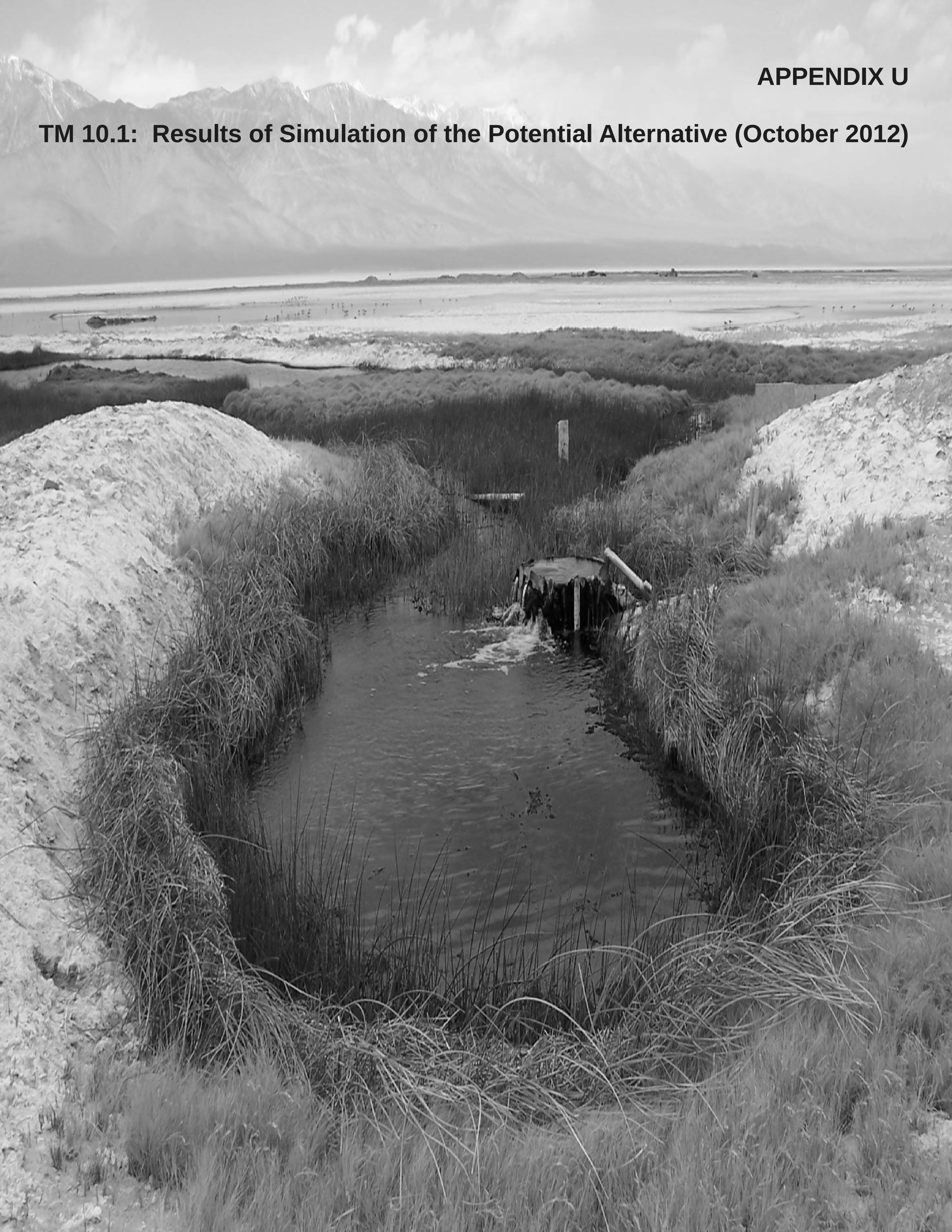
APPENDIX U

TM 10.1: Results of Simulation of the Potential Alternative (October 2012)



TO: *LADWP*

FROM: *MWH*

DATE: *October 2012 (rev. Jan 6, 2013)*

REFERENCE: *Task 401.1.10*

SUBJECT: *Technical Memorandum 10.1: Results of Simulation of the Potential Alternative*

Executive Summary

The Owens Lake Groundwater Evaluation Project (OLGEP) involves several sequential tasks culminating in construction of a numerical groundwater model and the preparation of a potential groundwater pumping alternative that meets pre-determined criteria. This Technical Memorandum describes the preparation of one such groundwater pumping alternative, termed the "potential alternative". The model-calculated influence that the potential alternative has on groundwater discharge zone flow, water budget, and relationships between zone discharge and hydraulic head is also described, as are recommendations for new monitoring well locations.

The terminology of "potential alternative" is used in lieu of "preferred" or "selected" alternative in recognition that although the groundwater model on which it is based is the most up-to-date information on Owens Lake hydrology, there are still uncertainties regarding the exact response of the groundwater system to pumping. The exact number of wells and total amount of sustainable groundwater pumping will be dependent on several variables that are unknown at this time, including:

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

The purpose of this Technical Memorandum is to analyze details of the response of the groundwater system given one set of assumptions regarding aquifer parameters and pumping criteria. To accomplish this, MWH first simulated a "no new groundwater pumping" comparative baseline using the OLGEP numerical groundwater model. Following the baseline simulation, MWH completed three sets of groundwater simulations. The first set of simulations consisted of 10-year simulations based on concepts summarized in a previous Technical Memorandum (TM 6-3, MWH, 2011b). Twenty (20) different iterative simulations were conducted in an effort to maximize groundwater pumping while satisfying constraints based on sensitive environmental elements. The constraints include limits on drawdown at private wells, drawdown in confining layers of 50 feet, and the percent of discharge decrease at groundwater discharge zones. The results of the optimization became the "potential alternative". Groundwater pumping was simulated in 6-month on/off cycles to replicate historical demand for dust mitigation water. Characteristics of the potential alternative are:

- The potential alternative is comprised of 52 wells - 20 shallow, 14 artesian, and 18 deep.
- There is no aerially-extensive drawdown of 50 feet or greater in the confined layers.
- The greatest drawdown at a private well is approximately 12 feet, occurring at the Boulder Creek RV Park after 10 years of groundwater pumping.

- Given this set of assumptions regarding aquifer parameters, if the greatest allowable decrease in discharge at a highly-sensitive groundwater discharge zone is 10 percent, then the amount of water pumped is approximately 8,800 acre-feet per 6 months.
- Given this set of assumptions regarding aquifer parameters, if the greatest decrease in discharge at a highly-sensitive groundwater discharge zone is 20 percent, then the amount of water pumped is slightly less than 12,000 acre-feet per 6 months.
- A key assumption regarding aquifer parameters is the extent to which the Owens Valley Fault acts as a groundwater barrier. The Owens Valley Fault has been modeled both as a relatively incomplete and relatively complete barrier to groundwater flow. These various model simulations suggest that a range of maximum allowable pumping should be considered, rather than one single unchanging amount. The model scenarios do, however, serve to bracket the potential pumping amount in the range of 9,000 to 15,000 AF/yr (MWH, 2011ab; 2012a).

A second simulation set was extended to a time period of 20 years. This simulation assumed the same groundwater development conditions as the potential alternative for the first 10 years, but then included 10 more years in which project groundwater pumping ceased. The purpose of this simulation was to evaluate the recovery of the system from groundwater pumping. The third simulation set was a 100-year model to evaluate how storage in the groundwater system changes with long-term groundwater pumping.

At the conclusion of the 20-year simulation, 12 of the 30 discharge zones recover within 5 percent of baseline discharge and 20 are within 10 percent of baseline discharge. Along the eastern edge of the historic lake boundary, discharge zone flow averages 15 percent difference between baseline and the end of the 20-year simulation.

The change in storage was documented for the 100-year simulation. For the first 5 years, the average change (decrease) in storage is about 7,700 acre-feet per year (AF/year); this decreases to 985 AF/year after 40 years. The modeled cumulative change in storage is about 147,600 AF at the conclusion of the 100-year simulation, or an average of less than 1,500 AF/yr.

Monitoring locations are proposed in order to establish baseline (before pumping) conditions, understand the groundwater system's response to pumping, and provide an initial quantitative management trigger for groundwater pumping. Seven new monitoring locations were established based on the following criteria (in order of importance):

- The location is a source area (upgradient) of groundwater flow to discharge zone (s) of interest.
- The location is estimated to incur measurable drawdown as a result of groundwater pumping.
- LADWP land ownership is preferred, and the location is accessible by existing road (s) so that environmental disruption is minimized.

Quantitative relationships between the water level at the monitoring location and discharge at adjacent groundwater discharge zones are presented.

1.0 Introduction

Under Agreement 47830 between MWH and the Los Angeles Department of Water & Power (LADWP), MWH is conducting the Owens Lake Groundwater Evaluation Project (OLGEP) for the LADWP. The purpose of the OLGEP is to evaluate the feasibility of using groundwater in the study area for a portion of the dust mitigation activities on Owens Lake. In general, the project involves:

- Compilation of existing hydrogeologic and related data (Task 401.1.1),
- Development of a preliminary conceptual model and identification of data gaps (Task 401.1.2),
- Drilling of monitoring wells and collection of additional field data to fill data gaps (Task 401.1.3),
- Revision of the conceptual model (Task 401.1.4),
- Development of a numerical groundwater flow model (Task 401.1.5), and
- Model Simulations and Alternative Analysis (Task 401.1.6).

The purpose of Task 401.1.10, entitled "*Perform Additional Groundwater Model Improvements, Calibration, and Groundwater Pumping Simulation,*" (LADWP, 2012) is to:

1. Perform additional groundwater model improvements; then use the improved groundwater model to perform calibration and sensitivity analysis utilizing recent aquifer test data.
2. Simulate the potential groundwater pumping alternative utilizing the improved groundwater model, herein referred to as the *"potential alternative"*.

This Technical Memorandum (TM) addresses the simulation of the potential groundwater pumping alternative (item no. 2 above). MWH utilized the improved and calibrated groundwater model (developed under item no. 1 above) to simulate groundwater pumping. The potential alternative was developed using iterative refinement starting with information from previous alternative simulations and concepts documented in TM 6-3 (MWH, 2012a). An initial alternative was run and results were tabulated, after which results of each run were then used to formulate a revised version. Twenty of these iterative simulations are documented herein, culminating in a potential alternative.

This TM documents the model-calculated changes that the potential alternative has on groundwater discharge zone flow, water budget, and relationships between zone discharge and hydraulic head. Recommendations for new pumping well locations and associated infrastructure associated with implementation of the potential alternative will be documented in TM 6-4 (as part of Task 401.1.6).

2.0 Review of Sensitive elements and Identification of Groundwater Discharge Zones

An important goal of modeling various groundwater extraction alternatives is to evaluate the potential effect that groundwater pumping may have on various sensitive elements on and around Owens Lake. Sensitive elements may include: local wells, habitat areas, vegetation, springs, and seeps. Of the sensitive elements that may be adversely affected by groundwater extraction, it is recognized that springs and seeps are one of the most sensitive environmental elements. Therefore, initial evaluation of groundwater extraction alternatives focused on changes in groundwater outflow to springs and seeps. During conceptual and numerical modeling of the study area, it was recognized that groundwater comes to the surface not only in discrete springs, but also in wide zones of surfacing groundwater that form saturated soils, seeps, and wetlands on the margins of Owens Lake. Therefore, in the groundwater model, the margin of Owens Lake was divided into discrete zones, in which the change in groundwater flowing to the surface could be estimated. These zones, shown on **Figure 1**, and are based on a Habitat Suitability Index model being created for the Owens Lake under separate studies.

Maximum Decrease in Discharge Limits

Development of maximum decrease percentages in discharge limits has been an ongoing, collaborative effort among stakeholders, including LADWP, Inyo County Water Department, the Owens Lake Master Planning group, and Dr. Donald Sada. For modeling purposes, the maximum decreases in groundwater discharge are herein referred to as *"discharge constraints"*.

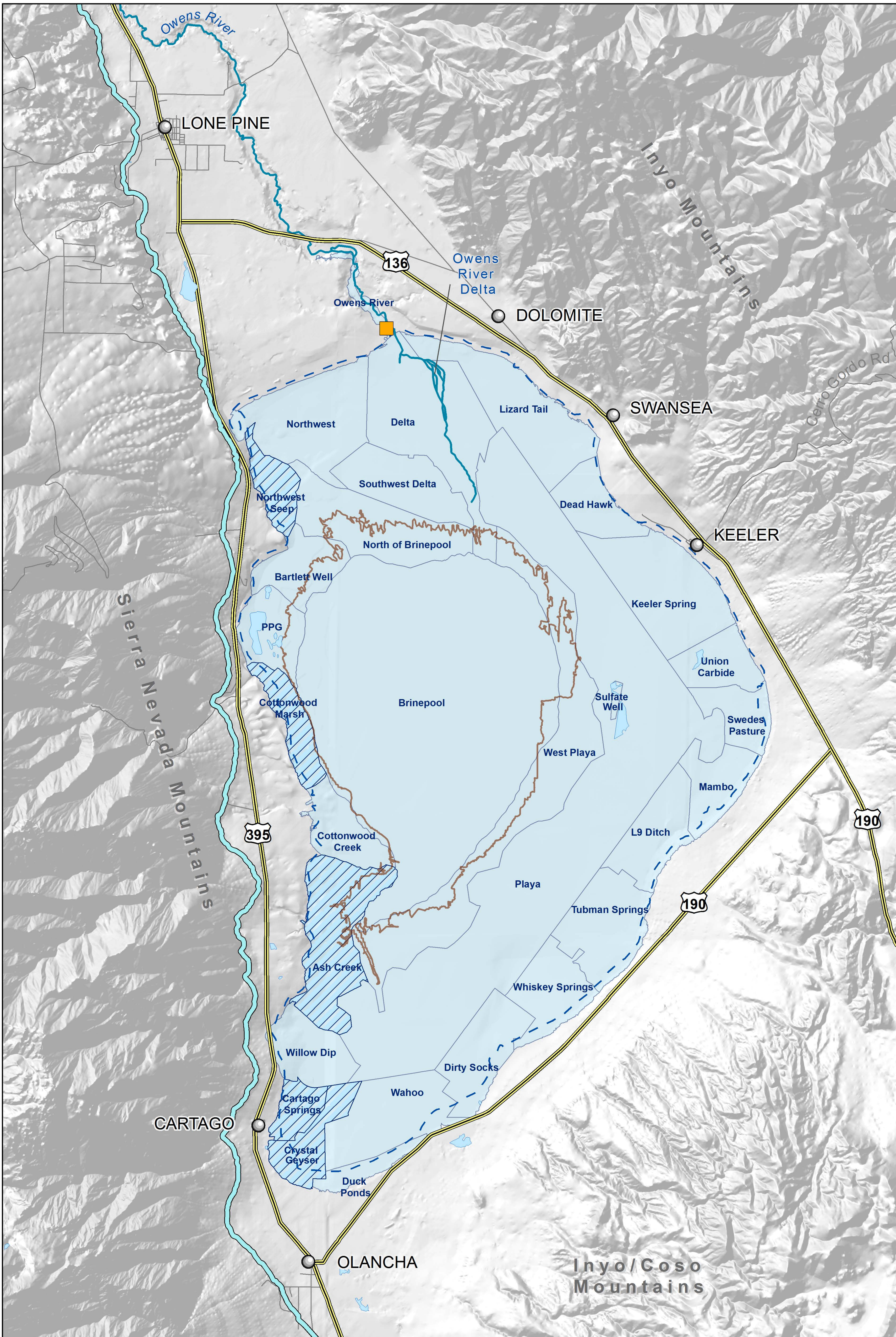
The most sensitive areas have been distinguished as *"highly sensitive"* in order to maintain sensitive habitat. This designation is based on the potential presence of a sensitive springsnail. For the purpose this modeling effort, a maximum of 10% decrease in discharge was used for the highly sensitive areas. For the remaining sensitive areas in the study area, the maximum decrease in discharge was set at 70 percent. Highly-sensitive locations include:

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

3.0 Approach

MWH first simulated a “no new groundwater pumping” comparative baseline using the revised OLGEP numerical groundwater model. This simulation sets the baseline discharge for all groundwater discharge zones described in Section 2 and shown on **Figure 1**. Following the baseline simulation, MWH completed three sets of groundwater simulations:

1. A 10-year model (for which 20 different iterative simulations were conducted) to select and optimize the potential alternative;
2. A 20-year model of the potential alternative to evaluate groundwater level recovery; and
3. A 100-year model of the potential alternative to evaluate how storage in the groundwater system changes with long-term pumping.



Key to Features

- Towns
- LORP Pump Back Station
- Roads
- Highway
- Los Angeles Aqueduct
- Owens River
- Brine Pool
- Owens Lake (Historic Shoreline)
- Groundwater Discharge Zone (Discharge change criteria -70% of baseline.)
- Groundwater Discharge Zone (Discharge change criteria -10% of baseline)

N

0 1 2 Miles

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Results of Simulation of Preferred Alternative Technical Memorandum

Locations of Groundwater Discharge Zones

Figure 1

Los Angeles Department of Water & Power

MWH

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

This section describes the modeling approach for each simulation.

For each 10-year model run, MWH simulated a 10-year period in which pumping was simulated in alternate 6-month time periods. During this 10-year period, pumping was simulated in cyclical on-off cycles of 6 months, which replicates the 6-month period when water would be needed for dust control. The “on” cycle of pumping was the last six months of each year simulated.

Results of each 10-year simulation are presented in the following manner.

- Water Budget Summary:
  - The total model budget estimate separates Lone Pine area and Owens River boundary conditions.
  - Each groundwater discharge zone shown in **Figure 1** is accounted for in the budget.
- Comparison of change in discharge from each groundwater discharge zone from the baseline case (no OLGEP pumping) at the end of ten years of pumping in tabular format.
- Maps showing drawdown after ten years in the shallow zone (Layer 1) if drawdown exceeds one foot.

Determination of the Potential Alternative

To evaluate a potential alternative, groundwater pumping at well locations was optimized by trial-and-error in an iterative manner using a 10-year simulation. The optimization was conducted in order to determine ideal pumping locations and quantities so as to maximize groundwater pumping for dust mitigation and to satisfy numerical discharge constraints. This optimization process also contributed to the development of a better understanding of the hydrologic system and its response to pumping, and how pumping from various locations and depths affects spring flow and piezometric head.

Twenty Optimized Pumping Scenarios (OPS) were evaluated using a 10-year simulation period (OPS-1 through OPS-20). These scenarios varied in the amount of water pumped and the location of the pumping (both vertically and horizontally). Upon completion of the optimization, the optimal solution was considered the potential alternative. The optimized solution met all numerical discharge constraints. The generalized steps for the optimization process are illustrated in **Figure 2**.

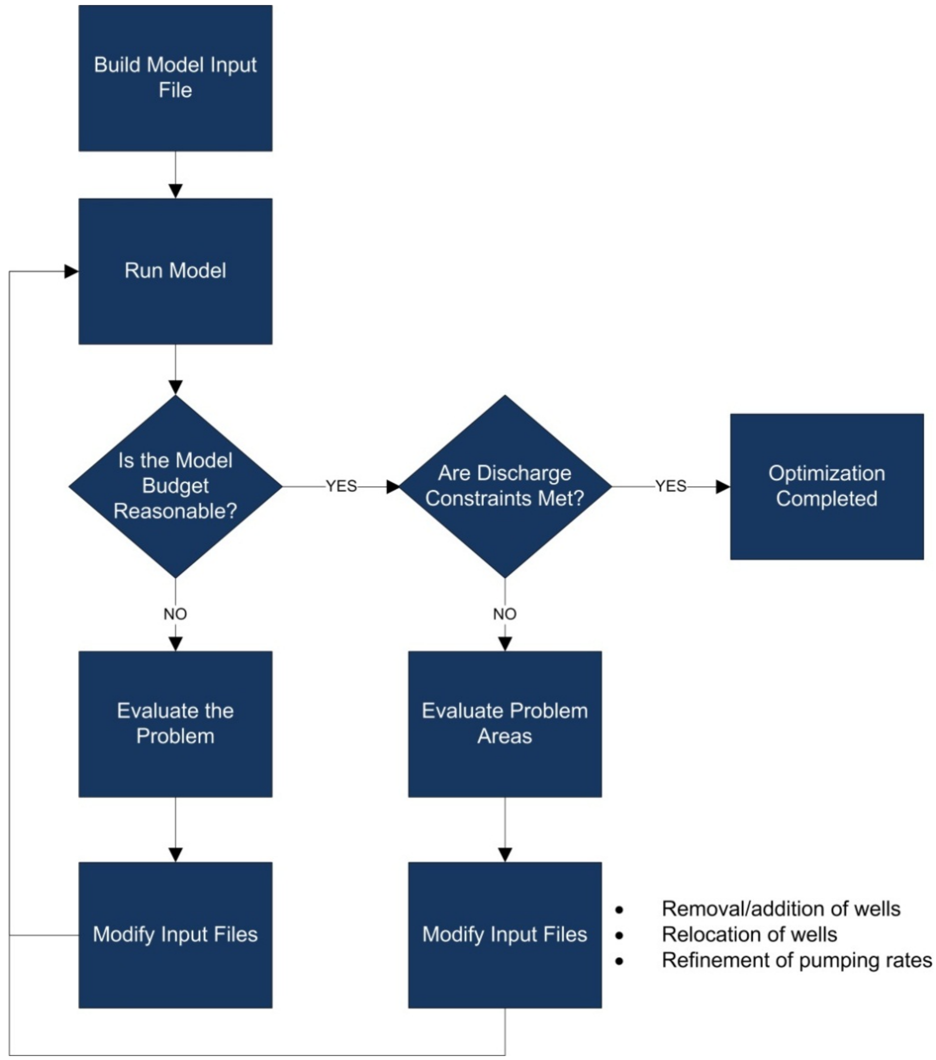


Figure 2
Generalized Steps for the Optimization of the Potential Alternative

Other Modeling of the Potential Alternative

Once the potential alternative was determined, a single 20-year simulation and a single 100-year simulation were completed. The objective of the 20-year simulation was to evaluate how groundwater levels and groundwater discharge zones would recover after 10 years of groundwater pumping. MWH simulated the potential alternative for the first 10 years groundwater pumping in cyclical on-off cycles of 6 months (to replicate the 6-month period when water would be needed for dust control). The “on” cycle of groundwater pumping was the last 6 months of each year. The last 10 years simulated recovery with no OLGEP pumping. Water levels from the simulation were reviewed to determine the extent of groundwater level recovery.

A single 100–year simulation was also completed. The objective of the 100-year simulation was to evaluate the effect of long-term pumping on the water budget. MWH simulated the potential alternative for a 100-year period in which pumping was simulated in alternate 6-month time periods for 100-years.

Using these results, MWH documented the changes in system storage in 5-year increments for a 100-year simulation.

4.0 POTENTIAL ALTERATIVE MODEL RESULTS

The success of an Optimized Pumping Scenario (OPS) was determined by its ability to meet the discharge constraints at groundwater discharge zones. The summary water budget for the baseline (no OLGEP pumping) is presented in **Table 1**. Discharge from each zone occurs either as evapotranspiration (ET) or via drains. Within the model, ET can occur when the water level (hydraulic head) in a cell is higher than 5 feet below the ground surface of the cell. Drains within the model can discharge water when the water level is above the ground surface for the cell. The total discharge from each groundwater discharge zone is the sum of the ET and drain discharge. **Table 2** lists the discharge in acre-feet per six months (AF/6 mos) at the end of 10 years with no OLGEP pumping (baseline) for ET, drains, and the total. **Table 2** also lists the maximum change in discharge relative to baseline. These are the criteria that were utilized for each zone that constrains the optimization (discharge constraints).

Table 1
Baseline Water Budget Summary

Water Budget Element	Baseline (AF/6 months) No New Wells - No New Pumping		
	In	Out	Net
Storage	**4**	**(3)**	**1**
Constant Heads	**4,018**	**(4,375)**	**(357)**
Brine Pool	-	(4,375)	(4,375)
Haiwee Reservoir	4,018	-	4,018
Drains	**-**	**(5,790)**	**(5,790)**
Drains	-	(5,790)	(5,790
New Artesian Wells	-	-	-
General Heads	**6,551**	**(378)**	**6,173**
Rivers	**8,499**	**(9,522)**	**(1,023)**
Owens River	6,325	(9,352)	(3,027)
Lone Pine Streams	2,053	-	2,053
Diaz Lake	121	(170)	(49)
Wells[1]	**8,762**	**(1,046)**	**7,716**
Evapotranspiration	**0**	**(6,715)**	**(6,715)**
Total Source/Sink	**27,833**	**(27,829)**	**4**

1. The "in" column of this row represent groundwater recharge from Sierra Nevada stream drainages and model boundary inflow.

Table 2
Baseline Zone Discharge and Maximum Change Critiera used in Optimization Simulations

Discharge Zone[1]	Layers	Baseline (AF/6 months)			Maximum Decrease Criteria (%)
		Drain (AF 6 Months)	ET (AF/ 6 Months)	Sum (AF/ 6 Months)	
Owens River	Layer 1	-	-	-	70
Delta	Layer 1	24	676	701	70
Lizard Tail	Layer 1	886	521	1,407	70
Dead Hawk	Layer 1	64	203	267	70
Playa	Layer 1	4	146	150	70
West Playa	Layer 1	4	14	18	70
Sulfate Well	Layer 1	-	-	-	70
Keeler Spring	Layer 1	140	389	529	70
Union Carbide	Layer 1	19	158	177	70
Swedes Pasture	Layer 1	3	160	163	70
Mambo	Layer 1	15	294	310	70
L9 Ditch	Layer 1	12	98	110	70
Tubman Springs	Layer 1	11	236	248	70
Whiskey Springs	Layer 1	8	142	150	70
Dirty Socks	Layer 1	74	108	182	70
Wahoo	Layer 1	1	9	10	70
Duck Ponds	Layer 1	-	7	7	70
Crystal Geyser	Layer 1	63	76	139	10
Cartago Springs	Layer 1	194	222	416	10
Willow Dip	Layer 1	587	314	901	70
Ash Creek	Layer 1	401	428	828	10
Cottonwood Creek	Layer 1	8	20	28	70
Cottonwood Marsh	Layer 1	41	304	345	10
PPG	Layer 1	251	95	345	70
Bartlett Well	Layer 1	70	105	175	70
North of Brinepool	Layer 1	71	130	201	70
Southwest Delta	Layer 1	1	44	45	70
Northwest Seep	Layer 1	173	300	473	10
Northwest	Layer 1	341	243	584	70
Brinepool	Layer 1	-	-	-	70
Lizard Tail (S)	Layer 2	-	NA	-	70
Dead Hawk (S)	Layer 3	7	NA	7	70
Black Sand (FW)	Layer 3	65	NA	65	70
Horse Pasture (FW)	Layer 3	389	NA	389	70
Whiskey Spring (S)	Layer 3	9	NA	9	70
Dirty Socks (FW)	Layer 5	168	NA	168	70
Duck Wells (FW)	Layer 2 & 3	125	NA	125	70
Bartlett (FW)	Layer 2 to 4	178	NA	178	70
PPG (FW)	Layer 5	13	NA	13	70
Sulfate Well (FW)	Layer 5	291	NA	291	70

1. Deep Source Springs (S) and Flowing Wells (FW)

The OPS simulations consisted of 20 model runs. Each iteration was checked to determine if the model budget was reasonable, and also checked to determine if the numerical decrease in discharge at each groundwater discharge zone met the specified discharge constraints (10% percent and/or 70% decrease, depending on the zone). The purpose of the first check was to determine if the numerical model was providing a practical result with regard to model boundary conditions and model convergence.

Results of the OPS simulations are shown in tabular form in **Table 3**. All wells used in the optimization process are shown on **Figure 3**. Note that many more wells are shown on **Figure 3** than were ultimately feasible in the potential alternative. OPS-1, shown in the first column of **Table 3**, uses the wells shown on **Figure 3**, but does not meet the discharge constraints. Therefore, the pumping amount and configuration was modified iteratively until OPS-20, when the discharge constraints ultimately were met.

The upper third of **Table 3** summarizes modifications in the locations or amount of pumping wells in that OPS simulation relative to the first (OPS-1) simulation. The upper third of **Table 3** also summarizes the amount of water produced from each groundwater source type (shallow sand sheet, layer 3 artesian, layer 9, layer 11, and layer 12). Groundwater source types are the four depth zones in which OPS wells are located in the model.

The bottom two thirds of the table documents the percent of discharge change relative to the no new pumping OLGEP baseline for each groundwater discharge zone, deep-sourced spring, or flowing well. The total amount of pumping by groundwater source for each OPS is also shown on **Figure 4**. This figure shows the vertical (layer) source of water pumped by OPS; note the majority of water is pumped from layers 11 and 12. The totalized pumping for each OPS is shown on **Figure 5**. Pumping started near 16,000 AF/6 mos in OPS-1, and eventually was reduced to about 8,800 AF/6 mos in OPS-20. All simulations were based on modification and iterative refinement of the initial pumping alternative (OPS-1). The OPS-1 simulation consisted of:

- 20 Sand sheet wells (in the delta area) with a pumping rate of 25 gpm each (approx. 400 AF/6 mos)
- 14 Artesian wells (approx. 1,200 (AF/6 mos)
- 15 Layer 9 wells with a pumping rate of 200 gpm each (approx. 2,420 (AF/6 mos)
- 15 Layer 11 wells with a pumping rate of 500 gpm each (approx. 6,050 (AF/6 mos)
- 15 Layer 12 well with a pumping rate of 200 gpm each (approx. 6,050 (AF/6 mos)

For each of the highly-sensitive areas where springnsail habitat is present, the discharge constraint was set at a 10 percent. Listed below are five figures that present a graphical summary of the change in discharge for each highly-sensitive area relative to the baseline.

- **Figure 6** Change in Discharge at Crystal Geyser Groundwater Discharge Zone
- **Figure 7** Change in Discharge at Cartago Springs Groundwater Discharge Zone
- **Figure 8** Change in Discharge at Ash Creek Groundwater Discharge Zone
- **Figure 9** Change in Discharge at Cottonwood Marsh
- **Figure 10** Change in Discharge at Northwest Seep

Table 3
Pumping Optimization Groundwater Discharge Zone Results Summary

Optimized Pumping Scenario (OPS)	OPS-1	OPS-2	OPS-3	OPS-4	OPS-5
	All wells are active. Located to the east of the Owens Valley fault in a high K-Value zone.	Wells not active: DP-13, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13 DP-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13 DP-12 AT-11 AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12 DP-13, DP-12 DP-13, DP-12 AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9
Sand Sheet Production (AF/6 Mo)	403	403	403	403	403
AT (Production (AF/6 Mo)	1,202	1,212	1,222	1,125	1,196
Layer 9 Production (AF/6 Mo)	2,420	2,258	2,097	2,097	2,097
Layer 11 Production (AF/6 Mo)	6,049	6,049	6,049	6,049	5,242
Layer 12 Production (AF/6 Mo)	6,049	6,049	6,049	6,049	5,243
TOTAL (AF/6 Mo)	**16,123**	**15,971**	**15,820**	**15,723**	**14,181**

Spring Zones (Layer 1)

Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria

Spring Zones (Layer 1)	OPS-1	OPS-2	OPS-3	OPS-4	OPS-5
Owens River	0%	0%	0%	0%	0%
Delta	-3%	-3%	-3%	-3%	-3%
Lizard Tail	-6%	-6%	-6%	-6%	-5%
Dead Hawk	-25%	-25%	-24%	-24%	-20%
Playa	-9%	-9%	-9%	-9%	-9%
West Playa	0%	0%	0%	0%	0%
Sulfate Well	0%	0%	0%	0%	0%
Keeler Spring	-42%	-41%	-40%	-39%	-30%
Union Carbide	-59%	-58%	-57%	-56%	-41%
Swedes Pasture	**-83%**	**-82%**	**-81%**	**-80%**	-68%
Mambo	**-85%**	**-85%**	**-84%**	**-83%**	**-75%**
L9 Ditch	-48%	-47%	-46%	-46%	-37%
Tubman Springs	-61%	-60%	-59%	-58%	-50%
Whiskey Springs	-55%	-54%	-54%	-54%	-47%
Dirty Socks	-29%	-29%	-29%	-28%	-24%
Wahoo	-15%	-15%	-15%	-15%	-14%
Duck Ponds	0%	0%	0%	0%	0%
Crystal Geyser	0%	0%	0%	0%	0%
Cartago Springs	0%	0%	0%	0%	0%
Willow Dip	0%	0%	0%	0%	0%
Ash Creek	-2%	-2%	-2%	-2%	-2%
Cottonwood Creek	-8%	-8%	-8%	-8%	-8%
Cottonwood Marsh	-9%	-9%	-9%	-9%	-9%
PPG	-6%	-6%	-6%	-6%	-6%
Bartlett Well	-6%	-6%	-6%	-6%	-5%
North of Brinepool	-10%	-10%	-10%	-10%	-10%
Southwest Delta	-46%	-46%	-46%	-46%	-46%
Northwest Seep	**-22%**	**-22%**	**-22%**	**-22%**	**-21%**
Northwest	-14%	-14%	-14%	-14%	-14%
Brinepool	0%	0%	0%	0%	0%

Deep Source Springs (S) and Flowing Wells (FW)

Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria

Deep Source Springs (S) and Flowing Wells (FW)	OPS-1	OPS-2	OPS-3	OPS-4	OPS-5
Lizard Tail (S)	0%	0%	0%	0%	0%
Dead Hawk (S)	-33%	-33%	-32%	-32%	-27%
Black Sand (FW)	-43%	-42%	-41%	-41%	-34%
Horse Pasture (FW)	**-80%**	**-78%**	**-76%**	**-76%**	-63%
Whiskey Spring (S)	**-73%**	**-72%**	**-71%**	-70%	-59%
Dirty Socks (FW)	**-100%**	**-100%**	**-100%**	**-100%**	**-90%**
Duck_3	0%	0%	0%	0%	0%
Duck_1	0%	0%	0%	0%	0%
Duck_2	0%	0%	0%	0%	0%
Duck Wells (FW)	-1%	-1%	-1%	-1%	-1%
Bartlett (FW)	**-81%**	**-80%**	**-80%**	**-80%**	**-76%**
PPG (FW)	-28%	-28%	-28%	-28%	-26%
Sulfate Well (FW)	-45%	-44%	-43%	-42%	-35%

Table 3
Pumping Optimization Groundwater Discharge Zone Results Summary

Optimized Pumping Scenario (OPS)	**OPS-6**	**OPS-7**	**OPS-8**	**OPS-9**	**OPS-10**
	Wells not active: DP-13, DP-12, DP-13 DP-12, DP-13, DP-12 DP-11, DP-11, DP-11 AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13 DP-12, DP-13, DP-12 DP-11, DP-11, DP-11 DP-15, DP-15, DP-15 AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13 DP-12, DP-13, DP-12 DP-11, DP-11, DP-11 DP-15, DP-15, DP-15 DP-3, DP-3, DP-3 AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12 DP-13, DP-12, DP-11, DP-11 DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4 DP-4, DP-4, AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12 DP-13, DP-12, DP-11, DP-11 DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4 DP-4, DP-4, DP-5, DP-6 DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7, DP-16, AT-11, AT-12, SW_OPT_DP_1 to , SW_OPT_DP_9
Sand Sheet Production (AF/6 Mo)	403	403	403	403	403
AT (Production (AF/6 Mo)	1,237	1,286	1,336	1,387	1,539
Layer 9 Production (AF/6 Mo)	1,936	1,774	1,613	1,452	968
Layer 11 Production (AF/6 Mo)	4,839	4,436	4,033	3,630	2,420
Layer 12 Production (AF/6 Mo)	4,839	4,436	4,033	3,630	2,420
TOTAL (AF/6 Mo)	**13,254**	**12,335**	**11,418**	**10,502**	**7,750**

Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria

Spring Zones (Layer 1)	OPS-6	OPS-7	OPS-8	OPS-9	OPS-10
Owens River	0%	0%	0%	0%	0%
Delta	-3%	-3%	-3%	-3%	-3%
Lizard Tail	-5%	-5%	-4%	-4%	-3%
Dead Hawk	-18%	-17%	-16%	-15%	-12%
Playa	-9%	-9%	-9%	-9%	-9%
West Playa	0%	0%	0%	0%	0%
Sulfate Well	0%	0%	0%	0%	0%
Keeler Spring	-24%	-22%	-21%	-20%	-14%
Union Carbide	-33%	-30%	-28%	-25%	-18%
Swedes Pasture	-60%	-56%	-53%	-50%	-39%
Mambo	-69%	-66%	-63%	-60%	-48%
L9 Ditch	-32%	-30%	-29%	-27%	-21%
Tubman Springs	-45%	-42%	-40%	-38%	-29%
Whiskey Springs	-43%	-40%	-38%	-35%	-26%
Dirty Socks	-21%	-19%	-18%	-16%	-12%
Wahoo	-14%	-14%	-13%	-13%	-11%
Duck Ponds	0%	0%	0%	0%	0%
Crystal Geyser	0%	0%	0%	0%	0%
Cartago Springs	0%	0%	0%	0%	0%
Willow Dip	0%	0%	0%	0%	0%
Ash Creek	-2%	-2%	-2%	-1%	-1%
Cottonwood Creek	-7%	-7%	-6%	-5%	0%
Cottonwood Marsh	-8%	-8%	-7%	-6%	-4%
PPG	-5%	-5%	-4%	-4%	-3%
Bartlett Well	-5%	-5%	-4%	-4%	-2%
North of Brinepool	-10%	-10%	-10%	-10%	-10%
Southwest Delta	-46%	-46%	-46%	-46%	-46%
Northwest Seep	**-21%**	**-19%**	**-17%**	**-15%**	-10%
Northwest	-14%	-13%	-12%	-11%	-9%
Brinepool	0%	0%	0%	0%	0%

Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria

Deep Source Springs (S) and Flowing Wells (FW)	OPS-6	OPS-7	OPS-8	OPS-9	OPS-10
Lizard Tail (S)	0%	0%	0%	0%	0%
Dead Hawk (S)	-23%	-22%	-21%	-19%	-15%
Black Sand (FW)	-28%	-27%	-25%	-23%	-18%
Horse Pasture (FW)	-53%	-50%	-47%	-44%	-34%
Whiskey Spring (S)	-53%	-49%	-45%	-42%	-29%
Dirty Socks (FW)	**-82%**	**-74%**	-69%	-63%	-44%
Duck_3	0%	0%	0%	0%	0%
Duck_1	0%	0%	0%	0%	0%
Duck_2	0%	0%	0%	0%	0%
Duck Wells (FW)	-1%	-1%	-1%	0%	0%
Bartlett (FW)	**-73%**	-65%	-59%	-53%	-35%
PPG (FW)	-26%	-23%	-21%	-19%	-12%
Sulfate Well (FW)	-30%	-28%	-27%	-25%	-20%

Table 3
Pumping Optimization Groundwater Discharge Zone Results Summary

Optimized Pumping Scenario (OPS)	**OPS-11**	**OPS-12**	**OPS-13**	**OPS-14**	**OPS-15**
	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-13, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7, AT-11, AT-12 Wells added at 500 gpm West_DP_2, West_DP_3, West_DP_6, West_DP_7, West_DP_8	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-13, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Wells added at 500 gpm: West_DP_2, West_DP_3, West_DP_6, West_DP_7, West_DP_8,	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Wells added at 500 gpm: West_DP_2, West_DP_3, West_DP_6, West_DP_7, West_DP_8 and DP-13,	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Wells added at 500 gpm: West_DP_2, West_DP_3, West_DP_6, West_DP_7, West_DP_8 Well DP-13 at 480 gpm	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm, SS Wells at 50 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9
Sand Sheet Production (AF/6 Mo)	403	403	403	403	806
AT (Production (AF/6 Mo)	1,510	1,669	1,645	1,646	1,695
Layer 9 Production (AF/6 Mo)	968	968	968	968	968
Layer 11 Production (AF/6 Mo)	2,420	2,420	2,420	2,420	2,420
Layer 12 Production (AF/6 Mo)	4,436	4,437	4,839	4,823	2,807
TOTAL (AF/6 Mo)	**9,737**	**9,897**	**10,275**	**10,260**	**8,696**

Spring Zones (Layer 1)	**Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria**				
Owens River	0%	0%	0%	0%	0%
Delta	-3%	-3%	-3%	-3%	-6%
Lizard Tail	-3%	-4%	-4%	-4%	-4%
Dead Hawk	-13%	-14%	-14%	-14%	-13%
Playa	-9%	-9%	-9%	-9%	-18%
West Playa	0%	0%	0%	0%	-10%
Sulfate Well	0%	0%	0%	0%	0%
Keeler Spring	-18%	-19%	-21%	-21%	-18%
Union Carbide	-25%	-26%	-29%	-29%	-23%
Swedes Pasture	-49%	-51%	-55%	-55%	-47%
Mambo	-59%	-62%	-66%	-65%	-57%
L9 Ditch	-28%	-29%	-31%	-31%	-27%
Tubman Springs	-38%	-39%	-42%	-42%	-36%
Whiskey Springs	-36%	-36%	-39%	-38%	-33%
Dirty Socks	-17%	-18%	-19%	-19%	-16%
Wahoo	-14%	-14%	-14%	-14%	-13%
Duck Ponds	0%	0%	0%	0%	0%
Crystal Geyser	-5%	-5%	-5%	-5%	0%
Cartago Springs	-3%	-3%	-3%	-3%	0%
Willow Dip	-2%	-2%	-2%	-2%	0%
Ash Creek	-4%	-4%	-4%	-4%	-1%
Cottonwood Creek	-10%	-10%	-10%	-10%	0%
Cottonwood Marsh	-9%	-9%	-9%	-9%	-4%
PPG	-4%	-4%	-4%	-4%	-2%
Bartlett Well	-3%	-3%	-3%	-3%	-2%
North of Brinepool	-10%	-10%	-10%	-10%	-20%
Southwest Delta	-46%	-46%	-46%	-46%	-68%
Northwest Seep	-10%	-10%	**-10%**	-10%	-10%
Northwest	-9%	-9%	-9%	-9%	-14%
Brinepool	0%	0%	0%	0%	0%

Deep Source Springs (S) and Flowing Wells (FW)	**Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria**				
Lizard Tail (S)	0%	0%	0%	0%	0%
Dead Hawk (S)	-17%	-18%	-18%	-18%	-17%
Black Sand (FW)	-21%	-22%	-23%	-23%	-20%
Horse Pasture (FW)	-40%	-41%	-43%	-43%	-38%
Whiskey Spring (S)	-41%	-42%	-45%	-45%	-38%
Dirty Socks (FW)	-63%	-64%	-68%	-68%	-58%
Duck_3	0%	0%	0%	0%	0%
Duck_1	0%	0%	0%	0%	0%
Duck_2	0%	0%	0%	0%	0%
Duck Wells (FW)	-7%	-7%	-7%	-7%	0%
Bartlett (FW)	-33%	-34%	-35%	-35%	-33%
PPG (FW)	-17%	-18%	-18%	-18%	-11%
Sulfate Well (FW)	-24%	-25%	-27%	-27%	-24%

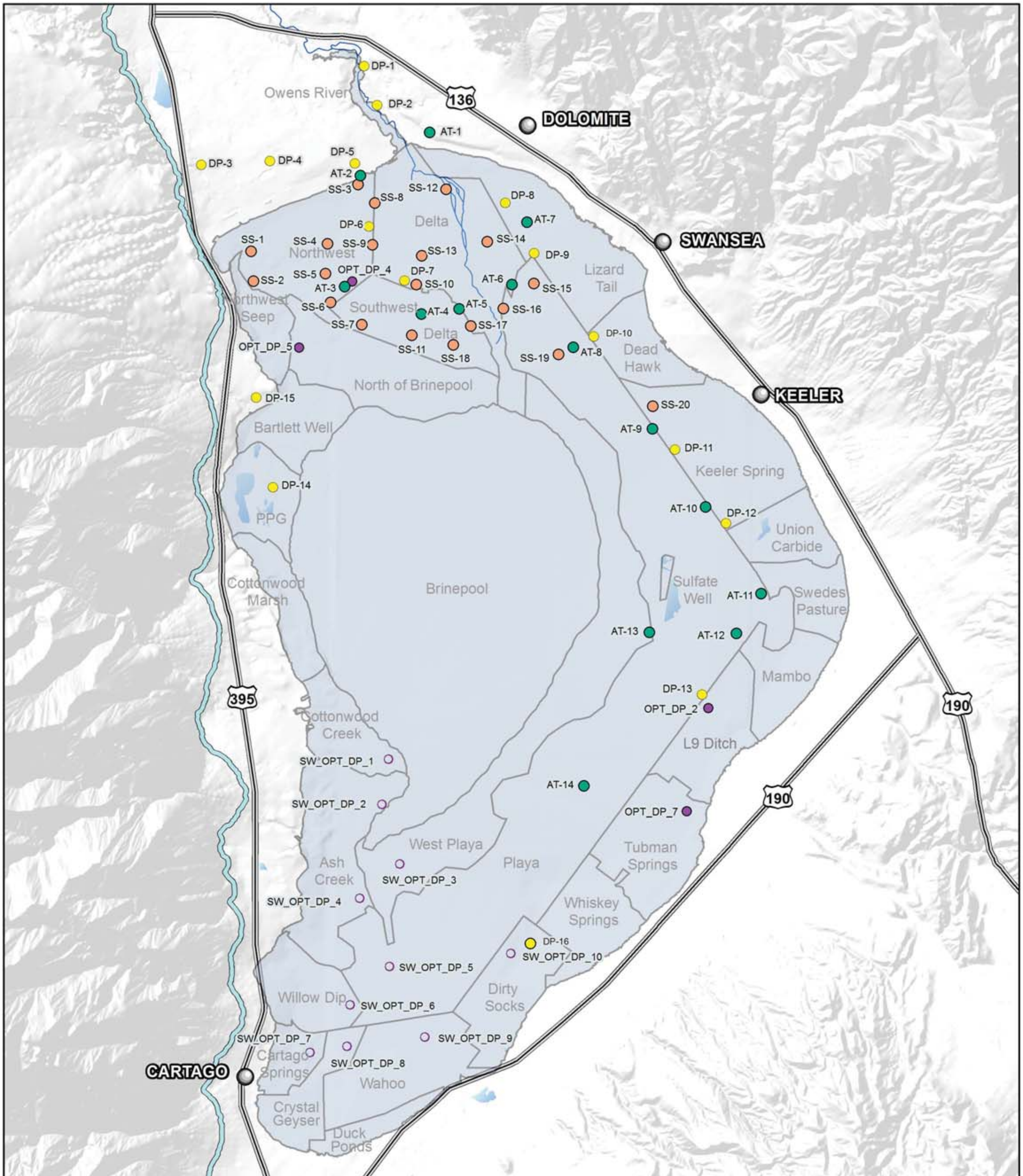
Note: OPS-11 through OPS-15 are not feasible due to location of wells relative to DCM sites and drilling difficulty.

Table 3
Pumping Optimization Groundwater Discharge Zone Results Summary

Optimized Pumping Scenario (OPS)	**OPS-16**	**OPS-17**	**OPS-18**	**OPS-19**	**OPS-20**
	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm SS Wells at 50 gpm DP-4 at 500 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm SS Wells at 50 gpm DP-4 at 300 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm SS Wells at 75 gpm DP-4 at 140 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm SS Wells at 55 gpm DP-4 at 140 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9	Wells not active: DP-13, DP-12, DP-13, DP-12, DP-12 DP-11, DP-11, DP-11, DP-15, DP-15, DP-15 DP-3, DP-3, DP-3, DP-4, DP-4 DP-5, DP-6, DP-7, DP-5, DP-6, DP-7 DP-5, DP-6, DP-7 Well DP-13 at 480 gpm SS Wells at 55 gpm DP-4 at 140 gpm, SW_OPT_DP_1 to , SW_OPT_DP_9
Sand Sheet Production (AF/6 Mo)	806	806	1,210	887	806
AT (Production (AF/6 Mo)	1,672	1,681	1,688	1,688	1,689
Layer 9 Production (AF/6 Mo)	968	968	968	968	968
Layer 11 Production (AF/6 Mo)	2,420	2,420	2,420	2,420	2,420
Layer 12 Production (AF/6 Mo)	3,210	3,049	2,920	2,920	2,920
TOTAL (AF/6 Mo)	**9,076**	**8,924**	**9,206**	**8,883**	**8,803**

Spring Zones (Layer 1)	**Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria**				
Owens River	0%	0%	0%	0%	0%
Delta	-6%	-6%	-8%	-6%	-6%
Lizard Tail	-4%	-4%	-4%	-4%	-4%
Dead Hawk	-13%	-13%	-13%	-13%	-13%
Playa	-18%	-18%	-25%	-19%	-18%
West Playa	-10%	-10%	-15%	-11%	-10%
Sulfate Well	0%	0%	0%	0%	0%
Keeler Spring	-18%	-18%	-18%	-18%	-18%
Union Carbide	-25%	-24%	-24%	-24%	-24%
Swedes Pasture	-49%	-48%	-47%	-47%	-47%
Mambo	-59%	-59%	-58%	-58%	-58%
L9 Ditch	-28%	-27%	-27%	-27%	-27%
Tubman Springs	-37%	-37%	-36%	-36%	-36%
Whiskey Springs	-35%	-35%	-34%	-34%	-34%
Dirty Socks	-17%	-16%	-16%	-16%	-16%
Wahoo	-13%	-13%	-13%	-13%	-13%
Duck Ponds	0%	0%	0%	0%	0%
Crystal Geyser	0%	0%	0%	0%	0%
Cartago Springs	0%	0%	0%	0%	0%
Willow Dip	0%	0%	0%	0%	0%
Ash Creek	-1%	-1%	-1%	-1%	-1%
Cottonwood Creek	-4%	0%	0%	0%	0%
Cottonwood Marsh	-4%	-4%	-4%	-4%	-4%
PPG	-3%	-2%	-2%	-2%	-2%
Bartlett Well	-2%	-2%	-2%	-2%	-2%
North of Brinepool	-20%	-20%	-29%	-22%	-20%
Southwest Delta	-68%	-68%	**-71%**	**-70%**	-68%
Northwest Seep	**-10%**	**-10%**	**-11%**	**-10%**	-10%
Northwest	-14%	-14%	-17%	-14%	-14%
Brinepool	0%	0%	0%	0%	0%

Deep Source Springs (S) and Flowing Wells (FW)	**Change in Discharge Relative to Baseline - Bold Value Indicates the Change in Discharge Violated the Control Criteria**				
Lizard Tail (S)	0%	0%	0%	0%	0%
Dead Hawk (S)	-17%	-17%	-17%	-17%	-17%
Black Sand (FW)	-21%	-21%	-21%	-21%	-21%
Horse Pasture (FW)	-40%	-39%	-39%	-39%	-39%
Whiskey Spring (S)	-41%	-40%	-39%	-39%	-39%
Dirty Socks (FW)	-62%	-61%	-60%	-60%	-60%
Duck_3	0%	0%	0%	0%	0%
Duck_1	0%	0%	0%	0%	0%
Duck_2	0%	0%	0%	0%	0%
Duck Wells (FW)	0%	0%	0%	0%	0%
Bartlett (FW)	-35%	-34%	-33%	-33%	-33%
PPG (FW)	-12%	-12%	-12%	-12%	-12%
Sulfate Well (FW)	-25%	-24%	-24%	-24%	-24%



Key to Features

- Town
- Highways
- Los Angeles Aqueduct
- Owens River
- Water Bodies

Optimization Well Locations

- Deep Well
- Artesian Well
- Sand Sheet Well
- Optimization Deep Well
- Southwest Optimization Deep Well
- Groundwater Discharge Zone

N

0 1.5 3 Miles

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Technical Memorandum for Modeled Well Sensitivity Analysis

Groundwater Pumping
Optimization Location Map

Figure 3

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

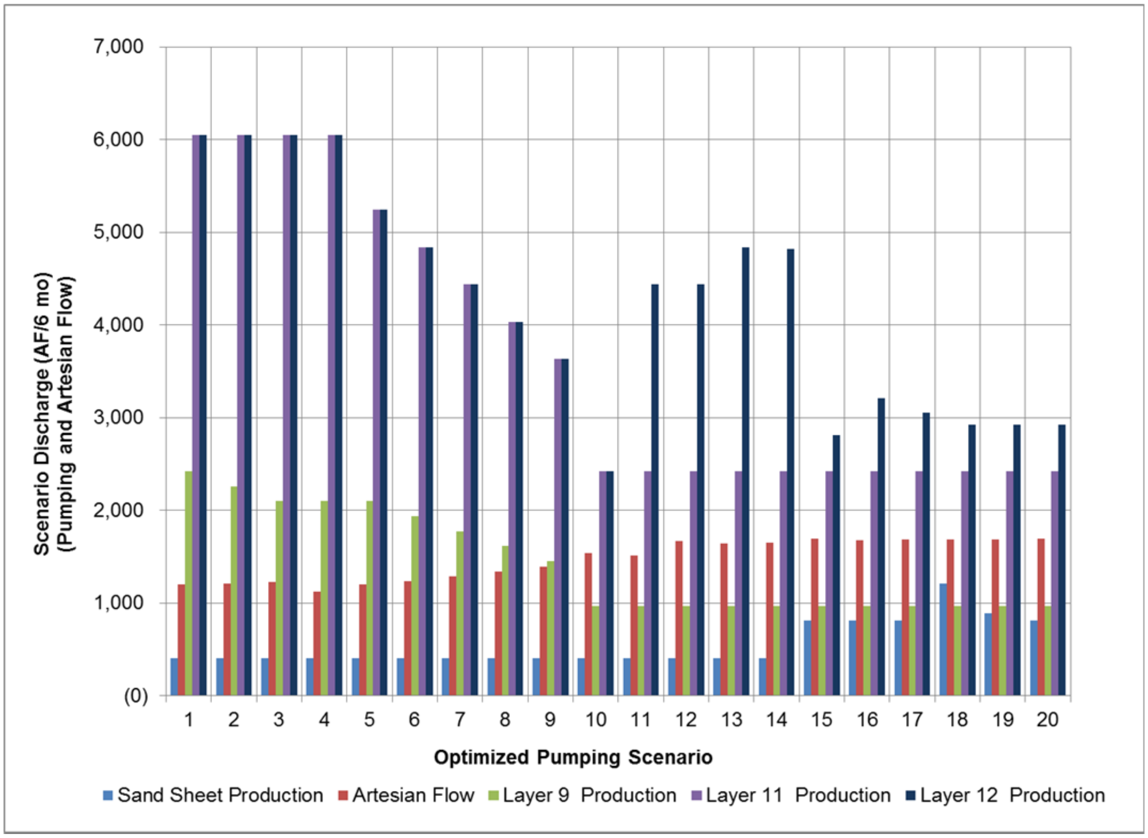


Figure 4
Groundwater Pumping by Source for Each Optimized Pumping Scenario

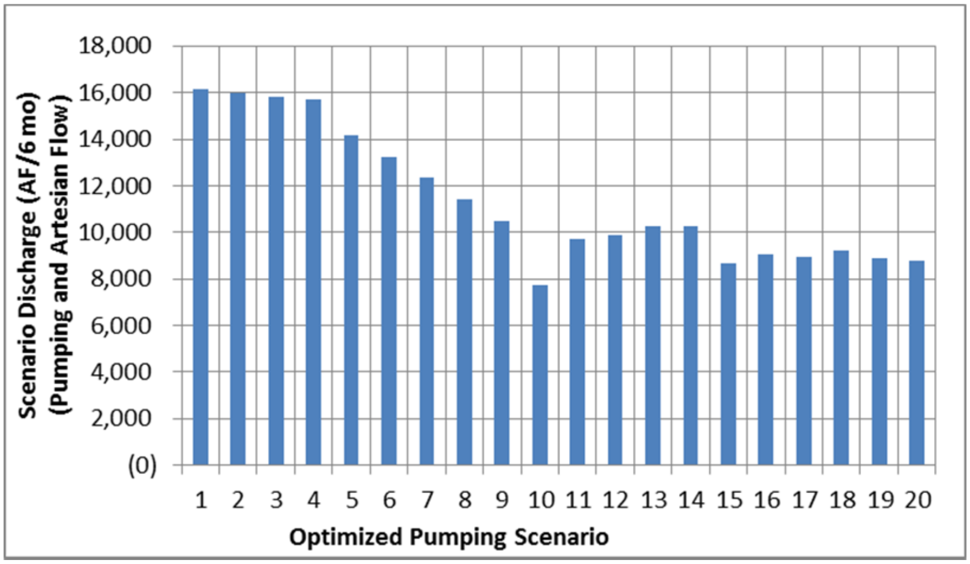


Figure 5
Total Groundwater Pumping by Optimized Pumping Scenario

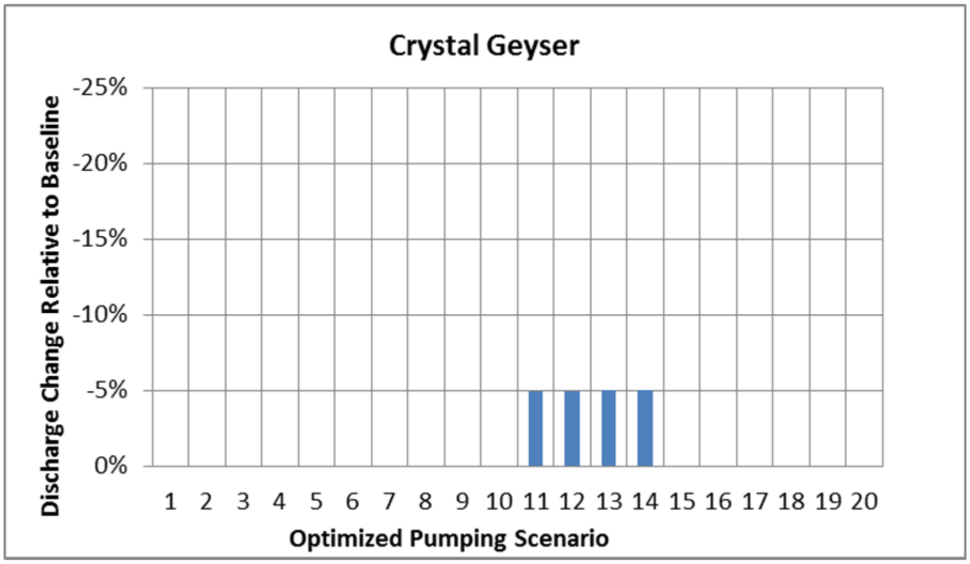


Figure 6
Change in Crystal Geyser Zone Discharge Relative to Baseline by Optimized Pumping Scenario

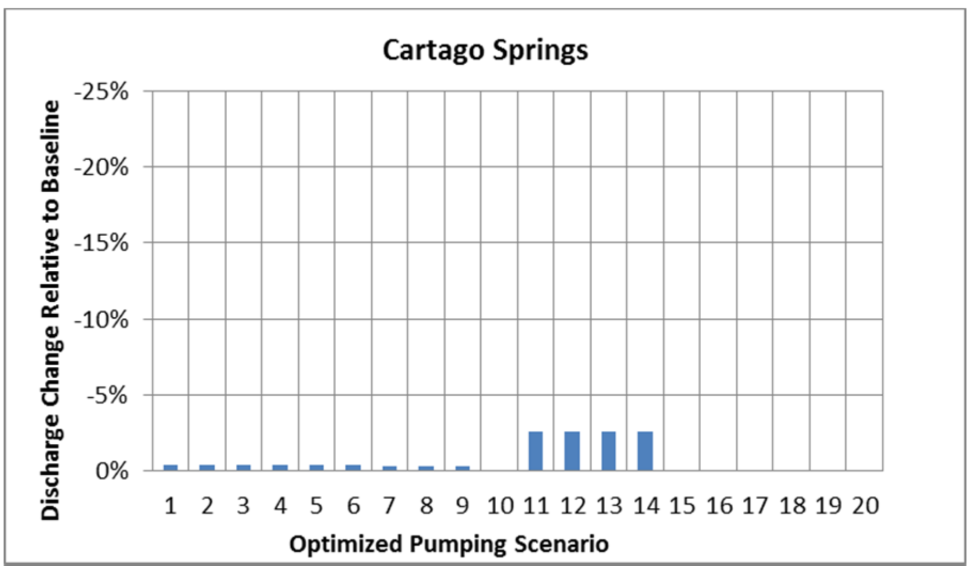


Figure 7
Change in Cartago Springs Zone Discharge Relative to Baseline by Optimized Pumping Scenario

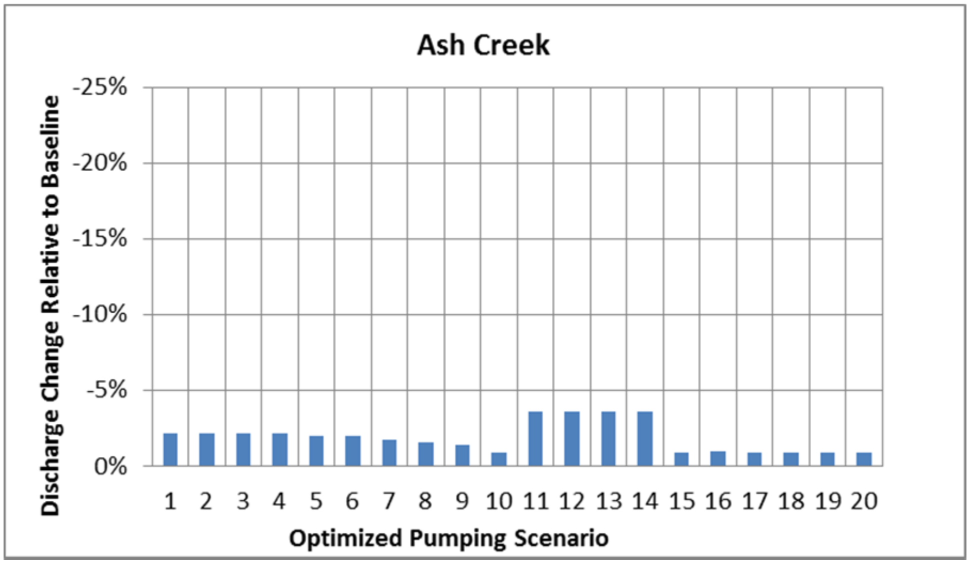


Figure 8
Change in Ash Creek Zone Discharge Relative to Baseline by Optimized Pumping Scenario

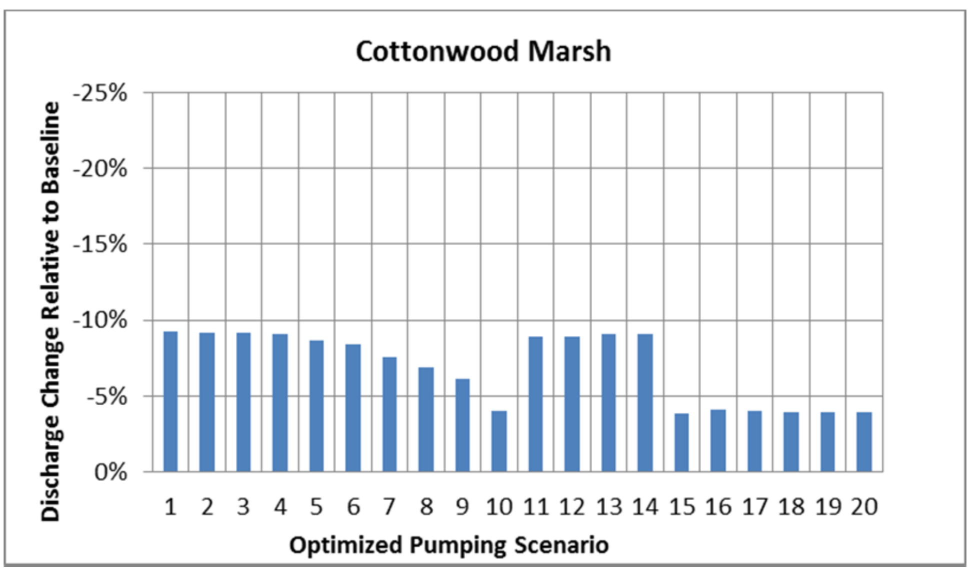


Figure 9
Change in Cottonwood Marsh Zone Discharge Relative to Baseline by Optimized Pumping Scenario

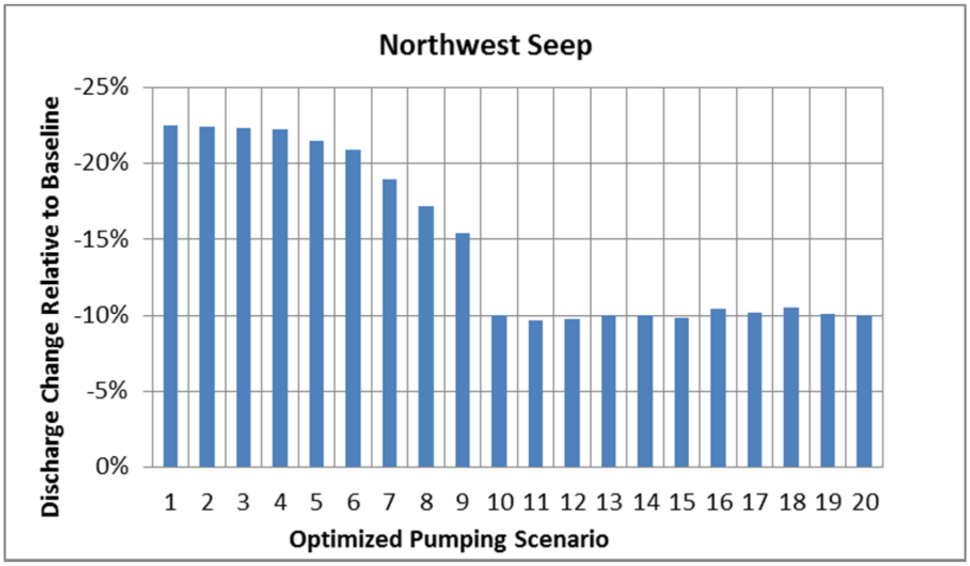


Figure 10
Change in Northwest Seep Zone Discharge Relative to Baseline by Optimized Pumping Scenario

The OPS model iterations can be categorized into three groups:

- OPS 1 through OPS-10 (pumping well reduction) - Within the first 10 OPSs, the optimization process consisted of removal of wells, leaving the total pumping amount low, but most discharge constraints were met or exceeded.
- OPS-11 through OPS-14 (Increased pumping with well addition) - Wells were added and/or removed in different locations and depths varied in an effort to increase pumping, while simultaneously meeting discharge constraints. These simulations were instrumental for determining well locations with the least effect.
- OPS-15 through OPS-20 (Final refinement) - The focus of OPS-16 through OPS-20 was to refine pumping rates for the well locations determined to have the least effect.

Early OPS results (OPS-1 through OPS-10) showed that discharge reduction in seven zones exceeded the discharge constraints, especially for the two zones on the eastern edge of the model. Swedes Pasture and Mambo had decreases in discharge of 83 and 85 percent, respectively. Well DP-13, located in Layer 9 close to these two zones, was identified as the cause. OPS-2 eliminated pumping at DP-13 in layer 9. This iterative process of reviewing results and eliminating pumping was completed until OPS-10, wherein 29 of the original wells from OPS-1 were eliminated, and the total flow was 7,750 AF/6 mos in OPS-10.

Wells were then added in new locations, and pumping rates for previously-eliminated wells were decreased for subsequent OPS simulations OPS-11 through OPS-14. As many as 16 deep “optimization” pumping wells were utilized in the simulation scenarios from OPS-11 through OPS-14. The wells labeled OPT_DP_4 and OPT_DP_5 are located in the north-northwestern area, while

OPT_DP_2, OPT_DP_3, OPT_DP_6, OPT_DP_7 and OPT_DP_8 are in the south and southwest area of the lake basin. Wells labeled SW_OPT _1 through SW_OPT_SW9 were all located in the south and southwest of the lake. To satisfy the constraining criteria, both well location and flow rate of these optimization wells were adjusted. What is shown on **Figure 3** are representative locations.

The final group of OPS simulations (OPS-15 through OPS-20) removed wells and made further refinements (pumping rates) to individual wells. Many of wells added in OPS-11 through OPS-14 were eventually determined to be infeasible either due to failure to meet a discharge constraint and or distance to transmission lines or DCM projects. The addition of five deep pumping wells in the south-southwest area (done in OPS-11 through OPS-14) that were theoretically possible were eliminated due to their proximity to the southwestern highly-sensitive areas. The final five OPS simulations modified well pumping rates at multiple locations until all discharge constraints were met. **Table 4** documents the maximum drawdown at existing private production wells for the potential alternative.

Table 4
Private Well Drawdown Summary after 10 Years of Pumping

Well Identification	Drawdown (ft)
Pangborn CSD	1.9
Shoshone Reservation	3.4
Spainhower Anchor Ranch	3.4
Interagency Visitor Center	4.1
Boulder Creek RV Park	11.9
Dolomite Wells	2.3[1]
Swansea Area Private Wells	2.1[1]
Dunn Production Well	5.1[1]
Keeler CSD Wells	6.0
LADWP Sulfate Facility	10.8
Olancha Private Wells	0.2
Butterworth/Haiwee Private Wells	0.2
Cartago Mutual Water Company Well	0.2
Cartago town wells (lumped)	0.2
Rio Tinto Well	0.2
Cottonwood Powerhouse	0.3[1]
OLSAC Wells	0.4
Carol Creek Domestic Wells	1.1[1]
Diaz Well	5.4
Cabin Bar Ranch Private Wells	0.2
Crystal Geyser Roxane Bottling Plant	0.2

[1] The well is located outside the model domain. Drawdown value is read in the cell that is closest to the well.

The optimization process revealed important characteristics about the effect that pumping has on the groundwater regime in the vicinity of the lake. Notable observations include:

- There was no drawdown greater than 50 feet in any confining layer.
- With time, pumping of the deep aquifers results in lowering of the shallow water table. Effects from pumping at depth are realized by pressure changes propagating to the perimeter of Owens Lake where vertical conductivities allow for vertical groundwater flow. In these areas, lakebed clay deposits are not present and pressure changes can be transmitted vertically (from deep to shallow) relatively quickly.
- The Owens Valley Fault acts as a barrier to flow and prohibits effects of pumping east of the fault from propagating westward to sensitive habitat areas on the west side of the fault (e.g., Cottonwood Marsh).
- Groundwater pumping west of the Owens Valley Fault limits pumping influences to a smaller area. Due to the smaller area, there is limited storage available to buffer drawdown and the effects that pumping west of the fault has on western springs is magnified. There is limited storage on the west side of the Owen Valley Fault so that pumping here quickly reduces groundwater discharge.
- Northwest Seep is a sensitive zone that acted as a primary constraint during optimization. This zone is on the east side of the Owens Valley Fault, and is modeled as alluvial deposits with a high vertical conductivity. During pumping, pressure changes from deep pumping on the east side of the Owens Valley Fault are propagated vertically below the Northwest Seep zone. This indicates that the model is very sensitive to aquifer parameter assumptions that will need to be tested during project implementation. Additional lithologic data in the area of the Northwest Seep would increase certainty in this conclusion.
- Discharge zones on the eastern edge of the model (Union Carbide, Swedes Pasture, and Mambo) are the most sensitive to deep pumping.

5.0 Description of the Potential Alternative

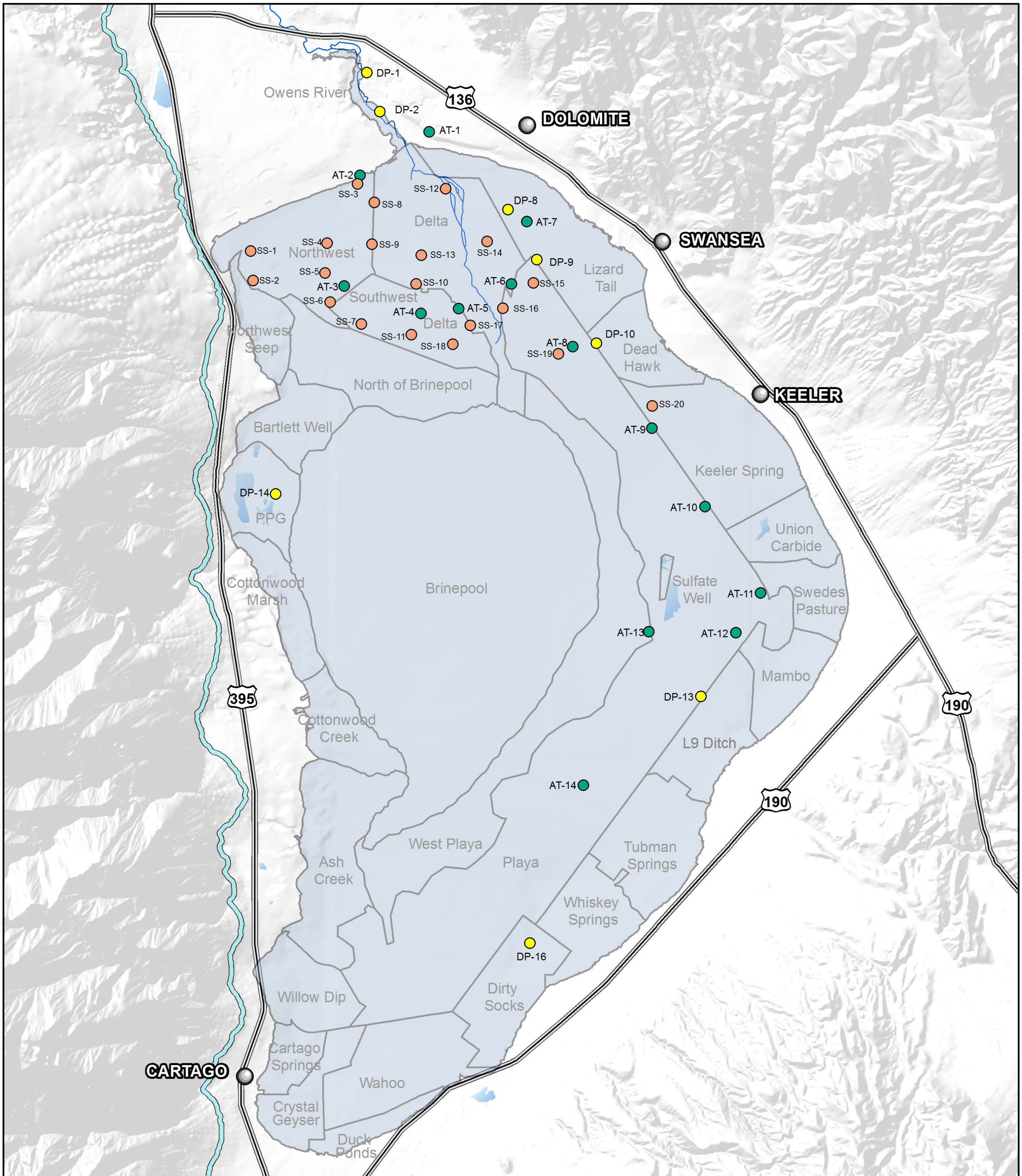
The potential pumping alternative is summarized in **Table 5**; the locations of the simulated pumping wells are shown on **Figure 11**. **Table 5** lists the following for each well:

- Identification
- Group (geographic or model layer) of wells each well is associated with
- Number of wells in the group
- Group total pumping rate
- Coordinates
- Capacity
- 6-month capacity
- Depth
- Model layers screened
- Aquifers pumped

Table 5
Potential Alternative Well Description

Group	Well ID	No. of Wells	X Coordinate (ft)	Y Coordinate (ft)	Simulated Pumping Rate (gpm)	Group Pumping Rate (gpm)	Total (AF/6 mos.)	Depth (ft)	Model Layers Screened	Aquifers Pumped
Shallow Sand Sheet Production Well	SS-1	20	1339027.322	13261513.48	50	1,000	807	30	1	Shallow
	SS-2		1339245.662	13258886.49						
	SS-3		1348487.303	13267453.47						
	SS-4		1345801.649	13262186.48						
	SS-5		1345616.745	13259556.24						
	SS-6		1346065.649	13256994.49						
	SS-7		1348822.084	13255029.88						
	SS-8		1349981.641	13265794.48						
	SS-9		1349761.641	13262098.48						
	SS-10		1353660.191	13258583.38						
	SS-11		1353259.499	13254102.27						
	SS-12		1356290.561	13267026.02						
	SS-13		1354131.1	13261138.3						
	SS-14		1359937.28	13262363.48						
	SS-15		1364054.039	13258691.67						
	SS-16		1361351.277	13256451.49						
	SS-17		1358473.624	13254926.5						
	SS-18		1356915.583	13253243.52						
	SS-19		1366244.295	13252392.04						
	SS-20		1374556.568	13247807.94						
Artesian Flowing Wells[1]	AT-1	14	1354839.494	13272037.9	145	2,030	1,689	760	7	3
	AT-2		1348707.303	13268213.46				850		
	AT-3		1347321.428	13258403.01				1070		
	AT-4		1354095.196	13255992.3				920		
	AT-5		1357432.433	13256419.17				900		
	AT-6		1362092.565	13258575.64				700		
	AT-7		1363455.377	13264107.07				570		
	AT-8		1367527.315	13253039.7				690		
	AT-9		1374540.321	13245815.09				700		
	AT-10		1379240.509	13238893.77				590		
	AT-11		1384141.173	13231240.83				450		
	AT-12		1381978.164	13227713.32				440		
	AT-13		1374270.425	13227821.56				670		
	AT-14		1368461.646	13214226.17				630		
Deep Pumping wells	DP-1	5	1349048.248	13277936.24	200	1,000	807	1530	9	4
	DP-2		1350184.932	13274474.92				1780		
	DP-8		1361525.011	13265820.02				1450		
	DP-9		1364083.939	13261386.95				1570		
	DP-10		1369345.96	13253998.49				1250		
	DP-1	5	1349048.248	13277936.24	500	2,500	2,016	1530	11	5
	DP-2		1350184.932	13274474.92				1780		
	DP-8		1361525.011	13265820.02				1450		
	DP-9		1364083.939	13261386.95				1570		
	DP-10		1369345.96	13253998.49				1250		
	DP-1	5	1349048.248	13277936.24	500	2,500	2,016	1530	12	5
	DP-2		1350184.932	13274474.92				1780		
	DP-8		1361525.011	13265820.02				1450		
	DP-9		1364083.939	13261386.95				1570		
	DP-10		1369345.96	13253998.49				1250		
	DP-14	1	1340971.985	13240659.12	140	140	113	1330	12	5
	DP-13	1	1378949.184	13222316.83	480	480	387	1500	12	5
	DP-16	1	1363469.853	13200895.9	1,200	1,200	968	980	12	5
	Total:	**52**				**10,850**	**8,803**			

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



Key to Features

Town

Highways

Los Angeles Aqueduct

Owens River

Alternative Well Locations

Deep Well

Artesian Well

Sand Sheet Well

Groundwater Discharge Zone

Water Bodies

N

0 1.5 3 Miles

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Technical Memorandum for
Modeled Well Sensitivity Analysis

Potential Alternative Pumping Well Map

Los Angeles Department of Water & Power

Figure 11

MWH

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

The potential alternative is equivalent to OPS-20. This scenario has 52 wells with pumping rates ranging from 50 to 1,200 gallons per minute. Estimated total pumping is approximately 9,000 AF/6 mos. The water budget summary for the potential alternative is presented in **Table 6**. Pumping wells are grouped by location and or type. There are 20 wells associated with the shallow sand sheet, 14 artesian wells, and 18 deep (layers 9, 11, or 12) pumping wells.

Figure 12 illustrates the layer 1 total drawdown after a 10-year period in which pumping was simulated in alternate 6-month time periods. **Figure 13** shows layer 1 depth to water at the end of the same period. The greatest drawdown (approximately 13 feet) occurs on the eastern and southeastern edge of the model. There is no drawdown in the west and southwestern portion of the model. The Owens Valley Fault limits drawdown in this area. A maximum drawdown of approximately 3 feet occurs south and west of Lone Pine area. The Owens River Fault Zone causes increased drawdown in the western portion of the sand sheet, but limits drawdown (acting as a barrier) east of the fault zone in the northeastern portion of the Owens Lake.

On the perimeter of the Owens Lake, drawdown in layer 1 as a result of deep pumping is often greatest at a large distance from pumping on the alluvial fans surrounding the lake. Typically, drawdown decreases with distance from the pumping well, but this is not necessarily the case with deep pumping at Owens Lake. A similar phenomenon was observed in pump testing near Owens Lake at the Cabin Bar Ranch (JMM, 1989). At the Cabin Bar Ranch, the response in the shallow zone (layer 1) to deep pumping tended to be delayed and of lesser magnitude than drawdown measured in the deep zones. At the Cabin Bar Ranch, drawdown in the shallow zone was not highest near the pumping well, but instead was highest at a greater distance from the pumping well higher on the alluvial fans to the west. Conversely, monitoring wells east of the pumping well (moving toward the lake) showed relatively little change in water level. The cause of this phenomenon is believed to be the presence of confining layers of relatively low permeability (lakebed deposits) that limit vertical transmission of pressure changes. Lakeward of the historic shoreline, the shallow aquifer is partially hydraulically separated from the deeper pumping zones.

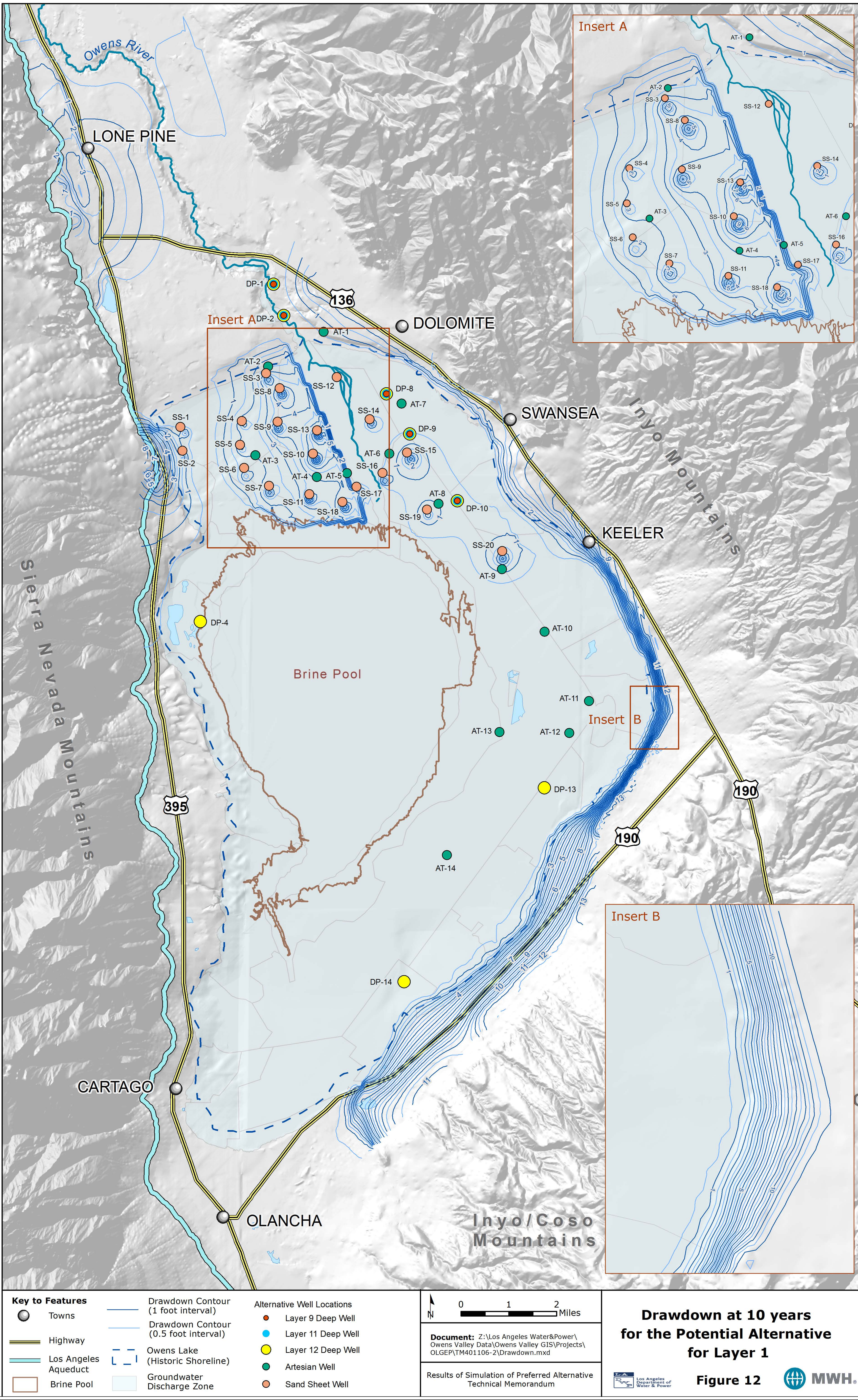
The total water budget for the potential alternative after 10 years of pumping shown in **Table 6** allows for comparison against the baseline water budget (**Table 1**). Key observations are:

- Constant Head, General Head, and River boundary conditions did not provide significant water or unrealistic water supply due to the nature of these boundary conditions.
- Major changes (when compared to the baseline) in the water budget include extraction at pumping wells (-7,114 AF/6 mos), new Artesian Wells (-1,689 AF/6 mos), and Storage (6,487 AF/6 mos).
- Storage provided the majority (74 percent) of the water removed by new pumping wells in the potential alternative. The next greatest contributing sources were reduction of flow to ET and drains, both approximately 9 percent each. ET and drains provide the discharge to groundwater discharge zones.

Table 6
Water Budget Summary for the Potential Alternative after 10 Years of Pumping

Water Budget Element	Preferred Alternative (AF/6 mos)			Net Diff. Between Pref. Alt and Baseline
	In	Out	Net	
Storage	**6,488**	**0**	**6,488**	**6,487**
Constant heads	**4,024**	**(4,326)**	**(302)**	**55**
Brine Pool	-	(4,326)	(4,326)	**49**
Haiwee Reservoir	4,024	-	4,024	**6**
Drains	**-**	**(6,655)**	**(6,655)**	**-865**
Drains	-	(4,966)	(4,966)	**824**
New Artesian Wells	-	(1,689)	(1,689)	**-1,689**
General Heads	**6,914**	**(329)**	**6,585**	**412**
Rivers	**8,634**	**(9,379)**	**(745)**	**278**
Owens River	6,408	(9,221)	(2,813)	**214**
Lone Pine Streams	2,082	0	2,082	**29**
Diaz Lake	144	(158)	(14)	**35**
Wells [1]	**8,762**	**(8,160)**	**602**	**-7,114**
Evapotranspiration	**0**	**(5,966)**	**(5,966)**	**749**
Total Source/Sink	**34,822**	**-34,815**	**7**	

1. The "in" column of this row represent groundwater recharge from Sierra Nevada stream drainages and model boundary inflow.



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Results of Simulation of Preferred Alternative Technical Memorandum

Drawdown at 10 years for the Potential Alternative for Layer 1

Figure 12

Los Angeles Department of Water & Power

MWH

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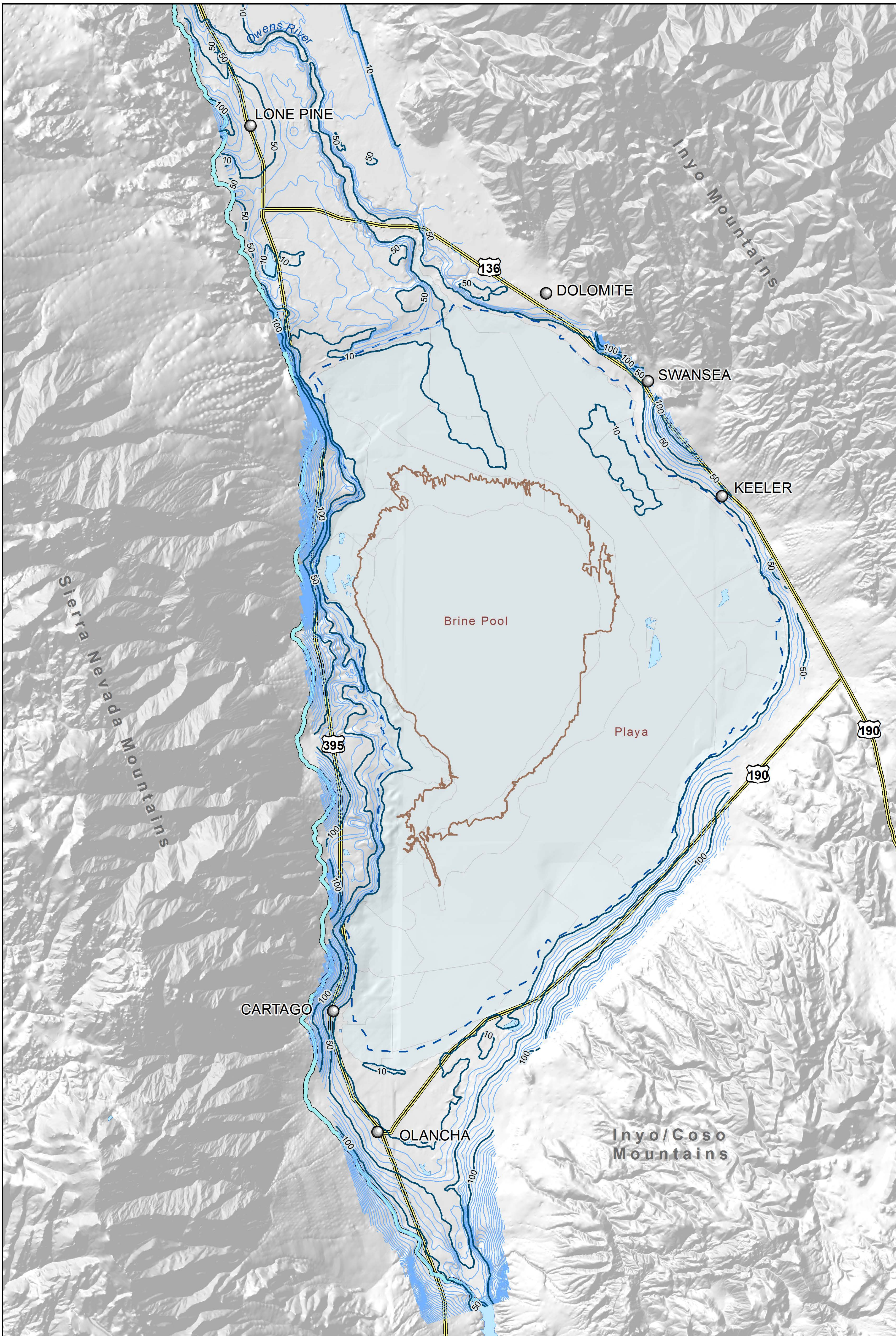

Key to Features

Towns

Highway

Los Angeles Aqueduct

Depth to Water (10, 50, 100 foot contours)

Depth to Water (10 foot contour intervals)

Brine Pool

Owens Lake (Historic Shoreline)

Groundwater Discharge Zone

N

0 1 2 Miles

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Results of Simulation of Preferred Alternative Technical Memorandum

Depth to water at 10 years
Preferred Alternative for Layer 1

Los Angeles Department of Water & Power

Figure 13

MWH.

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

6.0 Other Modeling Results of the Potential Alternative

This section presents modeling results of the potential alternative in a 20-year simulation designed to evaluate recovery of the system from pumping, and a 100-year simulation designed to evaluate the role of groundwater from storage during pumping. In the 20-year simulation, pumping was conducted during the first 10 years every other 6 months (the same as the previously described 10-year simulation), while the last 10 years were simulated with no new project pumping. The 100-year simulation was the same as the 10-year simulation, except that it was conducted for a longer period of time.

20-Year Simulation

Table 7 shows discharge from each groundwater discharge zone at the end of the 20-year simulation. At the conclusion of the 10-year recovery period, 12 of the 30 zones are within 5 percent of baseline discharge; 20 are within 10 percent of baseline discharge. The greatest percent difference is the Southwest Delta zone, although the magnitude of difference is relatively small (13 AF/6 mos). The area with the least complete recovery is the easternmost portion of the model at Keeler Spring, Union Carbide, Swedes Pasture, Mambo, L9 Ditch, Tubman Springs, Whiskey Springs, Dirty Socks, and Wahoo. These zones average a 15 percent difference between baseline and the end of the 20-year simulation. This portion of the model had the highest drawdown and is also the most sensitive to deep pumping due to the vertical conductance of materials in this area that allows communication with deeper aquifers.

Figure 14 shows the change in water level at the end of 20 years relative to the initial conditions (baseline). Full recovery occurs throughout the model domain with exception of the area between Lone Pine and State Route 136; the area immediately west of the Northwest Seep, the Delta area, and the south eastern shoreline. The greatest difference between pre-pumping and the final water levels at the end of the 20-year model is approximately 4 feet.

Recommended Monitoring Wells

Results of the model simulations are useful for determining optimal locations for monitoring changes in groundwater levels and changes in groundwater discharge. Monitoring is proposed in order to establish baseline (before pumping) conditions and to collect data to understand the system's response to pumping.

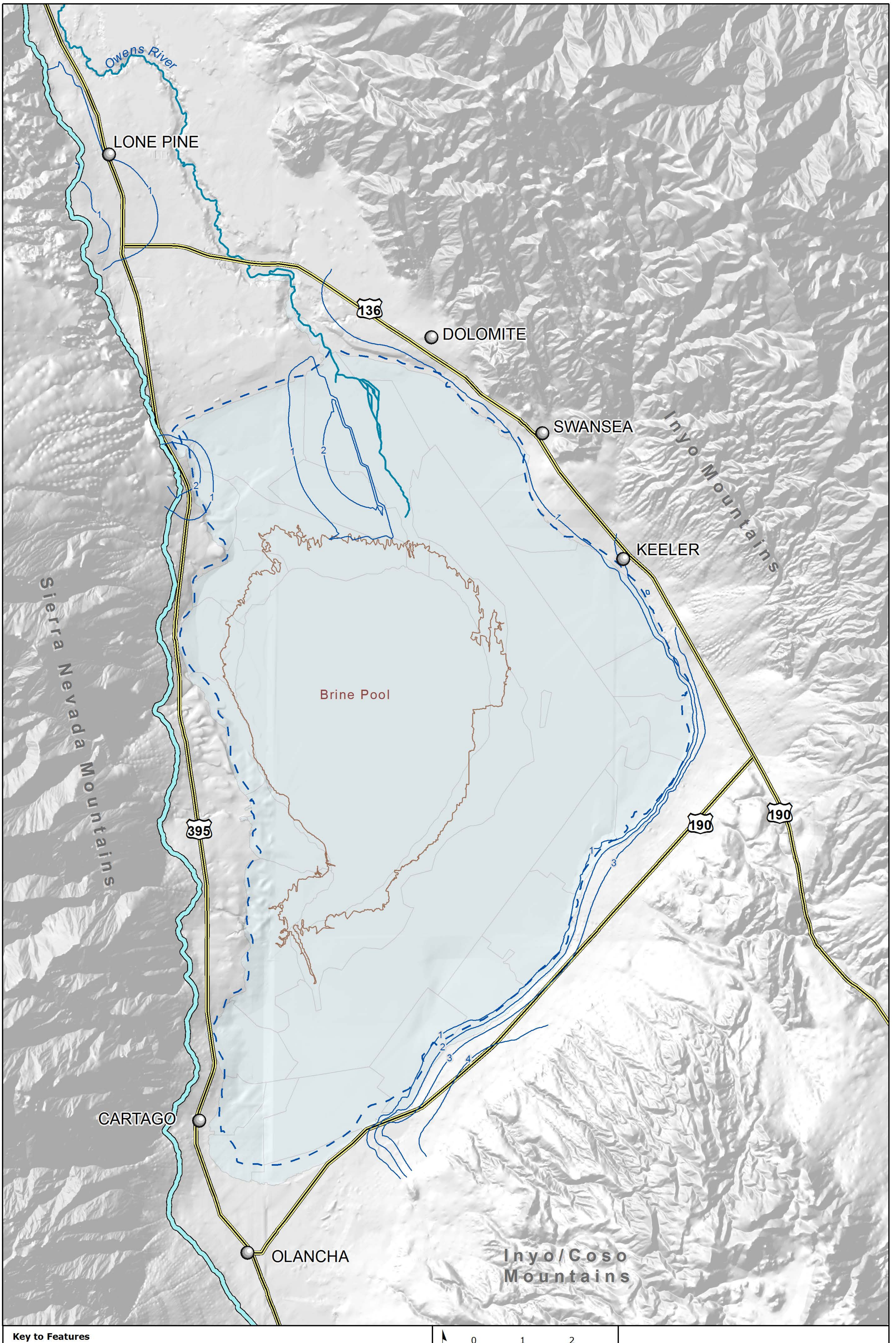
Each monitoring location was established based on the following criteria (in order of importance):

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

Table 7

Discharge from Each Groundwater Discharge Zone at the End of the 20-year Simulation (10 Years of Pumping Followed by 10 Years of Recovery)

Groundwater Discharge Zone	Discharge after 20-Year Simulation			Total Discharge at Baseline (AF/6 mo)	Difference (AF/6mo)	Percent Difference
	Drain (AF/6 mo)	ET (AF/6 mo)	Total Discharge (AF/6 mos)			
Owens River	-	-	-	-	-	NA
Delta	24	676	700	701	1	0%
Lizard Tail	823	518	1,341	1,407	66	5%
Dead Hawk	58	190	247	267	20	7%
Playa	3	140	143	150	7	5%
West Playa	3	14	17	18	1	6%
Sulfate Well	-	-	-	-	-	NA
Keeler Spring	96	369	465	529	64	12%
Union Carbide	11	144	154	177	22	13%
Swedes Pasture	0	143	143	163	20	12%
Mambo	6	255	262	310	48	15%
L9 Ditch	8	83	91	110	19	17%
Tubman Springs	9	202	211	248	37	15%
Whiskey Springs	5	119	124	150	26	17%
Dirty Socks	51	96	147	182	35	19%
Wahoo	0	8	8	10	2	16%
Duck Ponds	-	7	7	7	0	2%
Crystal Geyser	62	76	138	139	1	1%
Cartago Springs	192	221	413	416	3	1%
Willow Dip	583	313	896	901	4	0%
Ash Creek	394	426	819	828	9	1%
Cottonwood Creek	8	19	27	28	1	3%
Cottonwood Marsh	38	298	336	345	9	3%
PPG	243	94	336	345	9	3%
Bartlett Well	65	104	169	175	5	3%
North of Brinepool	63	121	184	201	17	8%
Southwest Delta	1	31	32	45	13	28%
Northwest Seep	141	293	434	473	39	8%
Northwest	307	228	534	584	50	9%
Brinepool	-	0	0	-	(0)	NA
Total	3,194	5,186	8,380	8,906	526	6%



Key to Features

- Towns
- Highway
- Los Angeles Aqueduct
- Brine Pool
- Change in Drawdown Contour (0.5 foot interval)
- Owens Lake (Historic Shoreline)
- Groundwater Discharge Zone

N 0 1 2 Miles

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Results of Simulation of Preferred Alternative Technical Memorandum

Remaining Drawdown at the end of 20 Years

Los Angeles Department of Water & Power

Figure 14

MWH

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

To site the monitoring well locations, groundwater flow vectors were traced upgradient to the point of greatest drawdown. **Figure 15** shows lines of drawdown and a monitoring well sited for Northwest Seep. If a single monitoring site was used for several groundwater discharge zones (e.g. L9 Ditch, Tubman Springs, and Whiskey Springs), a central discharge zone was used as the starting point to trace the flow vector. **Figure 16** illustrates tracing the flow vector back to the point of greatest drawdown and shows the flow vectors for layer 1 of the groundwater model.

A vector map shows direction and magnitude of data at points (model cells in this case) on a map. The angle of the arrow indicates the direction water flows, from high elevation (hydraulic head) to low elevation. The magnitude is indicated by arrow length. Larger flow amounts have longer arrows; while lower flow amounts have short arrows. High-magnitude flows are observed near Haiwee Reservoir, on the west central portion of the model near the Cottonwood Creek alluvial fan, and near the discharge outlet at the southern end of the Alabama Hills.

The proposed monitoring sites are shown on **Figure 17**. Each well is assumed to be shallow (less than 100 feet), and located in layer 1 of the groundwater model. An additional monitoring well (MW-8) was added due to the uncertainty of Northwest Seep source water. Given that groundwater modeling indicates significant connection/source with deep aquifers and isotopic data indicate Sierra Nevada runoff recharge the source (MWH, 2012b), monitoring wells are suggested on two sides of the zone to track both potential sources.

Drawdown and Discharge Relationships

Using the results of the 20-year simulation, charts were prepared plotting water levels at monitoring well locations and groundwater discharge at discharge zones. The results used include the 10-year pumping period and the 10-year recovery period.

Figure 18 illustrates one such plot for the Tubman Zone. The x-axis lists percent change in discharge relative to the baseline, while the y-axis lists decrease in groundwater elevation relative to the baseline (drawdown). The dashed orange line indicates the decrease in discharge constraint, in this case 70 percent. The red closed circles plot the relationship during the pumping period. Each dot represents the end of a 6-month period. The pairs of dots are indicative of a 1-year on/off pumping cycle. As the pumping period continues, water levels and discharge decreases until the water level has decreased about 13 feet, and the discharge decreases 36 percent. The blue closed circles show the relationship between percent change in discharge and water level elevation during the recovery period. When pumping is ceased at 10 years, the water level immediately responds and begins to recover. Zones and wells with less connection to deep aquifers being pumped tend show a quick recovery in head and a delayed recovery in discharge.

Figures 19 shows plots of the modeled decrease in groundwater elevation at monitoring locations and groundwater discharge at discharge zones, deep-sourced seeps, or flowing wells. The plots presented are for zones that have a discharge decrease limit of 20 percent, a decrease in discharge of more than 30 percent relative to baseline, or are associated with MW-7. MW-7 is located in the northeast portion of the model. These data are presented to provide a complete picture of the response to pumping.

Of the highly-sensitive groundwater discharge zones, only Northwest Seep has a discernible relationship between head and groundwater discharge. Cottonwood Marsh, Ash Creek, Cartago Springs, and Crystal Geyser all have negligible drawdown and percent decrease in discharge, and therefore, there is no discernible relationship.

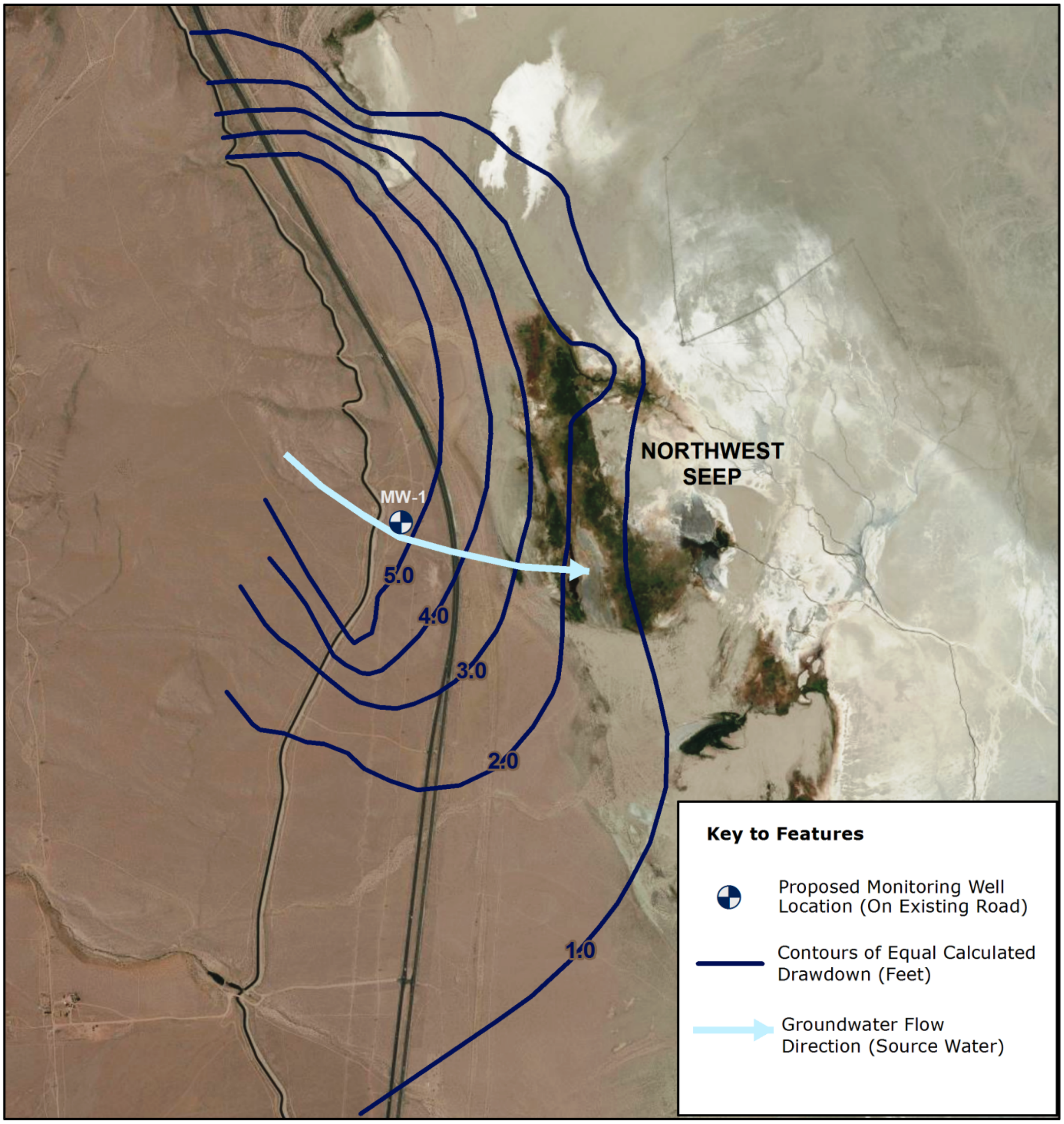
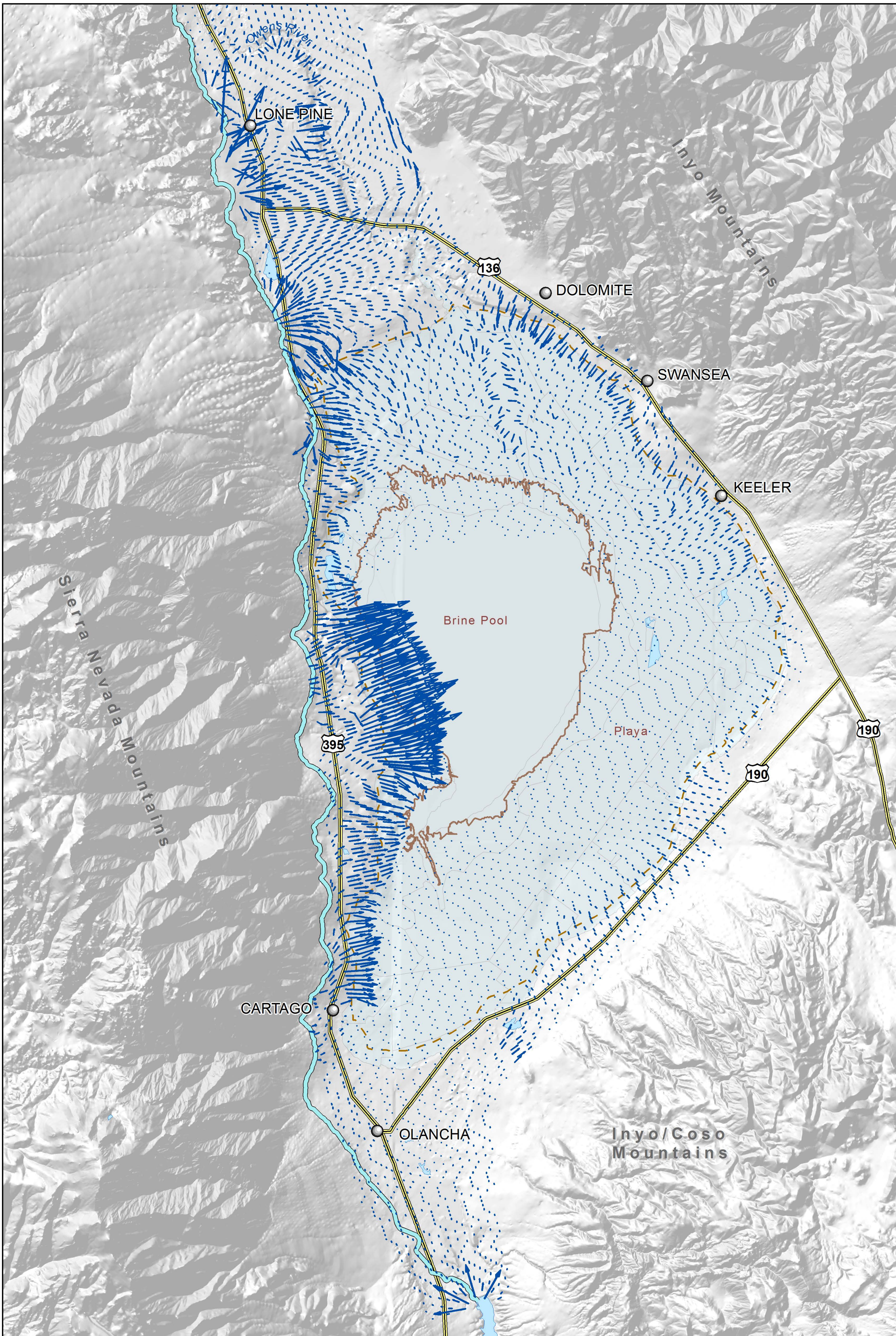


Figure 15
Northwest Seep Monitoring Well Locating Concept



Key to Features

Towns

Highway

Los Angeles Aqueduct

Groundwater Discharge Zone

Brine Pool

Owens Lake (Historic Shoreline)

Flow Vector

These flow vectors represent the direction and magnitude of groundwater flow within Layer one of the OLGEP model.

N

0 1 2 Miles

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Results of Simulation of Preferred Alternative Technical Memorandum

Layer 1 Vector Map at 10 years

Los Angeles Department of Water & Power

Figure 16

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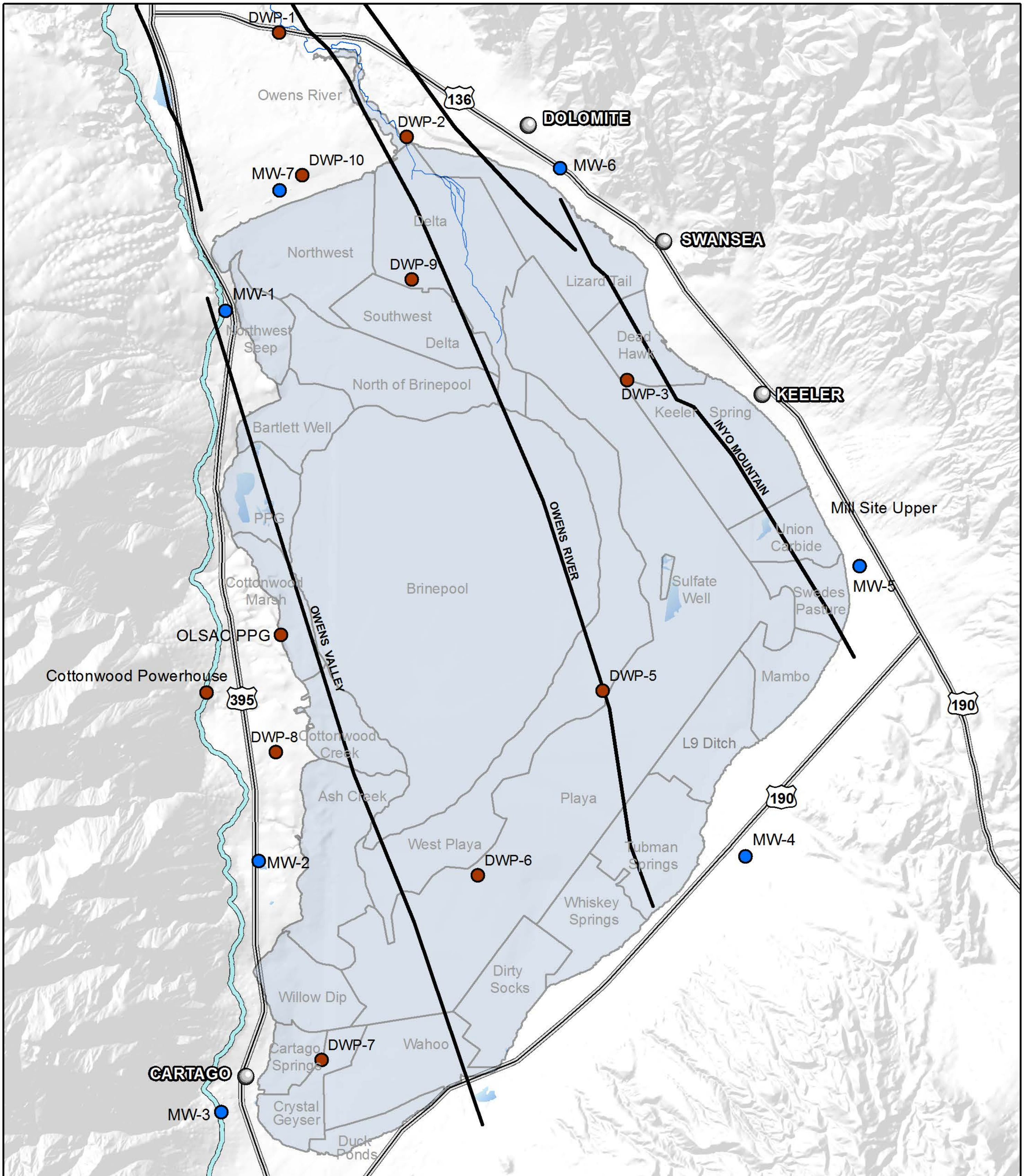

Key to Features

- Town
- Highways
- Los Angeles Aqueduct
- Owens River
- Modeled fault location
- Existing Monitoring Well
- Proposed Monitoring Well
- Groundwater Discharge Zones
- Water Bodies

N

0 1.5 3 Miles

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Technical Memorandum for Modeled Well Sensitivity Analysis

Proposed Monitoring Well Sites

Figure 17

MWH.

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Figure 18
Relationship between Groundwater Level at MW-5 and Groundwater Discharge at Tubman Zone (10 years of Pumping and 10 years of Recovery

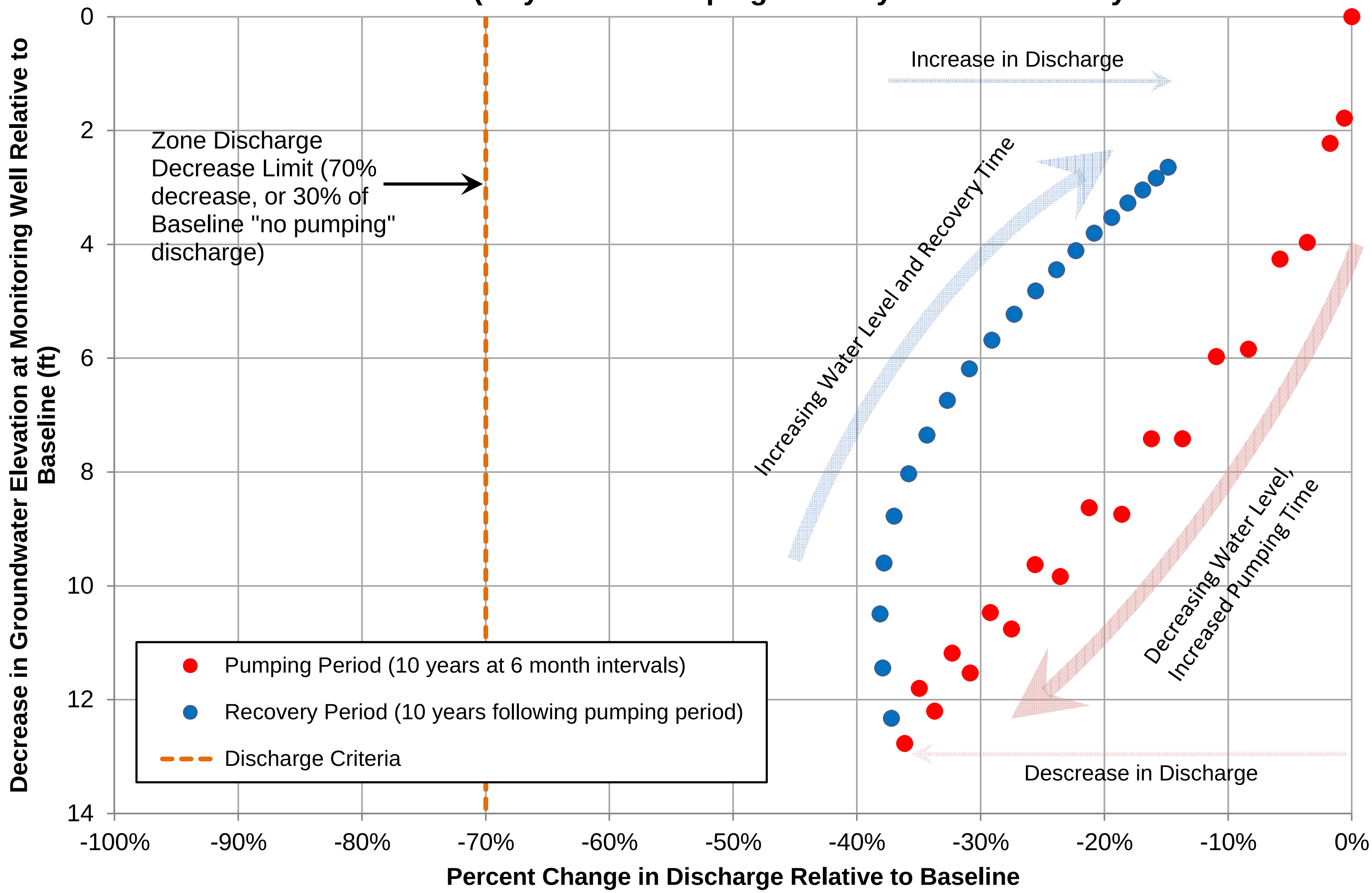
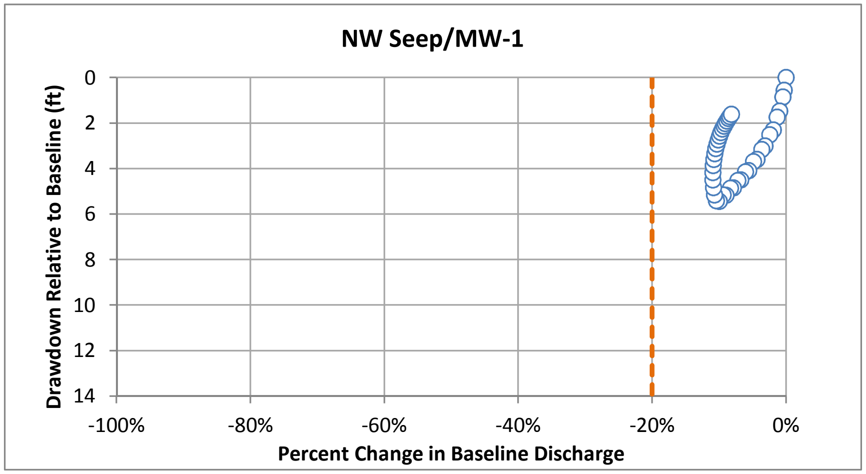
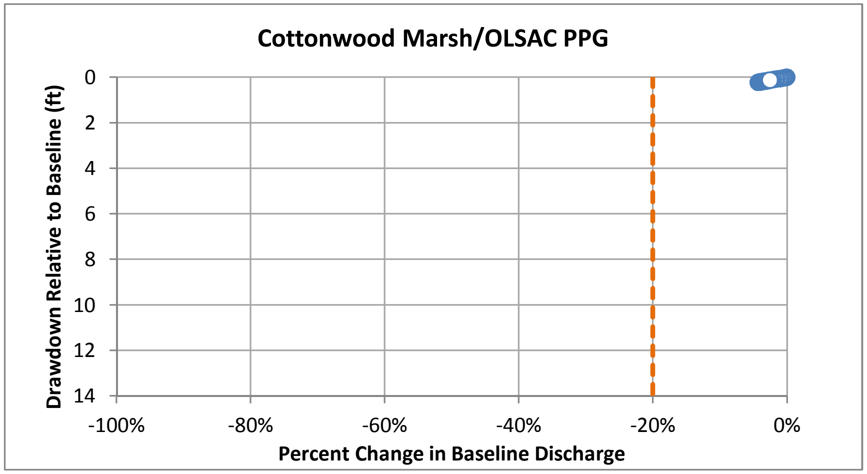


Figure 19

Relationship between Groundwater Level at Monitoring Wells and Groundwater Discharge (10 years of Pumping and 10 years of Recovery)





LEGEND

Water Level and Discharge Relationship Data Point for Discharge Zones

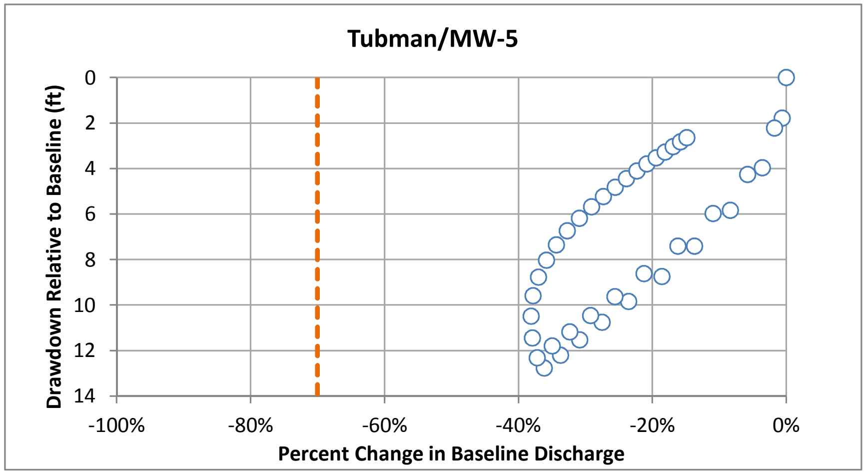
Water Level and Discharge Relationship Data Point for Deep Source Springs or Wells

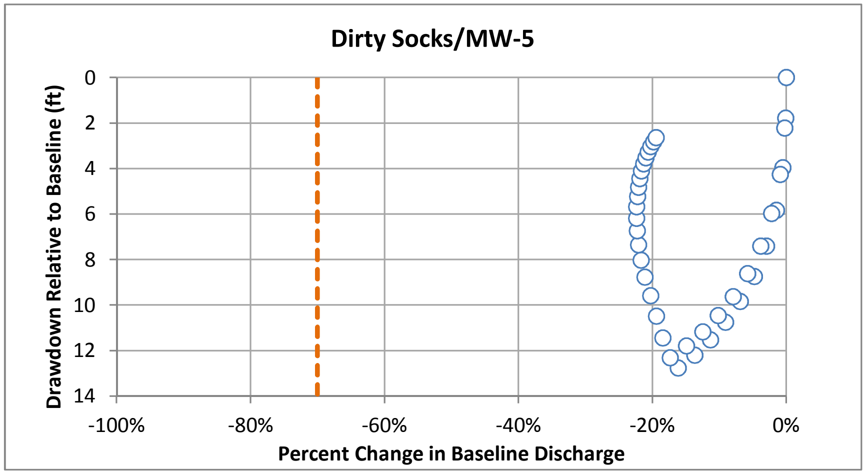
Discharge Decrease Limit Relative to Baseline

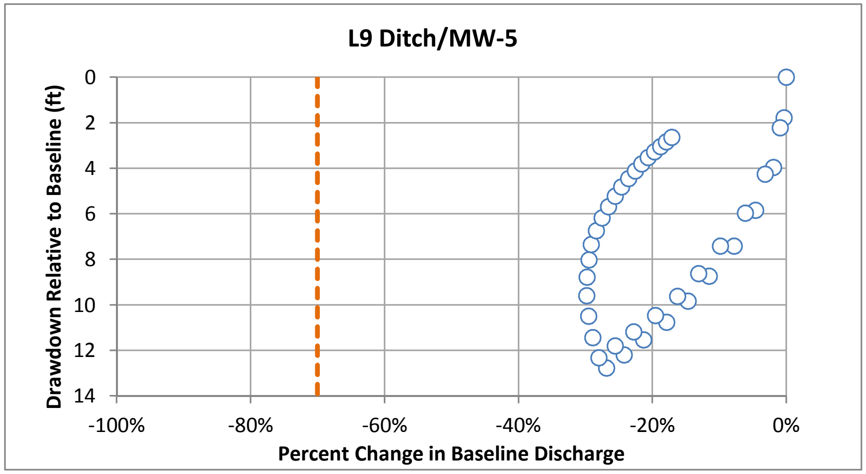
Each plot represents the modeled relationship between groundwater level at monitoring wells and groundwater discharge at discharge zones or deep sourced seeps or flowing wells. Plotted discharge zones and seeps/wells have a discharge decrease limit of 20 percent, a decrease in discharge of more than 30 percent relative to baseline, or discharge zones monitored by MW-7. Zones near MWH-7 show little impact but were provided for completeness. The modeled period includes 10 years of pumping (six months on and six month off) and 10 years of recovery with no pumping.

Figure 19 (cont)

Relationship between Groundwater Level at Monitoring Wells and Groundwater Discharge (10 years of Pumping and 10 years of Recovery)







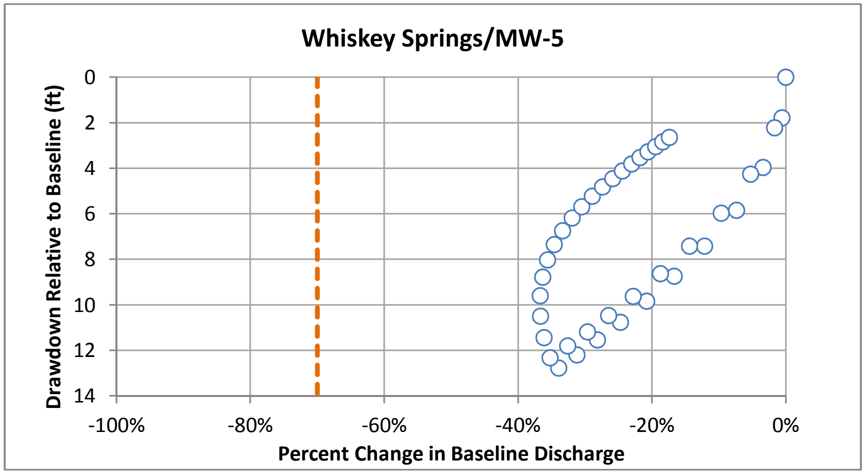
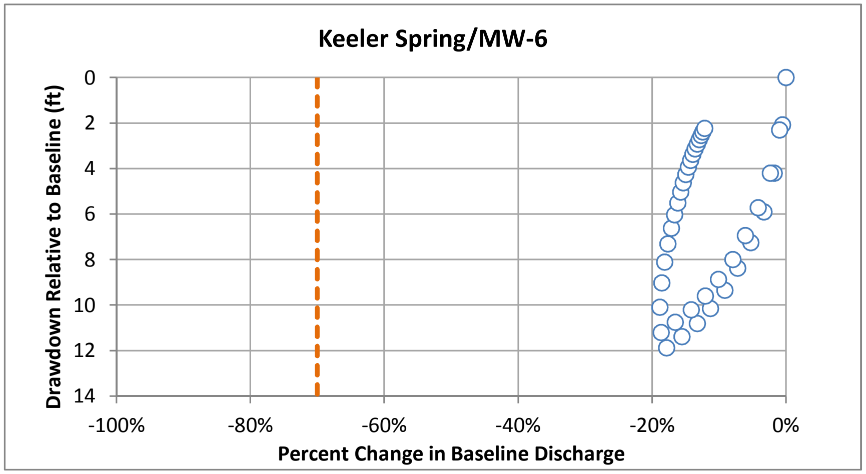
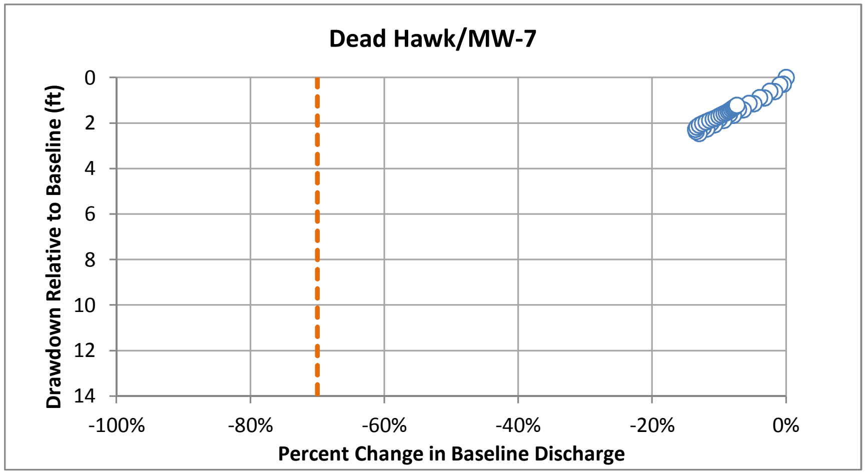
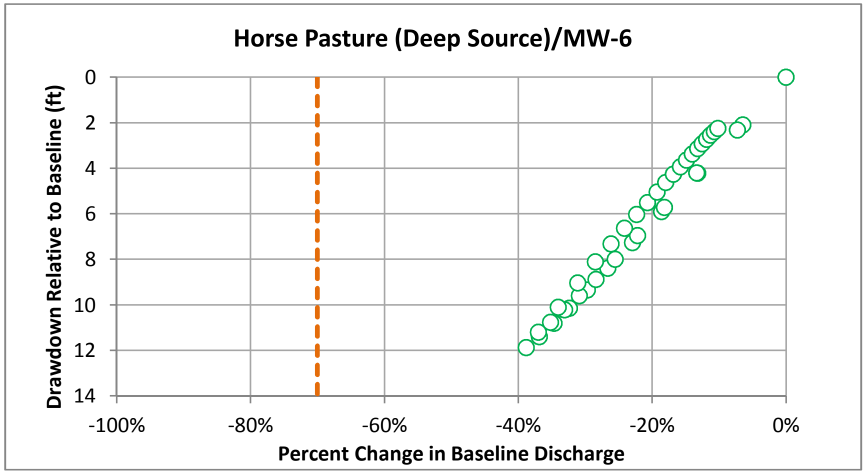


Figure 19 (cont)

Relationship between Groundwater Level at Monitoring Wells and Groundwater Discharge (10 years of Pumping and 10 years of Recovery)







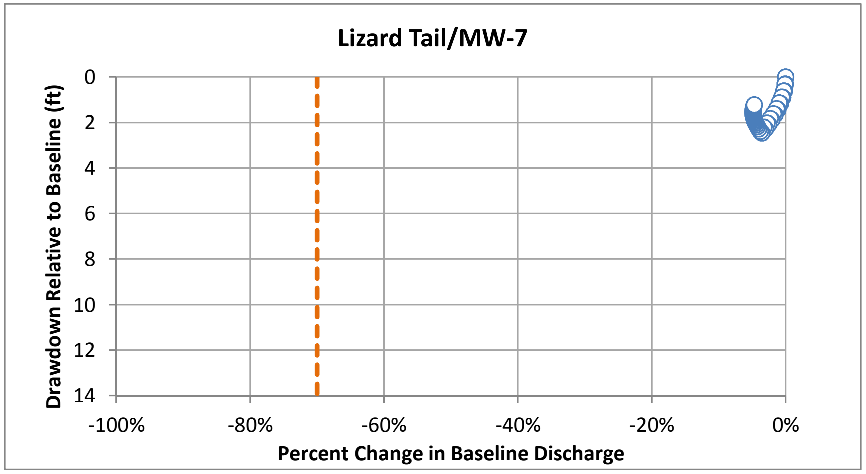
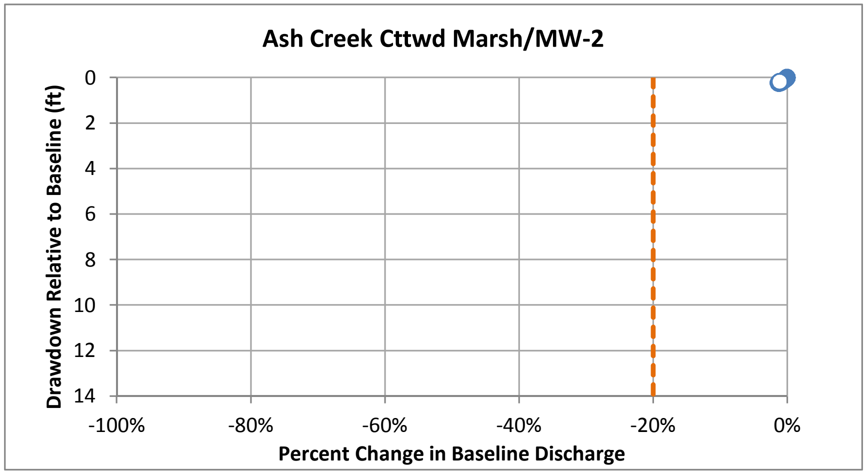
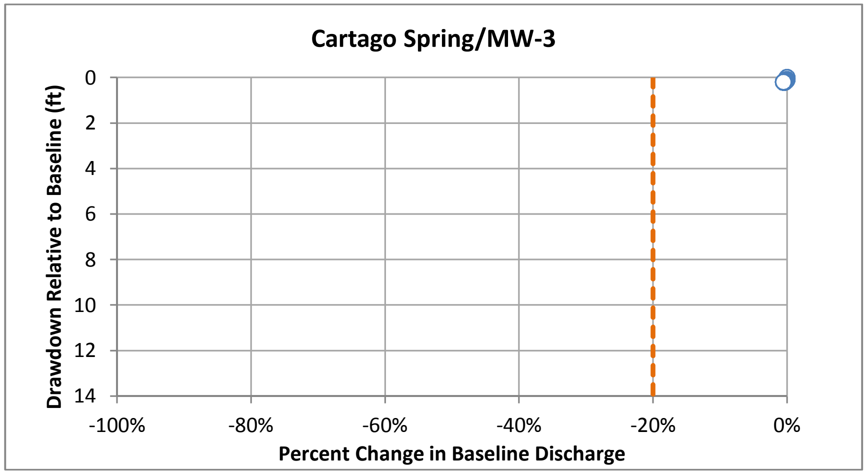
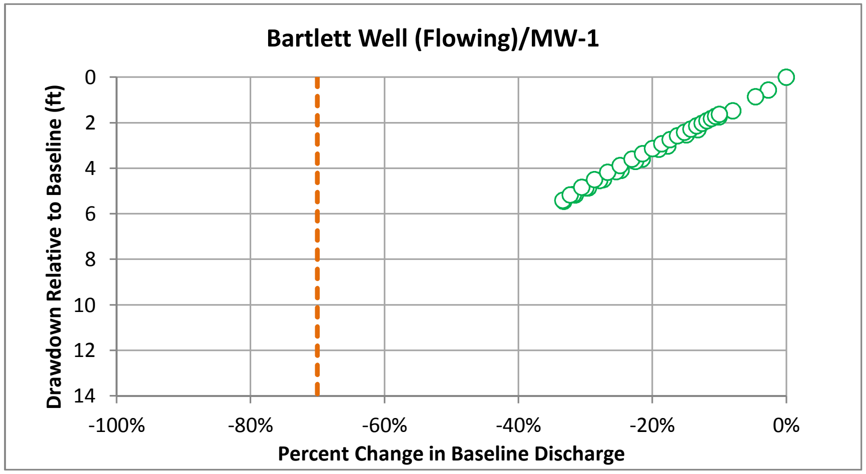


Figure 19 (cont)

Relationship between Groundwater Level at Monitoring Wells and Groundwater Discharge (10 years of Pumping and 10 years of Recovery)







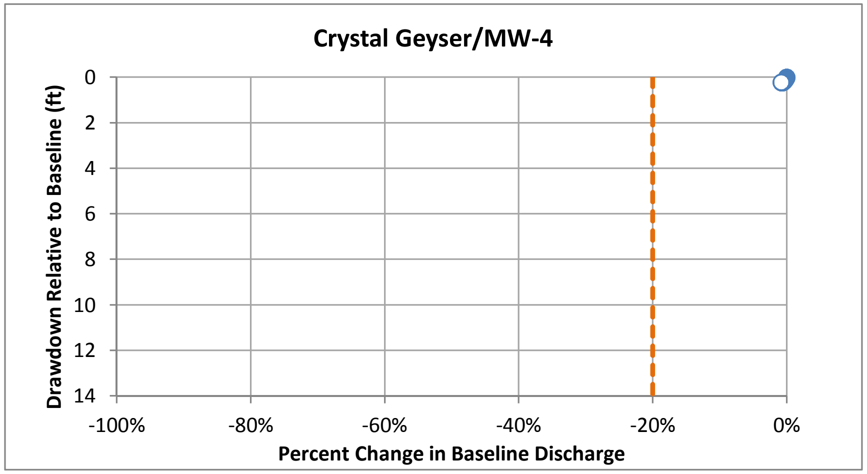
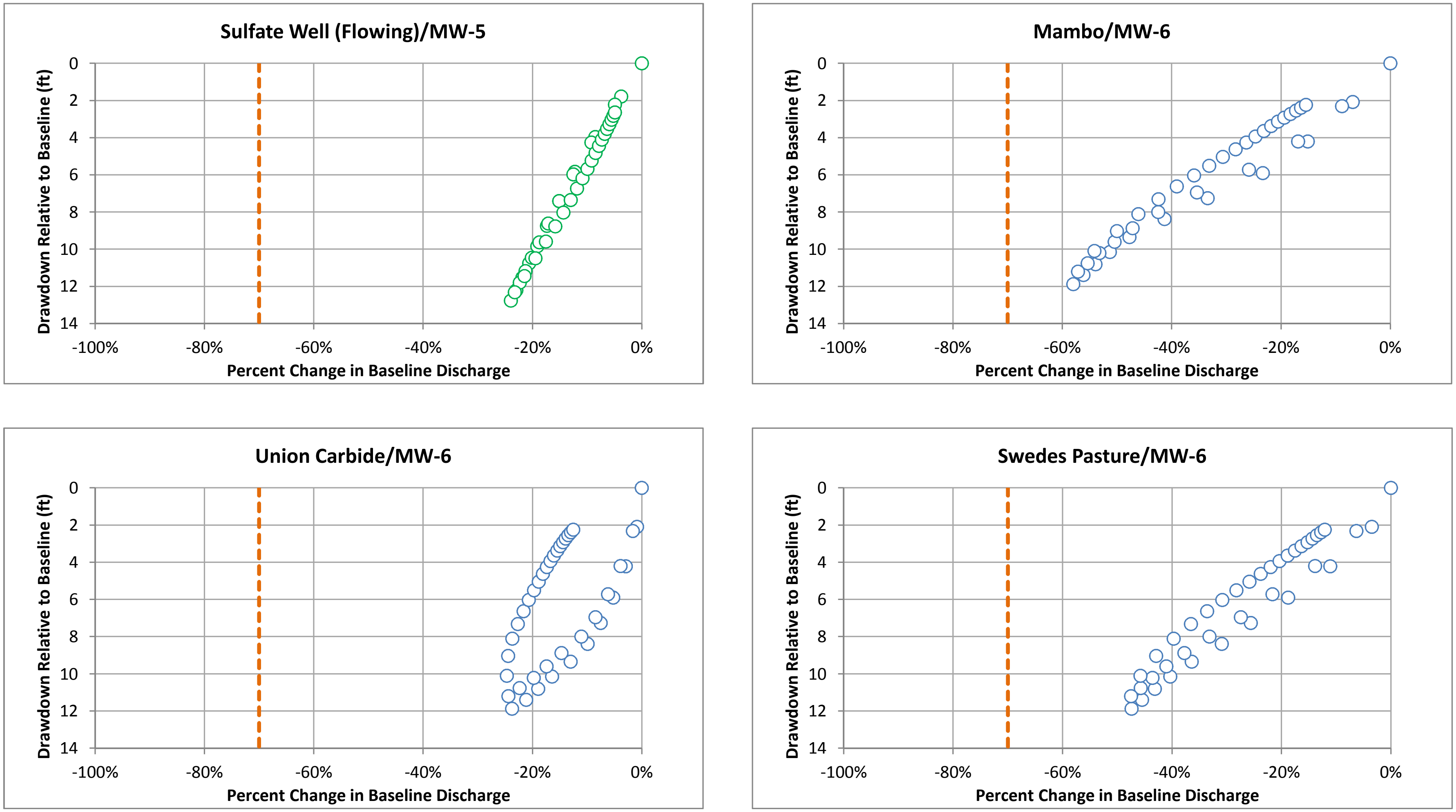


Figure 19 (cont)
Relationship between Groundwater Level at Monitoring Wells and Groundwater Discharge (10 years of Pumping and 10 years of Recovery)



100-Year Simulation

MWH simulated the potential alternative with a 100-year model run in which pumping was simulated in alternate 6-month time periods. The objective of the 100-year simulation was to evaluate long-term changes in groundwater storage due to pumping.

Table 8 presents the change in storage for the 100 years simulated. The table summarizes data in 5-year increments. For the first 5 years, the average change (decrease) is about 7,700 AF/year; this decreases to 985 AF/year after 40 years. **Figure 20** shows the average annual change in storage graphically. The modeled cumulative change in storage is about 147,600 at the conclusion of the 100-year simulation. **Figure 21** shows the cumulative change in storage.

Table 8
Summary of Potential Alternative 100-Year Change in Storage

Period	Storage Change (AF)	Average Change Per Year (AF)	Cumulative Storage Change (AF)
Year 1 - 5	38,513	7,703	38,513
Year 6 - 10	25,505	5,101	64,018
Year 11 - 15	18,322	3,664	82,340
Year 16 - 20	13,647	2,729	95,987
Year 21 - 25	10,413	2,083	106,399
Year 26 - 30	8,097	1,619	114,496
Year 31 - 35	6,209	1,242	120,705
Year 36 - 40	4,924	985	125,629
Year 41 - 45	4,131	826	129,760
Year 46 - 50	3,212	642	132,973
Year 51 - 55	2,609	522	135,582
Year 56 - 60	2,198	440	137,780
Year 61 - 65	2,032	406	139,812
Year 66 - 70	1,610	322	141,422
Year 71 - 75	1,364	273	142,785
Year 76 - 80	1,095	219	143,880
Year 81 - 85	1,197	239	145,077
Year 86 - 90	772	154	145,849
Year 91 - 95	971	194	146,820
Year 96 - 100	779	156	147,599

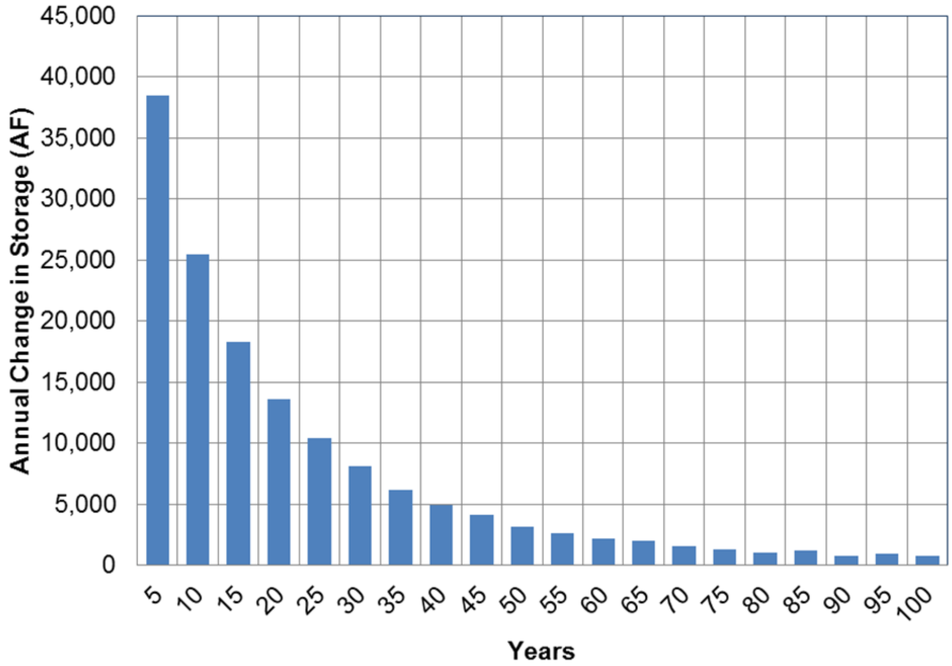


Figure 20
Potential Alternative Change in Storage for 100-Year Simulation (5-Year Increments)

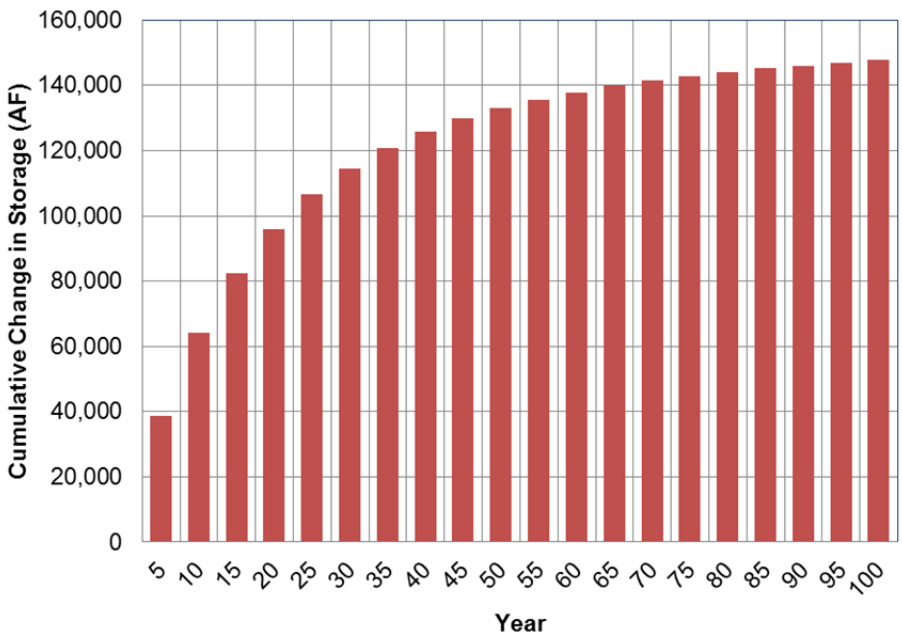


Figure 21
Potential Alternative Cumulative Change in Storage
for 100-Year Simulation (5-Year Increments)

7.0 Next Steps

Using the potential alternative described in this TM, MWH will develop detailed recommendations for new pumping well locations. In addition, MWH will conceptualize how the conveyance of water from the proposed facilities can make use of existing infrastructure and what new infrastructure will be required to implement the potential alternative's groundwater extraction plan. MWH will also develop protocols for pumping and monitoring. This information will be presented in TM 6-4 as part of Task 401.1.6.

8.0 References

James M. Montgomery, 1989. Anheuser-Busch Companies Cabin Bar Ranch Report of Test Drilling, Well Construction, and Aquifer Testing.

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