DCM in northern, central , and southern portions of the lake bed.
			12/06	Operation of shallow flooding DCM in northern, central, and southern portions of the lake bed begins.
7	Shallow Flooding	2010	2007 - 8/10	Construction of Phase 7 shallow flooding DCMs
			8/10	Operation of shallow flooding Phase 7 DCMs begins.

Adapted from GBUAPCD, 2009 (Table 4)
Note - Phase III was the construction of the central segment of the zonal mainline pipe from T8 to T23 (no shallow flood or managed vegetation. There was no Phase VI.
Note that Phase 7 has a numeric designation rather than a roman numeral designation.

6.5.1.2 Review of Hydrographs and Monitoring Data

A key concept in the evaluation of the DCM's effect on the water budget and the groundwater regime in the vicinity of Owens Lake is that if the DCM has had a significant effect on groundwater, it should be reflected by a change to measured water levels which reflect a change in storage and/or gradient since the DCMs were initiated. The most significant database of shallow groundwater levels comes for monitoring performed by the Great Basin Unified Air Pollution Control District (GBUAPCD). GBUAPCD's shallow hydrology monitoring program includes a network of shallow groundwater piezometers and spring flow monitoring sites (**Appendix F**) (GBUAPCD, 2009). In addition, several deep monitoring wells are located throughout the study area (**Figure 2**). Combined, these wells provide a baseline to compare pre-DCM conditions to those that exist today.

In order to evaluate the effect of DCMs on groundwater, wells and piezometers across the study area were selected for a review of water level data. Selected wells have a period of record from pre- to post-DCM so that changes would be apparent on the hydrograph. Both deep wells and shallow piezometers were included in this analysis, along with selected springs. Hydrographs are included in **Appendix G**.

Notable conclusions from a review of the hydrographs include:

- Some existing shallow piezometers, such as Delta West (3) at Site 3413 and Keeler (3) at Site 3015 (see **Figure 28**) Northwest playa and North Sand Sheet areas, show increases in the shallow water levels when DCM operation began. Delta West (3) shows a consistent upward gradient evident in the 4- and 10-foot piezometers before and after start of the DCMs until 2005. Keeler (3) also shows an upward gradient until 2005, the last year in which data is available.

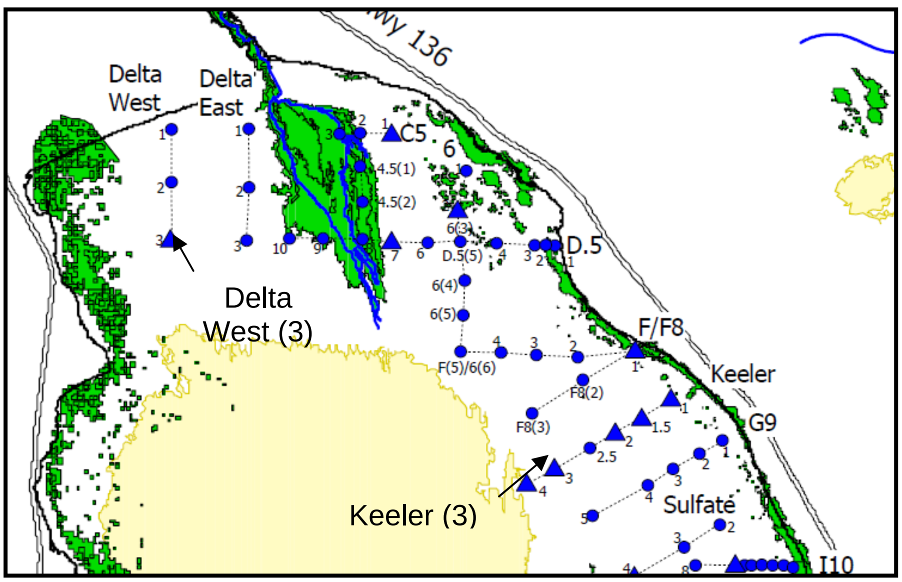


Figure 28
Snapshot from GBUAPCD (2009) Showing Location of Delta West (3) and Keeler (3)

- In some cases, wetland areas and associated piezometers suggest an influence by DCM operation. The 4- and 10-foot piezometers at Keeler Spring in the northeastern area of the playa show a general trend of increasing water levels from 2001 - 2008. Dead Hawk Mound is a flowing spring on the northeastern playa, and flows have increased steadily at the site since the start of the DCMs in December 2001 along with water levels in the 4- and 10-foot piezometers (**Figure 29**).

- None of the deep wells show a clear influence of DCMs.

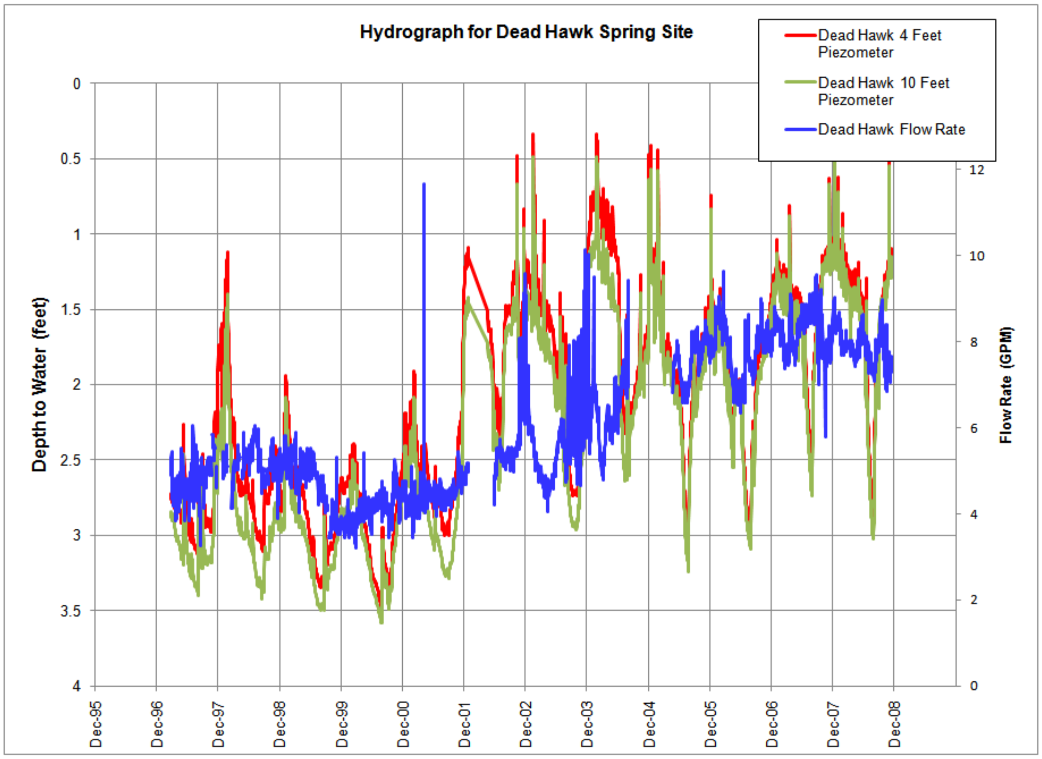


Figure 29
Hydrograph for the Dead Hawk Spring Site showing Spring Flow and Shallow Piezometers

6.5.1.3 Effect of Dust Control Measures on Groundwater

A review of hydrographs suggests that DCMs are locally influencing water levels in the very shallow piezometers on the lake bed. Shallow flooding is seasonal (October through June) and this seasonality is reflected in the affected hydrographs. The effect of DCMs on groundwater appears to be limited to thin sand layers on the surface of the lake, because DCMs have no apparent effect on deeper aquifer zones. The presence of strong upward vertical gradients and artesian conditions would prohibit water from DCMs migrating downward into deeper aquifers. A review of hydrographs in combination with strong vertical gradients and artesian conditions suggests that water from DCMs is not affecting gradients or the amount of groundwater in storage in deeper aquifers. This is consistent with the fact that the DCMs are underlain by a large thickness of relatively impermeable clays which effectively isolate them from the deeper groundwater system.

6.5.1.4 Dust Control Measures Evaporation Analysis

An analysis was conducted to estimate the amount of applied water to DCMs which evaporates, as shown in **Table 18**. The DCMs and associated acreage is shown, along with an assumed percent wetted area (90%) for the shallow flood zones. The high and low water use per DCM developed by CDM (2007) in their Phase 7 analysis was used to calculate consumptive use by DCMs for 2010. The total estimated evaporation from DCMs ranges from 65,174 to 71,189 AF/yr. This amount accounts for most of the total applied water (75,267 acre-feet) in 2010. Therefore, it is concluded that most applied water (greater than 90 percent) is lost to evaporation from shallow flooding or ET from the managed vegetation areas. In effect, ET alone can account for the fate of most of the DCM-applied water, and the remainder may flow toward the brine pool, where it too evaporates. This tends to reinforce the conclusion that applied water for DCMs has no effect on aquifers below the surficial lakebed clays.

6.5.2 Lower Owens River Project

This section provides an overview of the LORP followed by an analysis of LORP's effect on the OLGEP study area water budget.

6.5.2.1 Overview of LORP

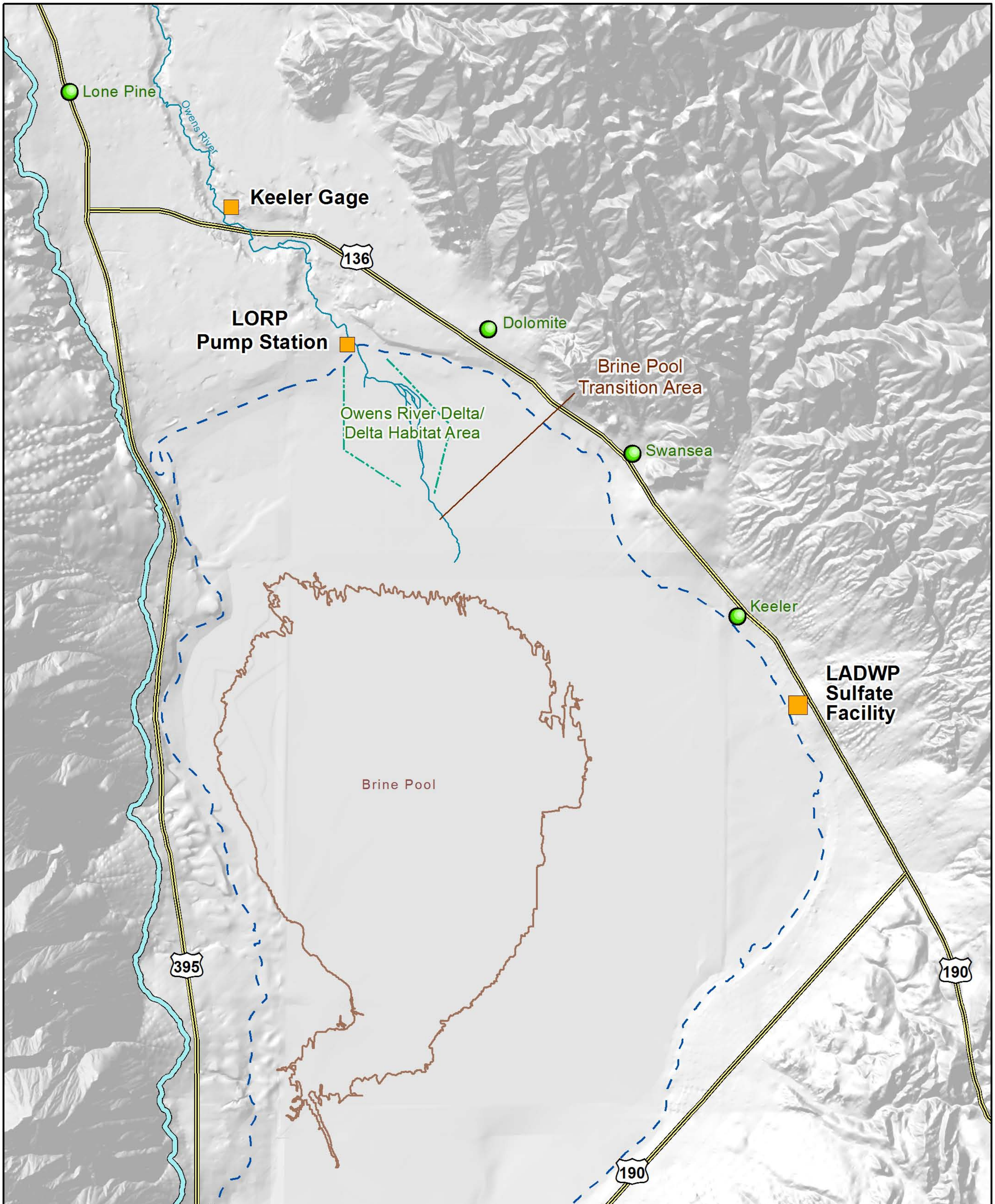
Key elements of LORP are shown on **Figure 30**. LORP is a large-scale habitat restoration project that includes:

- 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 s off-river lakes and ponds,
- Release of flows to the Delta Habitat Area to maintain and enhance wetlands, and
- Modification of grazing practices on LADWP leases adjacent to the river.

The river intake structure completed in 1913 located north of Independence formerly diverted all of the Lower Owens River flows to the LAA. Under the relatively new LORP project, 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 (to be ramped up and down over a period of up to approximately 14 days) 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 (see **Figure 30**), is the only existing flow monitoring station on the river downstream of the river Intake.

Table 18
Consumptive Use Analysis of Applied Water for Dust Control

Dust Control Measure Management Area		Area (acres)		Subarea (acres)	Assumed % of Wetted Area	Period of DCM Use		Water Used (inches per year)		Consumptive Use (acre-feet/yr)	
		Phases I, II, IV, V	Phase 7					Low	High	Low	High
Shallow Flood	Shallow Flood with Laterals	16,900	6,000	9,400	90%	15-Oct	30-Jun	40	45	19,933	22,425
	Shallow Flood with Ponds			13,500	90%			60	65	42,941	46,520
Managed Vegetation	Saltgrass	2,300	0	2,300	Not Applicable	1-Jan	1-Jan	12	15	2,300	2,875
Total		19,200	6,000	25,200						65,174	71,819



Key to Features

- Town
- Facilities
- Owens River
- Los Angeles Aqueduct
- Highway
- Owens Lake (Historic Shoreline)

N

0 1 2 Miles

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Key Elements of the Lower Owens River Project

Los Angeles Department of Water & Power

Figure 30

MWH.

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. The LORP pump station (**Figure 30**) captures and diverts some of the baseflows so that the amount of river flows released towards the Owens River Delta range from approximately 6 to 9 cubic feet per second (cfs) on an annual average basis; minimum releases at any time are approximately 3 cfs. In addition, portions of the seasonal habitat flows bypass the pump station and are released towards the Owens River Delta. Water not released towards the Owens River Delta is conveyed via a pipeline to the Owens Lake Dust Control Mitigation Program and/or to the LAA.

6.5.2.2 Review of Previous Work

Hollett and others (1991) characterized a portion of the Owens River between Lone Pine and the delta as a gaining reach, whereby groundwater is discharged to the Owens River in areas where water levels in the aquifer are above that of the river and where there is hydraulic communication between the river and aquifer.

Jackson (2009) conducted a loss study on the LORP between Spring 2007 and Winter 2008-09 (geographic features are shown on **Figure 1**). He divided LORP into nine (9) reaches using channel water balance methods to determine gains and losses by reach. The study concluded that the first four reaches from the Intake to Mazourka Canyon Road are losing reaches. The next reach from Mazourka Canyon Road to Manzanar-Reward Road is initially losing, but ends up gaining. Reach 6 from Manzanar-Reward Road to Reinhackle Springs shows seasonal effects of gains and losses, whereby the reach is gaining in the winter and fall and losing in the spring and summer. Reach 7 from Reinhackle Springs to Lone Pine Station Road is a losing reach, whereas Reach 8 from Lone Pine Station Road to Keeler Bridge is gaining. The last reach (Reach 9) from Keeler Bridge to the LORP Pump Back Station is both losing and gaining, but consistently gained in the final seasons of the study.

CDM adopted work from previous investigators, concluding that the Lower Owens River was a gaining reach with discharge from the aquifer. In CDM's calibrated model, discharge was simulated at 1,687 AF/yr (CDM, 2000). These findings suggest that the Owens River in this area is discharging from the aquifer, which would prohibit recharge to the main aquifer body.

6.5.2.3 Analysis

In similar fashion as the review of DCM's effect on groundwater, it is expected that if the LORP project has a significant effect on groundwater, a change in groundwater elevations and flow patterns should be evident in hydrographs that include both pre- and post-LORP information. An analysis was performed to determine the effect of LORP on the water budget, whereby an increase in down-valley flow through time would indicate that LORP is providing additional inflow to the water budget or perhaps increasing the degree of freshwater mounding in the sandy shallow delta aquifer. If the addition of water through LORP does increase down-valley flow through time, a change in the gradient between wells north of Lone Pine and north of the Owens Lake delta should be apparent.

The following wells are shown on **Figure 2** and were selected for analysis:

Upgradient Wells

- T692 - located west of the Owens River near Lone Pine
- T378 - located east of the Owens River northeast of Lone Pine

Downgradient Wells

- DVFS Upper Piezometer
- DVFS Middle Piezometer
- DVFS Lower Piezometer
- River Site Upper Piezometer
- River Site Lower Piezometer
- T348

Combined, these two groupings of wells were used to evaluate the pre- and post LORP gradient. Hydrographs for these wells are shown on **Figure 31**, and selected water level data is shown on **Table 19**.

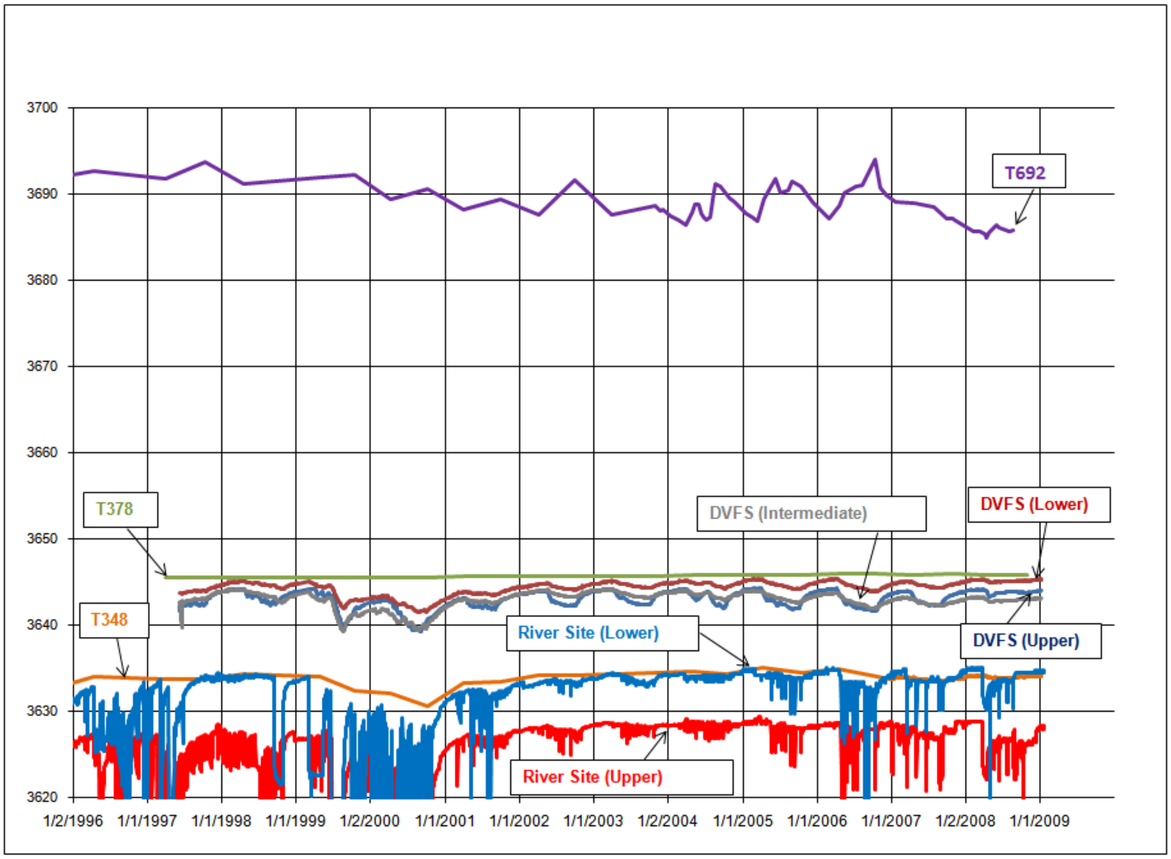


Figure 31
Hydrograph for Selected Wells to Evaluate the Effect of the Lower Owens River Project through Time

Table 19
Summary of Well Data to Evaluate the Effect of the Lower Owens River Project

Aquifer	Well ID	Depth/ Screen Interval (fbgs)	Start of Water Level Record	Pre-LORP Average Groundwater Elevation (6/97 - 6/98) (fmsl)	Post-LORP Average Groundwater Elevation (01/02 - 12/04) (fmsl)	Pre- to Post-LORP Difference in Elevation
1	T378	27	8/28/73	3,645.55	3,645.77	-0.22
	T348	20	12/14/71	3,634.00	3,634.40	-0.4
	T692	23	10/17/87	3,692.38	3,688.39	4.0
	DVFS Upper	212 - 272	6/10/97	3,643.31	3,643.31	0
2	DVFS Middle	512 to 592	6/10/97	3,643.48	3,643.65	-0.17
3	DVFS Lower	662 - 722	6/10/97	3,644.45	3,644.67	-0.22

Based on a review of hydrographs and the data shown on **Table 19**, the following observations are made:

- Upgradient Wells - Between August 1973 to October 2008, no water level change is observed in T378. The average water level difference before 1998 (aka pre-LORP) (from June 1997 to June 1998) and after (aka post-LORP) (from Jan 2002 to December 2004) was 0.22 ft. During the same time period, water levels at T692 dropped approximately 4 feet, which could be the result of pumping in nearby production wells in the Lone Pine Wellfield.
- River Site Wells - Due to pumping activities, significant water level changes were observed at the River Site Upper and Lower Piezometers, complicating use for this analysis. However, no change in static water levels is obvious in these wells.
- Groundwater levels in the DVFS monitoring wells exhibit seasonal fluctuation. The water level reduction from 1999 to 2001 appears to be a result of groundwater pumping at the River Site production wells. **Table 19** shows that the average pre-LORP water level at DVFS (upper), DVFS (intermediate), and DVFS (lower) from June 1997 - June 1998 was 3,643.31, 3,643.48, and 3,644.45 fmsl respectively. In comparison, the average post-LORP water level at DVFS (upper), DVFS (intermediate), and DVFS (lower) from January 2002 - December 2004 was 3,643.31, 3,643.65, and 3,644.67 fmsl respectively. The maximum water level variation of 0.22 ft was observed at DVFS (lower) between the two observation periods.

Table 20 cross compares each upgradient well with each downgradient well for both pre- and post-LORP. Similarly, a groundwater gradient for each well pairing is shown for pre- and post-LORP. Finally, the difference in gradient before and after LORP is shown. Data suggest that the difference in gradient between T692 and downgradient wells after LORP has decreased by 0.0002 to 0.0003. The gradient between T378 and downgradient wells after LORP is unchanged.

As evidenced by the change in gradient between T692 and downgradient wells, 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 (2) 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, meaning that water from the LORP could not substantially change the groundwater regime. This leads 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.

Table 20
Summary of Pre- and Post-LORP Gradient Using Selected Wells

Pre-LORP Difference between Upgradient and Downgradient Wells					Post-LORP Difference between Upgradient and Downgradient Wells					Difference between Pre- and Post-LORP Conditions				
	Water Level (fbgs)		Gradient			Water Level (fbgs)		Gradient			Water Level (fbgs)		Gradient	
	T692	T378	T692	T378		T692	T378	T692	T378		T692	T378	T692	T378
T348	58.38	11.55	0.0023	0.0004	T348	53.99	11.37	0.0022	0.0004	T348	4.39	0.18	0.0002	0.0000
DVFS Upper	49.07	2.24	0.0037	0.0002	DVFS Upper	45.08	2.46	0.0034	0.0002	DVFS Upper	3.99	-0.22	0.0003	0.0000
DVFS Middle	48.90	2.07	0.0037	0.0001	DVFS Middle	44.74	2.12	0.0034	0.0001	DVFS Middle	4.16	-0.05	0.0003	0.0000
DVFS Lower	47.93	1.10	0.0036	0.0001	DVFS Lower	43.72	1.10	0.0033	0.0001	DVFS Lower	4.21	0.00	0.0003	0.0000

Upgradient wells shown at top; downgradient rows shown on left.

Distances between upgradient and downgradient wells calculated using GIS mapping tools are as follows:

	T692	T378
T348	24,864	31,151
DVFS	13,266	14,736

7.0 Soil Data

Four (4) soil samples were collected and submitted for geotechnical analysis as summarized in **Table 21**. Full analytical reports are provided in **Appendix H**. The samples were submitted to LADWP's soils and material testing laboratory and analyzed as follows:

- Soils classification per ASTM D2487-06,
- One-Dimensional Consolidation Testing per ASTM D2435-04, and
- Hydraulic Conductivity Using a Flexible Wall Permeater per ASTM D5084, Method A - Constant Head Test.

The following notations were made:

For T898, there were a few testing issues:

- The Soils and Materials Testing Laboratory experienced a power outage as the permeability test was running, which required the retesting of the sample (T898).
- It was noted that the percent saturation of the sample was unusually low in comparison to the high water content.
- The sample provided was highly disturbed and very wet. There was an unusually large decrease in volume of the sample materials after it was dried in the oven, and it was noted that samples felt very light after drying, which would suggest large void ratios.
- The drilling/sampling method may have affected the results. The sample may contain bentonite, which tends to burn off during the oven drying process.
- One or a combination of the above mentioned scenarios could skew the void ratios.

For T909, T912, and T914, due to the impervious nature of the fat clay, the permeability test did not provide hydraulic conductivity values (**Appendix H**).

These soil data tend to confirm the very low hydraulic conductivity values for the lakebed clays.

Table 21
Summary of Soils Data from OLGEP Well Drilling Program

Well ID	OLGEP Well Site	Date	Depth	Soil Classification (ASTM D2487-06)	Atterberg Limits		Maximum Particle Size (US Sieve)	Consolidation Testing (ASTM D2435-04)			Hydraulic Conductivity (ft/s) (ASTM D5084)
					Liquit Limit	Plasticity Index		Void Ratio		Specific Gravity	
								Placing	Removal		
T898	DWP-9	7/12/2010	N/A	N/A	N/A	N/A	N/A	4.7322	3.9199	2.46	2.59E-09
T909	DWP-7	2/16/2011	350	CH, Fat Clay w/Sand	60	32	No. 40	1.8632	1.7498	2.69	N/A
T912	DWP-6	3/29/2011	N/A	CH, Fat Clay	52	25	No. 40	1.6171	1.2594	2.78	N/A
T914	DWP-5	6/27/2011	N/A	CH, Fat Clay	59	29	No. 10	1.5466	1.1865	2.78	N/A

N/A - Not Available

8.0 Water Quality

Existing data on groundwater quality in the OLGEP study area was summarized in the OLGEP preliminary conceptual model report (MWH, 2011a). Water quality data collected for the new OLGEP monitoring wells since that time is summarized in **Table 22**. Groundwater samples were taken from wells and submitted to LADWP's Environmental Laboratory for analysis general parameters and metals. Notable findings are summarized below.

8.1 Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the salinity of water. Freeze and Cherry (1979) characterize TDS concentrations according to concentration in groundwater as follows:

Fresh water	0 - 1,000 mg/l
Brackish water	1,000 - 10,000 mg/l
Saline water	10,000 - 100,000 mg/l
Brine water	> 100,000 mg/l

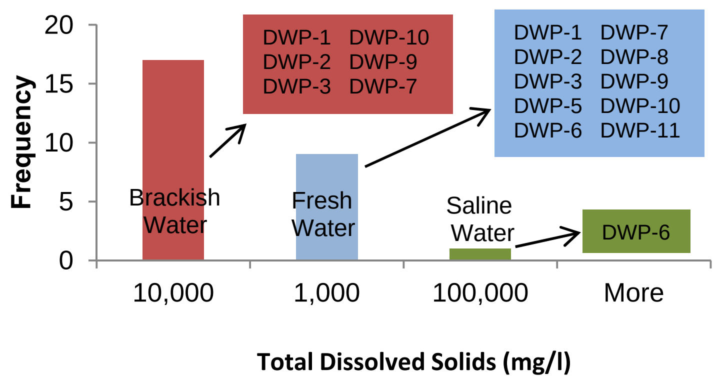
TDS concentrations in the new OLGEP monitoring wells range from fresh water (222 mg/l) to saline water (20,983 mg/l). **Figure 32** is a histogram plot showing the frequency of TDS measurements by groupings. **Figure 33** shows the distribution of TDS by aquifer unit.

Higher concentrations of TDS are found to the south at sites DWP-5, -6, and -8. The highest concentration of TDS was found at site DWP-6. At this location, Well T913, which is screened in aquifer unit 1, has a TDS concentration of 20,983 mg/l which is characterized as saline water. In general, TDS in groundwater is lower in the north, typically less than 2,000 mg/l. TDS in aquifer units 3 and 5 appear similar. With the exception of the single high data point of 20,983 in aquifer unit 1 near the brine pool, the general trend for TDS appears highest in aquifer units 3 and 5.

Table 22
Summary of Water Quality Data for OLGEP Monitoring Wells

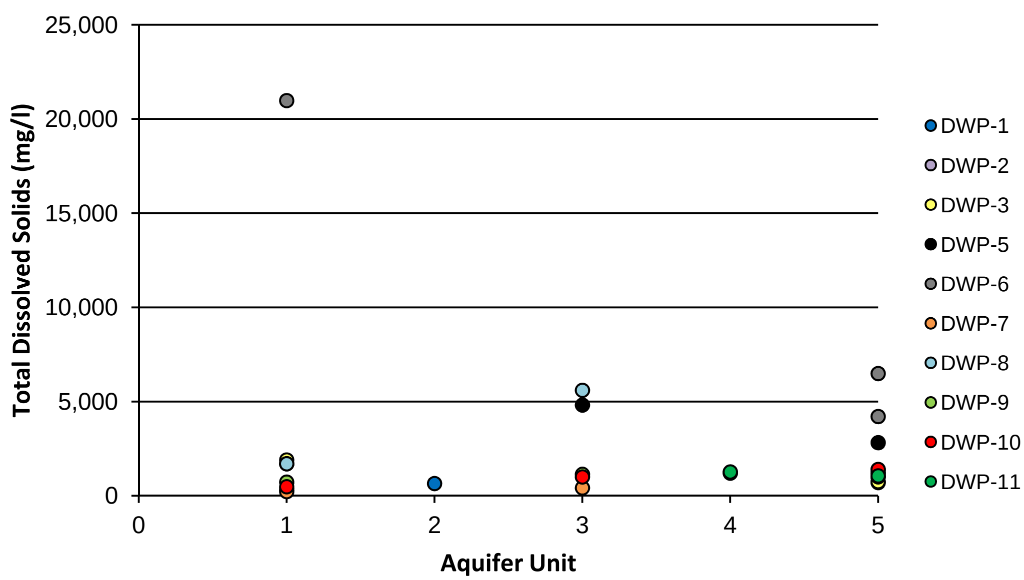
Well Site	Well ID	Water Quality																																	
		Temp (˚C)	DO (mg/L)	pH	Specific Conductivity (uS/cm)	Turbidity (NTU)	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Total Chromium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Lead (mg/L)	Lithium (mg/L)	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



*Note: See **Table 22** for a tabular summary of water quality data.*

Figure 32
Histogram Showing the Frequency of Total Dissolved Solids Concentrations in OLGEP Monitoring Wells

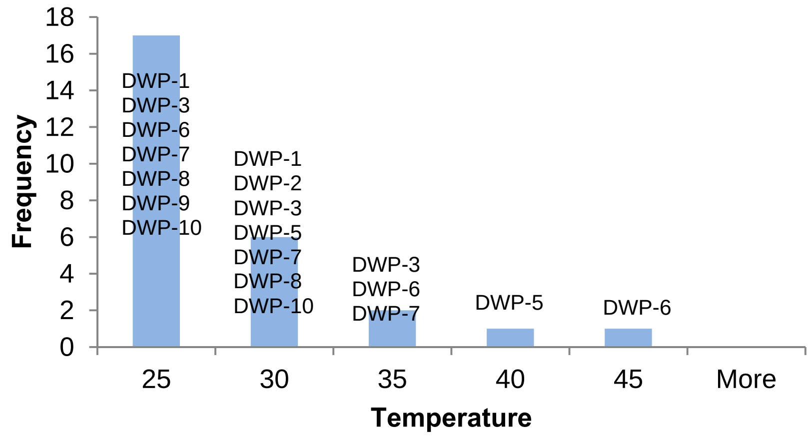


*Note: See **Table 22** for a tabular summary of water quality data.*

Figure 33
Distribution of Total Dissolved Solids in OLGEP Monitoring Wells by Aquifer Unit

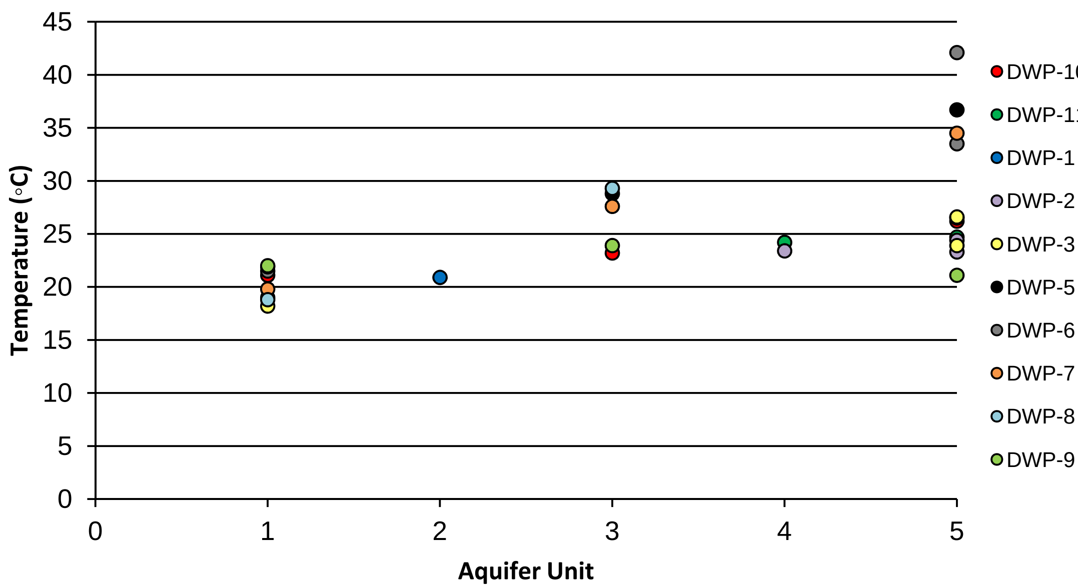
8.2 Temperature

Temperature measurements in OLGEP wells range from 18.2 to 42.1 C as shown in **Table 22**. **Figure 34** is a histogram plot showing the frequency of temperature measurements by groupings. **Figure 35** shows the distribution of temperature by aquifer unit. The highest temperature readings were from DWP-6 and DWP-7 located in the south and southwest of the study area, suggestive of geothermal conditions. The highest temperatures were recorded from aquifer unit 5. As might be expected, temperature tends to increase with depth.



*Note: See **Table 22** for a tabular summary of water quality data.*

Figure 34
Histogram Showing the Frequency of Temperature in OLGEP Monitoring Wells

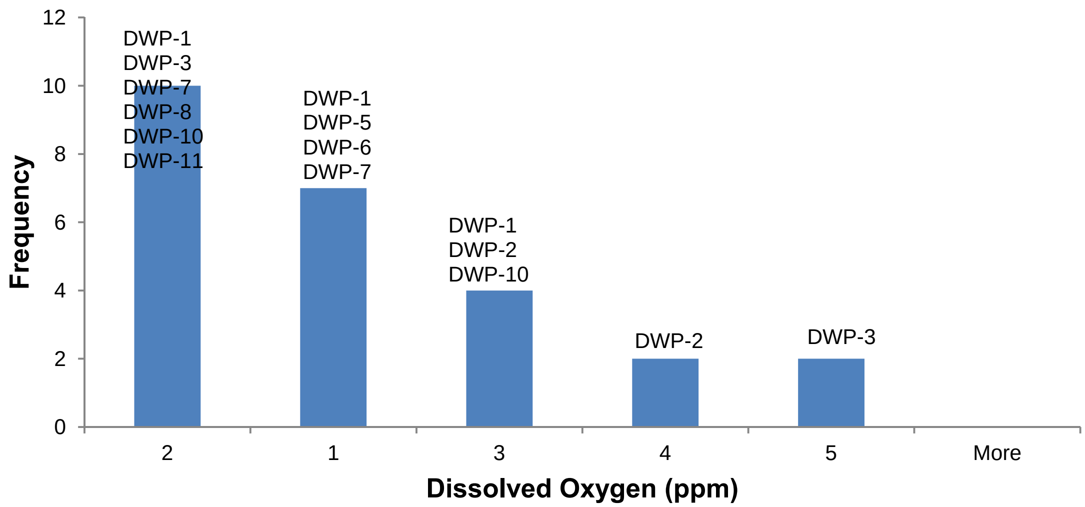


*Note: See **Table 22** for a tabular summary of water quality data.*

Figure 35
Distribution of Temperature in OLGEP Monitoring Wells by Aquifer Unit

8.3 Dissolved Oxygen

Dissolved oxygen (DO) ranges from 0.06 to 4.98 parts per million (ppm) as shown on **Table 22**. **Figure 36** is a histogram plot showing the frequency of dissolved oxygen measurements by groupings. The majority of measurements are between 1-2 ppm. **Figure 37** shows the distribution of dissolved by aquifer unit. Note that DWP-9 did not include DO readings. The highest DO readings are from DWP-3, located immediately west of Keeler. The highest DO readings were recorded deeper wells, which is counter-intuitive and may indicate a problem with the sampling or analysis method.

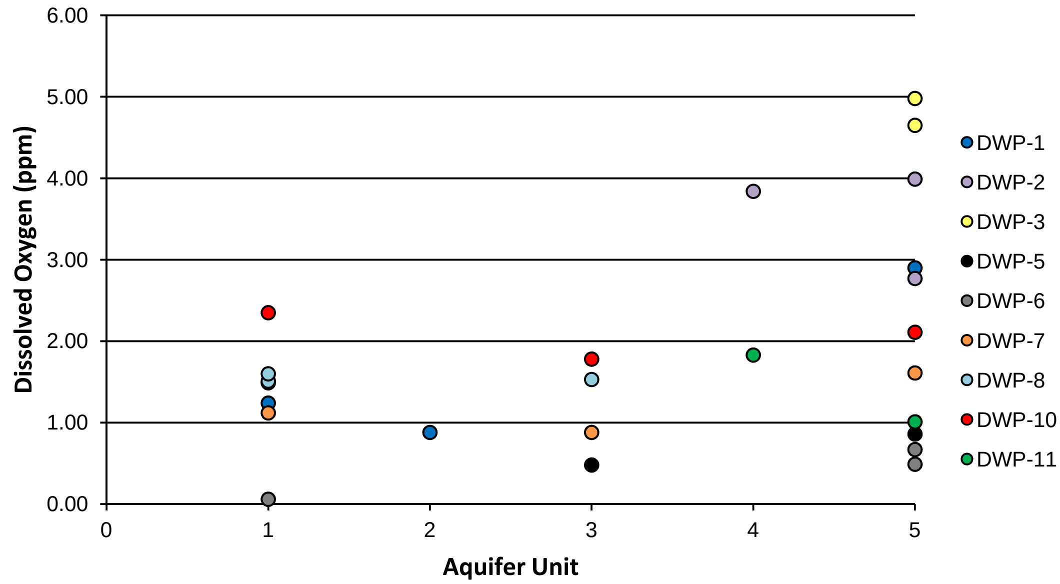


Note: See **Table 22** for a tabular summary of water quality data; DO was not recorded at DWP-9.

Figure 36
Histogram Showing the Frequency of Dissolved Oxygen in OLGEP Monitoring Wells

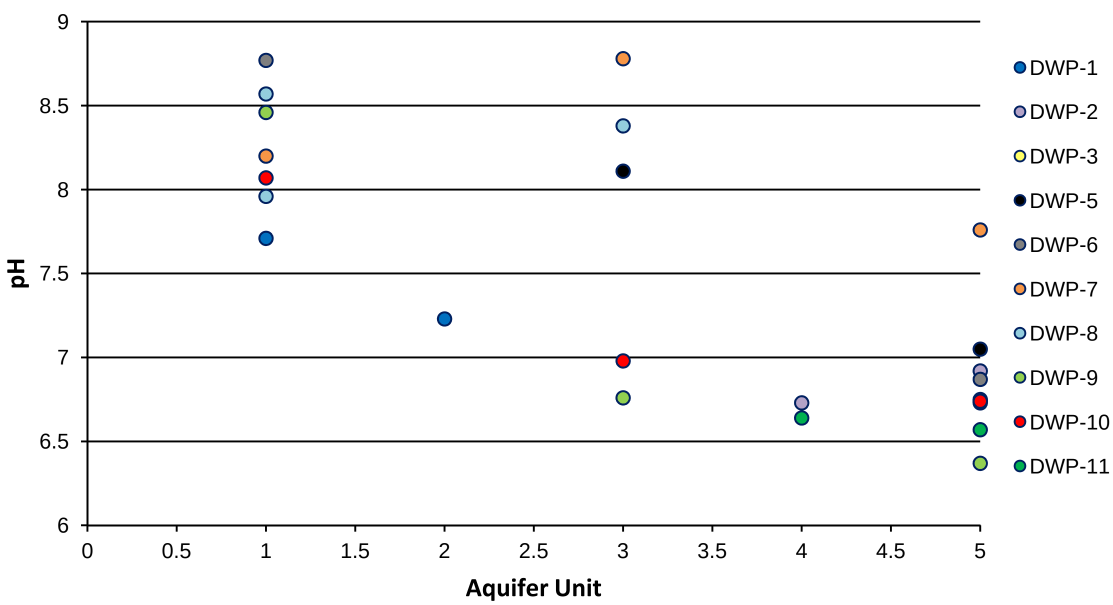
8.4 pH

Measurements of pH range from 6.37 to 9.2 as shown on **Table 22**. Most groundwater in the U.S. have a range of 6 - 8.5 (Driscoll, 1986). Of the measurements recorded, three are greater than this range and occur in the wells to the south. The highest reading of 9.2 was recorded at DWP-3 in aquifer unit 1. The distribution of pH by aquifer unit is shown on **Figure 38**. The trend shown on this plot suggests that pH decreases with increasing depth.



*Note: See **Table 22** for a tabular summary of water quality data; DO was not recorded at DWP-9.*

Figure 37
Distribution of Dissolved Oxygen in OLGEP Monitoring Wells by Aquifer Unit



*Note: See **Table 22** for a tabular summary of water quality data.*

Figure 38
Distribution of Dissolved pH in OLGEP Monitoring Wells by Aquifer Unit

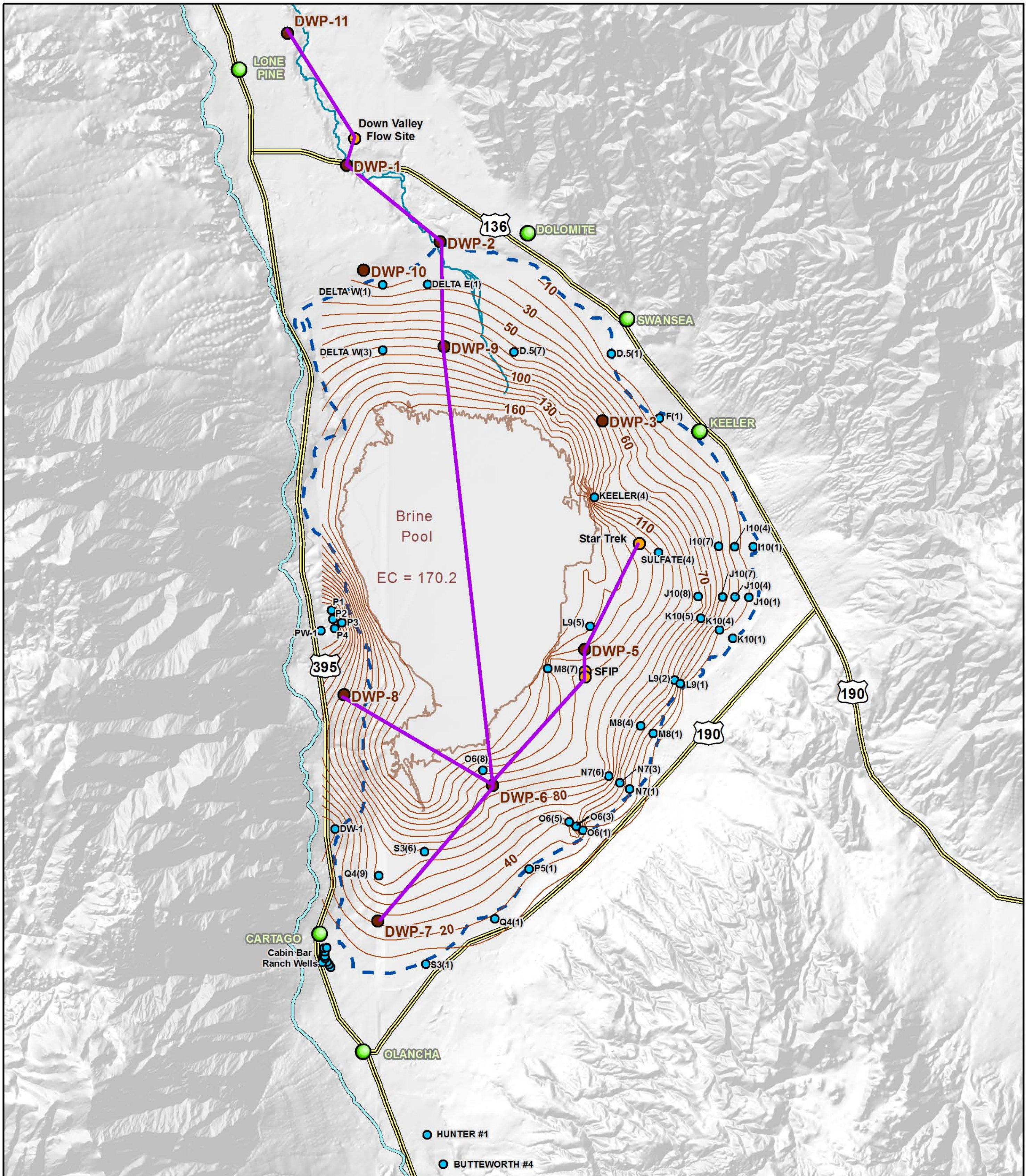
8.5 Electrical Conductivity

Electrical conductivity in shallow groundwater and surface water based on previously-available data are depicted in **Figure 39**. These data show a clear and relatively consistent increase in electrical conductivity in a radial direction toward the brine pool, which may be expected as water is subjected to increasing amounts of evaporation. Surface measurements range from less than 10,000 to over 170,000 µs/cm near the brine pool (10 to 170 mS/cm). For comparison, specific conductivity of typical waters is shown in **Table 23** (Eutech, 2011). These data indicate that shallow groundwater and surface water in the vicinity of the brine is much more saline than typical seawater.

Table 23
Conductivity of Typical Waters

Typical Water Type	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)
Pure water	0.055	.04
Power plant boiler water	1.0	0.7
Potable municipal supply	500	350
Ocean water	53,000	36,800

Specific conductivity measurements from the new OLGEP wells provide a means to evaluate changes in specific conductivity with depth. **Figure 40** and **41** depict cross sections in an east-west and north-south direction that show variation of specific conductivity with depth based on the new drilling data. Cross section locations are shown on **Figure 39**. Contours of equal specific conductivity shown on these figures are obviously gross generalizations, but they do show a trend of low-salinity groundwater becoming increasingly more saline as it flows toward the discharge point at Owens Lake.



Key to Features

- Highway
- Los Angeles Aqueduct
- Cross Section
- Owens Lake (Historic Shoreline)
- Calibration Well
- Electrical Conductivity Monitoring Site
- Equal Contour of Estimated Electrical Conductivity (10 mS/cm contour interval)

Source: GBUAPCD, 2002

N
0 1.5 3 Miles

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Electrical Conductivity of Surface Water and Groundwater from 10-Foot Piezometers

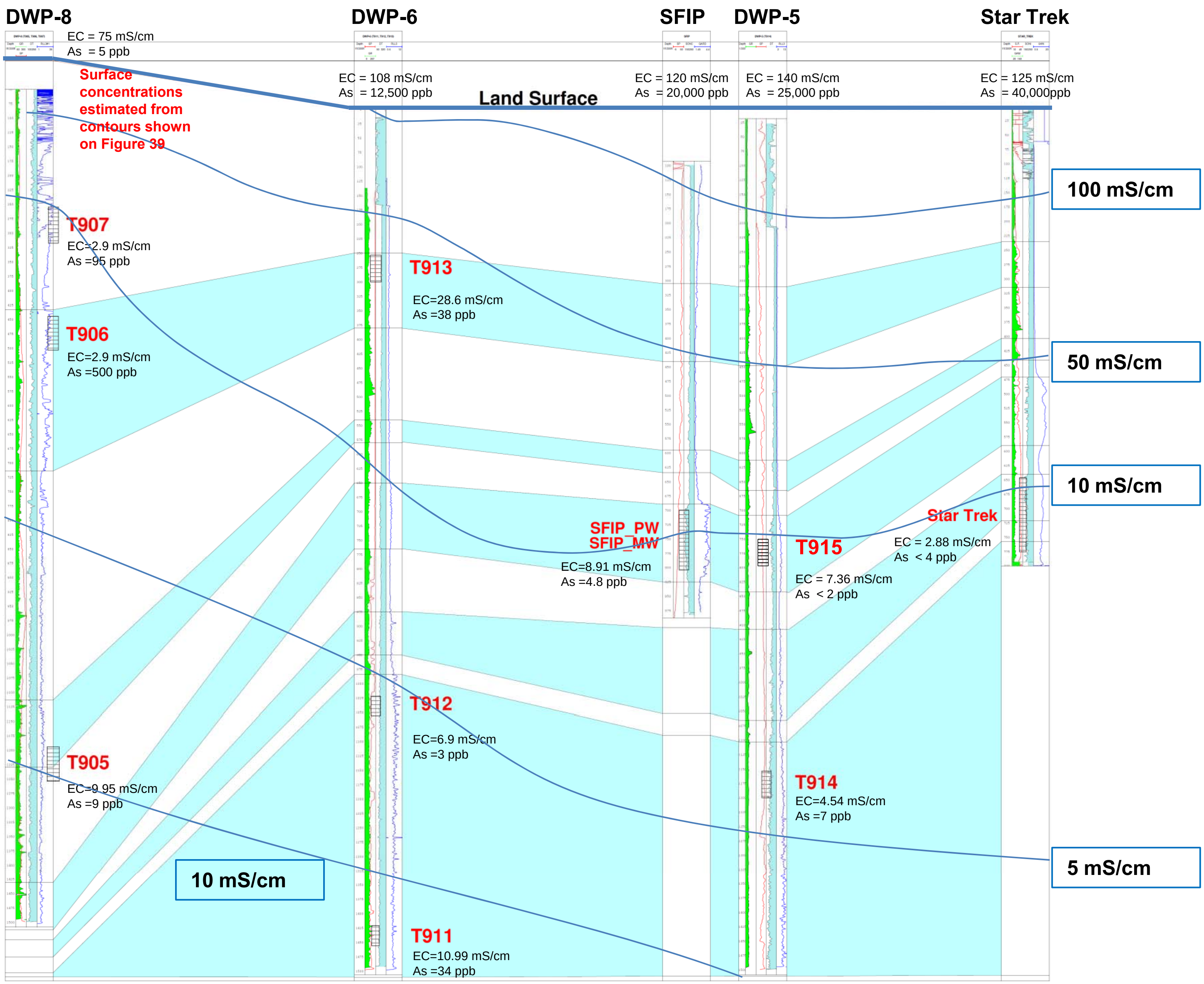
Los Angeles Department of Water & Power

Figure 39

MWH

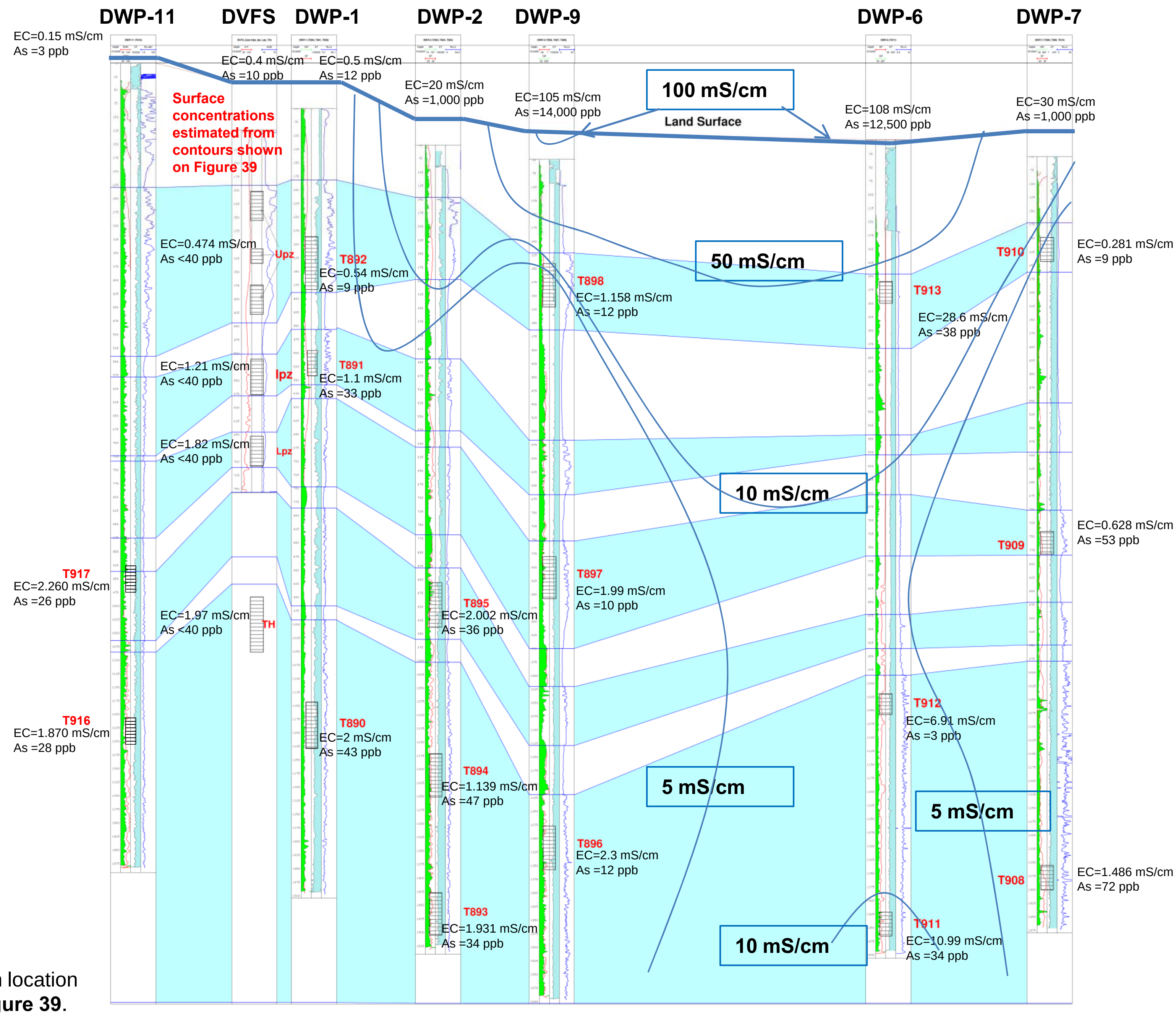
This map was designed to print 8.5'' by 11''.

Figure 40
Contours of Electrical Conductivity Along an East-West Cross Section



Cross section location shown on **Figure 39**.

Figure 41
Contours of Electrical Conductivity Along a North-South Cross Section



Cross section location shown on **Figure 39**.

In general, salinity of deeper groundwater is much lower than shallow groundwater and does not exceed that of typical ocean water. Specific conductivity of groundwater in the new wells range between 281 to 28,600 µs/cm as shown on **Table 22**. As expected, specific conductance varies directly with the amount of dissolved solids as shown on **Figure 42**.

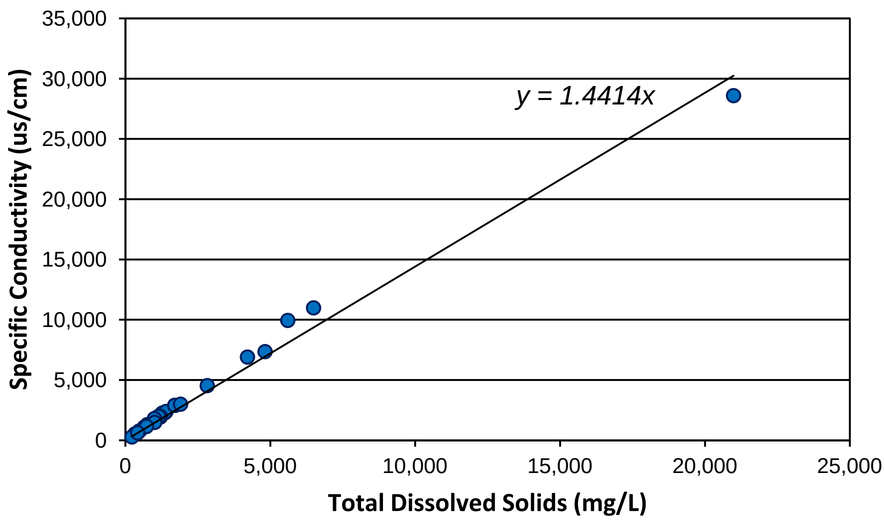
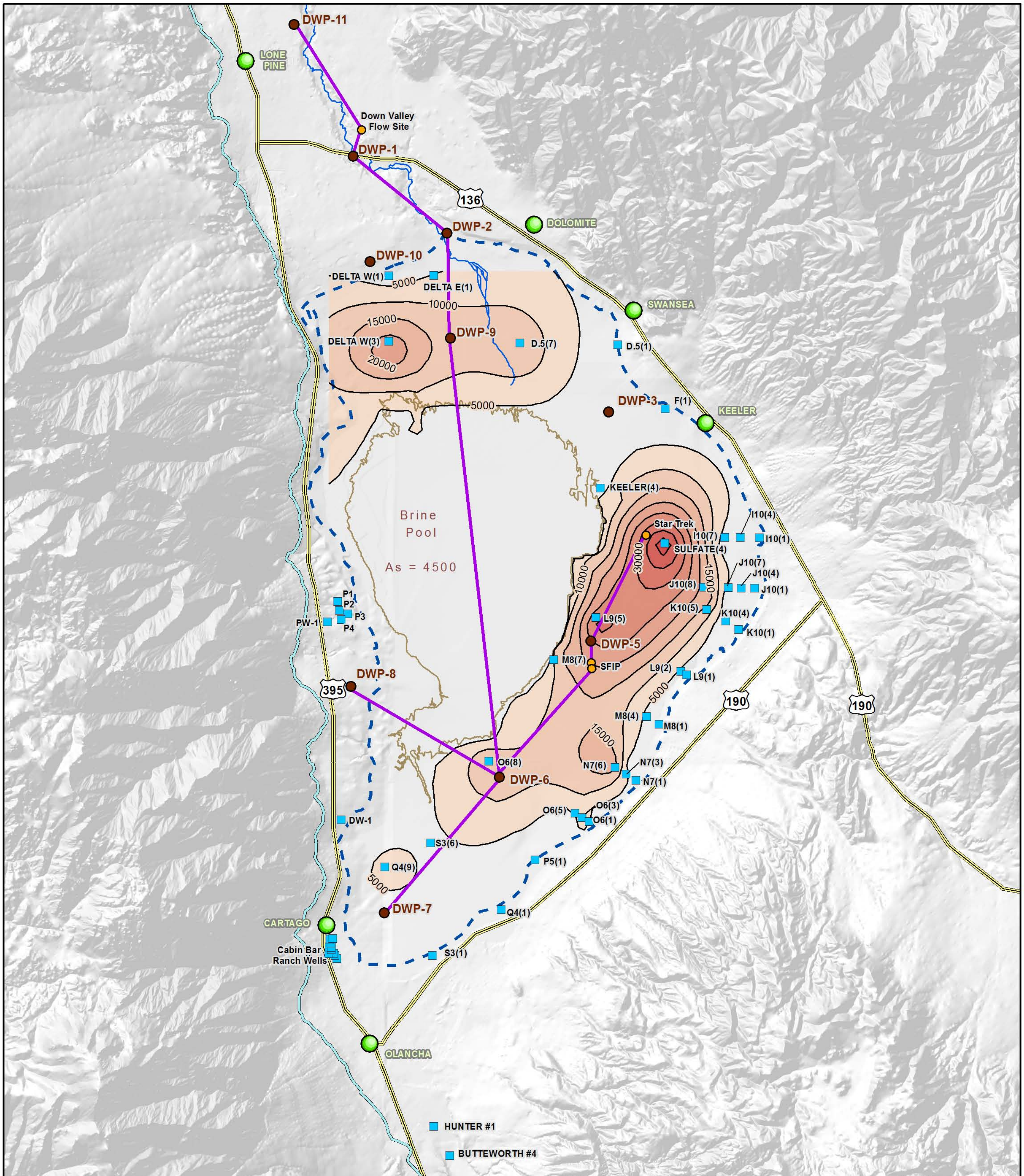


Figure 42
Total Dissolved Solids Concentration Compared with Specific Conductivity for OLGEP Monitoring Wells

8.6 Arsenic

Arsenic concentrations in shallow groundwater and surface water based on previously-available data are depicted in **Figure 43**. These data show very high arsenic concentrations in areas of historically high evaporation rates such as in the delta area and in the vicinity DWP-5, DWP-6, and the Sulfate Well. Surface measurements range from less than 5,000 to over 40,000 ppb near the Sulfate Well. For comparison, the drinking water limit or maximum contaminant level for arsenic is 10 ppb.

Data on arsenic in the new wells is summarized in **Table 22**. Arsenic measurements from the new OLGEP wells provide a means to evaluate changes in arsenic concentration with depth. **Figure 44** and **45** depict cross sections in an east-west and north-south direction that show variation of arsenic with depth based on the new drilling data. Cross section locations are shown on **Figure 43**. Contours of equal specific arsenic concentration shown on these figures are obviously gross generalizations, but they do show a trend of increasing arsenic toward the east side of Owens Lake, and decreasing arsenic levels with depth.



Key to Features

- Highway
- Los Angeles Aqueduct
- Cross Section
- Owens Lake (Historic Shoreline)
- Calibration Well
- Arsenic Concentration (ppb)
- Contour of Estimated Equal Arsenic Concentration (5,000 ppb contour interval)

Note: EPA MCL for Arsenic is 10 ppb.
Source: GBUAPCD, 2002, Font, 1995, and Olancha Water Development Project, 1998

N 0 1 2 Miles

Document: \\Uspas1netapp1\muni\Clients\Los Angeles Water&Power LADWP\Owens Valley Data\Owens Valley GIS\Projects\OLGEP\ElectricalConductivityArsenic.mxd

Arsenic Concentrations of Surface Water and Groundwater from 10-Foot Piezometers

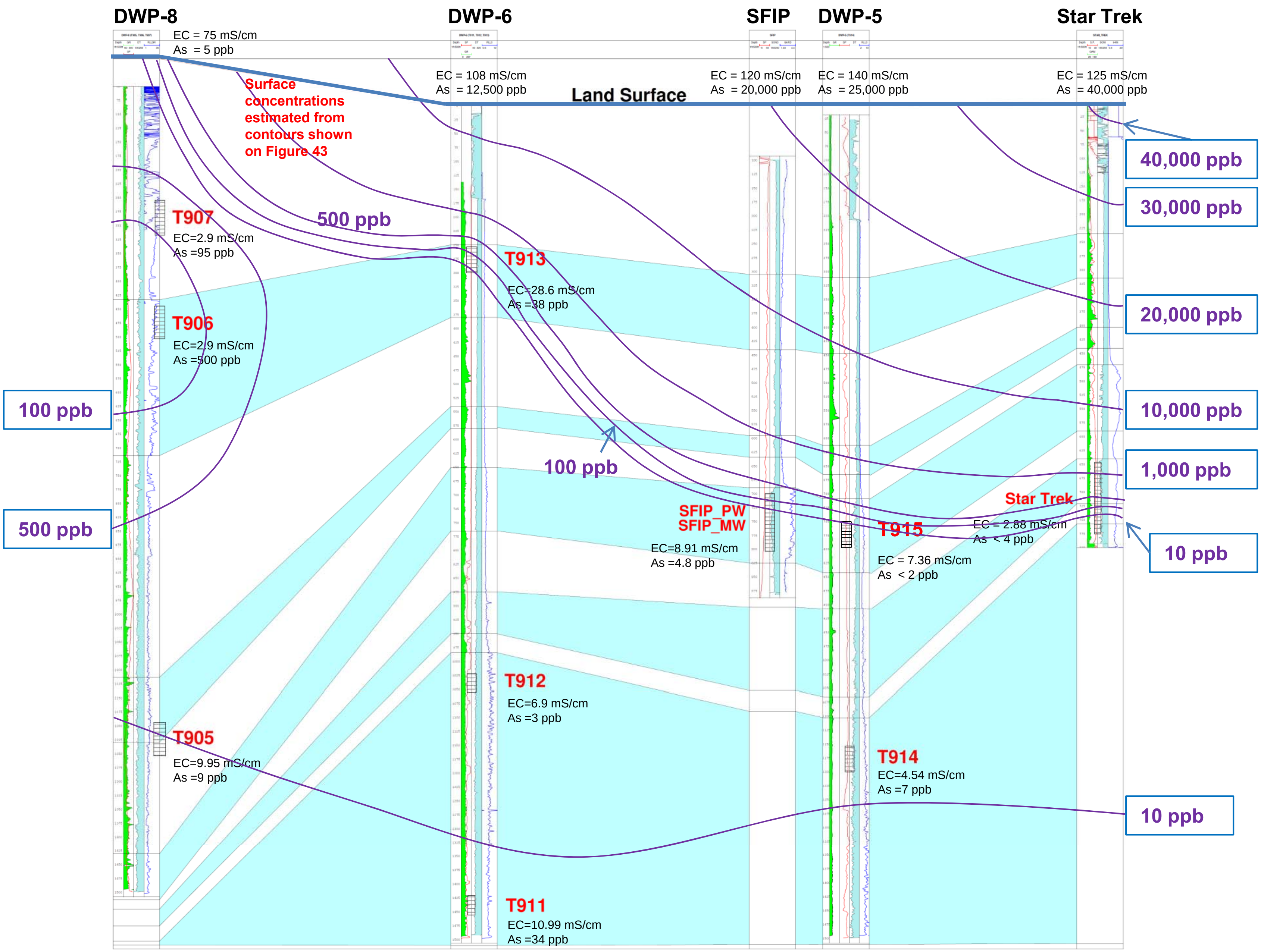
Los Angeles Department of Water & Power

Figure 43

MWH

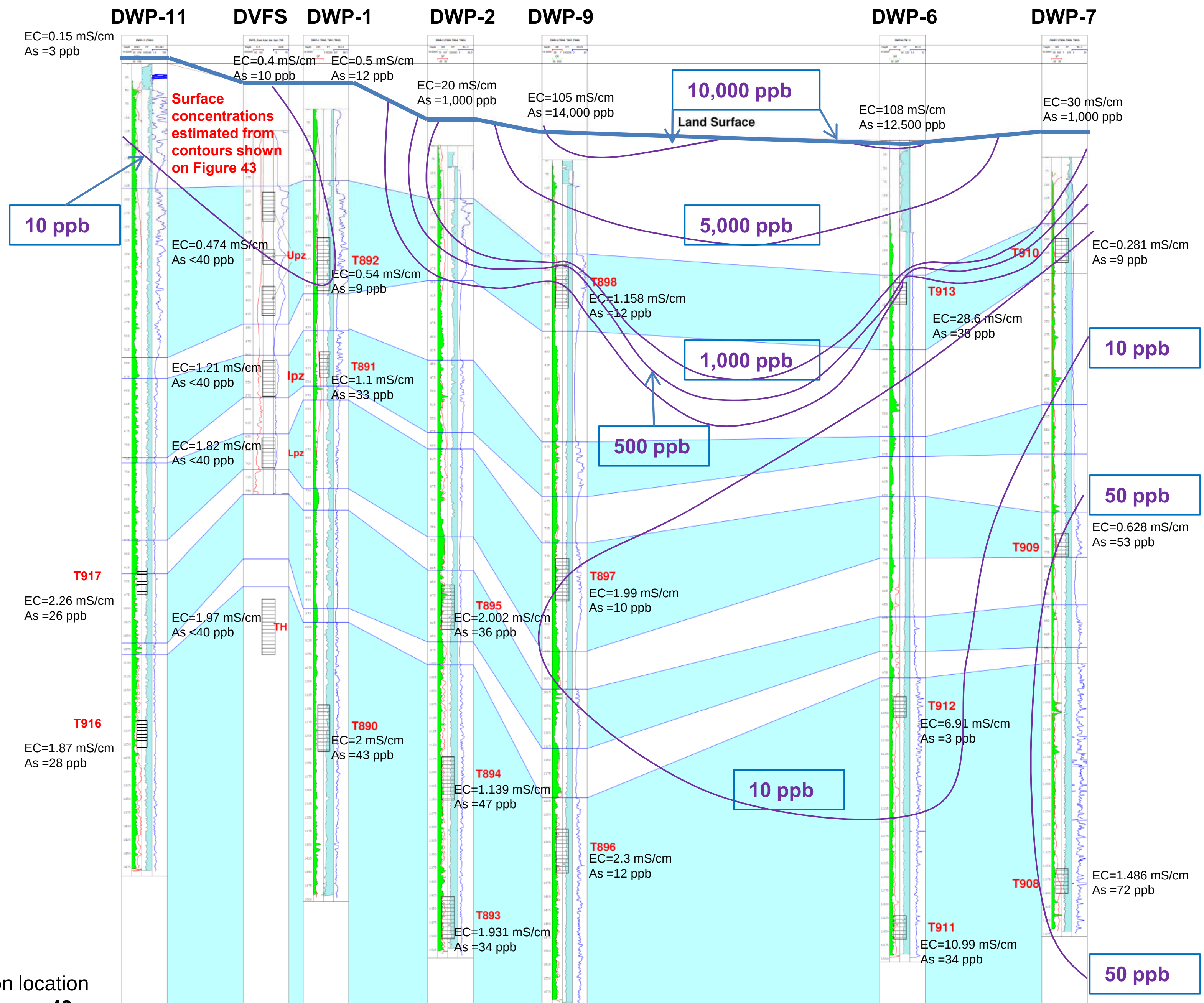
This map was designed to print 8.5'' by 11''.

Figure 44
Contours of Arsenic Concentration Along an East-West Cross Section



Cross section location shown on **Figure 43**.

Figure 45
Contours of Arsenic Concentration Along a North-South Cross Section



Cross section location shown on **Figure 43**.

9.0 Spring Characterization

MWH conducted an initial evaluation of environmental criteria for the development of groundwater resources at Owens Lake (MWH, 2011f). As part of this work, MWH developed a list of sensitive environmental elements in and around the Owens Lake study area. It is clear that development of groundwater near Owens Lake will affect the groundwater and surface water environments in varying ways; therefore, an objective of this work was to identify those impacts that may be considered significant, and to initiate development of potential methods for mitigating significant impacts. It became clear that springs in the study area are one of the most important sensitive resources. Therefore, a characterization of springs was conducted to identify sources of springs and relationships to aquifer units. Study area springs are shown on **Figure 46**, and a summary spring table is included in **Appendix I**.

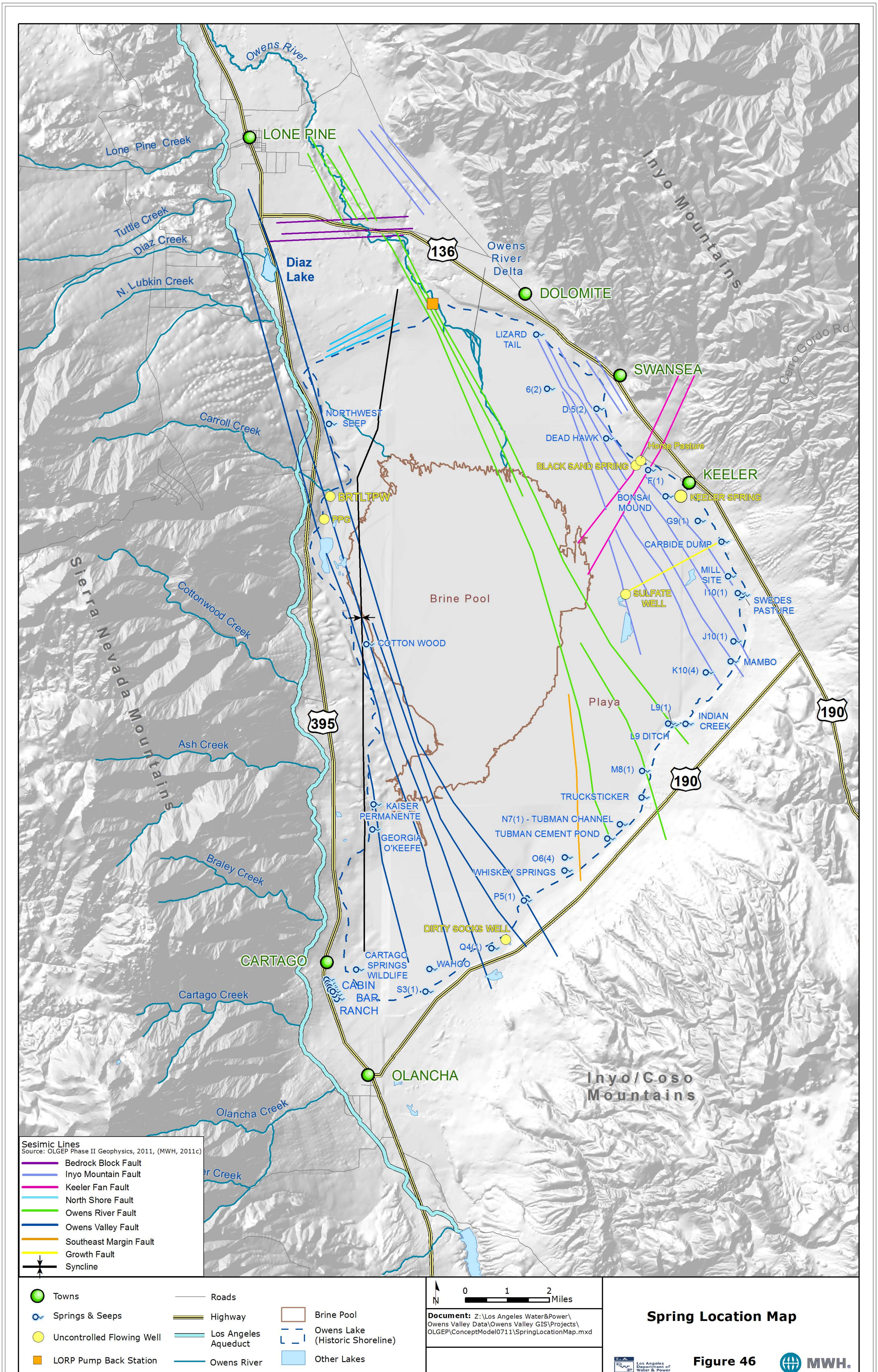
This effort included compilation of data from multiple sources into a single table. Information was drawn primarily from GBUAPCD (2009) as well as ancillary GBUAPCD data, the preliminary hydrogeologic conceptual model report (MWH, 2011a), information supplied by LADWP, and data collected under OLGEP. Data on springs and flowing wells is described in the following sections.

9.1 Flowing Wells

Flowing wells (**Figure 46**) were segregated from natural springs and include the following locations:

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

It is assumed that flowing wells are sourced from deeper aquifers. However, no construction, lithologic, or geophysical logs are available for any of these wells. As a result, the depth and screened intervals is not known; therefore, the association of flowing wells with specific aquifer units cannot be ascertained with certainty.



Spring Location Map

Figure 46

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

9.2 Spring Flow

Spring flow was plotted against the following data in order to identify patterns and to draw correlations:

- Precipitation - Significant variability in precipitation exists between the east and west sides of the study area. Therefore, west side springs were plotted against precipitation data from the Cottonwood Power Plant, and east side springs were plotted against precipitation using data from the town of Keeler.
- Runoff - Spring flow was plotted against runoff data using stream gauging runoff data from Cottonwood Creek (Note - there is not an east side runoff gauge).

These plots (provided in **Appendix J**) were used to determine if spring flow could be correlated to either precipitation and/or runoff. An example of an observable correlation between spring flow and precipitation is Cottonwood Spring as shown on **Figure 47**.

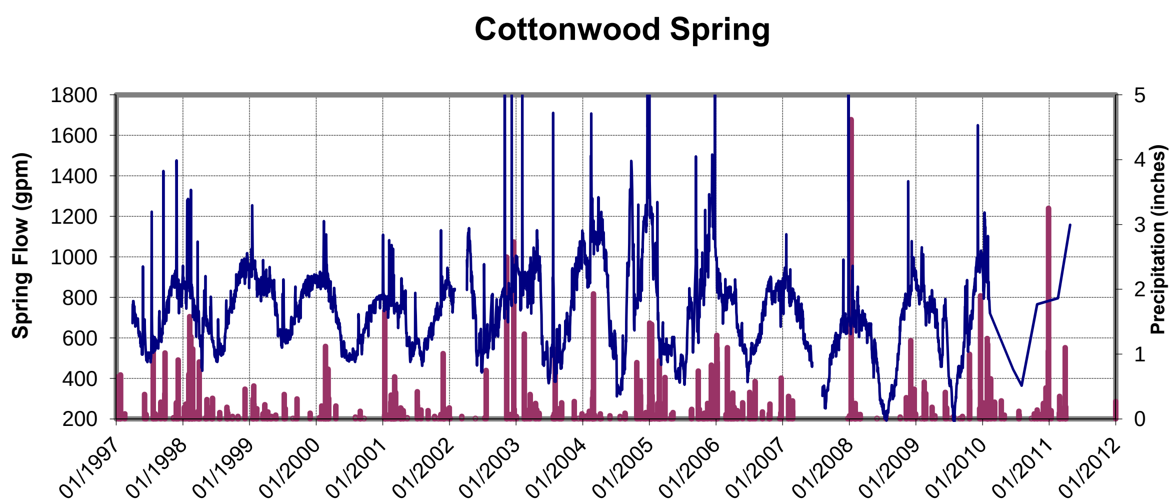


Figure 47
Cottonwood Spring Flow Plotted Against Precipitation

Relative to flow patterns, the following inferences were noted:

- A seasonal (sinusoidal) flow patterns may be more indicative of a shallower source for spring flow.
- A positive runoff correlation is indicative of a shallower source, showing the influence of shallow recharge.
- A positive precipitation correlation shows the influence of shallow recharge and is may be indicative of a shallow source.

9.3 Water Quality

Spring water quality data was compiled to assist with the identification of trends and provide potential indicators of the source of the springs. Specifically, temperature, dissolved oxygen, electrical conductivity, pH, and hydrogen sulfide data were evaluated (plots are included with **Appendix K**). Of these, the two parameters that seem to provide the most insight into the source of the springs were temperature and dissolved oxygen.

Temperature. In general, a constant temperature may be indicative of a deeper groundwater source, whereas variability in temperature is suggestive of a shallow influence (i.e., air temperature). Temperature alone was not used as an indicator of the source of springs, but was combined with other characteristics. Temperature was grouped as follows:

- Temperature = Constant (C) if the temperature variance is less than 10 degrees
- Temperature = Variable (V) if the temperature variance is greater than 10 degrees.

Dissolved Oxygen. Dissolved oxygen data were used to determine high, low, and average levels. Next the data was ranked based upon concentration thresholds as follows:

- Low=O_2 concentration less than 1.0 ppm,
- Medium =O_2 concentration from 1.0 - 2.0 ppm, and
- High=O_2 concentration greater than 2.0 ppm.

Lower dissolved oxygen levels tend to be indicative of a deeper groundwater source. Similar to temperature, the variance in dissolved oxygen was considered whereby:

- Dissolved Oxygen = Constant (C) if the variance less than 1.0 ppm, and
- Dissolved Oxygen = Variable (V) if the variance greater than 1.0 ppm.

Variable concentrations in dissolved oxygen may be more indicative of shallow sourcing and are presumably exhibiting the effects of shallow recharge. Constant concentrations of dissolved oxygen are suggestive of a deeper source.

Concentration of dissolved oxygen and spring water temperature were compared with OLGEP monitoring well water quality data in an attempt to characterize the source of springs. Attempts to correlate these two characteristics were generally not successful.

It is noted that at several of the springs, the point at which monitoring and/or measurement of flow occurs is some distance away from the point at which water first emanates from the ground. In these cases (as noted on Table 24), water quality parameters are affected by surface flow, and although the parameters may have characteristics of a shallow source, these conclusions should be used with caution because of the influence of exposure to the atmosphere as water flows across the landscape. The location of selected springs relative to monitoring locations has been mapped by LADWP and is complemented by photos of spring sites which are included in **Appendix L**.

9.4 General Characteristics

Spring well characteristics as listed below were also considered:

- Surface expression – A spring surface expression consisting of a single point is more suggestive of a deeper source (but not definitively). A diffuse, multiple point surface expression (such as a seep) is more likely to be structurally controlled by either faulting or abrupt changes in facies, such as at the boundary of alluvial and lacustrine deposits. Therefore, a diffuse source may be more indicative of a shallower source.
- Location – Wells located on or near the contact between alluvial and lacustrine deposits are more likely to be indicative of shallow groundwater as shown in the conceptual diagram on **Figure 48** for shallow spring flow. Those located farther out on the playa may have a greater likelihood of being structurally controlled. The spring locations were plotted in conjunction with the updated structure map as shown on **Figure 46** to ascertain spring occurrence relative to faults. Many of the springs are aligned with existing faults.

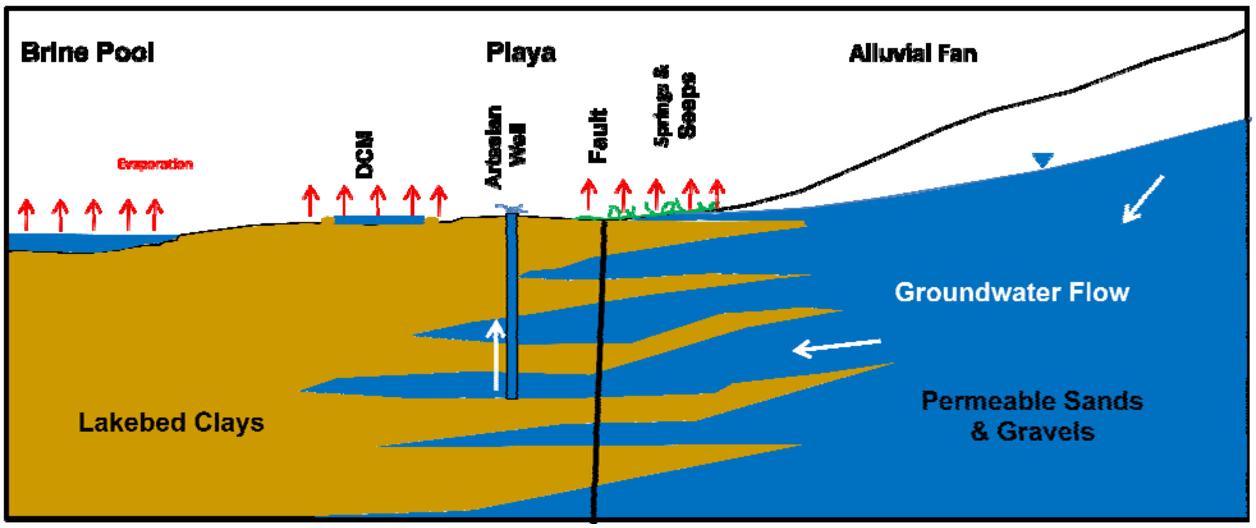


Figure 48
Conceptual Model for Shallow Spring Flow at Owens Lake

9.5 Evaluation of Spring Source

The criteria discussed previously were used to develop an overall summary to characterize the source of springs:

- Spring flow,
- Water quality (including temperature and dissolved oxygen), and
- General characteristics (including surface expression and location).

This summary of various evidence related to the source of each spring is presented as **Table 24**. It is important to point out that the decision as to whether or a not a spring is thought to be originating from a shallow or deep source is not based on any single criteria. Rather, the preponderance of evidence were used collectively to make inferences on a shallow versus deep source.

Although the information summarized on **Table 24** is considered the best method to summarize existing data, conclusions relative to the source of spring flow must be 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. For example, if the distance between the initial surface outflow of a spring and the point at which water quality parameters is measured is great, the dissolved oxygen content and temperature may be more indicative of exposure to the atmosphere (causing evaporation and temperature change) than the spring water itself.

Table 24
Spring Characterization Summary for Owens Lake Area Springs Showing Inferred Sourcing Information

	Shallow								Deep									
	Flow Patterns			Water Quality			Surface Expression	Location	Water Quality			Surface Expression	Location					
Spring	Seasonal	Runoff Correlation	Precipitation Correlation	Temp = V	O_2 = Med - High	O_2 = V	Diffuse/ Multiple Points	At or Near Boundary b/t Alluvial & Lacustrine Deposits	Temp = C	O_2 = Low	O_2 = C	Point	On Playa	No. of Shallow Points	No. of Deep Points	Source	Monitoring and/or Measuring Point is located Some Distance Away Spring Source	Notes
Lizard Tail Spring					X	X		X	X			X		3	2	Shallow		
Dead Hawk Spring									X	X	X	X	X	0	5	Deep		
Bonsai Mound				X	X	X						X	X	3	2	Indeterminate		This site is different in that channelized surface flow has never been observed, so no flow measurements can be made.
Carbide Dump	X	X			X	X		X	X			X		5	2	Indeterminate	X	The spring origin is at the edge of an old mill site and the spring flow may be due to an old well. The only visual evidence of a man-made structure is a wooden frame built around a hole above the spring; however, the water does not flow out of this frame. Spring may be man-made singular mound on playa with diffuse surface expression.
Mill Site	X	X		X	X	X	X					X	X	6	2	Shallow	X	
Swedes Pasture				X			X			X	X			2	2	Indeterminate		
Mambo	X	X		X				X		X	X	X		4	3	Shallow	X	
L9 Ditch Seep	X	X		X	X	X	X							6	0	Shallow		
Indian Creek Seep	X	X		X	X	X	X	X						7	0	Shallow	X	
Trucksticker Seep	X	X		X	X	X	X	X						7	0	Shallow	X	
Tubman Springs	X	X				X	X	X	X	X				5	2	Shallow	X	
Cement Pond									X	X	X	X		0	4	Deep	X	
Whiskey Springs					X	X			X			X	X	2	3	Deep	X	
Wahoo				X	X	X						X	X	3	2	Indeterminate/ Deep	X	May be issues with the sampling location for water quality. Part of a north-south trending linear array of spring mounds on the southern portion of the playa, including Whiskey Springs, which is also deep.
Georgia O'Keefe	X	X		X	X	X	X	X						7	0	Shallow	X	
Northwest Seep																Indeterminate		
Kaiser Permanente				X	X	X		X				X		4	1	Shallow/ Indeterminate	X	Does not exhibit flow characteristics of other shallow wells.
Cottonwood Springs	X	X	X	X	X	X	X	X						8	0	Shallow	X	
Cartago Springs Wildlife Area																Indeterminate		
Cabin Bar Ranch Springs																Deep/ Indeterminate		Thought to be deep, similar to CGR springs.

Notes:
V - Variable
C - Constant
O2 - Dissolved Oxygen
Low=O_2 concentration less than 1.0 ppm, **Med**=O_2 concentration from 1.0 - 2.0 ppm, **High**=O_2 concentration greater than 2.0 ppm
If monitoring and/or measuring point is some distance from the spring source, then the water quality parameters likely are affected by surface flow.

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