HYDROFOCUS INC.

Solutions for Land and Water Resources

September 23, 2016

Mr. Ray Heimstra
Orange County Coastkeeper
Costa Mesa, CA

Mr. Joe Geever
Residents for Responsible Desalination
Long Beach, CA

Subject: Huntington Beach Seawater Desalination Facility Groundwater Model Evaluation

Dear Mr. Heimstra and Mr. Geever,

Please find enclosed the subject report prepared by HydroFocus. We critically reviewed and analyzed the results from the groundwater-flow model developed by Geosyntec Consultants to help in the evaluation of impacts and feasibility of subsurface intakes for the proposed Huntington Beach Seawater Desalination Facility. We reviewed the model structure, verified model inputs and outputs, assessed groundwater flow patterns, and evaluated the sensitivity of model outputs to model inputs. We ascertained the source of groundwater flowing to the proposed slant wells and groundwater travel times.

Our sensitivity analysis to assess the effects of varying different model inputs on model results revealed that the model outputs were most affected by changes in the aquifer properties of the Talbert Aquifer and the overlying aquitard. Varying these properties produced large changes in model-estimated groundwater-level declines and inland flow to the production wells. These results indicate that more data is needed for these inputs to improve model certainty.

Several additional steps can be taken to improve the model and increase confidence in evaluating impacts of the project. We recommend: (1) aquifer tests to determine properties of the Talbert Aquifer, the overlying sediments, and the wetland sediments; (2) an assessment of the effects of the lateral model boundaries, (3) correction of inconsistencies in model construction, (4) calibration/verification using water level data, and (5) subsidence modeling to preliminarily evaluate the subsidence potential due to slant well pumping. The improved model can then be used to more effectively simulate potential impacts and project feasibility.

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Operation of the slant wells will affect the extent of seawater intrusion in the Talbert Aquifer; pumping will likely increase the gradient from inland areas toward the project wells which will enhance the movement of inland freshwater toward the coast and move the seawater/freshwater interface closer to the coastline.

Thank you for the opportunity to work on this project and be of service. Please contact us if you have any further questions.

Sincerely,

David Leighton
Senior Hydrologist

PROFESSIONAL GEOLOGIST
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Huntington Beach Seawater Desalination Facility
Groundwater Model Evaluation

HydroFocus, Inc., Davis, CA
September 23, 2016

Executive Summary

HydroFocus critically reviewed and analyzed outputs from the groundwater-flow model developed to evaluate the impacts and feasibility of subsurface intakes for the proposed Huntington Beach Seawater Desalination Facility in a coastal lowland area known as the Talbert Gap. The Talbert Gap is part of the Coastal Plain of Orange County Groundwater Basin and the primary water-bearing zone in the Talbert Gap is the Talbert Aquifer. The Orange County Water District operates the Talbert Seawater Intrusion Barrier at the northern edge of the Talbert Gap and a series of coastal marsh and wetland areas exist along the coast in the project area.

Geosyntec Consultants developed a groundwater-flow model to simulate the effects of pumping 127 million gallons per day (MGD) of groundwater from 40 slant wells located along the coast and screened in the Talbert Aquifer. HydroFocus reviewed model structure, ran the model to verify output and assess groundwater flow patterns, and evaluated model sensitivity. We used particle tracking to determine the source of groundwater flowing to the slant wells and evaluate groundwater travel times for various scenarios. We verified that the model geometry, boundary conditions, and aquifer properties generally agreed with information reported by Geosyntec Consultants with some exceptions. The cell dimensions were slightly different than reported and the ocean in model Layer 1 was not represented as constant head in all areas as was reported.

We conducted a model sensitivity analysis to assess the effects of varying model inputs on model results. Specifically, we evaluated the effect on simulated flow to the slant wells from inland groundwater and the wetlands and the average water-level decline due to varying model inputs for aquifer transmission properties (i.e. hydraulic conductivity), pumping rates, well location and length, and water levels at the seawater intrusion barrier . The model was most sensitive to changes in the aquifer properties of the Talbert Aquifer and the overlying sediments. Varying these properties produced large changes in model-estimated groundwater-level drawdowns and inland flow to the slant wells. These results indicate that more data is needed for these inputs to improve model certainty.

Pumping at lower rates than originally simulated will reduce impacts on the groundwater system. Operation of the slant wells will affect the extent of seawater intrusion in the Talbert Aquifer; pumping will likely increase the gradient from inland areas toward the project wells which will enhance the movement of inland freshwater toward the coast and move the seawater/freshwater interface closer to the coastline. This increase in seaward gradient along with capture of seawater by the slant wells will have the effect of reducing the inland migration of seawater.

We identified model limitations and uncertainty that affect the ability of the model to accurately predict impacts of project pumping. The model was not calibrated or verified using observed water level data. There is very limited information on the water transmitting and storage properties of the aquifers and aquitards in the Talbert Gap on which to base model inputs. Groundwater flow paths suggest that model results may be affected by the lateral boundaries of the model domain. The constant water levels specified for the seawater intrusion barrier assumes that the quantity of injection water will be available to maintain the water levels at the barrier regardless of the impact of the slant well pumping. Variable head cells representing parts of the ocean may result in an inaccurate estimation of the contribution of the ocean to the slant wells.

Several additional steps can be taken to improve the model and increase confidence in evaluating impacts of the project. We recommend (1) aquifer tests to determine properties of the Talbert Aquifer, the overlying sediments, and the wetland sediments; (2) an assessment of the effects of the lateral model boundaries, (3) correction of inconsistencies in model construction, (4) calibration/verification using water level data, and (5) incorporation of the US Geological Survey MODFLOW Subsidence Package to preliminarily evaluate the subsidence potential due to slant well pumping. The improved model can then be used to more effectively simulate potential impacts and project feasibility.

Huntington Beach Seawater Desalination Facility Groundwater Model Evaluation

HydroFocus, Inc., Davis, CA
September 23, 2016

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Introduction and Background

Geosyntec Consultants (Geosyntec) on behalf of Poseidon Resources (Poseidon) evaluated the feasibility of subsurface intake for the proposed Huntington Beach Seawater Desalination Facility (Desal Facility). Poseidon proposes to locate the Desal Facility site in a coastal lowland area known as the Talbert Gap.

Brief description of hydrogeology

The Talbert Gap is part of the Coastal Plain of Orange County Groundwater Basin identified by the California Department of Water Resources (CDWR).[1] The Talbert Gap is an erosional channel filled with permeable alluvium between Huntington Beach mesa to the northwest and the Newport mesa to the southeast. The primary water-bearing zone in the Talbert Gap is the Talbert Aquifer. The Talbert Aquifer extends offshore and, therefore, allows exchange of groundwater with the ocean. The Talbert Aquifer is overlain by fine-grained sediments and underlain by a zone of fine-grained sediments and deeper aquifers.

The connection of the Talbert Aquifer with the ocean has allowed seawater to intrude into the aquifer as a result of inland pumping. The Orange County Water District (OCWD) operates the Talbert Seawater Intrusion Barrier at the northern edge of the Talbert Gap.[2] The barrier is comprised of 36 wells that inject water into the aquifers to control seawater intrusion and replenish the basin.

A series of coastal marsh and wetland areas exist along the coast in the study area. These wetland areas are hydraulically connected to the open ocean[3]. However, the hydraulic conductivity of the bed sediments in these wetland areas likely differ significantly from the hydraulic conductivity values in shallow sediments in the surrounding area[4].

Groundwater modeling

Geosyntec[5] developed a groundwater-flow model to simulate the effects of pumping groundwater from multiple slant wells along the coast. The model simulates a pumping rate of 127 million gallons per day (MGD) from 40 slant wells screened in the Talbert Aquifer. The model was designed to evaluate the effects on the Talbert Injection Barrier to the northeast and the effects on coastal marsh and wetlands adjacent to the coast.

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[1] California Department of Water Resources, California's Groundwater, Bulletin 118 – Update 2003. www.water.ca.gov/groundwater/bulletin118/update_2003.cfm

[2] Orange County Water District Groundwater Management Plan, 2015 Update.

[3] Detwiler, Russel, 2015, Review of groundwater flow modeling developed by Geosyntec to simulate pumping from slant wells beneath the beach in Huntington Beach

[4] ibid

[5] Geosyntec Consultants, 2013, Feasibility Assessment of Shoreline Subsurface Collectors Huntington Beach Seawater Desalination Project Huntington Beach, California.
Thrup, Gordon, 2015, Revision and Sensitivity Analyses of Slant Well SSI Model, Geosyntec Consultants Technical Memorandum to Scott McCreary.

HydroFocus obtained the Geosyntec model versions 6, 7 and 8. The model was developed using the U.S. Geological Survey MODFLOW 2000 code[6]. Model version 6 incorporates several recommended changes from previous versions of the model. This version includes the addition of constant head cells[7] to represent a portion of coastal marsh and wetland areas, and the model grid was refined to provide a larger portion of the coast with finer grid spacing. Model version 6 was used to conduct several sensitivity runs to test the effects of varying aquifer properties and slant well pumping rates. Model versions 7 and 8 are similar to version 6 with the exception of the location of the slant wells.

The model consists of 10 layers; Layer 1 represents the ocean only, layers 2-4 represent fine-grained sediments[8] above the Talbert Aquifer, layers 5-8 represent the Talbert Aquifer, layer 9 represents the fine-grained sediments below the Talbert Aquifer, and Layer 10 represents the deep aquifers. The Talbert Aquifer is represented using four layers to allow the pumping wells to be simulated with a slanted configuration increasing in depth as the wells extend away from the coast toward the ocean. Pumping from the slant wells occurs in layers 5-8.

HydroFocus critically reviewed the model used in the Well Investigation Team Report, performed model runs using varying model input values and assessed the sensitivity of model outputs to variations in model inputs. Our overall objectives were to:

1. Critically review the Geosyntec models;
2. Assess the sensitivity of the model outputs to varying values of model inputs;
3. Assess the effects of the proposed project;
4. Provide recommendations for further data collection, modeling, and assessment of project impacts.

Approach

We reviewed model structure and ran the model to verify output and assess groundwater flow patterns. Model runs with varying input parameters were analyzed to assess the sensitivity of model outputs and thus provide guidance for further data collection and input parameter assessment. The results of these runs, literature review, and the use of particle tracking were used to assess the possible effects of the project. Based on the results of our analyses, we have provided recommendations for data collection and additional modeling, and assessed potential project impacts.

Methods

Model review

The Geosyntec models were provided in the format used by the Visual MODFLOW[9] graphical user interface (GUI). These files included the MODFLOW input and output files. We used the MODFLOW

[6] Harbaugh, Arlen W., et al., 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model-Users Guide to Modularization Concepts and The Ground-Water Flow Process.
[7] In constant head model cells, the hydraulic head is specified in advance by the user and remains constant throughout all time steps of the simulation.
[8] Fine-grained sediments typically consist of clays and silts. Coarse-grained sediments typically consist of sands and gravels.
[9] Visual Modflow is a product to Waterloo Hydrologic

input files to run the model to verify that the model produces the same results as those provided by Geosyntec. The Geosyntec models used a propriety solver that is part of the Visual MODFLOW GUI. We ran the model using the USGS MODFLOW 2000 code and the Preconditioned Conjugate-Gradient (PCG) solver. We also imported the model into the Groundwater Vistas[10] GUI to facilitate running the model, visualizing the results, and extracting model output.

We imported model input values including the IBOUND values, layer elevations, and aquifer properties into Geographic Information System (GIS) layers to facilitate mapping and model verification. We evaluated the model geometry, aquifer properties, and stresses (recharge and pumping) and compared the modeled values to the values reported by Geosyntec.

Sensitivity runs

We tabulated model--calculated groundwater flow to the slant wells from the inland barrier and from the wetlands for each of the sensitivity runs with varying inputs (sensitivity runs) (see Appendix A). We also extracted the water level declines simulated in the Talbert Aquifer (Layers 5-8) and calculated the maximum and mean decline in these layers. For most model runs, the largest water level decline occurred in Layer 8. Therefore, we used the average water level decline for Layer 8 for our analysis of the sensitivity runs. Model inputs and results for all runs are shown in Appendix A. We plotted the flow and water level decline values against the changes in model inputs to graphically display the results of the sensitivity analysis.

Groundwater flow paths

We used particle tracking to determine the source of groundwater flowing to the slant wells and evaluate groundwater travel times for various scenarios. We placed eight particles in each cell having a slant well. We used backward particle tracking with a porosity[11] of 20% to generate the pathlines and calculate travel times. We used the US Geological Survey computer program MODPATH[12] to simulate particle tracking. MODPATH is a particle-tracking post-processing model that computes three-dimensional flow paths using output from groundwater-flow simulations based on MODFLOW.

Results

Model review

Geometry

Geosyntec reported that the model cell dimensions range from 60x60 to 500x500 ft. We found that the grid cell dimensions range from 52 to 869 ft. along the columns (X direction) and from 56 to 672 ft. along the columns (Y direction). It is unlikely that these inconsistencies significantly affect model results. Table 1 lists the minimum, maximum, and mean thicknesses for the active cells in each layer and the thickness values reported by Geosyntec.

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[10] Copyright Environmental Simulations, Inc.

[11] Porosity is the fraction of void space in a given volume of aquifer material.

[12] Pollock, D.W., 2012, User guide for MODPATH version 6—A particle-tracking model for MODFLOW: U.S. Geological Survey Techniques and Methods, book 6, chap. A41, 58 p. http://pubs.usgs.gov/tm/6a41/

Table 1: Model layer thickness.

<table>
<tr><th rowspan="2">Layer</th><th colspan="3">Actual Layer Thickness (ft)</th><th rowspan="2">Reported Thickness (ft)</th><th rowspan="2">Represents</th></tr>
<tr><th>Min</th><th>Max</th><th>Mean</th></tr>
<tr><td>1</td><td>10</td><td>132</td><td>55</td><td>--</td><td>Ocean</td></tr>
<tr><td>2</td><td>18</td><td>58</td><td>33</td><td>--</td><td rowspan="3">Fine-grained Sediments</td></tr>
<tr><td>3</td><td>8</td><td>51</td><td>22</td><td>--</td></tr>
<tr><td>4</td><td>3</td><td>21</td><td>9</td><td>--</td></tr>
<tr><td>5</td><td>19</td><td>24</td><td>22</td><td rowspan="4">100</td><td rowspan="4">Talbert Aquifer</td></tr>
<tr><td>6</td><td>20</td><td>25</td><td>23</td></tr>
<tr><td>7</td><td>20</td><td>25</td><td>23</td></tr>
<tr><td>8</td><td>22</td><td>27</td><td>25</td></tr>
<tr><td>9</td><td>11</td><td>49</td><td>21</td><td>15</td><td>Fine-grained Sediments</td></tr>
<tr><td>10</td><td>34</td><td>149</td><td>63</td><td>50</td><td>Deep Aquifers</td></tr>
</table>

Constant Head Cells

Geosyntec reported that a constant head of 0.57 ft. was specified for all cells in the offshore portion of Layer 1. We found two significant areas of Layer 1 offshore along the coast that are represented as variable head cells. In these areas of variable head cells, the simulated head may vary as a result of the slant well pumping, which is not an appropriate way to simulate the ocean which should be simulated using specified constant head cells.

The Talbert Injection Barrier is represented by constant head cells along the northeast boundary of the model. The head in these cells varies from about 6-10 ft. There is some inconsistency in the spatial distribution of constant head cells between layers, but it likely does not significantly affect model results. Some of the marsh and wetland areas are represented by constant head cells with the head specified as 0.57 ft. The reasons for the specified distribution of these constant head cells are not reported by Geosyntec and are not clear to us.

Aquifer Properties

Table 2 shows the reported hydraulic conductivities[13] for each layer of the model. In all layers, the vertical hydraulic conductivity was reported to be 1/10th of the horizontal hydraulic conductivity. The horizontal hydraulic conductivity values specified in the model agreed with the reported values in both magnitude and spatial distribution. The vertical hydraulic conductivity was represented in the model by vertical conductance between layers. Vertical conductance is calculated using the vertical hydraulic conductivity and thickness of adjacent layers. We calculated the vertical hydraulic conductivity from the vertical conductance values specified in the model and the calculated vertical hydraulic conductivity values agreed with the reported values.

[13] Hydraulic conductivity is a measure of the ability of the aquifer material to transmit water and depends on the size and arrangement of the pores and fractures in the aquifer material. Horizontal hydraulic conductivity represents the transmission of water in the horizontal direction and vertical hydraulic conductivity represents transmission in the vertical direction. Vertical hydraulic conductivity is often less then horizontal hydraulic conductivity due to the nature in which aquifer materials are typically deposited in layers. See Heath, Ralph C., 1983, Basic Ground-Water Hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86 pp.

Table 2. Hydraulic Conductivity values specified in the model.

Layer	Horizontal Hydraulic Conductivity (ft/d)	Vertical Hydraulic Conductivity (ft/d)	Represents
1	1000	100	Ocean
2	1/10	0.1/1	Fine-grained Sediments
3	10	1	
4	10	1	
5	10/300/325	1/30/32.5	Talbert Aquifer
6	10/300/325	1/30/32.5	
7	10/300/325	1/30/32.5	
8	10/300/325	1/30/32.5	
9	10	1	Fine-grained Sediments
10	300	30	Deep Aquifers

Pumping and Recharge

The MODFLOW well file was checked and verified to simulate a pumping rate of 127 MGD (2,200 gallons per minute, GPM, per well) from the layers representing the Talbert Aquifer (Layers 5-8) representing the slant well. Recharge[14] was verified to be 1 inch per year as reported by Geosyntec.

Sensitivity of Model Outputs to Model Inputs

In the following sections, we report the assessed effects on model outputs of varying modeling inputs for hydraulic conductivity, well screen length, pumping rate, barrier water level and slant well location. The change in model output in relation to model input provides a measure of model parameter sensitivity. Increased sensitivity of model inputs, i.e. large changes in output relative to changes in model inputs, provides direction for collection of additional data to better quantify the parameters.

Effects of Varying Model Hydraulic Conductivity Values

Figures 1 through 3 illustrate the relative effects of changes in model hydraulic conductivity on model outputs for flow to the slant wells from inland groundwater and the wetlands and average water-level decline in Layer 8. The red point on the graphs represents model version 6 and the blue points represent sensitivity model runs in which hydraulic conductivity values for different layers were varied. Horizontal and vertical hydraulic conductivity were varied by the same proportion for each run.

[14] Recharge is the percolation of water through the soil to the water table.

Hydraulic Conductivity – Talbert Aquifer

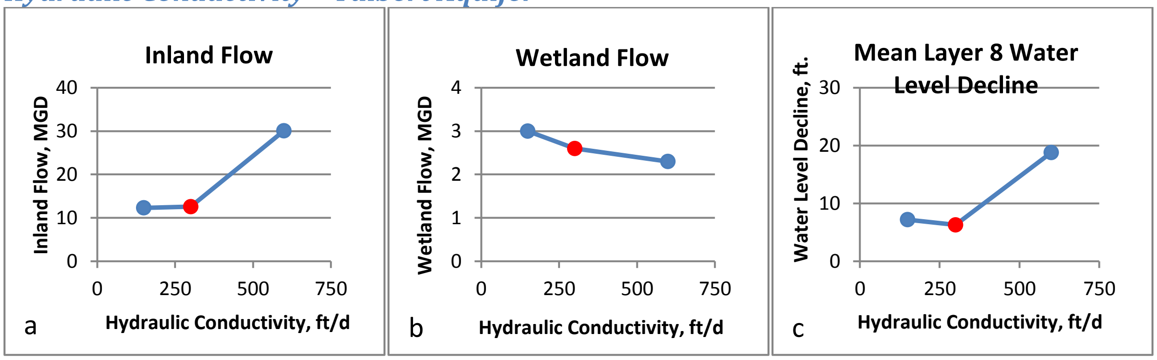

Figure 1. Effects of changes to the Talbert Aquifer hydraulic conductivity on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

Model results are more sensitive to increases in the hydraulic conductivity of the Talbert Aquifer than to decreases. Specifically, a 100% increase in the horizontal and vertical hydraulic conductivity (these parameters were varied together) of the Talbert Aquifer resulted in significant increases in flow from the inland boundary (140%) (Figure 1a) and Layer 8 water level decline (200%)(Figure 1c). Decreasing the horizontal and vertical hydraulic conductivity by 50% had a minimal effect on inland flow and water level decline (-2% and 14%, respectively) (Figures 1a and 1c). Increasing and decreasing the hydraulic conductivity of the Talbert aquifer resulted in minimal changes to the wetland flow (-12 to 15%) (Figure 1b).

Hydraulic Conductivity – Overlying Layers

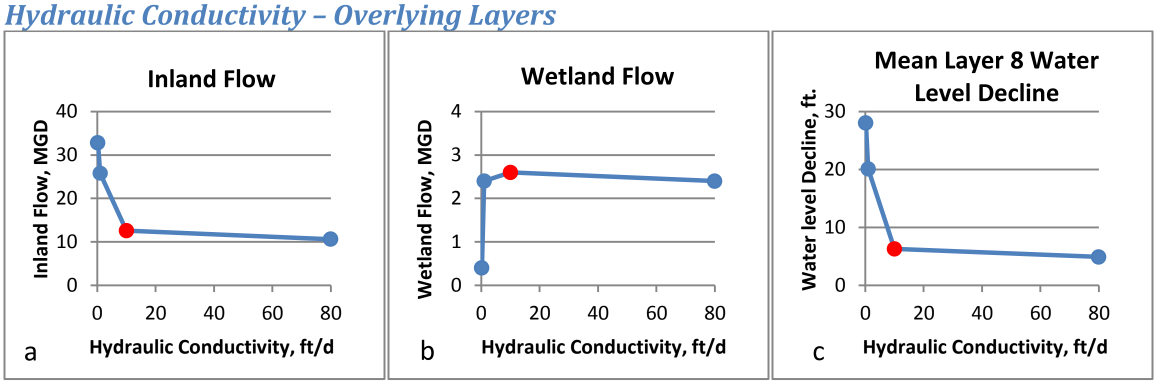

Figure 2. Effects of changes to the hydraulic conductivity in the layers overlying the Talbert Aquifer on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

The horizontal and vertical hydraulic conductivity in the model layers overlying the Talbert Aquifer was decreased and increased. Inland flow changed as much as 160% (Figure 2a) and wetland flow changed as much as -85% (Figure 2b) due to decreasing the hydraulic conductivity from 10 ft/d to 0.2 ft/d. Layer 8 water level decline was most sensitive to decreasing the hydraulic conductivity of the overlying layers (220% to 340% change in water level declines) (Figure 2c). Inland flow was also most sensitive to decreasing the hydraulic conductivity. Changes to inland and wetland flow and Layer 8 water level decline were relatively insensitive to increasing hydraulic conductivity.

The results shown in Figures 3 through 5 were for model runs in which the specified pumping rate was 100 MGD. A 50% decrease in the hydraulic conductivity of the layers underlying the Talbert Aquifer resulted in relatively small changes of -24%, 14%, and 20% change in inland flow, wetland flow, and Layer 8 water level decline, respectively (Figures 3a, 3b, and 3c).

Hydraulic Conductivity – Underlying Layers

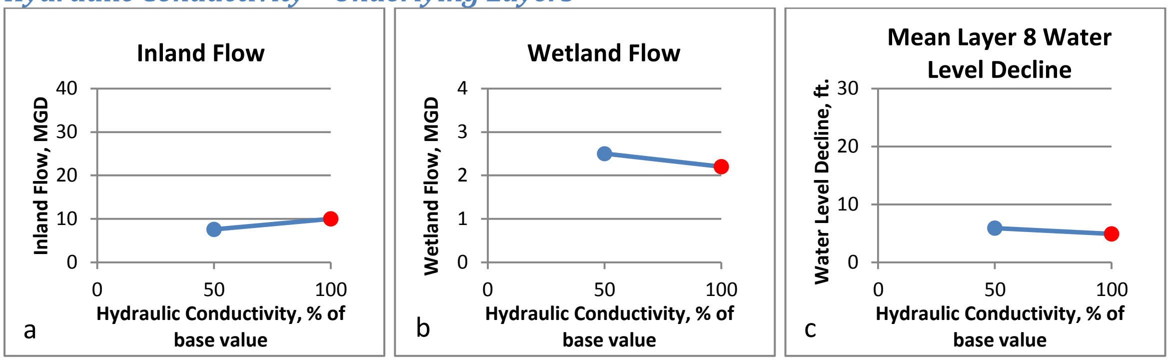

Figure 3. Effects of changes to the hydraulic conductivity in the layers underlying the Talbert Aquifer on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

Effects of Varying Model Screen Length

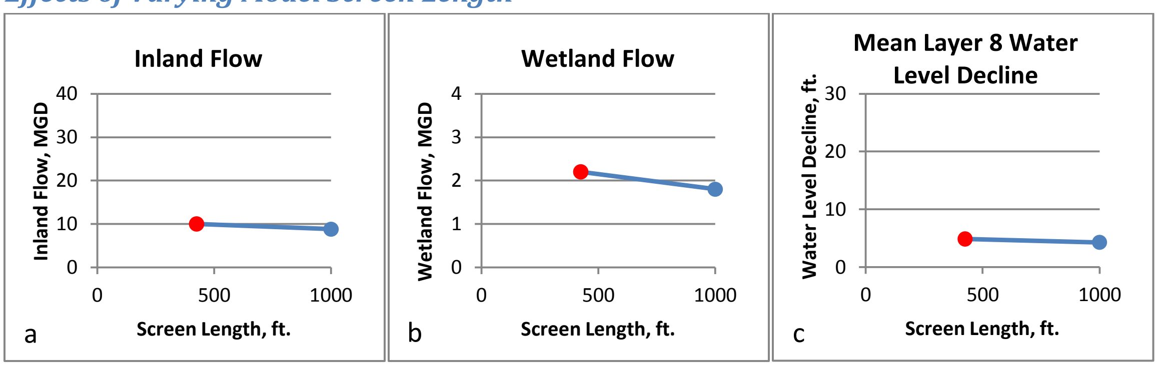

Figure 4. Effects of slant well screen length on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

The slant well screen was lengthened and extended farther offshore than the 425-ft well screens used in the base run. These runs were conducted using a pumping rate of 100 MGD. A 135% increase in the well screen length resulted in relatively small changes of -12%, -18%, and -12% changes in inland flow, wetland flow, and Layer 8 water level decline, respectively (Figures 5a, 5b, and 5c).

Effects of Varying Model Barrier Head Elevation

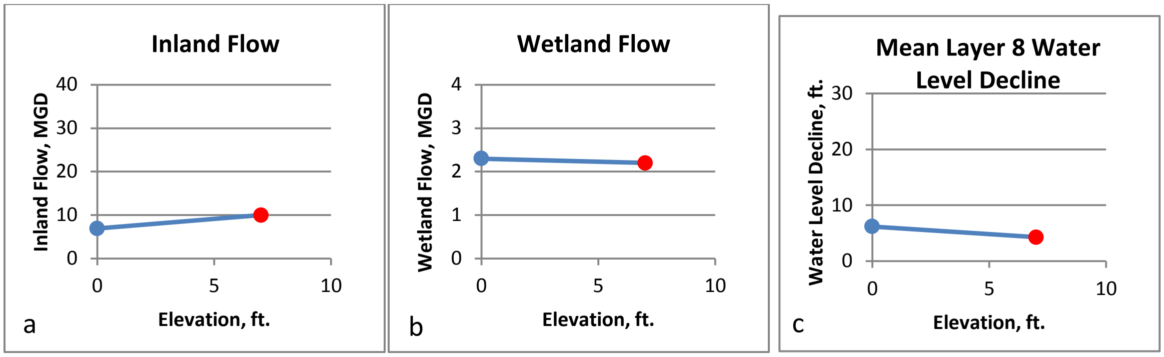

Figure 5. Effects of barrier head elevation on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

The water levels specified in the constant head cells representing the seawater intrusion barrier were reduced from the base value (about 7 ft. in Layers 2-8, 10 ft. in Layers 9-10) to 0 ft. in all layers. Because slant well pumping would likely reduce sea water intrusion, lower water levels at the Talbert Gap seawater intrusion barrier will likely result in an effective barrier. These runs were made using a pumping rate of 100 MGD. The change in the barrier water level resulted in a -31%, 5%, and 29% change in inland flow, wetland flow, and Layer 8 water level decline, respectively (Figures 5a, 5b, and 5c).

Effects of Varying Model Slant Well Pumping Rate

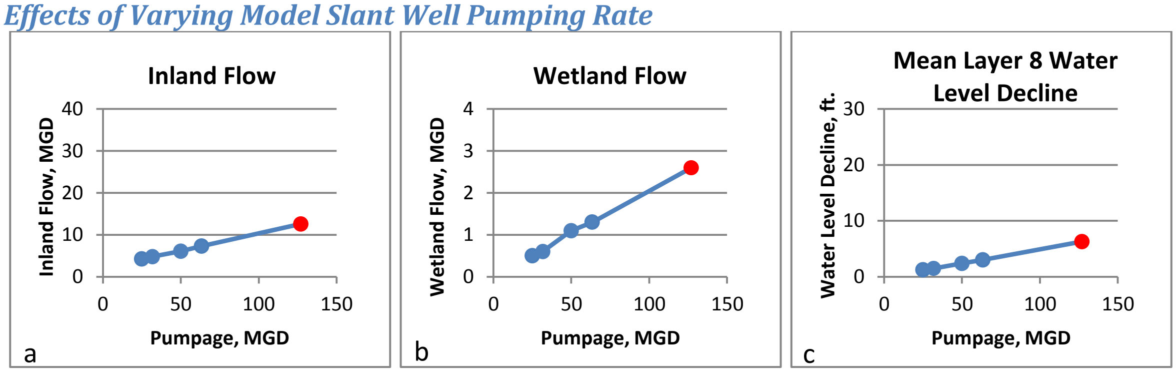

Figure 6. Effects of changes to the slant well pumping rates on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

Inland and wetland flow and Layer 8 water level decline are linearly related to the slant well pumping rate. Decreases in the slant well pumping rate result in corresponding decreases in inland and wetland flow and water level decline. The relative impact of reduced pumping is greater on the wetland flow (Figure 6b) and Layer 8 water level decline (Figure 6c) (up to -81% change) than on inland flow (Figure 6a) (up to -67% change).

Effects of Varying Model Slant Well Location

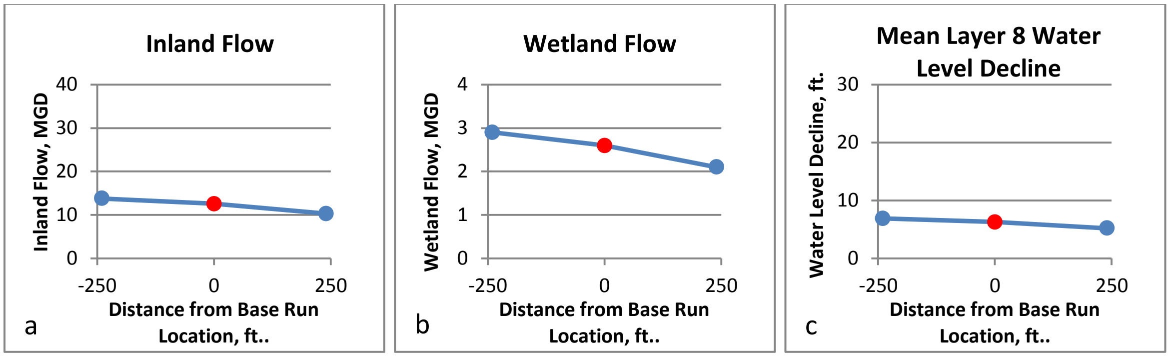

Figure 7. Effects of slant well location on inland flow (a), wetland flow (b), and mean Layer 8 water level decline (c).

The location of the slant wells were moved both farther inland and farther seaward relative to the location used in the base run. The run with the well location farther inland is shown as a negative distance and the run with the well location farther seaward is shown as a positive distance from the base run location, respectively (Figures 7a, 7b, and 7c). Moving the wells farther inland resulted in relatively small changes of 10%, 12%, and 10% change in inland flow, wetland flow, and Layer 8 water level decline, respectively. Moving the wells farther seaward resulted in relatively small changes of -18%, -19%, and -17% in inland flow, wetland flow, and Layer 8 water level decline, respectively.

Groundwater flow path analysis

Figure 8 shows the groundwater flow paths to the slant wells (Geosyntec model 6, 127 MGD slant-well pumping rate). Eighty-seven percent of the groundwater flow pathlines originate in the ocean and 13 percent originate inland. This is similar to the percentage of flow to the slant wells from the ocean and from inland (wetlands and intrusion barrier). Average travel time for the groundwater flow pathlines that originate near the intrusion barrier is about 20 years. Using a pumping rate of 63.5 MGD (one-half the base rate of 127 gpm) increased the Talbert Aquifer travel time from the barrier to the slant wells to about 37 years. Using the base pumping rate of 127 MGD and setting the barrier constant heads to 0.0 ft. results in an average travel time in the Talbert Aquifer of 24 years.

Many of the pathlines in Figure 8 extend from the slant wells to the northwest and southeast toward the lateral boundaries of the model and turn sharply toward the ocean or the constant head cells representing the barrier. This sharp turn in some pathlines suggest that the simulated groundwater flow paths are being affected by the lateral extent of the model, primarily in Layers 9 and 10.

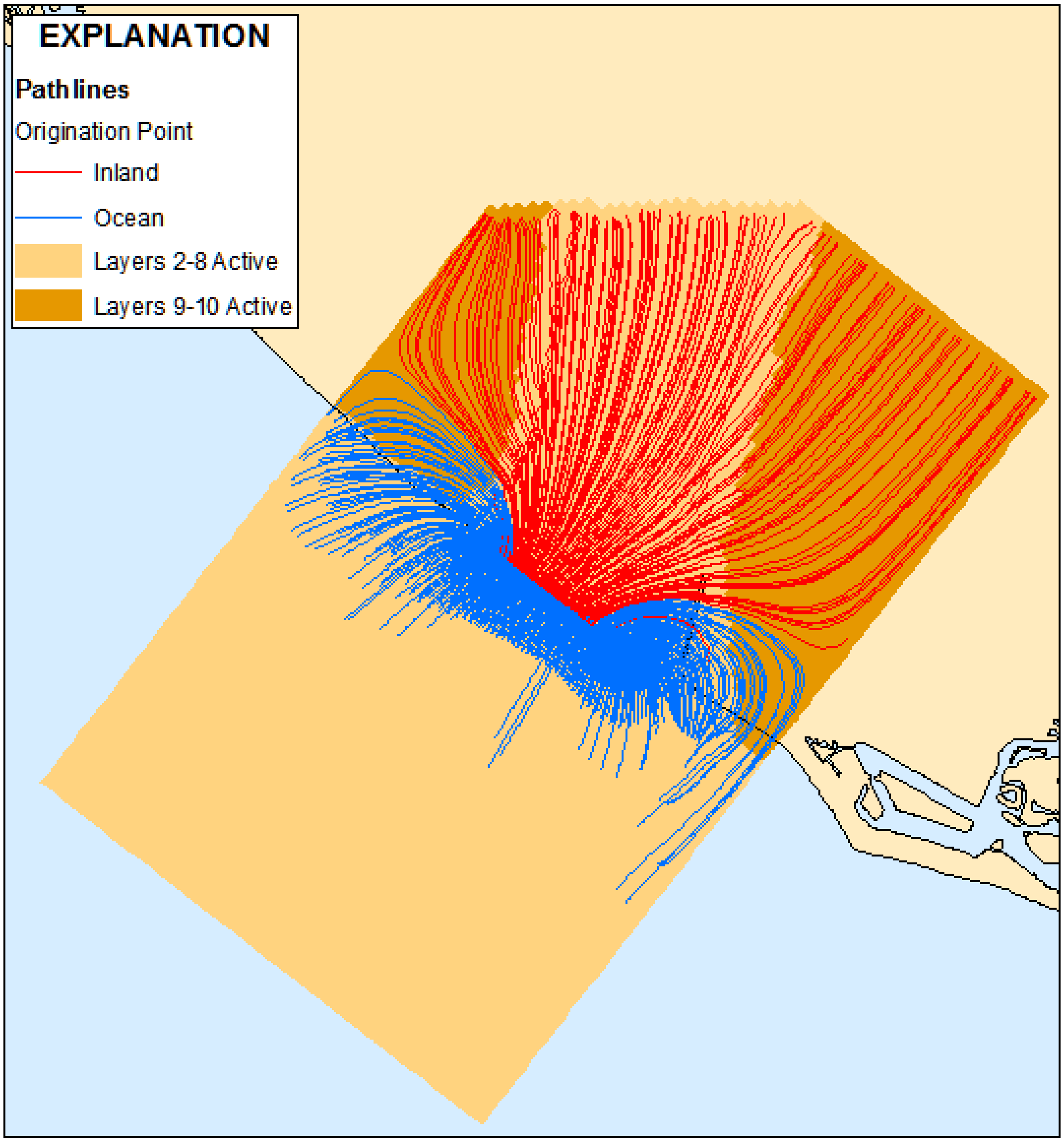

Figure 8. Groundwater flow paths to the slant wells.

Discussion

Model Limitations and Uncertainty

A groundwater-flow model is an approximation of the actual aquifer system. The model relies on estimates of aquifer properties and stress, which are uncertain. Our evaluation has identified several limitations and uncertainty in the model.

- The simulated water levels were not compared to observed water level data to evaluate the effectiveness of the model in representing the groundwater-flow system. The OCWD uses a network of observation wells to monitor groundwater levels and water quality in the Talbert Gap. If data from these wells are available, these data should be used to assess the effectiveness of the model and reduce uncertainty in how well the model represents the aquifer system.

- There is limited information on the aquifer properties in the model area. Geosyntec summarized results of previous investigations near the project location.[15] These investigations include limited aquifer tests that provide information on aquifer properties. The aquifer properties used in the model were taken from a regional model and no calibration of the local-scale model was performed. Sensitivity analysis shows that the model is most sensitive to the aquifer properties in the Talbert Aquifer and the overlying aquitard. Additional aquifer tests in the Talbert Gap area will provide better estimates of aquifer properties.
- Representing the seawater intrusion barrier using constant head cells assumes that the quantity of injection water will be available to maintain the water levels at the barrier regardless of the impact of the slant well pumping. Representing the barrier using injection wells and average injection rates may better represent the effects of slant well pumping on groundwater flow in the Talbert Aquifer.
- Parts of the ocean represented by Layer 1 are not designated as constant head cells as reported but are designated as variable-head cells. Some of these variable-head cells become dry in the simulation. These dry cells cannot provide water to the slant wells and, therefore, may result in an inaccurate estimation of the contribution of the ocean to the slant wells.
- Groundwater flow paths suggest that the model results may be affected by the lateral extent of the model domain.

Addressing these issues will reduce uncertainty and improve the effectiveness of the model in representing the aquifer system and simulating the impacts of the project. This will increase confidence that the model can be used to effectively evaluate project impacts.

Sensitivity of Model Outputs to Model Inputs and Implications for Project Impacts

Model results are most sensitive to variations in model hydraulic conductivity values for the Talbert Aquifer and the overlying aquitard. Specifically, the magnitude of groundwater level declines can be substantially affected by relatively small changes in hydraulic conductivity. An issue of concern is the potential for groundwater level decline from the slant well pumping to cause subsidence along the coast. Subsidence could impact the Pacific Coast Highway, the project facilities, or other structures in the area. The Talbert Aquifer is overlain by relatively fine-grained sediments both offshore and onshore near the coast.[16] Compaction of fine-grained sediments such as clays due to groundwater withdrawals is a primary cause of subsidence. The California Department of Water Resources (CDWR) identified the Coastal Plain of Orange County groundwater basin, including the project area, as having a high estimated potential for future land subsidence[17]. The OCWD reported that historical subsidence has occurred in coastal locations due to land management practices and oil extraction.[18] However, permanent subsidence due to groundwater withdrawals has not been documented since the OCWD

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[15] Geosyntec Consultants, 2013, Feasibility Assessment of Shoreline Subsurface Collectors, Huntington Beach Seawater Desalination Project, Huntington Beach, California, September 2013.
[16] Geosyntec Consultants, 2013, Feasibility Assessment of Shoreline Subsurface Collectors, Huntington Beach Seawater Desalination Project, Huntington Beach, California, September 2013.
[17] CDWR, 2014, Summary of Recent, Historical, and Estimated Potential for Future Land Subsidence in California.
[18] Orange County Water District, 2015, Orange County Water District, Groundwater Management Plan, 2015 Update, June 17, 2015.

began recharge operations in the basin in the late 1950s. The OCWD reported that seasonal temporary fluctuations in land surface are observed that are correlated with groundwater level changes.

Pumping Rate Effects on Barrier Flow to the Slant Wells

Model runs using varying pumping rates may potentially be used to select the optimum pumping rate to minimize the proportion of pumping originating as inland flow. The volume of water originating as inland flow is directly proportional to the pumping rate (Figure 9a). However, the percent of the pumping volume that originates as flow from the inland barrier is not directly proportional (Figure 9b). As the pumping increases, the percentage of the pumping that originates as inland flow decreases. At pumping rates of 63.5 MGD and above, the percentage of pumping that originates as inland flow does not change significantly and is about 10%.

The sensitivity results show that the specified aquifer properties and other model inputs affect the calculated percent of the simulated slant well pumping that originates as inland flow. For example, using a pumping rate of 127 MGD, doubling the hydraulic conductivity of the Talbert Aquifer increased the percent of pumping that originates as inland flow from 10% to 24%. Likewise, decreasing the hydraulic conductivity of the material overlying the Talbert aquifer up to 98% increased the percent of pumping that originates as inland flow from 10% to 26%. Using a pumping rate of 100 MGD, increasing the hydraulic conductivity of the material overlying the Talbert Aquifer or decreasing the hydraulic conductivity of the material underlying the Talbert Aquifer decreased the percent of pumping that originates as inland flow from 10% to 9% and 8%, respectively. Combing several changes to model input (increasing slant well length, increasing the hydraulic conductivity of the overlying material, decreasing the hydraulic conductivity of the underlying material, and lowering the water level maintained at the barrier) resulted in 4% percent of the slant-well pumping originating from inland flow.

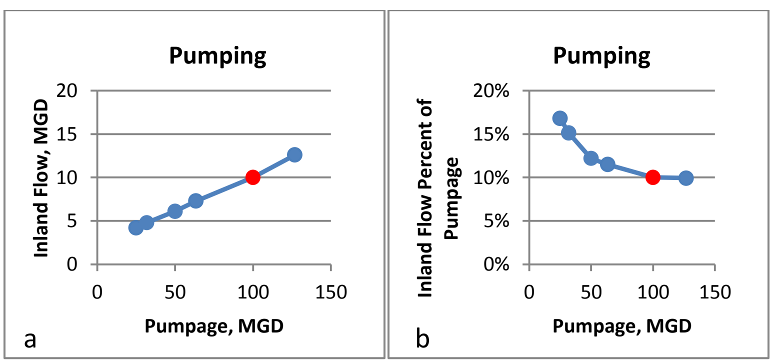

Figure 9. Relation of pumping rate and inland flow.

Particle Tracking and Groundwater Travel Times

Seawater/Freshwater Interface

Our analysis indicates that the large majority of the water flowing to the slant wells will come from the ocean. Figure 8 indicates that operation of the slant wells will affect the extent of seawater intrusion in the Talbert Aquifer. The OCWD monitors groundwater levels and quality in the Talbert Gap to assess the effectiveness of the seawater intrusion barrier.[19] The OCWD monitoring well OCWD-M26 is

[19] Ibid.

strategically located and screened in the Talbert Aquifer and deeper aquifers for evaluating barrier injection requirements versus seawater intrusion potential. The OCWD has a goal of maintaining the water level in the vicinity of this well at 3 feet above mean sea level to keep brackish water from moving inland in the Talbert Aquifer and migrating downward to deeper aquifers tapped by inland production wells.

Water level declines induced by the slant well pumping may extend inland to the location of this well and, therefore, affect the ability of the OCWD to maintain the desired water levels at this well. Conversely, project pumping from the slant wells will likely increase the gradient from inland areas toward the project wells. This increase in seaward gradient will enhance the movement of inland freshwater toward the coast and will likely move the seawater/freshwater interface to the west, closer to the coastline. This increase in seaward gradient along with capture of seawater by the slant wells will have the effect of reducing the inland migration of seawater and may allow the OCWD to maintain a lower water level in the well while still obtaining the objective of reducing seawater intrusion. Lowering of the head in the barrier wells will likely also result in decreased inland flow to the slant wells (Figure 5).

Summary and Recommendations

Our model review indicates that minor modifications will improve model functioning. Specifically, model calibration and validation using local groundwater and aquifer test data will likely provide insight about project performance and effects. Model boundary conditions and inconsistencies may affect model performance and merit re-examination and evaluation.

Model results indicate that the project will affect ground water levels and gradients in the Talbert Gap. Water level declines will be greatest in the vicinity of the project wells. Model simulations indicate that most of the water extracted from the project wells comes from the ocean, but some originates inland (about 10%) and some originates in the coastal wetlands (about 2%). Project pumping will likely impact the operation of the seawater intrusion barrier by increasing hydraulic gradients towards the ocean and reducing the impact of seawater intrusion into the inland portion of the Talbert Aquifer.

The model is most sensitive to the aquifer properties in the Talbert Aquifer and in the overlying aquitard. Sensitivity tests show that changes in these aquifer properties result in significant changes to the estimated contributions from inland flow and the coastal wetlands. Therefore additional data collection and aquifer tests will improve the estimates and uncertainty in the aquifer properties and improve the confidence in the model results. Calibration of the model using water level data would also improve the effectiveness of the model.

Specific recommendations follow.

- Conduct aquifer tests or pilot well pumping to determine hydraulic conductivity values in the Talbert Aquifer and overlying sediments.
- Hydraulic conductivity values of wetland sediments should also be determined.
- Assess effects of lateral model boundary conditions on model results and modify as needed.
- Inconsistencies in model construction (cell size, variable head cells in the ocean, etc.) should be resolved to eliminate any concern that these issues may affect model results.
- Incorporate MODFLOW Subsidence Package to preliminarily evaluate the subsidence potential due to slant well pumping.

- Use revised model to more effectively simulate potential impacts and project feasibility.
- Additional questions that could be answered with an improved model include the following.
    - How will long term pumping likely affect land-surface elevations?
    - How will the project likely affect the presence of intruded seawater and the functioning of the barrier injection wells?
    - What will be the likely withdrawal of inland water by pumping wells? How will this change over time?

Appendix A - Summary of Model Inputs and Model Results for Model Scenarios

Consultant	Model Run	Model Inputs										Model Results								
		Project Pumping with Slant Wells, MGD	Length of Slant Well, ft	Relative Location of Slant Wells	Strata Above Talbert Aquifer			Talbert Aquifer	Strata Below Talbert Aquifer		Seawater Intrusion Barrier Water Level Elevation at the Talbert Gap, ft amsl	Flow Contributed to Slant Well, MGD				Flow Contributed to Slant Well, %				Average Layer 8 Water Level Decline, feet
					Layer 2	Layer 3	Layer 4	Layers 5-8	Layer 9	Layer 10		Ocean	Wetlands	Areal Recharge	Inland	Ocean	Wetlands	Areal Recharge	Inland	
					Kh/Kv, ft/d	Kh/Kv, ft/d	Kh/Kv, ft/d	Kh/Kv, ft/d	Kh/Kv, ft/d	Kh/Kv, ft/d										
Geosyntec	V6	126.7	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	110.5	2.6	1.0	12.6	87%	2%	1%	10%	6.3
Geosyntec	V6A	126.7	425	Base	**1/0.1**	**1/0.1**	**1/0.1**	300/30	10/1	300/30	Approximately 7	85.6	2.4	1.0	25.8	68%	2%	1%	20%	19.8
Geosyntec	V6B	126.7	425	Base	**0.2/0.02**	**0.2/0.02**	**0.2/0.02**	300/30	10/1	300/30	Approximately 7	56.9	0.4	1.0	32.8	45%	0%	1%	26%	26.1
Geosyntec	V6C	126.7	425	Base	10/1	10/1	10/1	**150/15**	10/1	300/30	Approximately 7	110.5	3.0	1.0	12.3	87%	2%	1%	10%	7.2
Geosyntec	V6D	126.7	425	Base	10/1	10/1	10/1	**600/60**	10/1	300/30	Approximately 7	93.3	2.3	1.0	30.1	74%	2%	1%	24%	18.8
Geosyntec	V6Half	**63.5**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	53.7	1.3	1.0	7.3	85%	2%	2%	11%	3.0
Geosyntec	V6Qtr	**31.8**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	25.2	0.6	1.0	4.8	79%	2%	3%	15%	1.5
Geosyntec	V7	126.7	425	**240 ft. landward**	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	109.0	2.9	1.0	13.8	86%	2%	1%	11%	6.9
Geosyntec	V8	126.7	425	**240 ft. seaward**	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	133.3	2.1	1.0	10.3	105%	2%	1%	8%	5.2
HydroFocus	HF R1	126.7	425	Base	10/1	**80/8**	**80/8**	300/30	10/1	300/30	Approximately 7	111.8	2.4	1.0	10.6	89%	2%	1%	8%	4.9
HydroFocus	HF R2	**100.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	86.7	2.2	1.0	**10.0**	87%	2%	1%	**10%**	4.9
HydroFocus	HF R3	**100.0**	**1,000**	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	88.3	1.8	1.0	**8.8**	88%	2%	1%	**9%**	4.3
HydroFocus	HF R4	**100.0**	425	Base	10/1	**80/8**	**80/8**	300/30	10/1	300/30	Approximately 7	88.3	2.0	1.0	**8.7**	88%	2%	1%	**9%**	3.8
HydroFocus	HF R5	**100.0**	425	Base	10/1	10/1	10/1	300/30	**5/0.5**	**150/15**	Approximately 7	88.9	2.5	1.0	**7.6**	89%	3%	1%	**8%**	5.9
HydroFocus	HF R6	**100.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	**0**	89.8	2.3	1.0	**6.9**	90%	2%	1%	**7%**	6.3
HydroFocus	HF R7	**100.0**	**1,000**	Base	10/1	**80/8**	**80/8**	300/30	**5/0.5**	**150/15**	**0**	93.6	1.9	1.0	**3.5**	94%	2%	1%	**4%**	4.9
HydroFocus	HF R8	**50.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	41.8	1.1	1.0	**6.1**	84%	2%	2%	**12%**	2.4
HydroFocus	HF R9	**50.0**	**1,000**	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	42.6	0.9	1.0	**5.5**	85%	2%	2%	**11%**	2.1
HydroFocus	HF R10	**50.0**	425	Base	10/1	**80/8**	**80/8**	300/30	10/1	300/30	Approximately 7	42.5	1.0	1.0	**5.5**	85%	2%	2%	**11%**	1.9
HydroFocus	HF R11	**50.0**	425	Base	10/1	10/1	10/1	300/30	**5/0.5**	**150/15**	Approximately 7	43.3	1.3	1.0	**4.3**	87%	3%	2%	**9%**	2.9
HydroFocus	HF R12	**50.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	**0**	44.8	1.2	1.0	**2.9**	90%	2%	2%	**6%**	3.7
HydroFocus	HF R13	**50.0**	**1,000**	Base	10/1	**80/8**	**80/8**	300/30	**5/0.5**	**150/15**	**0**	46.7	0.9	1.0	**1.3**	94%	2%	2%	**3%**	3.0
HydroFocus	HF R14	**25.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	19.2	0.5	1.0	**4.2**	77%	2%	4%	**17%**	1.2
HydroFocus	HF R15	**25.0**	**1,000**	Base	10/1	10/1	10/1	300/30	10/1	300/30	Approximately 7	19.6	0.4	1.0	**3.9**	79%	2%	4%	**16%**	1.0
HydroFocus	HF R16	**25.0**	425	Base	10/1	**80/8**	**80/8**	300/30	10/1	300/30	Approximately 7	19.6	0.4	1.0	**4.0**	78%	2%	4%	**16%**	0.9
HydroFocus	HF R17	**25.0**	425	Base	10/1	10/1	10/1	300/30	**5/0.5**	**150/15**	Approximately 7	20.6	0.6	1.0	**2.8**	82%	2%	4%	**11%**	1.5
HydroFocus	HF R18	**25.0**	425	Base	10/1	10/1	10/1	300/30	10/1	300/30	**0**	22.3	0.6	1.0	**1.1**	89%	2%	4%	**4%**	2.5
HydroFocus	HF R19	**25.0**	**1,000**	Base	10/1	**80/8**	**80/8**	300/30	**5/0.5**	**150/15**	**0**	23.2	0.5	1.0	**0.3**	93%	2%	4%	**1%**	2.1

Bold indicates model input that was changed from inputs specified in the base run (V6)

Kh = Horizontal Hydraulic Conductivity

Kv = Vertical Hydraulic Conductivity

MGD = Million Gallons per Day

Geosyntec - Geosyntec Technical Memorandum, November 9, 2015.

HydroFocus - Sensitivity runs conducted by HydroFocus, Inc.

Average layer 8 water level decline calculated by HydroFocus using model results.