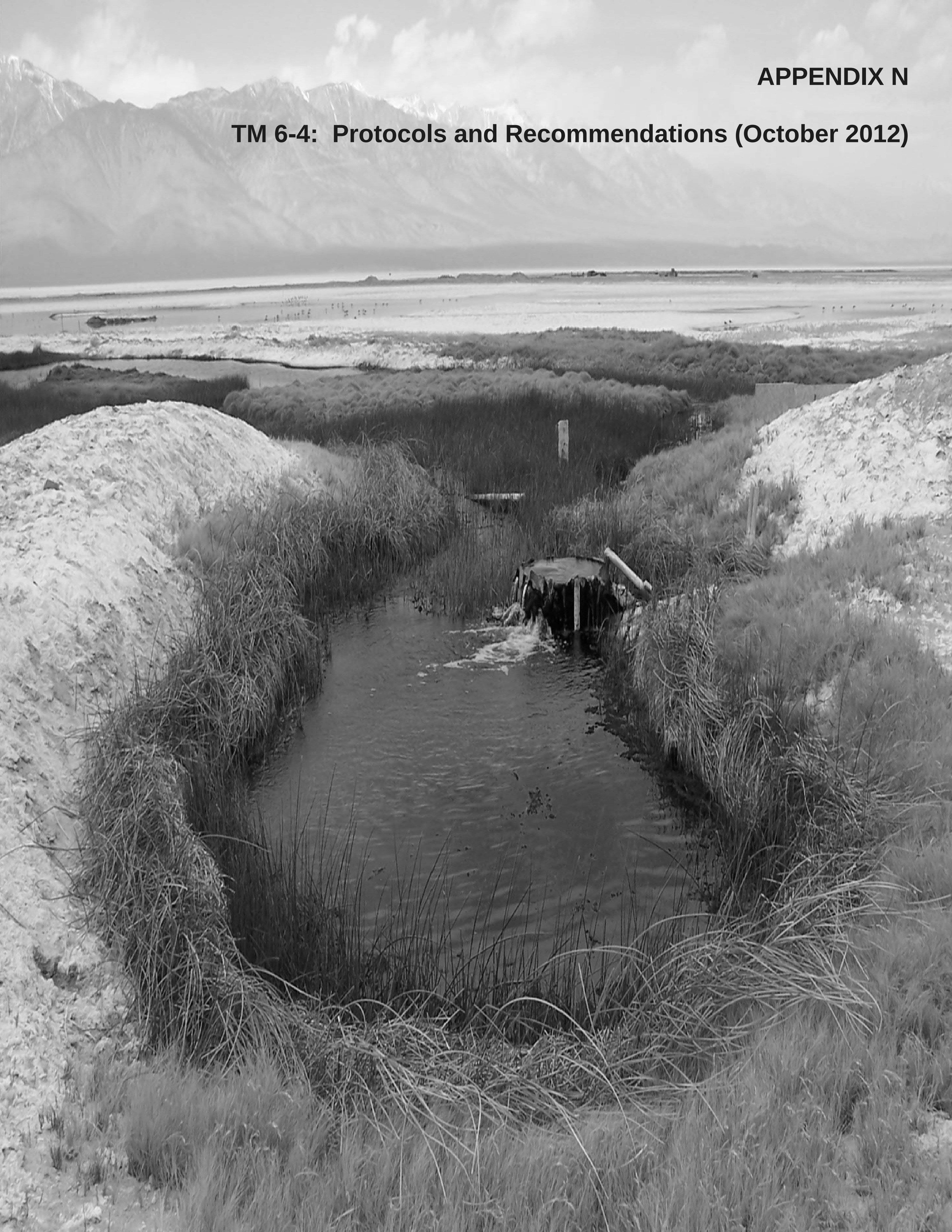
APPENDIX N

TM 6-4: Protocols and Recommendations (October 2012)



TO:	*LADWP*	DATE:	*October 2012*
FROM:	*MWH*	REFERENCE:	*Task 401.1.6*

SUBJECT: *Technical Memorandum 6-4: Protocols and Recommendations*

SUMMARY

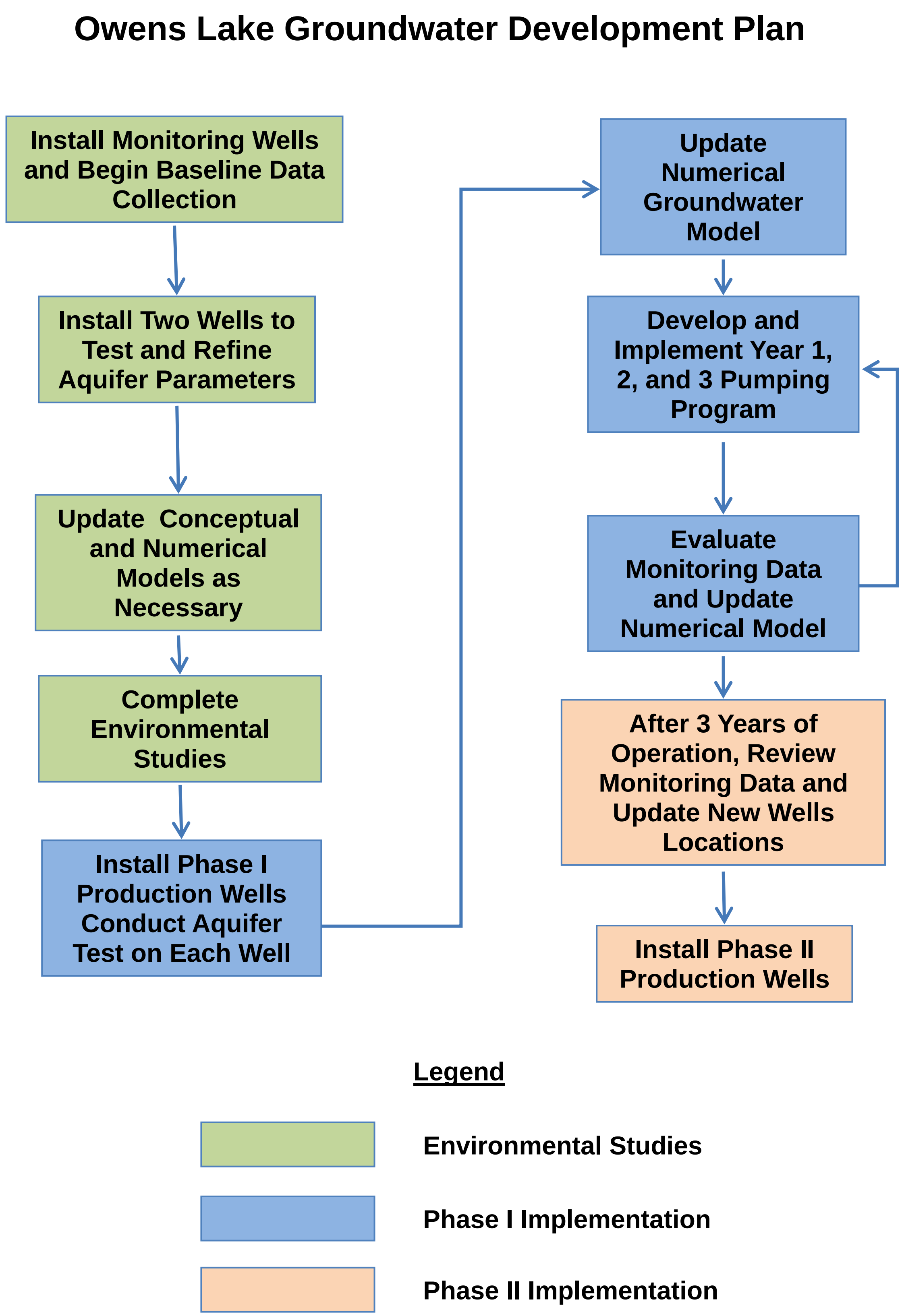
Groundwater modeling at Owens Lake has shown that approximately 9,000 to 15,000 acre-feet per year (AF/yr) of groundwater development at Owens Lake can be environmentally sustainable, depending on what criteria for springflow is used, and what key assumptions for aquifer parameters are used. This Technical Memorandum summarizes the recommended implementation strategy for the project. It is recommended that at least 9 new monitoring wells be installed on the margins of the lake that will serve to monitor flow to the springs surrounding the lake. These wells should be installed as soon as possible in order to begin collecting baseline groundwater level data. Two new test wells as part of California Environmental Quality Act (CEQA) related activities are recommended to evaluate the hydrologic characteristics of the Owens Valley Fault. A phased implementation and adaptive management approach is recommended that develops new hydrogeologic information and modifies groundwater development plans accordingly, as information becomes available. The recommended initial phase of the implementation plan involves groundwater development at a rate of approximately 7,000 AF/yr, and 3 years of monitoring, before implementing additional groundwater development. The recommended project implementation steps are shown in the flowchart on the following page and described in more detail in subsequent sections of this technical memorandum.

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. 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),
- Model simulations and alternative analysis (Task 401.1.6),
- Additional groundwater model improvements, calibration, and groundwater pumping simulation (Task 401.1.10), and
- Development of a potential pumping alternative.

The purpose of this TM (TM 6-4) is to summarize recommended well locations and recommended protocols for project implementation, pumping, and monitoring.


Owens Lake Groundwater Development Plan
Install Monitoring Wells and Begin Baseline Data Collection
Install Two Wells to Test and Refine Aquifer Parameters
Update Conceptual and Numerical Models as Necessary
Complete Environmental Studies
Install Phase I Production Wells Conduct Aquifer Test on Each Well
Update Numerical Groundwater Model
Develop and Implement Year 1, 2, and 3 Pumping Program
Evaluate Monitoring Data and Update Numerical Model
After 3 Years of Operation, Review Monitoring Data and Update New Wells Locations
Install Phase II Production Wells
Legend
Environmental Studies
Phase I Implementation
Phase II Implementation

Pumping Criteria and Maximum Pumping Amount

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

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

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

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

RECOMMENDED IMPLEMENTATION STRATEGY

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

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

NEW WELL LOCATIONS IN THE POTENTIAL ALTERNATIVE

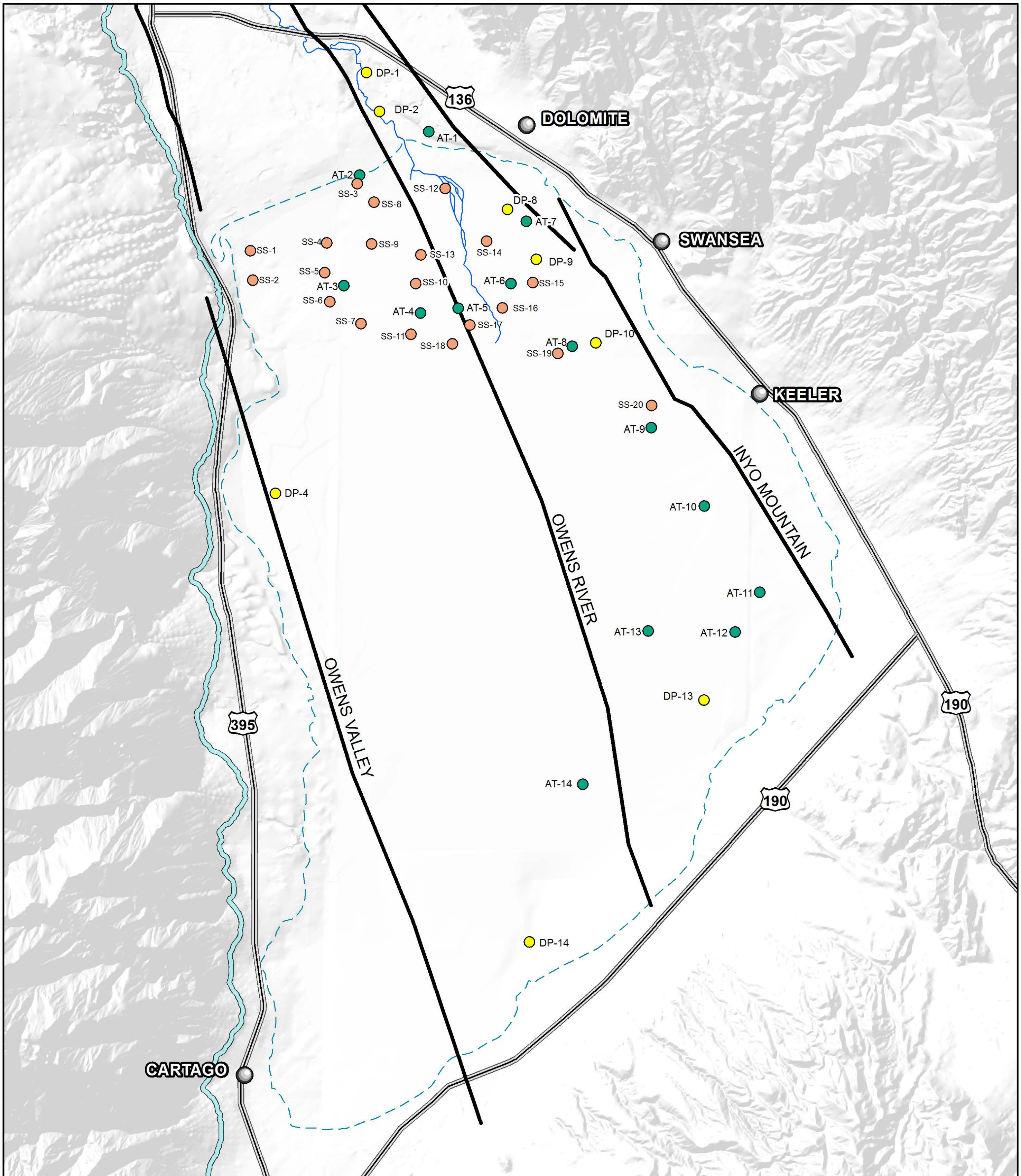
Potential or simulated well locations for production of groundwater for dust control measures are shown on **Figure 1**. Also shown on **Figure 1** are selected geologic structures that are important to the project's implementation. Three distinct well designs were simulated, as summarized in **Table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

Table 1

Recommended Types of Wells

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

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



Key to Features

- Town
- Highways
- Los Angeles Aqueduct
- Owens River
- Modeled fault Location

Alternative Well Locations

- Deep Well
- Artesian Well
- Sand Sheet Well
- Owens Lake (Historic Shoreline)

N

0 1.5 3 Miles

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Technical Memorandum 6-4

Modeled Well Locations

Los Angeles Department of Water & Power

Figure 1

MWH

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Table 2
Modeled Potential Alternative Well Locations [1]

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

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

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

Recommendations For Phased Implementation

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

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

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

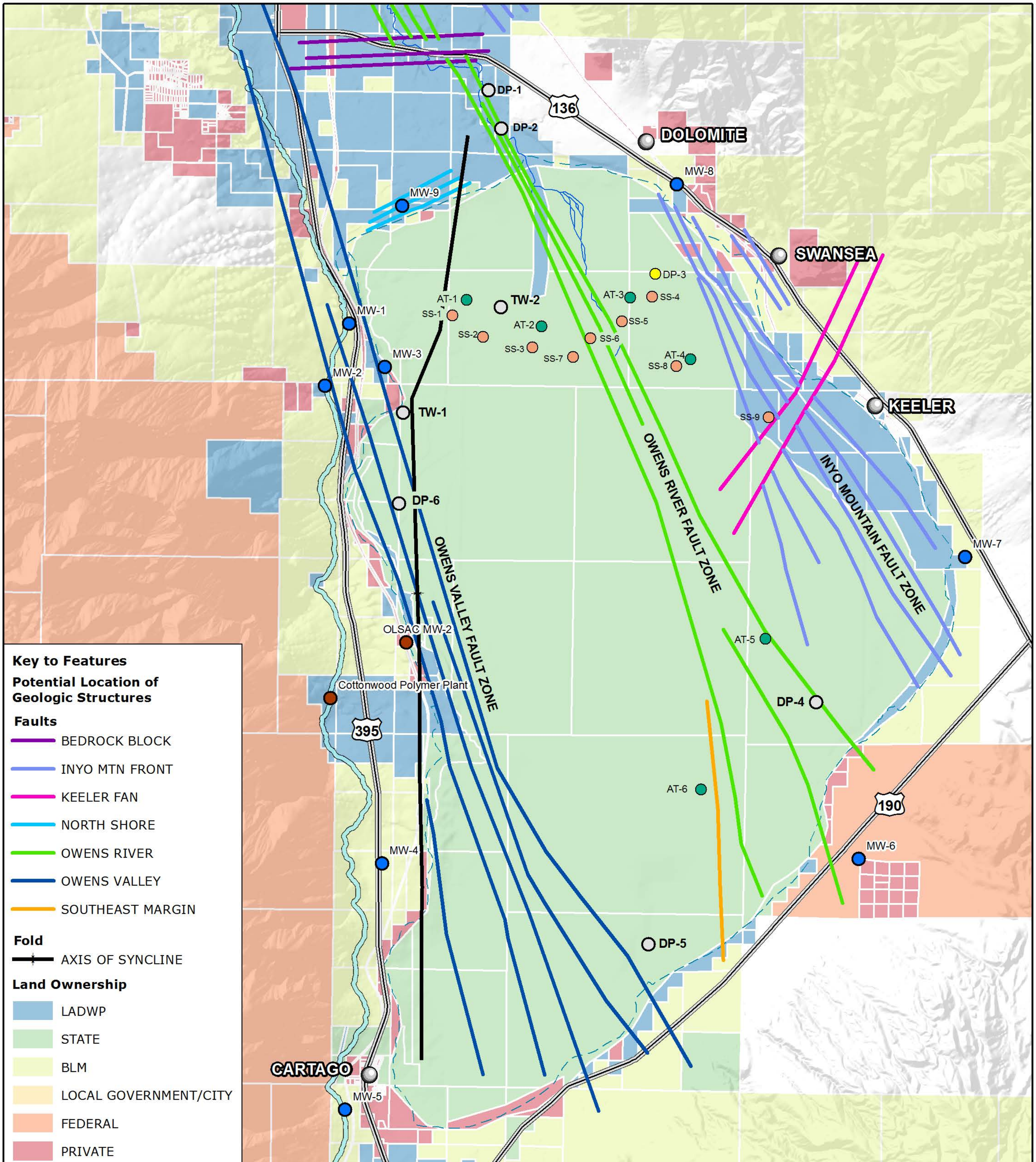
The wells shown on **Figure 2** and listed in **Table 3** are designed to test the productive capacity of the target aquifers at a diverse set of locations. Based on what is learned during construction and testing of these wells, it is recommended that the groundwater model be refined in accordance with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

Table 3
Recommended Phase I Wells

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

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

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



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

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

N

0 1.5 3 Miles

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Phase I Production and Monitoring Well Locations

Los Angeles Department of Water & Power

Figure 2

MWH.

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

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

Shallow Wells

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

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

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

Artesian Wells

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

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

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

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

Deep Wells

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

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

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

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

Recommendations for Protocols and Monitoring

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

Monitoring Locations

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

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

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

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

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

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

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

Monitoring Triggers

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

Recommendations for Future Study

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

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

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

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

REFERENCES

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MWH, 2012a. TM 6-2: Results of Simulation of Preliminary Alternatives. February.

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

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