3.2 Master Response on Groundwater Modeling

3.2.1 Introduction

Overview

This master response addresses comments raised on the modeling used to evaluate the Project. Commenters requested clarification as to which models were used for which purpose. Commenters expressed concerns regarding the ability and adequacy of the models to provide the desired information, the appropriateness of the input parameters used for the models, and the possibility that the recharge model might overestimate the recharge.

This master response is organized by the following subtopics:

- 3.2.2 List and Purposes of the Models
- 3.2.3 Watershed Soil Moisture Budget Model
- 3.2.4 Cadiz Groundwater Model
- 3.2.5 Hypothetical Springs Hydraulic Connectivity Model

3.2.2 List and Purposes of the Models

Summary of Issues Raised by Commenters

Commenters asked which model was used for which purpose. Note that responses to comments about specific models are provided in the subsequent sections of this Master Response.

R*esponses*

In support of the Project, water resources models were developed to simulate groundwater conditions, saline water movement, and subsidence in the groundwater basin within the Project area to quantify the potential impacts that could result from planned Project operations. Input to these models includes data, information, and observations from site-specific investigations, public records for precipitation, published literature data, and other modeling results. The models used are identified below, along with their primary purposes and who developed them. The subsequent sections provide additional information to address specific comments about specific models, the parameters used, and the model-projected results.

For the watershed soil moisture budget model, CH2M Hill used the distributed parameter watershed model INFIL3.0 to estimate the quantity of average annual recharge for the Fenner Watershed and Orange Blossom Wash area. The modeling software was released for public use by the U.S. Geological Survey (USGS) in 2008 and is the most current and robust model for this purpose. The model was used to estimate the volume of groundwater that is recharged in the Fenner Watershed and Orange Blossom Wash. The recharge estimate was then input into the regional three-dimensional groundwater flow models used to assess the quantity of groundwater that could be recovered through an array of pumping wells located in the Fenner Gap area. The recharge rate was estimated to be 32,000 AFY and was used in the flow and transport models listed next.

For the Cadiz Groundwater Model, Geoscience Support Services, Inc. (Geoscience) used the following models:

MODFLOW-2000/MT3DMS is the numerical groundwater flow and solute transport modeling software used to simulate flow in the groundwater basin. MODFLOW-2000 is a modular finite-difference flow model developed by the USGS to solve the groundwater flow equation. MODFLOW was originally developed in the early 1980's and has been modified and updated several times since then. It requires the development of a conceptual model of the groundwater basin to be simulated, including lateral and vertical extents of the basin, definition of top and bottom of aquifers and confining units, boundary conditions (such as no-flow rock, specified inflows and outflows, constant heads where groundwater levels are maintained as constant, or some combination of these), hydrological properties of the aquifers, and observations to calibrate against (e.g. measured groundwater levels). In other words, it takes into account a wealth of site specific data to describe groundwater conditions in the basin. MT3DMS is a modular three-dimensional multi-species solute[1] transport model for the simulation of advection (transfer of heat through the flow of a fluid), dispersion and chemical reactions of chemicals in groundwater systems developed for the U.S. Army Engineer Research and Development Center in 1999. This flow and transport model is the basis for the developing the variable density model listed next.

The SEAWAT-2000 Version 4 modeling software is a variable density flow and transport model that accounts for different fluid densities in different locations in aquifer systems. The presence of increasing salinity conditions towards the Dry Lakes requires accounting for the significantly different fluid densities to simulate flow and transport conditions. SEAWAT-2000 Version 4 was developed by combining MODFLOW and MT3DMS in a single program that solves the coupled flow and solute transport equations and was developed by the USGS in 2008. This model is specifically designed to estimate the response of groundwater levels and the freshwater/saline water interface to Project pumping.

The Subsidence and Aquifer-System Compaction (SUB) software package was incorporated into the SEAWAT-2000 model by Geoscience to simulate elastic and inelastic compaction of fine-grained materials within the aquifer. The SUB Package was developed by the USGS in 2003 to estimate the potential mount of subsidence that could occur in response to the extraction of groundwater from an aquifer.

In addition, while investigation determined that identified springs in the vicinity of the Project are not hydraulically connected to the alluvial and carbonate aquifers serving the Project, CH2M Hill, nonetheless developed a hypothetical model assuming a hydraulic connection. For the hypothetical model, the Cadiz Groundwater Model results were used as an indication of the potential magnitude of drawdown in the alluvial aquifer adjacent to the Bonanza Spring in the Clipper Mountains (the nearest identified spring). This drawdown was used as a boundary condition in a separate two-

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[1] Solutes are chemicals dissolved in and transported by groundwater.

dimensional groundwater flow model of the hypothetical regional groundwater table that is assumed to connect the alluvial aquifer groundwater with groundwater at the spring. A less than significant impact was detected, assuming a hypothetical hydraulic connection. See **Master Response 3.4** Springs for further details.

3.2.3 Watershed Soil Moisture Budget Model

Summary of Issues Raised by Commenters

Commenters express concerns and ask questions regarding how the model works and why the reliance on INFIL3.0, the input parameters used, what would happen if the model-predicted recharge estimate is too high, and why were areas west, south, and east of the Dry Lakes not included in the model domain.

Responses

How the Model Works

As discussed above, the Watershed Soil Moisture Budget model was used by CH2M Hill to estimate recharge in the Fenner and Orange Blossom Wash Watersheds. As described in the Draft EIR (Vol. 1, Section 4.9.1 Hydrology and Water Quality pp. 4.9-37 to 4.9-39, and Section 4.9.3 pp. 4.9-46 to 4.9-47), the soil-moisture budget model for the Project uses the most current and robust version of USGS modeling software, INFIL3.0, developed and released by the USGS in 2008. The INFIL3.0 software, not available for use in earlier recharge studies, computes daily, monthly, and annual average water-balance components for multi-year simulations. The model is described in detail in Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sub-Appendix A, Cadiz Groundwater Conservation and Storage Project, by CH2M Hill, July 2010.

The USGS computer program INFIL3.0 is a grid-based, distributed–parameter, deterministic water-balance watershed model used to estimate areal and temporal net infiltration below the vegetation root zone. The model is based on an earlier version of INFIL code that was developed by the USGS in cooperation with the Department of Energy to estimate net infiltration and groundwater recharge at the Yucca Mountain high-level nuclear-waste repository site in Nevada. Net infiltration is the downward movement of water that escapes below the vegetation root zone, is no longer affected by evapotranspiration, and is then capable of percolating to and recharging the groundwater system. Net infiltration may originate as rainfall, snow melt, and/or surface water runon (runoff and streamflow).

INFIL3.0 computes the daily water balance in the soil zone. For each day, the model computes sources of water that can infiltrate into the soil, such as precipitation, snow melt, or surface runon for each grid block in a watershed (for example, 500 x 500 meters over the 1,100 square miles of watershed in the Fenner Watershed). The rate of infiltration depends on the soil permeability. If the soil permeability is lower than the rainfall rate, then some of the precipitation will infiltrate at the permeability rate, while the remaining precipitation will run off the grid block to the next downstream grid block where it may infiltrate there or further downstream. If the precipitation quantity is sufficient to fill the available pore space of the soil zone beyond the rooting depth of local vegetation (and there may be residual soil moisture from the previous precipitation event), then the soil moisture will spill beyond the root depth and recharge the underlying groundwater. On other days, evaporation (where no vegetation exists) and evapotranspiration (where vegetation exists) will occur over the depth of the vegetation roots to remove soil moisture until the moisture supply is exhausted. INFIL3.0 computes a daily accounting of precipitation and soil moisture and tracks how much of this precipitation runs off, how much moisture infiltrates below the root depth to become recharge, how much is stored in the vegetation root zone, and how much is evaporated or evapotranspired. These daily computations were made using INFIL3.0 for the period of 1958 through 2007 to estimate the long-term average recharge rate over this period for the Fenner and Orange Blossom Wash Watersheds.

The model provides a computer simulation that describes how and in what quantity the infiltrating water flows through the soil and rock and enters the groundwater system. The modeling results indicate that most of the water entering the alluvial aquifer system within the Fenner Watershed originates from seepage through the hard rock foundations of the surrounding mountain ranges. Precipitation in the higher elevations of the mountain ranges percolates into the ground at the surface and is used by flora, fauna, and springs in the mountains. After wildlife, vegetation, and springs have taken what they can, the remaining groundwater continues to seep into the rocks through cracks and fissures and then percolates into the alluvial soils deep below ground surface.

The mountain ranges surrounding the Fenner Watershed experience more precipitation than other ranges in the Mojave Desert (as discussed in **Master Response 3.1** Groundwater Recharge and Evaporation) and, according to model results, it is this precipitation in the mountain ranges that predominantly feeds the groundwater aquifer that flows through the Fenner Gap. The model results indicate precipitation and percolation in the alluvial valleys constitute a relatively smaller volume of recharge to the aquifer system.

The Parameters Used

The details of the data used in the INFIL3.0 soil moisture budget model are provided in the Draft EIR Vol. 1, Section 4.9.1 Hydrology and Water Quality, pp. 4.9-37 to 4.9-39 and Section 4.9.3 pp. 4.9-46 to 4.9-47 and Draft EIR Vol. 4, Appendix H Hydrology Reports. The following list summarizes the actual data collected and used in the INFIL3.0 modeling effort distinguishing this new analysis from older, less substantiated recharge estimations for the Fenner and Orange Blossom Wash Watersheds:

- Topography was obtained from the National Elevation Dataset (NED), represented by a digital elevation model (DEM) and projected to Universe Transverse of Mercator (UTM) Zone 11 projection and to units of feet in elevation.
- Climate parameters, such as monthly atmospheric conditions were obtained from other USGS studies in the region.

- Daily precipitation and air temperature data were obtained from the National Oceanic and Atmospheric Administration (NOAA), the Climate Prediction Center, and San Bernardino County (which has six data stations with a range of date values).
- Soil parameters were obtained through the State Soil Geographic (STATSGO) database (2009).
- Hydrogeologic parameters were based on aquifer tests conducted in three wells installed in Fenner Gap as a part of this investigation to augment the previous aquifer tests conducted for the earlier EIS/EIR. In addition, recent geologic mapping by the USGS for the Amboy 30x60 Minute Quadrangle (2006) and by the State of California (1964) was used for the far northern portion of the study area, and used estimated values of hydrogeologic properties of rock types given in USGS reports by Bedinger (1989) and Belcher et. al., (2002), as well as data from Geoscience (1999).
- Vegetation distribution and coverage was obtained from the WESTVEG GAP database. Rooting depths and density were obtained from USGS reports for the vegetation types found in the study area.

The model domain considered the Watersheds of the Fenner Valley and Orange Blossom Wash because these are the areas from which the pumping wells would extract groundwater. The areas to the west, south, and east of the Dry Lakes were not included because as the topographic low points of the area, the Dry Lakes are a terminal boundary condition for groundwater flow, that is, groundwater from the areas west, south, and east of the Dry Lakes cannot flow past the Dry Lakes to the wellfield. Please also see **Master Response 3.1** Groundwater Water Recharge, specifically, Subsection 3.1.2. Therefore, flows from the west, south and east would not affect the groundwater flow and gradient north of the Dry Lakes and would not affect the movement of the saline/freshwater interface. While groundwater levels west, south, and east of the Dry Lakes are impacted by local recharge in these areas, the amount of recharge is not significant. As noted in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sub-Appendix A Cadiz Groundwater Conservation and Storage Project, Figure 2-6, PRISM isohyets establish the low levels of precipitation in the southern Bristol and Cadiz Watershed areas, which is typically below 4 inches per year over most of the area. Given the large range of recharge scenarios considered (5,000 AFY to 32,000 AFY), potential recharge from the west, south, and east of the Dry Lakes would not materially change the groundwater pumping analysis or saline/freshwater interface.

One commenter misinterpreted the discussion of the hydraulic conductivity values for the Edward Aquifer in Texas, erroneously assuming that the hydraulic conductivity values of the Edwards Aquifer were used in the groundwater flow model results. As discussed in the Draft EIR (Vol. 4 Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sub-Appendix A), the hydraulic conductivity results for the Edwards Aquifer were only analogized to the results of the Fenner Gap carbonates. This particular aquifer was chosen for purposes of analogy because, like the Fenner Gap aquifer, it is also a karstic (limestone carbonate) aquifer and not very many carbonate aquifers haven been developed in California. The reasons for choosing this particular aquifer are that: 1) the Edwards Aquifer has been extensively studied and modeled and, 2) it provides an example of high conductivity known to occur in karstic carbonate aquifers. Although it is not the only aquifer that could have been referenced, the Edwards Aquifer references provide a particularly comprehensive overview, discussion, and history of the hydrogeology and modeling of karstic aquifers. The carbonate units in the Fenner Gap are not necessarily as permeable or productive as those in the Edwards Aquifer, but the Edwards Aquifer does serve as a representative analog for the carbonates in the Fenner Gap. The comparison indicates that the hydraulic conductivity values simulated in the Fenner Gap model are reasonable estimates.

Another commenter asked why the results were not correlated with carbonate units in the closer Death Valley. The carbonate units in Death Valley do not generally function as extensive aquifers with significant production of freshwater and are therefore unrepresentative of the characteristic of the carbonate units in the Fenner Watershed (Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sub-Appendix A, Cadiz Groundwater Conservation and Storage Project, CH2M Hill, July 2010).

The Modeled Estimate of Recharge and Field Verification

The INFIL3.0 model results revealed a long-term average annual recharge of 32,000 AFY, which was used to define the Project Scenario recharge condition for the impacts assessments in the Draft EIR.

As discussed in **Master Response 3.1** Groundwater Recharge and Evaporation, the estimated volume of recharge was further supported by setting up instrumentation on Bristol and Cadiz Dry Lakes to estimate the evaporation discharge from the groundwater basin. Using the evaporation foot print of these Dry Lakes, the annual evaporation is estimated conservatively to be 31,590 AFY for Bristol and Cadiz Dry Lakes combined. This value further supports the INFIL3.0 model estimate of an annual average recharge of 32,000 AFY.

Both the soil moisture budget model and evaporation study of the Dry Lakes (above) were peer reviewed by the Groundwater Stewardship Committee (GSC). For more on the peer review process and the GSC, see Section 3.2.4 Peer Review Process, below.

3.2.4 Cadiz Groundwater Model

Summary of Issues Raised by Commenters

Commenters express concerns and ask questions regarding how the model works, the model domain and boundaries, the parameters used, the model calibration and sensitivity analyses, the predictive scenarios, and the peer review process. Commenters also ask why models were not run for each wellfield arrangement and all three recharge scenarios, why areas west, south, and east of the Dry Lakes were not included in the model domain, why model parameters differed from those used in previous estimates, and why the extinction depth is variable in some cases and 15 feet in others.

Responses

How the Model Works

As discussed above, the Cadiz Groundwater Model was developed by Geoscience and combines several software packages to develop a model that simulates the flow of groundwater through the subsurface geologic materials in the groundwater basin, the transport of solutes within that groundwater, the variations in flow and transport due to solute density variations, and potential aquifer responses (impacts) to changes in subsurface conditions. The models, input parameters, calibration techniques, and results of several scenarios are described in detail in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sections 5 and 6. An overview of how the model works is provided below. The subsequent sections provide additional information to address specific comments.

To develop a three-dimensional groundwater flow model of a groundwater subarea of a basin, the areal extent and depth to be modeled are selected and boundary conditions assigned based on site-specific investigations. Once defined, this three-dimensional “domain” is subdivided into layers to account for changes in geologic materials with depth, all based on the subsurface geology identified from field mapping and exploratory boring logs. The areal extent of the layers is divided into a grid pattern, resulting in model cells shown in three-dimensional space. Each cell is assigned aquifer parameters from site-specific field data, if available, or published literature values. Once the input parameters of the existing conditions have been assigned to each cell, the model is “run.” The results provide a simulation of the patterns of groundwater flow and solute transport. Details of the model setup are in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 5.

Before using the model, the model must be “calibrated” to account for the natural variations of the aquifer parameters, including hydraulic conductivity. This is because geologic units are typically not homogenous across an entire model domain; the subsurface conditions vary from place to place and with depth. To account for these variations, the model is “calibrated” by comparing model-simulated groundwater levels to field-measured values. Input parameters are adjusted using industry standard techniques and the model re-run until the model-calculated water level is consistent with the observed existing field conditions. The calibration process can require up to thousands of runs to adjust the aquifer parameters so that the simulated groundwater levels are representative of the measured levels. Details of the model calibration are in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 6.

The model is then ready to evaluate the response of the aquifer to the future conditions of the proposed Project. Input parameters, such as recharge to the aquifer, pumping rate and time periods, and the arrangement of the pumping wellfield, can be varied to evaluate the model-predicted impacts that would result from those changes. In the case of the proposed project, the model was used to evaluate groundwater drawdown, the migration of the freshwater/saline water interface between the Dry Lakes and the wellfield, and the potential for land subsidence using three recharge scenarios and two wellfield arrangements. Details of the model scenarios are in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 7.

The following sections provide additional information to address specific comments on the modeling.

Model Domain and Boundaries

The model domain and boundary conditions are described in detail in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sections 5.3 and 5.4. The Cadiz Groundwater Model divides the lateral modeled area into a north-south and east-west grid system with each model cell measuring about 500 by 500 feet. The depth is divided into the following six layers:

- Layer 1 - Upper Alluvium
- Layer 2 - Alluvium beneath the Upper Alluvium to a depth of approximately 1,200 feet[2]
- Layer 3 - Alluvium beneath a depth of 1,200 feet
- Layer 4 - Fanglomerate, carbonate, lower Paleozoic sequence, and weathered granitic rocks
- Layer 5 - Carbonate, lower Paleozoic sequence and weathered granitic rocks
- Layer 6 - A detachment fault zone (approximately 200 feet thick) in the Fenner Gap area and weathered granitic rocks

The purpose of the three-dimensional grid system is to enable the model to use input parameters specific to the geologic materials within each of the individual model cells within each of those layers. This is the reason different values may be used for the same input parameter in different places within the grid domain. For example, the porosity of a sandy alluvial material would be different than that for a carbonate rock unit. Even within the same geologic unit, the aquifer parameters may spatially vary across that unit. For example, the degree of consolidation of an alluvial unit may vary depending on the distance from the source mountains from which the alluvium originated, and that change in consolidation would also change aquifer parameters such as porosity.

The area of the Cadiz Groundwater Model included the Fenner and Orange Blossom Wash Watersheds and the northern portion of the Bristol and Cadiz Valley area. The modeled area is further bounded by crystalline rocks, i.e., bedrock in mountainous areas where groundwater flow in these rocks is orders of magnitude less than in the alluvial aquifer such that the bedrock can be treated as a no-flow boundary for analysis purposes and groundwater flow from the bedrock can be treated as a recharge input term to the model, along the perimeter of the contact between the saturated alluvial aquifer and bedrock. The focus of the modeled area is from the Fenner and Orange Blossom Wash Watersheds, where groundwater

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[2] Geoscience selected 1,200 feet as the assumed base of the primary groundwater production zone based on screen intervals of existing wells.

is flowing towards the Fenner Gap area, to the proposed wellfield at Fenner Gap, and finally to the Dry Lakes where the groundwater is evaporating. The areas to the west, south, and east are not included in the modeled area because the Dry Lakes, as the topographic low points in the area, represent a terminal boundary condition beyond which groundwater originating from the Fenner and Orange Blossom Wash Watersheds cannot flow, but must instead evaporate and leave the aquifer system. This also means that groundwater from the areas west, south, and east of the Dry Lakes also cannot flow past the Dry Lakes to the wellfield (in other words, that groundwater will continue to flow to the Dry Lakes, unimpaired, during Project operations). Furthermore, the contribution of groundwater from the smaller west, south, and east area is minimal compared to the larger Fenner Valley and Orange Blossom Wash to the north and northeast. Details of the modeled area are in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sub-Appendix A.

The large area of recharge in the middle of Fenner Valley is a projection by the INFIL3.0 watershed modeling. The recharge in the middle of Fenner Valley is relatively small, representing only about 50 AFY. The recharge on either side of this area represents inflow from the surrounding bedrock areas into the alluvial aquifer as opposed to recharge directly on the surface of the alluvial aquifer from direct infiltration and streamflow runoff. Details of the modeled area are in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 7.

As discussed above, evaporation from the Dry Lakes is a boundary condition, which in an undisturbed condition, as is the case here, is the only outlet for groundwater discharge from the basin. As the groundwater flow system must be in equilibrium, i.e., groundwater recharge must equal groundwater discharge, evaporation has to be equal to recharge. The use of a few cells along Cadiz Dry Lake is a modeling choice to represent this boundary condition as opposed to expanding the model grid to cover the whole Dry Lake and beyond. The model simulation results would be the same under both model configurations because, regardless of how the boundary condition is established in the model, the model is calibrated to the observed water levels to ensure the model results simulate actual site conditions. Therefore, using the smaller number of grid cells saves model run time without affecting model results.

Input Parameters

The aquifer input parameters are described in detail in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Sections 5.5 and 5.6 and include the site lithology, elevations of the layers, effective porosity and storativity (volume of water an aquifer releases from or takes into storage), hydraulic conductivity, vertical leakance (vertical transmissive properties between layers), groundwater elevations, dispersivity (taking into account the dispersion of particles), elastic and inelastic storage coefficients, pre-consolidation stress, and recharge and discharge. As discussed above, the aquifer parameters are not necessarily homogenous across the areal extent of the layers, thus requiring the calibration step discussed in the next section.

Most of the aquifer parameters were acquired from the recent site-specific investigations including field mapping of the local geology and structure, the logging of subsurface geology during well installations, and pump tests conducted on wells, replacing many of the less accurate input parameters from previous estimates. The remaining aquifer parameters were derived from published literature values based on the character of the aquifer materials and adjusted during the model calibration.

The maximum extinction depth of 15 feet below the ground surface was used for the evapotranspiration estimates. The extinction depth is that depth below which no evapotranspiration would occur. Extinction depths of 10 to 15 feet are the typical values used in arid environments. An extinction depth of 15 feet was used by Danskin et al.[3] The Cadiz Groundwater Model uses 15 feet as the maximum extinction depth to ensure that the depth interval within which significant evaporation could be occurring is accounted for in the model. The extinction depth of 15 feet was also based on the results from steady state model calibration. Since the only discharge is evaporation from the Dry Lakes under predevelopment conditions (i.e., steady state model calibration conditions), the model-calculated evaporation should be 32,000 AFY, 16,000 AFY, and 5,000 AFY for a natural recharge of 32,000 AFY, 16,000 AFY, and 5,000 AFY, respectively.

As noted above and discussed below in the section on model calibration, certain parameters, such as evapotranspiration, required calibration of the values to obtain better matches to observed conditions. Several commenters expressed concerns regarding the variable evapotranspiration rates used in the model, such as the following:

- The Cadiz Groundwater Model has problems with either the estimated recharge value or the aquifer parameters (either in values or spatial representation) that results in the need for unrealistically high evapotranspiration rates to be required to calibrate the model.
- The evapotranspiration rate should remain unchanged between the recharge scenarios because playa soils would remain unchanged, climate factors would be unchanged, and assuming the groundwater levels would be above the extinction depth allowing evapotranspiration to take place.
- The evapotranspiration rates are approximately ten times that of Death Valley.

The Cadiz Groundwater Model uses the Evapotranspiration Package[4] to simulate the evaporation from the Bristol and Cadiz Dry Lakes. The model calculates the evaporation based on model-calculated groundwater levels. The maximum evaporation rate is used when the water level is at the land surface, since the water would be exposed to the atmosphere. No evaporation occurs when the water level is below the specified maximum extinction

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[3] Danskin, W.R., McPherson, K.R. and Woolfenden, L.R., 2006. Hydrology, *Description of Computer Models, and Evaluation of Selected Water-Management Alternatives in the San Bernardino Area, California,* USGS Open-file Report 2005-1278.

[4] Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, *MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process:* U.S. Geological Survey Open-File Report 00-92.

depth. In between these two extremes, the evaporation rate is assumed to be linear. The model-calculated evaporation from the Dry Lakes depends on the specified maximum evapotranspiration rate, extinction depth, and model-calculated water levels over the entire area of each Dry Lake. The Evapotranspiration Package used in the Cadiz groundwater model is for the purpose of providing a "sink" boundary condition to remove water from the model, consistent with the amount of natural recharge used for the model. Since the only discharge is evaporation from Dry Lakes under predevelopment conditions, the model-calculated evaporation should be 32,000 AFY, 16,000 AFY, and 5,000 AFY for a natural recharge of 32,000 AFY, 16,000 AFY, and 5,000 AFY, respectively. Therefore, maximum evapotranspiration rates were treated as a variable so that the model-calculated evaporation can match the natural recharge and the recharge scenarios. The use of higher evaporation rate at a few cells along Cadiz Dry Lake is simply a modeling choice to represent this boundary condition as opposed to expanding the model grid to cover the whole Dry Lake and beyond. The modeling results would be the same by using this technique or expanding the model boundary because the calibration of the model ensures that the simulation is consistent with observed water levels.

As discussed in **Master Response 3.1** Groundwater Recharge and Evaporation, the precipitation and evaporation patterns in local subregions in the Mojave Region are not interchangeable. The USGS shows that evaporation from playas is much more variable than implied by the various commenters. Laczniak, et. al (2001)[5], who are also referenced by many of those authors of the USGS report and DeMeo, et. al. (2003)[6] cited by the NPS, present a broader study of evaporation rates of playas in California and Nevada. They show evaporation rates ranging from 0.1 to 0.7 feet per year for bare soil playas and 0.7 to 1.8 feet per year for areas dominated by moist bare soils. As noted above, the aquifer modeling is based on recent site-specific data and robust current USGS modeling techniques.

Model Calibration and Sensitivity Analyses

The model calibration procedures are described in detail in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 6, which describes the industry standard "history matching" technique used to calibrate the model and the software PEST (Parameter ESTimation), an inverse modeling technique used to estimate groundwater model parameter values, such as hydraulic conductivity, where measurements of groundwater levels and stresses (such as pumping or recharge) are known. PEST calculates values of hydraulic conductivity that make the groundwater model "calibrate" to the measured values, typically requiring up to thousands of model simulation runs to find the best set of parameter values that minimizes the residuals (differences) in simulated and observed measurements (e.g., groundwater levels).

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[5] Laczniak, Randell J.; Smith, J. LaRue; Elliott, Peggy E.; DeMeo, Guy A.; Chatigny, Melissa A.; Roemer, Gaius J., 2001. *Ground-water discharge determined from estimates of evapotranspiration, Death Valley regional flow system, Nevada and California.* Water-Resources Investigations Report 2001-4195.

[6] DeMeo, Guy A., Randal J. Laczniak, Robert A. Boyd, J. LaRue Smith and Walter E. Nylund, 2003. *Estimated Groundwater Recharge by Evapotranspiration from Death Valley, California, 1997-2001.* USGS Water-Resources Investigation Report 03-4254.

The sensitivity of the model to hydraulic conductivity and maximum evapotranspiration rates was partly tested by reducing the estimated natural recharge of 32,000 AFY to 16,000 AFY and 5,000 AFY. Each calibration run produced a set of best-estimated hydraulic conductivity values and maximum evapotranspiration rates. In general, a greater amount of natural recharge requires a higher hydraulic conductivity value and maximum evapotranspiration rate.

Additional sensitivity analysis was performed by varying the input parameters of specific yield/storativity and vertical leakance to assess the relative change in model error. The sensitivity analysis indicates that the model is not sensitive to changes in specific yield/storativity or vertical leakance.

Some commenters expressed concern that the sensitivity analyses performed for the Project (Sensitivity Scenarios 1 and 2) do not represent the form of a sensitivity analysis that is standard practice for modeling exercises such as this and as described in ASTM[7] and other references. Sensitivity Scenarios 1 and 2 model conservative worst-case scenarios, where recharge over the 50-year Project period is less than anticipated. This approach is far more conservative than doing simple sensitivity analysis, which forces the model out of calibration (i.e., groundwater levels will not match observed groundwater levels in many cases where the calibrated parameter values are deviated from the calibrated values), so the changes in projected groundwater levels may be due more to changes in the model parameter values than due to the change in stresses (e.g., introduction of pumping).

One commenter expressed concern that more sensitive parameters such as hydraulic conductivity from individual parameter zones and the evapotranspiration rate used as calibrated parameters have not been sensitivity tested. Model sensitivity to hydraulic conductivity and evapotranspiration rate was accomplished, and in a more conservative fashion than typical sensitivity analyses, by reducing the estimated natural recharge of 32,000 AFY to 16,000 AFY and 5,000 AFY and adjusting the hydraulic conductivity to account for these lower recharge values. For these reduced natural recharge model runs, the hydraulic conductivity values need to be reduced in order to maintain the hydraulic gradient established from the observed water levels that show that the basin is in balance. Evapotranspiration rates need to be reduced so that the model-calculated evaporation can match the amount of recharge.

Model Predictive Scenarios

The model predictive scenarios are described in detail in the Draft EIR Vol. 4, Appendix H1 Cadiz Groundwater Modeling and Impact Analysis, Section 7 and describe three recharge scenarios and two wellfield configurations.

As discussed above, the INFIL3.0 model estimates that the average annual volume of recharge is 32,000 AFY (the Project Scenario), and have been verified by onsite field measurements (see **Master Response 3.1** Groundwater Recharge and Evaporation). To take a conservative modeling approach, the model was also run using recharge estimates reduced by half (16,000 AFY) and to

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[7] Anderson, Mary P. and William W. Woessner, *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*, Academic Press, San Diego, 1992.

as low as 5,000 AFY for Sensitivity Scenarios 1 and 2, respectively, in order to examine the potential impacts in the unlikely event that the recharge is less than estimated. Even under these significantly reduced recharge scenarios, no significant impacts were identified.

The model was also run for two different wellfield arrangements. Configuration A uses two high-capacity wells and 17 lower capacity wells, and Configuration B uses 34 lower capacity wells. The purpose was to assess which extraction arrangement provides better efficiency and effectiveness and minimize effects on saline water migration and land subsidence. It was found that Configuration A resulted in less freshwater/saline water migration and land subsidence.

The two wellfield configurations were also used to address the potential range in recharge rates and thus transmissivity variations of the aquifer. Wellfield Configuration A focuses pumping in the Fenner Gap, including the use of high capacity wells in the carbonate aquifer, in the case of 32,000 AFY of recharge (the Project Scenario). If, while installing the production wells, it is determined that the aquifer is less transmissive at the production well location than indicated by the aquifer pump tests conducted in the test wells in the Fenner Gap, the lateral distance between each pumping well will be increased as shown in Configuration B (i.e., Sensitivity Scenarios 1 and 2). Thus, the installation of the wellfield would take into account the findings in the field.

Three additional groundwater flow model runs were made including:

- Natural Recharge of 32,000 AFY with Wellfield Configuration B,
- Natural Recharge of 16,000 AFY with Wellfield Configuration A, and
- Natural Recharge of 5,000 AFY with Wellfield Configuration A.

The following table summarizes the predicted drawdown at the end of 50 years (i.e., the end of Project pumping) under each wellfield configuration and natural recharge conditions.[8]

	Wellfield Configuration A		**Wellfield Configuration B**	
Natural Recharge	**Drawdown at Wellfield [ft]**	**Drawdown at Bristol Dry Lake [ft]**	**Drawdown at Wellfield [ft]**	**Drawdown at Bristol Dry Lake [ft]**
32,000 AFY	70 – 80	10 – 30	60 – 70	10 – 40
16,000 AFY	170 – 180	10 – 50	120 – 130	10 – 60
5,000 AFY	380 – 390	0 – 70	260 – 270	0 – 80

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[8] GEOSCIENCE Support Services, Inc., Techmical Memorandum, Addendum to September 1, 2011 *Cadiz Groundwater Modeling and Impact Analysis,* Draft EIR Vol. 4, Appendix H5, page 3

As seen in this figure, under natural recharge of 5,000 AFY conditions, an additional 120 feet of drawdown would occur with wellfield configuration A as compared to wellfield configuration B. As can be seen in the above table, when assumed recharge rates are low, drawdowns increase for the centralized wellfield configuration A. The drawdowns occur in these low recharge scenarios in order to calibrate the model. In addition, the transmissive characteristics of the aquifer are re-calibrated to be very low. In other words, for low recharge rates the wellfield needs to be “spread out” and not centralized as in Wellfield Configuration A. Because of this, wellfield construction will be “Phased” and the wellfield configuration will be based on previous site specific findings. That is, a group of wells will be constructed initially pursuant to Configuration A, and monitoring through long-term pumping tests will determine whether to implement wellfield Configuration B. Accordingly, both configurations were analyzed in the Draft EIR.

Peer Review Process

The Cadiz Groundwater Model was peer reviewed by the Cadiz Groundwater Stewardship Committee (GSC). The GSC is a multi-disciplinary panel of earth science and water professionals assembled to provide advice and comment on the proposed Cadiz Valley Conservation, Recovery and Storage Project.

The peer review started with a kickoff meeting. The purpose of this meeting was to discuss the scope of work, data collection, modeling approaches, coordination of efforts, and schedule. During model development, construction, predictive scenarios, and documentation processes, all the electronic files and associated data were provided for review, testing, and evaluation. The process included the following components:

- Conceptual Model;
- Model areas, model grid, and layering;
- Layering criteria and designation;
- Model input parameters including recharge and discharge terms;
- Aquifer parameters and boundary conditions;
- Consistency of calibrated input parameters to conceptual models;
- Assumptions and limitations;
- Calibration periods and basis for selection (including stress period and time step length and criteria);
- Convergence criteria and closure;
- Calibration targets selection;
- Water budget components;
- Calibration results including hydrographs, scatter plots, and residuals by area and by time;
- Sensitivity analysis and results; and,
- Assumptions of model predictive scenarios and results.

Comments and suggestions were provided by the GSC through conference calls, face-to-face meetings, and exchange of electronic modeling files.

In addition, modeling technical memorandum titled “Cadiz Groundwater Conservation and Storage Project Phase 1 – Conservation Scenarios” prepared by Geoscience, dated August 17, 2011 was provided to the members of the GSC for review[9]. During the August 29, 2011 GSC conference call, Dr. Dennis Williams provided an overview of the August 17, 2011 technical memorandum that presents the modeling scenarios and potential impacts of the Project. Discussion was focused on recharge and recovery, modeling data sources, wellfield configuration, and sensitivity scenarios. Dr. Jack Sharp of the GSC requested additional model data for review, which included:

- The thickness, hydraulic conductivity, and specific storage or specific yield, as appropriate, for each layer of the model;
- The vertical compressibility of the layers and the facies within them;
- The isopach (thickness) map of compressible sediments;
- How recharge is distributed over the model;
- How evapotranspiration from the Dry Lakes is estimated;
- The sources for the above values – sources of data and values estimates and data/control points to clarify data measurements and inferences;
- The model boundary conditions;
- Cross sections showing the lateral extent of the layers;
- Permeability and anisotropy of the detachment fault zone (layer 6) and the faults that splay from it; and
- Consideration of flow in fractures at depths below layers 5 and 6.

As per the GSC’s request, Geoscience provided the comprehensive modeling report “Cadiz Groundwater Modeling and Impact Analysis,” prepared by Geoscience and dated September 1, 2011, to the GSC for review. The peer review process was completed after additional clarifications were provided during the September 28, 2011 and September 29, 2011 conference calls to address GSC members’ outstanding questions. A summary report of the GSC findings is included as an appendix to the Updated GMMMP (Final EIR Vol. 7, Appendix B1 Updated GMMMP, Sub-Appendix A Groundwater Stewardship Committee April 2012 Summary of Findings and Recommendations).

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[9] GEOSCIENCE Support Services, Inc., *Cadiz Groundwater Conservation and Storage Project Phase 1 – Conservation Scenarios,* August 2011.

3.2.5 Hypothetical Springs Hydraulic Connectivity Model

Summary of Issues Raised by Commenters

Commenters asked for additional details regarding the hypothetical model used for the spring connectivity analysis.

Response

The Cadiz Groundwater Model results were used as an indication of the potential magnitude of drawdown in the alluvial aquifer adjacent to the Bonanza Springs in the Clipper Mountains. This drawdown was used as a boundary condition in a separate two-dimensional groundwater flow model of a hypothetical regional groundwater table assumed to connect the alluvial aquifer groundwater with groundwater at the spring. The approach was to evaluate whether changes in water levels in the alluvial aquifer in the valley below the springs could hypothetically cause a change in the water levels at the springs.

The two-dimensional groundwater flow model of the bedrock unit revealed the following. Any change in the groundwater levels in the alluvium would be a fraction of any changes (drawdown) in groundwater levels upgradient at the location of springs and would only occur if the groundwater levels in the alluvium remained depressed for extensive periods of time. This is not likely because the volume of water stored in the localized aquifer materials at the springs is much smaller in volume than the water storage space and areal extent of the alluvial aquifer in the lower-elevation valley. Consequently, the fluctuations in precipitation recharge and resultant fluctuations in groundwater levels in the area of the springs are expected to dwarf any fluctuation that might result from changes in groundwater levels in the alluvial aquifer.