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APPENDIX H-4
Sensitivity Analysis

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Groundwater Modeling Sensitivity Analysis

Soda Mountain Solar Project

BLM Case No. CACA 49584

August 2014

Groundwater Modeling Sensitivity Analysis

Soda Mountain Solar Project

BLM Case No. CACA 49584

Submitted by:

Soda Mountain Solar, LLC
5275 Westview Drive
Frederick, MD 21703-8306
301-228-8110

Prepared by:

Burns & McDonnell
1 Pointe Drive, Suite 540
Brea, CA 92821
Contact: Galen Kenoyer

and

Panorama Environmental, Inc.
One Embarcadero Center, Suite 740
San Francisco, CA 94111
650-373-1200

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1 INTRODUCTION

1.1 OVERVIEW

Soda Mountain Solar, LLC (SMS), proposes to construct, operate, maintain, and decommission the Soda Mountain Solar Project (project), which would be located in the Soda Mountain Valley in San Bernardino County, California, about 6 miles southwest of the Town of Baker (Figure 1.1-1). The proposed project would include withdrawal of approximately 192 acre-feet per year (AFY) of groundwater during a 24- to 30-month construction period and approximately 33 AFY during project operation. A groundwater flow model was developed for the project and presented in *Hydrogeologic Conditions and Groundwater Modeling Report* (RMT 2011) and *Hydrogeologic Conditions and Groundwater Modeling Report Addendum* (TRC 2013).

A groundwater modeling sensitivity analysis has been prepared to address National Park Service (NPS) and U.S. Geological Survey (USGS) comments on the groundwater flow model prepared by SMS. The sensitivity analysis incorporates a broad range of hydraulic conductivity values (0.2 feet/day [ft/day] to 20 ft/day) to reflect the potential for lower or higher recharge in the project area. The sensitivity analysis utilizing an analytical model also expands the model domain by excluding the limitations imposed by the bedrock present in the mountains that bound the valley in which the project would be located. The analysis provides a very conservative assessment of potential impacts to water resources within the Mojave National Preserve, located just east of the project area, and incorporates the range of hydraulic conductivity values that could characterize water-bearing sediments in the Soda Mountain Valley.

1.2 BACKGROUND

NPS and others have expressed concerns about potential impacts from project groundwater withdrawal in the Soda Mountain Valley on MC Spring (also referred to as Zzyzx Spring and Soda Spring) at the Desert Studies Center (DSC), which is located approximately 4 miles east of the eastern project boundary. MC Spring supports a population of Mohave tui chub (*Gila bicolor mohavensis*), which is a federal- and state-listed endangered species. SMS and NPS prepared separate groundwater models to assess the potential for the project to impact MC Spring.

The Department of the Interior requested that USGS conduct an independent evaluation of the SMS-prepared groundwater modeling reports and the NPS groundwater model. Keith Halford of USGS reviewed the groundwater flow models and provided comments in a June 30, 2014, letter to the Bureau of Land Management (BLM) (Halford 2014a). Mr. Halford concluded that the results of both models showed that construction and operational water use for the proposed project will "not measurably affect discharge from the Zzyzx area because a considerable volume of groundwater storage exists between the proposed production wells and the Zzyzx area"(Halford 2014a). USGS suggested that recharge and the associated values of hydraulic conductivity were likely overestimated in the SMS model. On a related note, BLM has directed SMS to conduct an aquifer test to define the aquifer parameters in the valley, including hydraulic conductivity. The aquifer test will be performed by September 2014, and resultant aquifer parameters will be used to test the assumptions used in the SMS model and recalibrate the numerical groundwater flow model, if appropriate.

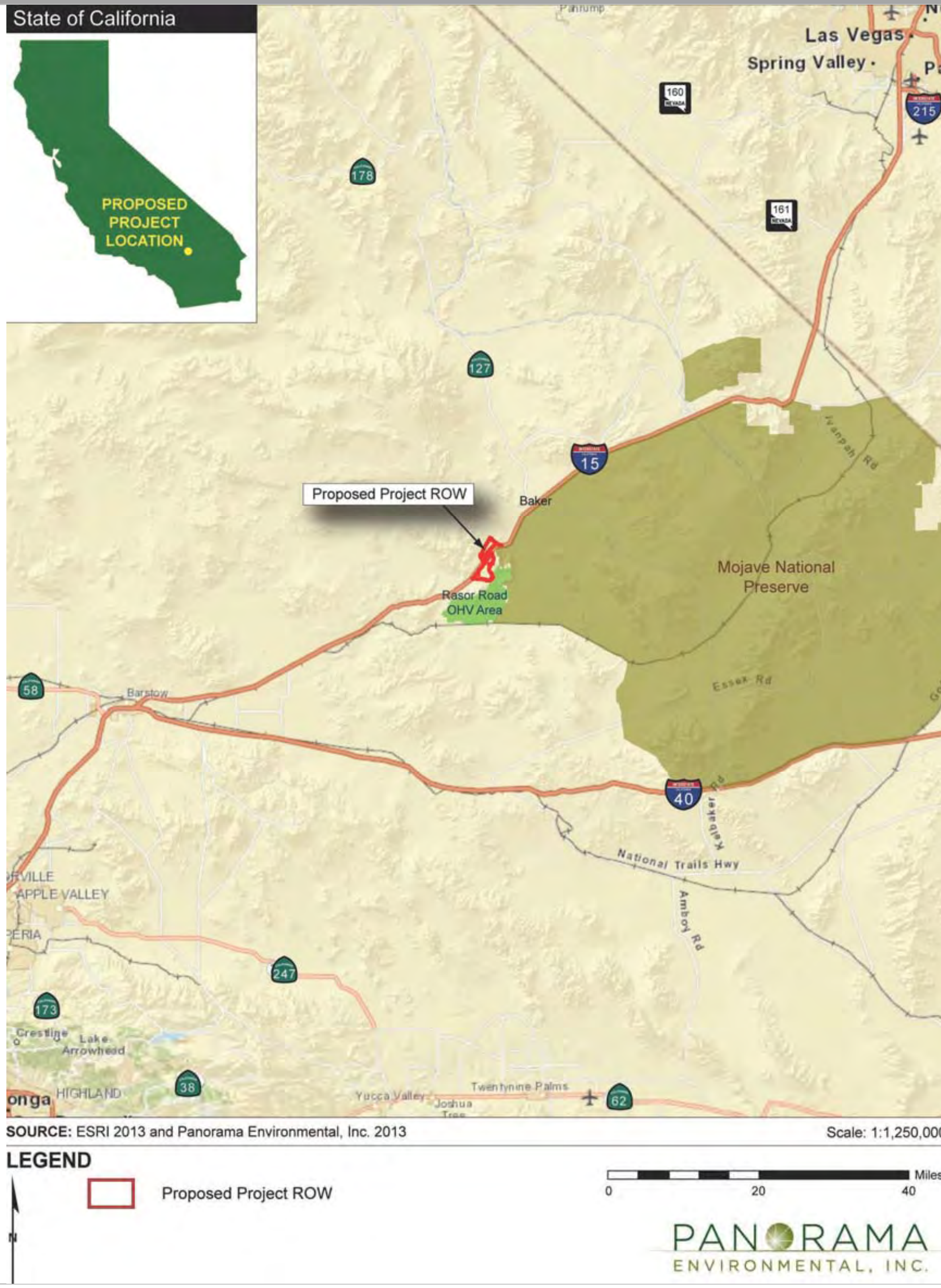
1.3 SENSITIVITY ANALYSIS OBJECTIVES

A sensitivity analysis is commonly performed in mathematical modeling to assess the sensitivity of the model results to individual model parameters. Sensitivity analyses are effective in assessing the robustness of model outcomes in situations where there is uncertainty about the model parameters.

SMS performed a sensitivity analysis using an analytical model to assess the sensitivity of the groundwater model predicted outcome at MC Spring to different values of hydraulic conductivity (and associated recharge). This sensitivity analysis addresses USGS comments regarding the potential overestimation of recharge and hydraulic conductivity by using a wider range including much lower values of recharge and hydraulic conductivity. The objectives of the sensitivity analysis were to:

1. Evaluate the impact of a larger range of values for recharge (R) and hydraulic conductivity (K) on the model outcomes at MC Spring
2. Expand the model domain to include MC Spring
3. Provide a conservative estimate of potential impacts in the Zzyzx area by assuming permeability in the mountain bedrock is equivalent to the permeability of the basin fill sediments

Figure 1.1-1: Project Location



2 GROUNDWATER MODELS

2.1 CONCEPTUAL MODEL

A conceptual model, as used in the analysis presented herein, is a written and/or illustrative (i.e., qualitative) description of an aquifer. The conceptual model for the project describes the physical characteristics of the aquifer that control the flow of groundwater in the Soda Mountain Valley and is based on knowledge of site geology and hydrogeology, as well as established concepts of groundwater flow and geology (e.g., effects of fractures, faulting, and topography on groundwater flow regimes). The conceptual site model is a dynamic model that is adapted and refined as additional data on site aquifer characteristics are collected. The conceptual model supports scientific and technical decisions for the site.

2.1.1 Geology and Hydrogeology

The project area is located within a valley that is mostly separated from the Soda Lake groundwater basin to the east by low-permeability volcanic and granitic bedrock. Inflow to the basin consists of recharge from precipitation. Groundwater inflow from other basins is expected to be minimal due to the presence of low-permeability bedrock surrounding the basin to the north and west. Groundwater flows out of the basin to the Soda Lake groundwater basin at two locations:

1. East of the proposed North Array at the approximate location where I-15 traverses through the mountains
2. East of the southeast corner of the proposed South Array

The conceptual model was developed using geologic mapping, groundwater data from other wells in the region, topographic data, and geophysical data from three locations in the project area (TerraPhysics 2010). Groundwater is present in an unconfined, alluvial aquifer. The alluvium is underlain by bedrock. Geophysical data indicate that groundwater is present approximately 150 to 300 feet below ground surface (bgs) and bedrock is present approximately 350 to 500 feet bgs throughout much of the valley and thins on the valley sides as bedrock elevation rises. Groundwater elevations in the Soda Mountain Valley are approximately 200 to 300 feet higher than groundwater elevations at Soda Lake, indicating the presence of low-permeability bedrock. Flow through the bedrock is expected to be minimal relative to flow through the more permeable basin-fill sediments.

2.1.2 Assumptions and Potential Limitations of Conceptual Model

The conceptual model assumes:

- The only input to groundwater is recharge from rainfall

- There is no permeability or flow through the bedrock into or out of the basin

The Soda Mountain Valley is generally separated from the rest of the Soda Lake groundwater basin by mountains to the south and east. The higher topographic and groundwater elevations in the valley relative to the rest of the basin indicate that there is no groundwater flow from the larger groundwater basin into the Soda Mountain Valley aquifer. The aquifer is, for the most part, physically separated from the Soda Lake groundwater basin by mountains that surround the valley and by higher groundwater elevations. Therefore, the sole input to groundwater recharge is rainfall.

Geologic mapping of the basin shows faulting in the north-south direction east of the proposed North Array. NPS asserts that there may be a preferential flow path along the west margin of the Soda Lake playa. Any flow through fractures in the bedrock is considered to be minimal and was not considered as a source of water to the Soda Mountain Valley nor to MC Spring at Zzyzx in the conceptual model.

2.2 NUMERICAL MODEL

A numerical model is a quantitative representation of the flow regime within an aquifer that is used to simulate and predict aquifer conditions. It provides quantitative predictions of how an aquifer will respond to a specific scenario (e.g., groundwater withdrawal at a given extraction rate). The model predictions are generated using groundwater flow equations based on the physics of groundwater flow. Numerical models are more robust when they use site-specific aquifer parameters as input parameters. The conceptual model is one of the sources used to develop the parameters for the numerical model.

A three-dimensional groundwater flow model was used to simulate groundwater conditions under steady-state and pumping scenarios. The numerical model used a single layer representing an unconfined aquifer. The results of the geophysical survey suggest that the entire thickness of unconsolidated sediments below the water table can be considered a single hydrologic unit, justifying the use of a single-layer model. No significant low-permeability layers such as clays or caliche units were found below the water table, based on geophysical survey results.

2.2.1 Model Inputs

Table 2.2-1 summarizes the selected aquifer parameters used in the numerical groundwater model.

Table 2.2-1: Selected Aquifer Parameters Used in Numerical Groundwater Model

Parameter Set Name	Hydraulic Conductivity (K) (ft/day)	Groundwater Recharge (R) (inches/year)	Storage Coefficient (unitless)
High End	3.2	0.4	0.1
Low End	0.86	0.12	0.1

Note: Values given are for main body of model domain. Nodes at the model boundaries have higher R values. Nodes near the northeast and southeast outlets have higher K values.

2.2.2 Results

The effects of pumping one or three water supply wells at the rate needed for construction and operation were evaluated by conducting transient flow simulations. Transient flow simulations take into account the change in hydraulic heads over time in a dynamic condition of pumping, where the cone of depression spreads downward and outward over time. Simulations were conducted using calibrated high-end and low-end values. The model grid spacing was refined in the vicinity of a simulated well to as small as 1 foot so that a more accurate estimate of drawdown in the well itself could be obtained. Drawdown data generated by the model at three potential well locations (PW-1, PW-2, and PW-3; Figure 2.2-1) are presented in Table 2.2-2.

Table 2.2-2: Summary of Modeling Results at Each Simulated Well[1]

Scenario	Predicted Drawdown Near PW-1 (ft)	Predicted Drawdown Near PW-2 (ft)	Predicted Drawdown Near PW-3 (ft)
3 Wells, 3 Years, High End	28	20	25
3 Wells, 30 Years, High End	5	4	5
3 Wells, 3 Years, Low End	110	68	91
3 Wells, 30 Years, Low End	16	12	15
1 Well, 3 Years, High End	N/A[2]	N/A	80
1 Well, 30 Years, High End	N/A	N/A	13
1 Well, 3 Years, Low End	N/A	N/A	Dry
1 Well, 30 Years, Low End	N/A	N/A	Not Modeled

Notes:

[1] Model predicts declines in hydraulic head and does not account for well loss (head losses due to friction flowing through the well screen). Actual drawdown in the well is expected to be greater due to well loss.

[2] "N/A" indicates the well was not included in the single-well scenario.

The results of the modeling show that it is possible to extract groundwater at the rate needed to supply the project using three wells with low-end conductivity and recharge and using one well with high-end recharge and conductivity.

The model-predicted declines in groundwater were used to extrapolate the predicted reduction in outflow from the valley. The model-predicted decline in water levels at the valley outlets were less than 1 foot in all scenarios. The estimated reduction in outflow out of the northeast outlet is presented in Table 2.2-3.

Figure 2.2-1: Potential Well Locations

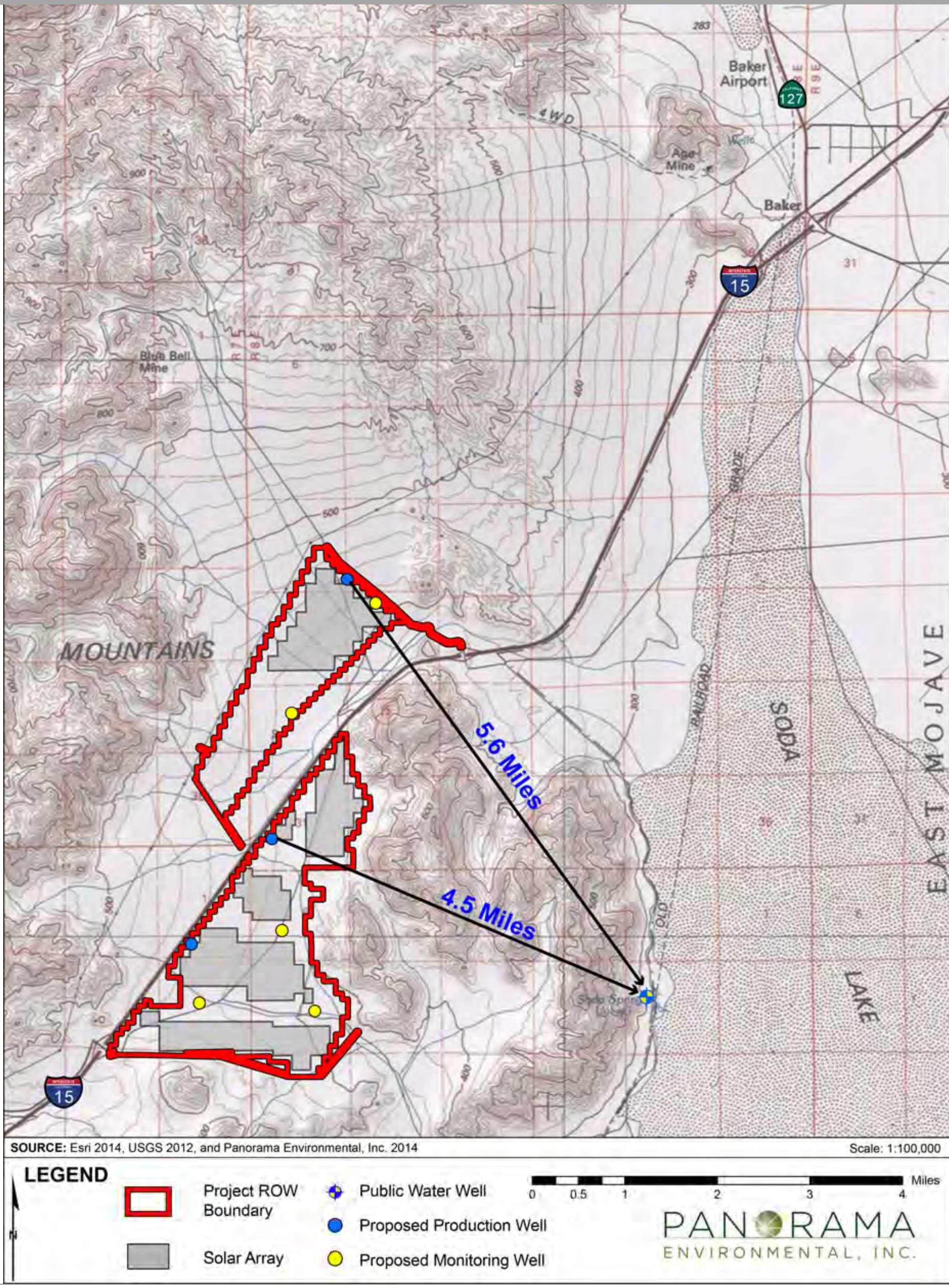


Table 2.2-3: Groundwater Discharge at Northeast Outlet of Soda Mountain Valley

Model Scenario	Discharge (AFY) After 3 Years	Reduction (AFY)	Discharge (AFY) After 30 Years	Reduction (AFY)
High Recharge, Current Conditions	**424.8**	**N/A**	**424.8**	**N/A**
High Recharge, 3 Wells	422.2	2.6	420.2	4.6
High Recharge, 1 Well	424.8	ND	424.3	0.5
Low Recharge, Current Conditions	**121.2**	**N/A**	**121.2**	**N/A**
Low Recharge, 3 Wells	121.2	ND	118.9	2.3

Notes:
N/A= Not Applicable; there is no reduction in outflow for the calibrated model of current conditions
ND = Not detectable; no change from existing conditions was measured by the model

The estimated reduction of outflow of 2.3 to 4.6 AFY is less than 2 percent of current outflow (121 AFY) for the low-recharge scenario and approximately 1 percent of the high-recharge scenario (425 AFY). The potential reduction in outflow from the valley over 30 years of water use is not measurable relative to uncertainty in the model and existing variability.

2.2.3 Assumptions and Potential Limitations of Numerical Model

Model assumptions and a brief discussion of the limitations for each assumption are presented in Table 2.2-4.

Table 2.2-4: Numerical Model Assumptions and Limitations

Model Assumption	Limitation
The model domain includes the Soda Mountain Valley and does not extend to Soda Lake	Impacts to MC Spring at Zzyzx cannot be directly measured because MC Spring is not included in the model domain. Instead the model evaluates if drawdown is significant at the edges of the valley.
A no-flow boundary was assigned to the Soda Mountains east of the project area	The model does not include any flow through the Soda Mountains. Geologic maps indicate the mountains are composed of crystalline bedrock; no major faults are known to exist there, and hydraulic conductivity is likely to be extremely low.
Recharge is assumed to be 3 to 10 percent of rainfall	The recharge and hydraulic conductivity in the valley may not be reflected in the model range.
The storage coefficient is 0.1 in all scenarios	The model may not reflect the actual volume of water in storage. However the storage coefficient used is at the conservative (low) end of the range of typical values.
The aquifer is assumed to be unconfined and homogeneous	Variability in the hydraulic conductivity is not reflected in the model. However, a large range of values thought to encompass a reasonable range of values (based on borehole and geophysical data) was used.

The numerical model was constructed using geophysical data collected in the valley. No groundwater wells have been constructed within the Soda Mountain Valley and therefore model values for hydraulic conductivity, storage coefficient, depth to groundwater, and thickness of saturated alluvium have not yet been confirmed by direct field measurement. A range of conductivity values was used in the model to account for the expected range of recharge in the valley aquifer. USGS commented that the low-end recharge and conductivity values are too high for the Soda Mountain area based on recharge rates from the Death Valley regional flow system (Hevesi et al. 2003).

3 ANALYTICAL MODEL SENSITIVITY ANALYSIS

3.1 METHODOLOGY

A sensitivity analysis was conducted using the Theis method (Theis 1935) to test the sensitivity of the predicted outcome at MC Spring to variations in hydraulic conductivity. The Theis equation is a two-dimensional model of groundwater flow to a point source in an infinite, homogeneous aquifer. It is used in hydrogeology to predict groundwater level (unconfined aquifer) or hydraulic head (confined aquifer) declines at distances from a pumping well.

The Theis equation was not adjusted for the presence of lower-permeability bedrock in the mountains east of the Soda Mountain Valley. The model therefore provides a conservative estimate of groundwater declines on the east side of the Soda Mountains by assuming that the geologic unit within the Soda Mountains is as permeable as the basin fill in the Soda Mountain Valley, and that groundwater declines will radiate outward at the same rate within the mountain bedrock as within the basin fill.[1] This is an extremely conservative assumption because the Soda Mountains are composed of granitic rocks that are impermeable except for limited fractures.

Hydraulic conductivity and recharge values used in the sensitivity analysis are presented in Table 3.1-1. The low-end value represents a recharge rate of 0.6 percent of rainfall and the high-end value represents a recharge rate of 50 percent of rainfall. The low-end value of 0.6 percent is identical to the low-end value for recharge that was suggested by USGS and is based on a value for the hydrologically similar Valjean Valley. The high-end value is about two orders of magnitude (83 times) higher than the low-end value. This wide range of values allows for an assessment of whether the model outcome is affected by vastly different values of hydraulic conductivity.

The proposed wells would be located in a valley that is underlain by an alluvial aquifer. Alluvium covers an area of approximately 12,632 acres within the valley. The storage coefficient is assumed to be 0.1, identical to that used for the numerical model, and a reasonable and

[1] The Theis method also provides a conservative assessment of drawdown in the Town of Baker. Baker is farther from the project area than MC Spring and impacts are predicted to be even less at a farther distance from the wells.

Table 3.1-1: Recharge and Conductivity Values Used in Sensitivity Analysis		
Parameter Value Set	**Hydraulic Conductivity (feet/day)**	**Groundwater Recharge (inches/year)**
Original Low-End	0.86	0.12
New Low-End	0.17	0.024
Original High-End	3.2	0.4
New High-End	16	2

conservative value to use for unconfined aquifers, which typically have storage coefficients between 0.1 and 0.3 (Lohman 1972).

Total water demand used in the model over the maximum 3-year construction period was estimated to be approximately 576 acre-feet (AF) (192 AFY over 3 years). Total water demand over the 30-year operational period was estimated to be approximately 990 AF (33 AFY over 30 years).

3.2 RESULTS

The results of the sensitivity analysis are presented in Table 3.2-1. Detailed calculations are presented in Appendix A. The maximum estimated drawdown at MC Spring is 0.061 feet under the high-end scenario. The maximum estimated drawdown at MC Spring is 0.0015 feet under the low-end scenario, and would be at the limit of detection. The impact at MC Spring decreases in proportion to the reduction in recharge and conductivity. If recharge and conductivity in the Soda Mountains were less than the low-end values used in this sensitivity analysis, the potential for impact at MC Spring would be even less.

Table 3.2-1: Sensitivity Analysis Results				
Hydraulic Conductivity Value (ft/day)		**Predicted Drawdown at MC Spring (ft) after 3 Years of Construction**	**Predicted Drawdown at MC-Spring (ft) after 30 Years of Operation**	**Total Predicted Drawdown at MC Spring (ft)**
Original Low End	0.86	<0.00025	<0.000044	<0.00029
New Low End	0.17	<<0.0013	<<0.00022	<<0.0015
Original High End	3.2	<0.000068	0.0037	0.0037
New High End	16	<0.000043	0.061	0.061
	Range	**<0.000043 to <<0.0013**	**<<0.00022 to 0.061**	**<<0.0015 to 0.061**

Notes:

The well function (W(u)) for the Theis equation was approximated using published tables for values of *u* (dimensionless time parameter). Where there was no exact value of *u*, < indicates that the value is lower than the value *u* and << indicates that the value is much lower than the nearest value of *u* available. See Appendix A for details.

3.3 SUMMARY

The results of the sensitivity analysis indicate that the potential impacts at MC Spring are not sensitive to variations in hydraulic conductivity and recharge. The project is not likely to affect MC Spring given any range of values of hydraulic conductivity and recharge because (1) there is approximately 4.5 miles between the nearest proposed project well and MC Spring, (2) the duration of construction, during which water use will be high, is only 3 years (maximum), and (3) the proposed volume of water to be used during the 30-year operational period (33 AFY) is small relative to the volume of water in storage and the distance to MC Spring.

The model results are very conservative because the model approach assumed that the bedrock separating the Soda Mountain Valley from MC Spring was as permeable as the basin fill. The predicted reduction in groundwater flow and groundwater levels at MC Spring were minimal under all modeled scenarios and demonstrate that the project will not affect the Mohave tui chub because the small potential reduction in water surface elevation (conservatively predicted at a maximum of 0.061 feet, which is less than 1/10 of 1 foot) will not adversely impact Mohave tui chub habitat suitability.

The sensitivity analysis results demonstrate that the proposed groundwater well test results will not change the analysis of impacts at MC Spring. The information provided in this report and in previous modeling reports provide evidence of the limited potential for impact at MC Spring.

SMS has also developed a Groundwater Monitoring and Mitigation Plan that includes the following measures to ensure impacts to MC Spring would not occur as a result of project groundwater withdrawal:

- **Groundwater monitoring within Soda Mountain Valley:** SMS will implement a groundwater monitoring program within the Soda Mountain Valley that will serve as an early warning system. If drawdown at the monitoring wells exceeds predicted values by 20 percent or more, the groundwater model will need to be recalibrated. If the recalibrated model predicts that outflow from the valley would decrease by more than 20 percent from existing conditions, SMS will need to curtail pumping to a safe extraction rate.
- **Groundwater monitoring at MC Spring:** Implementation of a groundwater monitoring program at MC Spring would allow for identification of drawdown effects at the spring. The monitoring program would involve collection of background water level data at the spring to provide information on static, non-pumping conditions. Background data would also provide information on the magnitude of water level variations that occur in the spring under normal conditions. After pumping is initiated the spring would continue to be monitored for changes in water levels. Water level data would be regularly analyzed by a qualified professional hydrologist or hydrogeologist to identify if project groundwater pumping is adversely affecting the spring.
- **Groundwater extraction activities assessment and revision:** The groundwater extraction activities being performed at the project site would be evaluated and possibly revised to minimize effects to the spring if the action thresholds at monitoring wells in

the valley and at the spring are triggered. This may involve discontinuation of or reduced use of wells that may have an effect on spring water levels (i.e., those closer to the eastern project boundary).

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Appendix A: Drawdown Calculations

Objective: Calculate potential drawdown at the Desert Studies Center due to pumping for the proposed Soda Mountain Solar project, assuming there are no hydraulic barriers from the Soda Mountains that form the eastern flank of Soda Mountain Valley.

Approach: Use Theis solution (Theis 1935) to calculate drawdown over time and distance, with assumption of uniform hydraulic conductivity and infinite aquifer (no hydraulic boundaries).

Drawdown ($h_o - h$) can be calculated using the Theis Equation:

$$h_o - h = \frac{Q}{4\pi T} W(u)$$

where h_o is the head at time t=0, h is the head at time t, Q is the pumping rate, and T is the transmissivity. The transmissivity is calculated using the following approximation that assumes uniform aquifer thickness and uniform horizontal conductivity:

$$T = Kb$$

where K is the hydraulic conductivity and b is the aquifer saturated thickness. The well function $W(u)$ can be approximated using published tables of values for values of u, which are calculated according to the following equation:

$$u = \frac{r^2 S}{4Tt}$$

where r is the distance to the closest well and S is the storage coefficient.

S = 0.1 (TRC 2013; typical value)

r = 4.5 miles (closest distance from production well to Desert Studies Center)

b = 100 ft (approximate at well location, based on geophysical measurements)

Q_1 = 192 AFY for t = 3 yrs

Q_2 = 33 AFY for t = 30 yrs

Calculations were performed using two different transmissivities, reflecting the upper and lower estimates for the hydraulic conductivity:

K_1 = 3.2 ft/d

K_2 = 0.86 ft/d

High-end K Case: Let K_1 = 3.2 ft/d

$$T_1 = K_1 b = (3.2\,\text{ft/d})(100\text{ ft}) = 320\,\text{ft}^2/\text{d}$$

Q_1 = 192 AFY = 22,914 ft^3/d for t_1 = 3 yrs

$$u = \frac{r^2 S}{4T_1 t_1} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(320\,\text{ft}^2/\text{d})(3\text{yrs})(365\text{d/yr})} = 40.3$$

$$W(u) < 0.000012 \text{ (Table 8.1, Freeze \& Cherry, 1979, p318)}$$

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{22{,}914\,\text{ft}^3/\text{d}}{(4)(\pi)(320\,\text{ft}^2/\text{d})} * (< 0.000012)$$

$$h_o - h < 0.000068\text{ ft}$$

Q_2 = 33 AFY = 3,938 ft^3/d for t_2 = 30 yrs

$$u = \frac{r^2 S}{4T_2 t_2} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(320\,\text{ft}^2/\text{d})(30\text{yrs})(365\text{d/yr})} = 4.03$$

$$W(u) = 0.0038 \text{ (Table 8.1, Freeze \& Cherry, 1979, p318)}$$

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{3{,}938\,\text{ft}^3/\text{d}}{(4)(\pi)(320\,\text{ft}^2/\text{d})} * (0.0038)$$

$$h_o - h = 0.0037\text{ ft}$$

Total drawdown = drawdown after t_1 = 3 yrs + drawdown after t_2 = 30 years

= <0.000068 ft + 0.0037 ft

Total possible drawdown = 0.0037 ft

Low-end K Case: Let K_2 = 0.86 ft/d

$$T_2 = K_2 b = (0.86\,\text{ft/d})(100\text{ ft}) = 86\,\text{ft}^2/\text{d}$$

Q_1 = 192 AFY = 22,914 ft^3/d for t_1 = 3 yrs

$$u = \frac{r^2 S}{4T_2 t_1} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(86\,\text{ft}^2/\text{d})(3\text{yrs})(365\text{d/yr})} = 150$$

$W(u) < 0.000012$ (Table 8.1, Freeze & Cherry, 1979, p 318)

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{22{,}914\,\text{ft}^3/\text{d}}{(4)(\pi)(86\,\text{ft}^2/\text{d})} * (< 0.000012)$$

$$h_o - h < 0.00025\text{ ft}$$

Q_2 = 33 AFY = 3,938 ft^3/d for t_2 = 30 yrs

$$u = \frac{r^2 S}{4T_2 t_2} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(86\,\text{ft}^2/\text{d})(30\text{yrs})(365\text{d/yr})} = 14.98$$

$W(u) < 0.000012$ (Table 8.1, Freeze & Cherry, 1979, p318)

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{3{,}938\,\text{ft}^3/\text{d}}{(4)(\pi)(86\,\text{ft}^2/\text{d})} * (0.0038)$$

$$h_o - h < 0.000044\text{ ft}$$

Total drawdown = drawdown after t_1 = 3 yrs + drawdown after t_2 = 30 years

= <0.00025 ft + <0.000044 ft

Total possible drawdown < 0.00029 ft

Sensitivity Testing - Extreme Ends of K Range Analysis

Assume for the Highest-end Case K = 5 times the High-end Case K, and for the Lowest-end Case, K = 1/5 of the Low-end K value.

Highest-end K: Let K = 5 x 3.2 ft/d = 16 ft/d

$$T_2 = K_2 b = (16 \text{ ft/d})(100 \text{ ft}) = 1600 \text{ ft}^2/\text{d}$$

Q_1 = 192 AFY = 22,914 ft^3/d for t_1 = 3 yrs

$$u = \frac{r^2 S}{4T_2 t_1} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(1600\text{ ft}^2/\text{d})(3\text{yrs})(365\text{d/yr})} = 8.05$$

$$W(u) = 0.000038 \text{ (Table 8.1, Freeze \& Cherry, 1979, p 318)}$$

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{22{,}914 \text{ ft}^3/\text{d}}{(4)(\pi)(1600\text{ ft}^2/\text{d})} * (0.000038)$$

$$h_o - h = 0.000043 \text{ ft}$$

Q_2 = 33 AFY = 3,938 ft^3/d for t_2 = 30 yrs

$$u = \frac{r^2 S}{4T_2 t_2} = \frac{[(4.5\text{miles})(5280\text{ft/mile})]^2 * 0.10}{(4)(1600\text{ ft}^2/\text{d})(30\text{yrs})(365\text{d/yr})} = 0.81$$

$$W(u) < 0.31 \text{ (Table 8.1, Freeze \& Cherry, 1979, p318)}$$

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{3{,}938 \text{ ft}^3/\text{d}}{(4)(\pi)(1600\text{ ft}^2/\text{d})} * (0.31)$$

$$h_o - h = 0.061 \text{ ft}$$

Total drawdown = drawdown after t_1 = 3 yrs + drawdown after t_2 = 30 years

= <0.000043 ft + <0.061 ft

Total possible drawdown < 0.061 ft

Lowest-end K Case: Let K_4 = 0.17 ft/d

$$T_2 = K_2 b = (0.17\ \mathrm{ft/d})(100\ \mathrm{ft}) = 17\ \mathrm{ft}^2/\mathrm{d}$$

Q_1 = 192 AFY = 22,914 ft^3/d for t_1 = 3 yrs

$$u = \frac{r^2 S}{4T_2 t_1} = \frac{[(4.5\mathrm{miles})(5280\mathrm{ft/mile})]^2 * 0.10}{(4)(17\ \mathrm{ft}^2/\mathrm{d})(3\mathrm{yrs})(365\mathrm{d/yr})} = 758$$

$W(u) \ll 0.000012$ (Table 8.1, Freeze & Cherry, 1979, p 318)

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{22{,}914\ \mathrm{ft}^3/\mathrm{d}}{(4)(\pi)(17\ \mathrm{ft}^2/\mathrm{d})} * (\ll 0.000012)$$

$$h_o - h \ll 0.0013\ \mathrm{ft}$$

Q_2 = 33 AFY = 3,938 ft^3/d for t_2 = 30 yrs

$$u = \frac{r^2 S}{4T_2 t_2} = \frac{[(4.5\mathrm{miles})(5280\mathrm{ft/mile})]^2 * 0.10}{(4)(17\ \mathrm{ft}^2/\mathrm{d})(30\mathrm{yrs})(365\mathrm{d/yr})} = 75.8$$

$W(u) \ll 0.000012$ (Table 8.1, Freeze & Cherry, 1979, p318)

$$h_o - h = \frac{Q}{4\pi T} W(u) = \frac{3{,}938\ \mathrm{ft}^3/\mathrm{d}}{(4)(\pi)(17\ \mathrm{ft}^2/\mathrm{d})} * (\ll 0.000012)$$

$$h_o - h \ll 0.00022\ \mathrm{ft}$$

Total drawdown = drawdown after t_1 = 3 yrs + drawdown after t_2 = 30 years

= <<0.0013 ft + <<0.00022 ft

Total possible drawdown << 0.0015 ft

Discussion

The conceptual model for the site is that the Soda Mountains, which form a crystalline intrusive bedrock mass at the eastern wall of the Soda Mountain Valley, serve as a hydraulic barrier to flow of groundwater. Some have proposed that the mountains may be fractured such that pumping effects could be transmitted outside the valley and affect water levels at the DSC. While this contention seems highly unlikely given the low permeability nature of crystalline bedrock compared to that of the sand aquifer in the Soda Mountain Valley, it can be tested readily by assuming the mountains had the same permeability as the sand and gravel aquifer, as if the sand aquifer extended all the way to the DSC and beyond.

The Theis equation can be applied to evaluate the drawdown in a uniform aquifer of infinite extent. It was applied here using projected pumping rates during the life of the project, and drawdown over time and distance was calculated.

At the reasonable upper end of hydraulic conductivity estimates for the aquifer, 3.2 ft/d, the drawdown, calculated based on the assumption of an infinite aquifer with uniform properties, would be approximately 0.004 ft at the distance of 4.5 miles to the DSC after 33 years of pumping. At the lower end of the K estimate (0.86 ft/d), the drawdown at the DSC after 33 years of pumping would be less than 0.0003 ft.

Sensitivity testing was conducted by extending the range of K values tested, with five times lower and five times higher estimates of K. The sensitivity testing showed that even for K values that were five times higher and five times lower than what has been selected as a reasonable range, the resulting drawdown calculations indicate that the drawdown at the DSC would be 0.06 feet or less for all K values, over the life of the project.

Conclusion:

The results indicate that even if the mountains that form the eastern wall of the valley did not exist, and the aquifer extended without any hydraulic barriers directly to the DSC, the drawdown that would result from pumping over the life of the project would not be reliably measurable (0.06 feet or less) at the DSC.