Water Science Associates

Technical Memorandum

To: Mr. Thomas Walker, FKAA Director of Operations
From: W. Kirk Martin, P.G., Water Science Associates
Date August 12, 2016
Re: Review of Groundwater Flow and Transport Model of the Biscayne Aquifer
Prepared by Tetra Tech for Evaluation of Remedial Measures to Address the Hypersaline Plume Created by the Cooling Canal System at the FPL Turkey Point Power Facility

1. INTRODUCTION

Florida Power and Light Company (FPL) maintains a cooling canal system (CCS) for operation of power generation units at their Turkey Point Power Generation Facility in southeast Miami-Dade County. The CCS consists of some 6000 acres of canals through which water is circulated for dissipation of heat created by the power generation units. The CCS is characterized as a "closed-loop" cooling system in that the same water is circulated through the extensive canal network without direct input of new water to the system. However, the CCS does not function as a closed loop system hydrologically in that as the warmed water is circulated, evaporation losses to the atmosphere remove freshwater from the canal system causing a concentration of salinity that exceeds typical ocean salinities by a factor of two or more. This increased salinity is accompanied by a corresponding increase in water density that causes hypersaline water to migrate downward into the underlying groundwater system and radially outward from beneath the CCS. Operation of the CCS includes manipulation of water levels in an "interceptor ditch" running along the west side of the CCS with the intent that control of water levels in the ditch would prevent CCS water from migrating west of the L-31E Canal. However, groundwater monitoring data shows that hypersaline water emanating from the CCS has moved westward of the L-31E Canal a distance of more than two miles and is influencing movement of the saline water interface within the Biscayne Aquifer more than four miles inland.

The Florida Department of Environmental Protection (FDEP) issued a Consent Order in June of 2016 outlining a number of remedial requirements to address the impacts of the CCS on the surrounding groundwater system. These included implementation of a remediation project using a recovery well system that will halt the westward migration of hypersaline water from the CCS within 3 years and reduce the westward extent of the hypersaline plume to the L-31E Canal within 10 years without adverse environmental impacts. The Consent Order further requires FPL submit detailed plans for the remediation project including supporting data.

A groundwater flow and solute transport variable density model was developed by Tetra Tech (Tetra Tech, 2016) on behalf of FPL to evaluate proposed remediation options. The USGS computer code SEAWAT (Guo and Langevin 2002) was the code selected for modeling purposes. The model went through several stages of calibrations and a number of remedial scenarios (predictions) were simulated. The calibration included a pre-development steady-state model (prior to 1940), a steady-state calibration model (1940 - 1968), a seasonal calibration model (1968 - 2010) and a monthly calibration model (2010 - 2015). Seven remediation scenarios were evaluated with the calibrated SEAWAT model.

Water Science Associates was contracted by the Florida Keys Aqueduct Authority (FKAA) to conduct a review of the Tetra Tech models. Water Science Associates used the services of Dr. Weixing Guo, coauthor of the SEAWAT modeling code to conduct the internal model analysis. The objectives of this model review were to evaluate the major assumptions and approaches; review the model construction, model calibration and model predictions to see if the assumptions were reasonable; and determine if the model was constructed correctly, the model calibration was acceptable and predictions were sound.

The model review was focused on the materials listed below:

- A technical memorandum, *A Groundwater Flow and Solute Transport Model of the Biscayne Aquifer*, from Tetra Tech dated June, 2016
- A PowerPoint presentation, *Variable Density Groundwater Model Analysis and Results – Model Use, Design, Calibration and Description of Alternatives* (Andersen and Ross of Tetra Tech dated May 16, 2016)
- A PowerPoint presentation, *Variable Density Groundwater Model Analysis and Results – Remedial Alternatives Modeling Evaluations and Selected Alternative* (Ross and Andersen of Tetra Tech dated May 16, 2016)
- The SEAWAT model input and output files provided by FPL

The technical memorandum indicates that the models were developed with Groundwater Vistas as the graphical user interface (GUI). However, the Groundwater Vistas files were not available for the model review effort. The Groundwater Vistas files would have helped facilitate visualization of the model input data greatly. However, Dr. Guo was able to directly access the model input files for the technical review.

2. GENERAL MODEL DESCRIPTION

The model has 295 rows and 274 columns with a variable grid spacing, ranging from 200 feet to 500 feet. The model has 11 layers with variable thicknesses to represent the Biscayne Aquifer. The uppermost layer consists of unconsolidated surficial sediments. Layers 2 to 4 represent the Miami Oolite limestone, and Layers 5 through 11 represent the Fort Thompson Formation. Layer 4 and Layer 8 were assigned with high permeability values, based on available well logs.

3. REVIEW OF MODELS

3.1 Steady-State Model

The steady-state model calibration has seven steady-state stress periods for the period from 1940 to 1968. The initial conditions of the steady-state model were derived from the model of pre- development conditions. The sea level for Biscayne Bay was set to -0.71 feet NAVD. The results from the steady-state models, including simulated heads, salinity, and temperature, were used as the initial conditions for the seasonal calibration model.

3.2 Seasonal Transient Calibration Model

The model simulated a 42-year period from 1968 to 2010. The seasonal calibration model has 84 stress periods. Each stress period represents one season, wet (May to October) or dry (November to April). The CCS was added in the model in stress period 10 representing May 1973.

Figure 1 shows the net recharge applied in each stress period or season in the model at a selected location (R255 C21). It indicates that the most recharge occurs during the wet seasons as expected. A recharge of 10 inches per year in the wet season is applied uniformly from 1968 to 1995 whereas variable recharge rates are applied from 1996 through 2010 including net recharge being applied during the dry season in certain years. The technical memorandum does not indicate why the recharge rates were varied. Presumably, the change could be part of the calibration process. However, it is not clear why the recharge from 1968 to 1995 are uniform or why the change was made for years after 1995.

The net recharge in some years appears to be very high. For example, the net recharge was almost 20 inches in the wet season in 2005, which is about one third of annual precipitation. It should be noted that since the following figure only shows the recharge at one arbitrarily selected location, it might not necessarily represent the entire model area.

The results of seasonal calibration model were used as the initial conditions for the monthly calibration model.

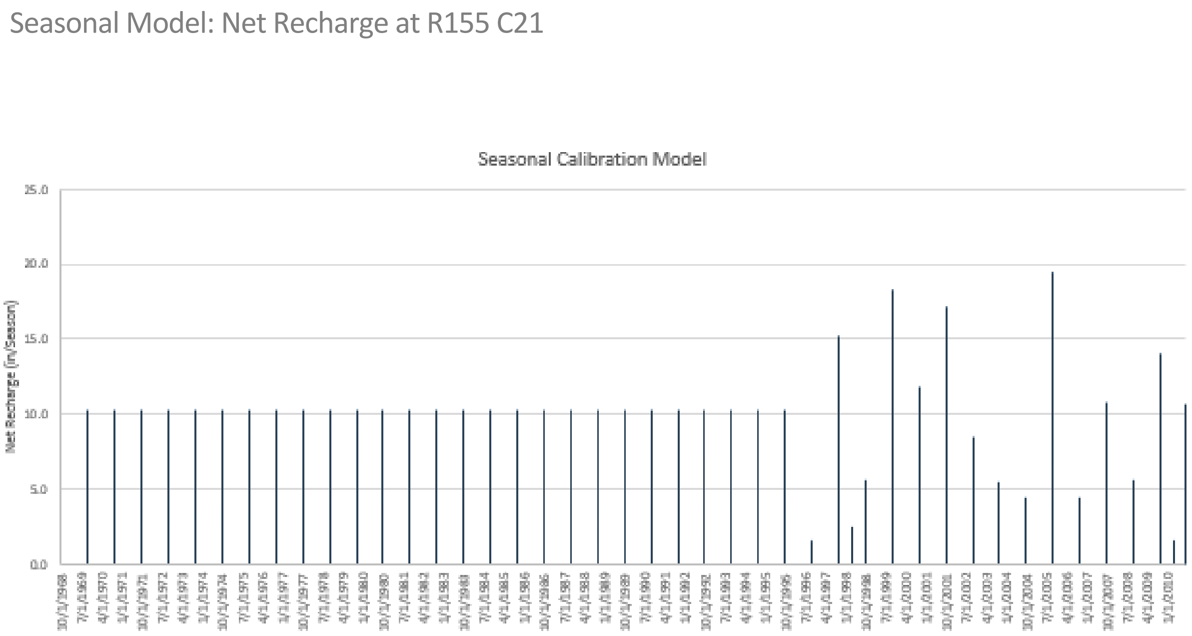


Figure 1. Net recharge (inches/season) applied in the seasonal calibration model.

3.3 Monthly Calibration Model

The monthly calibration model covers the period from October 1, 2010 to December 31, 2015. It has 63 monthly stress periods for a total simulation time of 5 years and 3 months.

A large area of dry cells appears at the west side of the model with some dry cells appearing just after the first stress period in the monthly calibration model (Figure 2).

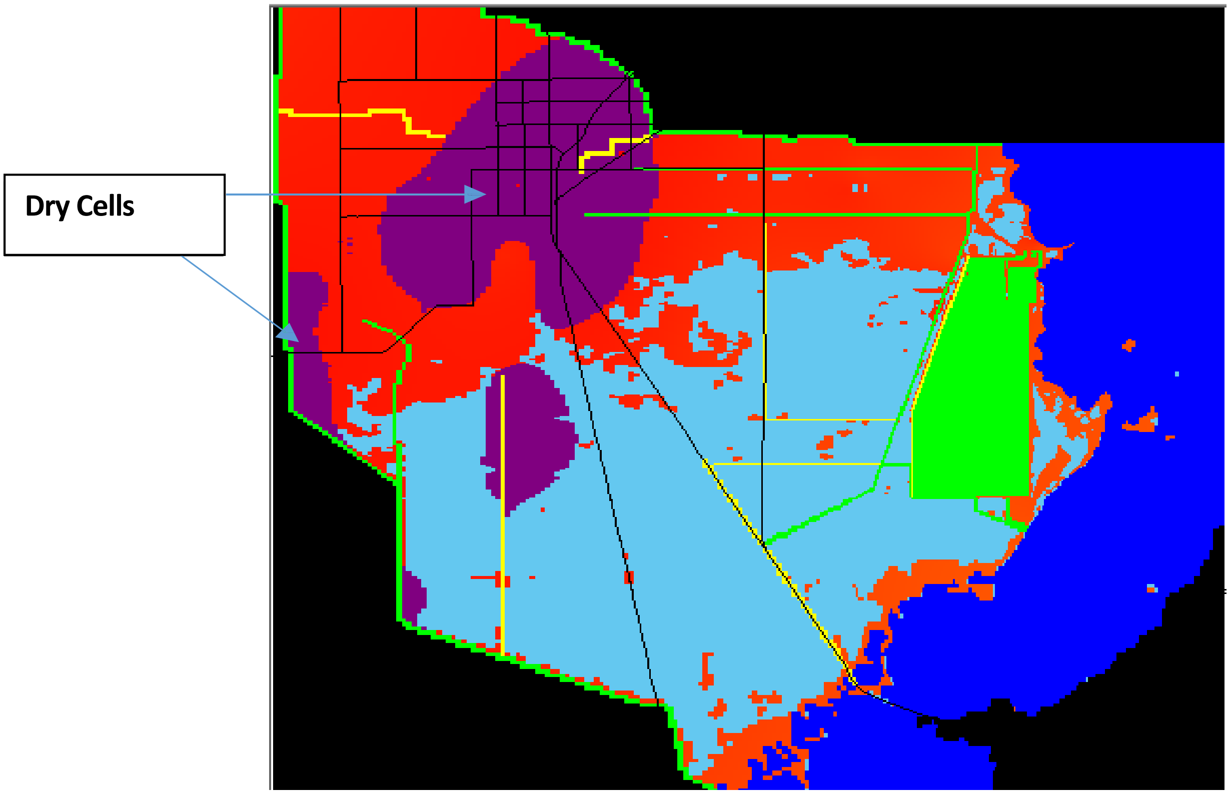


Figure 2. Dry cells in model Layer 1 at the end of stress period 1 in the monthly calibration model.

Table 1 shows the heads and bottom elevations at two cells located at the active-dry cell border at the end of stress period 1 in the monthly calibration model. In MODFLOW, a cell becomes dry when the simulated water level in the cell is below the layer bottom elevation. Simulated water levels drop from 0.929 feet at cell R55 C22 to a value below -0.758 foot at the adjacent cell (R55 C23) compared to the head change (0.05 feet) in underlying Layer 2.

Table 1. Water levels and bottom elevations at selected cells at the active-dry cell area border

	Cell (55, 22)	Cell (55, 23)
Head in Layer 1 (ft)	0.929	Dry
Bottom Elevation (ft)	-0.735	-0.758
Head in Layer 2 (ft)	0.893	0.846

Observation of the dry cells indicates that the river conductance along the C-111 canal, where dry cells are present, may be too low. The larger dry cell areas, appearing only in Layer 1 may not affect the simulation results but the model developers should investigate the reason for the dry cells.

In addition to the dry cells, the model results also showed large areas where the cells were “flooded” when calculated water levels were above the land surface. The flooded cells may be caused by inadequately accounting for evapotranspiration in the model’s “net recharge” approach or by using non-representative hydraulic parameters in the shallow layers. Monthly net recharge rates at a selected location (R155 C21) are presented on Figure 4.

The model results also show a large area of drawdown due to withdrawals from the FKAA wellfield (Figure 3). Such a large extent of cone of depression is not consistent with field measurements and likely represents an inaccurate simulation of the wellfield influence in an area of extremely high transmissivity. The effect of model boundary interference with wellfield drawdown may also be indicated.

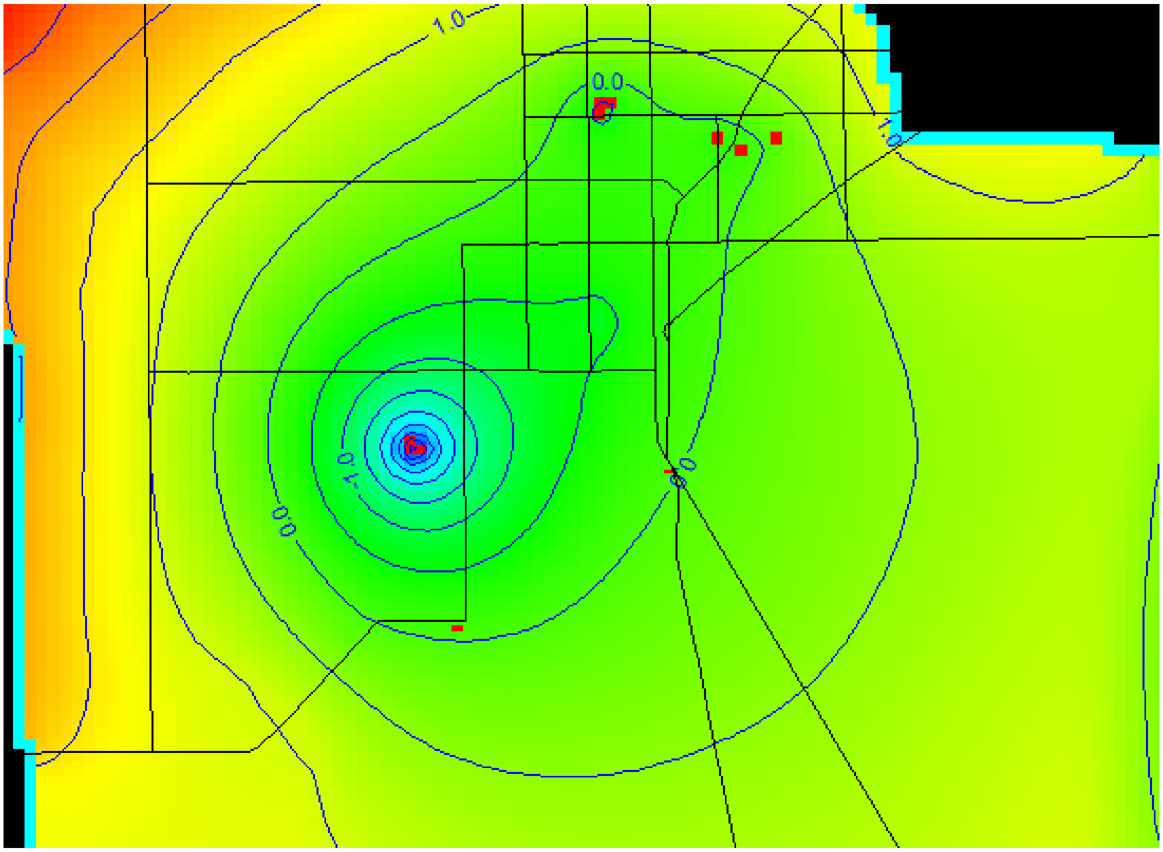


Figure 3. Simulated water levels (ft, NGVD) for December 2015, in Layer 8.

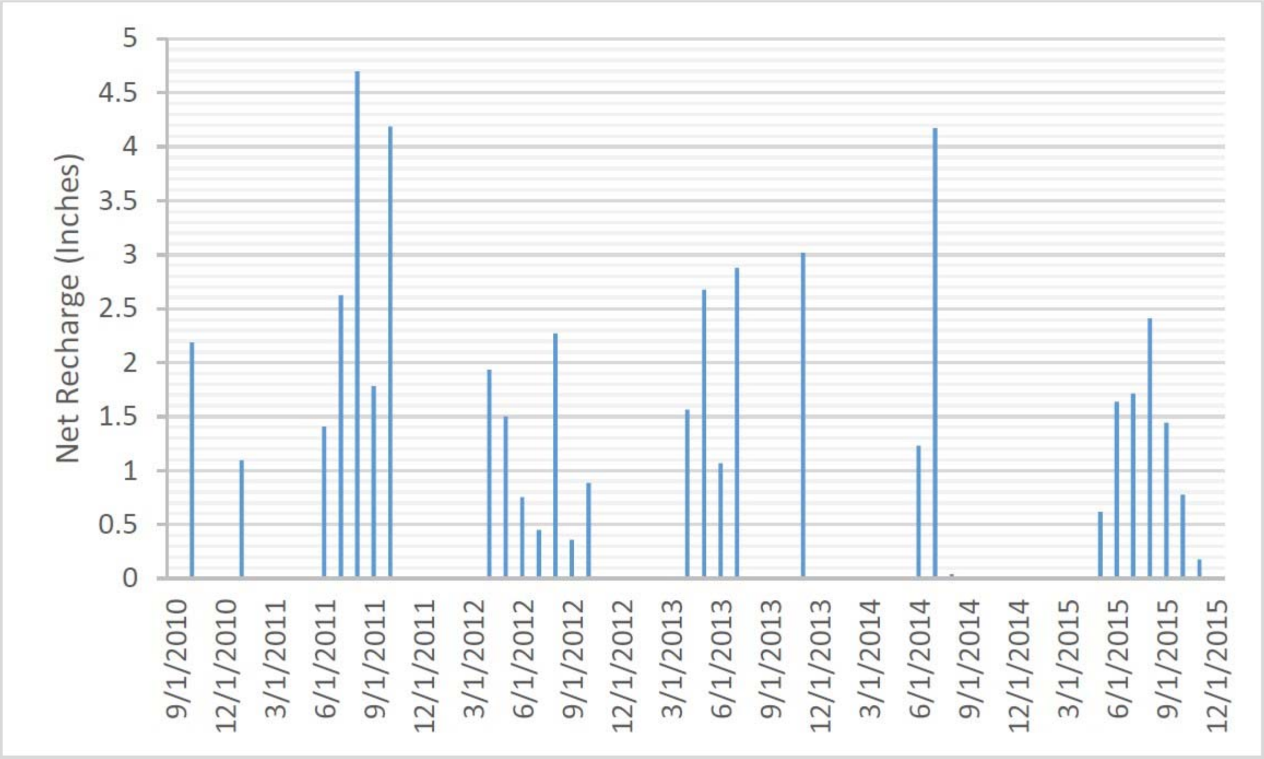


Figure 4. Net recharge (inches/season) applied in monthly calibration model.

3.4 Prediction Models

The calibrated SEAWAT model was used to assess 18 remediation scenarios. Seven general scenarios were evaluated and within some of the general scenarios, a number of different configurations were simulated. Each scenario is a 10-year simulation. The hydrologic stresses and boundary conditions of each scenario were derived from the period of 2011 to 2015, simulated in the monthly SEAWAT model and repeated one time. The 2011-2015 timeframe experienced reasonably wide-ranges of environmental conditions (dry and wet conditions) for model evaluation purposes.

Four remediation scenarios were selected for evaluation as part of this review. The selection of these four scenarios was based on the highest total “Rank Matrix” scores shown in the Power-Point presentation (Rose and Andersen, 2016). Among all of the scenarios, Alternative 3 (configurations ALT3B, ALT3C and ALT3D) were identified by Tetra Tech as the “superior alternatives.” Alternative 3 involved one year of extraction at 15 MGD from the base of the Biscayne Aquifer adjacent to the Underground Injection Control (UIC) well followed by 9 years of pumping at a combined rate of 15 MGD from a number of extraction wells spaced approximately 2000 feet apart along the western edge of the CCS.

Scenario ALT3B

Proposed extraction wells were open to model Layers 10 and 11. The locations of these wells are shown on Figure 5.

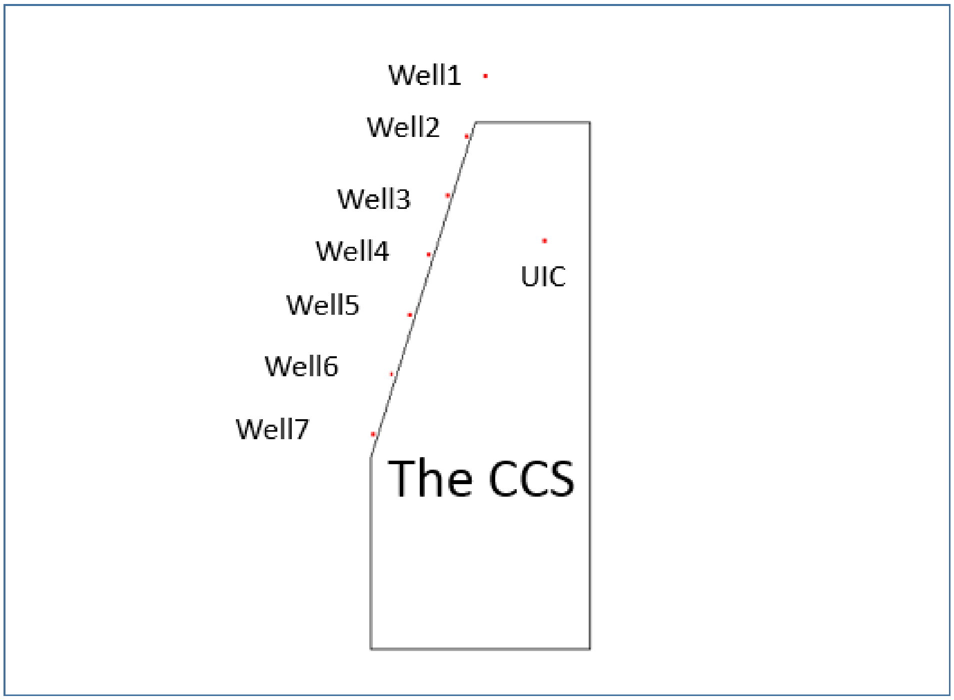


Figure 5. Location of proposed extraction wells in ALT3B.

The extraction rates for each of these wells are shown in the table below. A total extraction rate of 15 MGD is applied. In the first year, 15 MGD is to be extracted from the base of Biscayne Aquifer (Layers 10 and 11) from a single well located near the UIC disposal well. Then, all the pumping is shifted to the 7 extraction wells located along the western edge of the CSS. The pumping rates assigned to the extraction wells are summarized in Table 2.

Table 2. Proposed extraction rates (ALT3B)

ID	Row	Column	Layer 10	Layer 11	Sum (ft3/day)	Sum (MGD)	Active
Well1	66	179	-107565.1	-178893.22	-286458.32	2.1427	Years 2-10
Well2	82	174	-103984.37	-182473.95	-286458.32	2.1427	Years 2-10
Well3	98	169	-120169.26	-166289.05	-286458.31	2.1427	Years 2-10
Well4	114	164	-116588.53	-169869.78	-286458.31	2.1427	Years 2-10
Well5	130	159	-90377.598	-196080.72	-286458.318	2.1427	Years 2-10
Well6	146	154	-74622.391	-211835.92	-286458.311	2.1427	Years 2-10
Well7	162	149	-75052.078	-211406.24	-286458.318	2.1427	Years 2-10
Total					*-2005208.21*	*14.9990*	
Near UIC	110	195	-504309	-1500898.3	-2005207.3	14.9990	Year 1

Scenario ALT3C

Scenario ALT3C has a similar overall design to Scenario ALT3B but with a slightly revised configuration. The well locations for ALT3C are shown in the Figure 6 and extraction rates are tabulated in Table 3. The extraction has one well pumping in the first year at a rate of 15 MGD at the UIC well location and 7 wells along the west side of the CCS pumping at a total 15 MGD in simulation years 2 through 9.

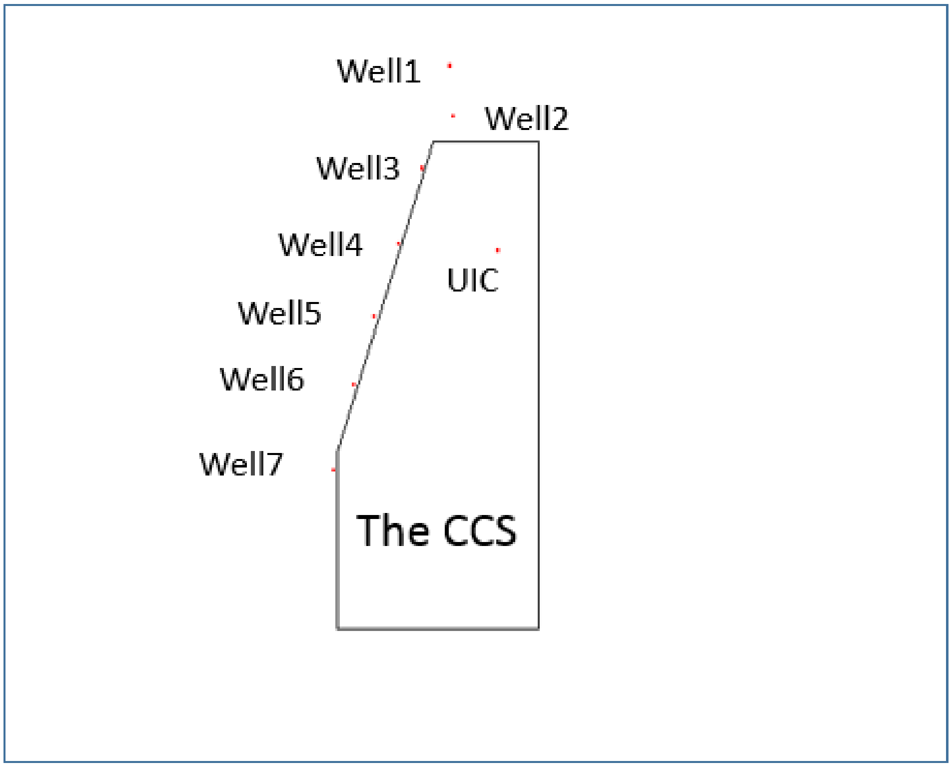


Figure 6. Location of proposed extraction wells in ALT3C.

Table 3. Proposed extraction rates (ALT3C)

ID	Row	Column	Layer 10	Layer 11	Sum (ft3/day)	Sum (MGD)	Active
Well1	57	181	-115872.39	-170585.93	-286458.32	2.1427	Years 2-10
Well2	71	182	-102981.76	-183476.55	-286458.31	2.1427	Years 2-10
Well3	86	173	-106922.18	-179466.13	-286388.31	2.1422	Years 2-10
Well4	108	166	-126757.8	-159700.51	-286458.31	2.1427	Years 2-10
Well5	129	159	-92096.348	-194361.97	-286458.318	2.1427	Years 2-10
Well6	149	153	-73763.016	-212695.30	-286458.316	2.1427	Years 2-10
Well7	174	147	-77343.745	-209114.57	-286458.315	2.1427	Years 2-10
Total					-2005138.2	14.9984	
Near UIC	110	195	-504309	-1500898.3	-2005207.3	14.9990	Year 1

Scenario ALT3D

Figure 7 shows the well configuration of ALT3D. Although the total extraction rate of 15 MGD remains the same as in ALT3B and ALT3C, 11 extraction wells were proposed: one near the UIC well and 10 extraction wells along the western edge of the CCS area. According to the performance "Ranking Matrix" (Tetra Tech, 2016), ALT3D has the highest performance score among 15 simulated remediation scenarios.

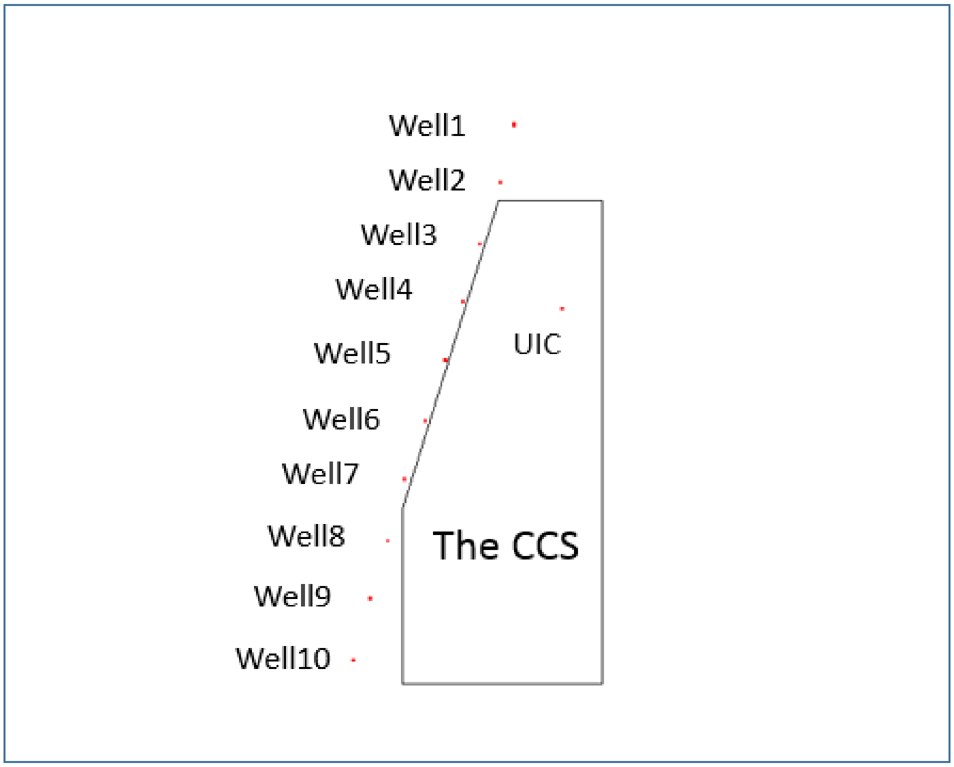


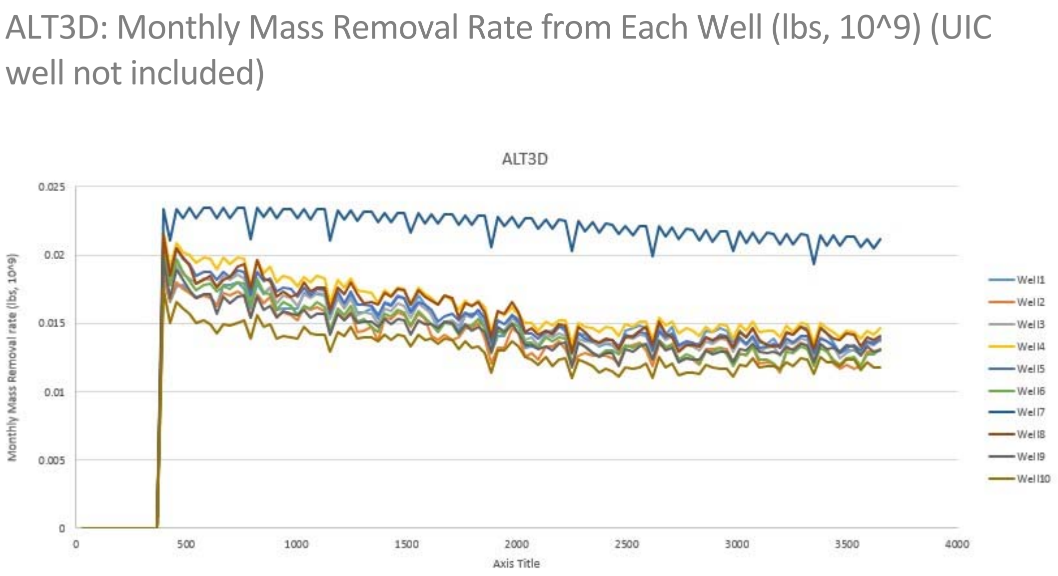
Figure 7. Location of proposed extraction wells in ALT3D.

The performance of individual extractions (except the near UIC well), at the monthly mass removal rate, is shown on Figure 8. The proposed extraction rates for ALT3D scenario is provided in Table 4. It seems most of these proposed extraction wells behave similarly except for Well 7. The reason for better performance at Well 7 should be investigated. It follows that optimal location of proposed extraction wells may be determined by looking into the performance of each well.

Table 4. Proposed extraction rates (ALT3D)

ID	Row	Column	Layer 10	Layer 11	Sum (ft3/day)	Sum (MGD)	Active
Well1	57	181	-81110.672	-119410.15	-200520.822	1.4999	Years 2-10
Well2	73	177	-72388.016	-128132.8	-200520.816	1.4999	Years 2-10
Well3	91	171	-78604.161	-121916.66	-200520.821	1.4999	Years 2-10
Well4	108	166	-88730.463	-111790.36	-200520.823	1.4999	Years 2-10
Well5	125	161	-68177.079	-132343.74	-200520.819	1.4999	Years 2-10
Well6	143	155	-53238.278	-147282.54	-200520.818	1.4999	Years 2-10
Well7	169	149	-52837.236	-147683.58	-200520.816	1.4999	Years 2-10
Well8	178	144	-56145.829	-144374.99	-200520.819	1.4999	Years 2-10
Well9	195	139	-55243.486	-145277.33	-200520.816	1.4999	Years 2-10
Well10	213	134	-54341.142	-146179.68	-200520.822	1.4999	Years 2-10
Total					-2005208.19	14.9990	
Near UIC	110	195	-504309	-1500898.3	-2005207.3	14.9990	Year 1

Figure 8. Performance of individual extraction wells in ALT3D (near UIC well is not shown).


ALT3D: Monthly Mass Removal Rate from Each Well (lbs, 10^9) (UIC well not included)

Scenario ALT4

In Scenario ALT4, six horizontal wells are proposed, in addition to the deep Biscayne Aquifer well near the UIC well. Total extraction rate is just under 15 MGD. The location of these wells are shown in Figure 9. Each of the horizontal wells were modeled as wells in three consecutive model cells. A horizontal well is typically modeled in MODFLOW as a series of cells with a high value of hydraulic conductivity. Since the horizontal wells were modeled as "wells," pumping rates were specified for each well cell as shown in Table 5. In reality, however, the flow to a horizontal well depends on a number of factors: aquifer permeability, head gradient, well size, skin effects, etc. that are typically unknown before some form of field-testing is conducted as part of the horizontal well construction process.

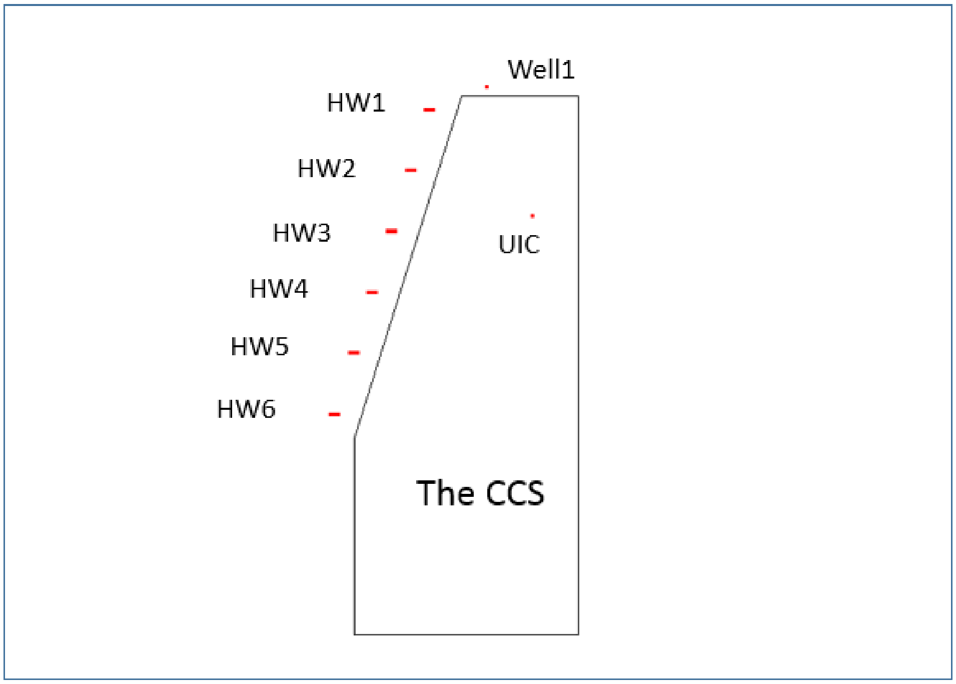


Figure 9. Location of proposed extraction wells in ALT4.

Table 5. Proposed extraction rates (ALT4)

ID	Row	Columns	Segment1	Segment2	Segment3	Sum (ft3/day)	Sum (MGD)	Active
Well1	76	183	-186785.14	n/a	n/a	-186785.14	1.3972	years 210
HW1	82	167-169	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 2-10
HW2	98	162-164	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 210
HW3	114	157-159	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 2-10
HW4	130	152-154	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 2-10
HW5	146	147-149	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 2-10
HW6	162	142-144	-57291.663	-114583.33	-114583.33	-286458.323	2.1427	years 2-10
Total						-1905535.078	14.2534	
			Layer 10	Layer 11				
Near UIC	110	195	-504309.86	-1500898.3		-2005208.16	14.9990	Year 1

4. DISCUSSION

Several issues were identified during this model review. Some of the issues may affect the validity or usability of the prediction models.

A. River Conductance

The CCS is modeled using the MODFLOW RIVER package. This package allows water exchange between surface water and groundwater. Three input parameters (river stage, riverbed conductance and river bottom elevation) are used to define a river cell. The flow between a river cell and the underlying aquifer is calculated using the following equation:

$$Q=C \times (DH)$$

Where, DH (L) is the head difference between the river cell and underlying aquifer, Q (L^3/T) is the flow, and C is the riverbed conductance (L^2/T), which is a lumped parameter of riverbed hydraulic conductivity and riverbed geometry. In SEAWAT, the salinity and temperature can be specified for the water within the river.

In MODFLOW, a river cell is also treated as an unlimited sink or source of water. MODFLOW does not track how much water is in a river cell. Therefore, a river cell could provide an unrealistic amount water to the aquifer and vice versa. Since the flow is proportional to the difference in head, the use of appropriate conductance values is critical. Rarely measured in the field, river conductance is typically a model parameter that may be adjusted during the model calibration process.

The CCS simulation was activated in the 10th stress period of the Seasonal Calibration model (which corresponds to late 1972). From that time, the river cells representing the CCS are active throughout the rest of the transient model calibration period (1968-2016) and remain active in all of the prediction models (10 years). During most of the transient model calibration period, relatively high values of river conductance values were assigned to the river cells representing the CCS. According to the model technical memorandum, the heads, salinity and temperature assigned to each river cell in the CCS were based on field-measured data.

For illustration purposes, a randomly selected location within the CCS (Row 154, Column 180) is shown in Figure 10. Simulated water levels changes and concentration changes in the canal and Layers 1 through 11 are shown on Figures 11 through 15.

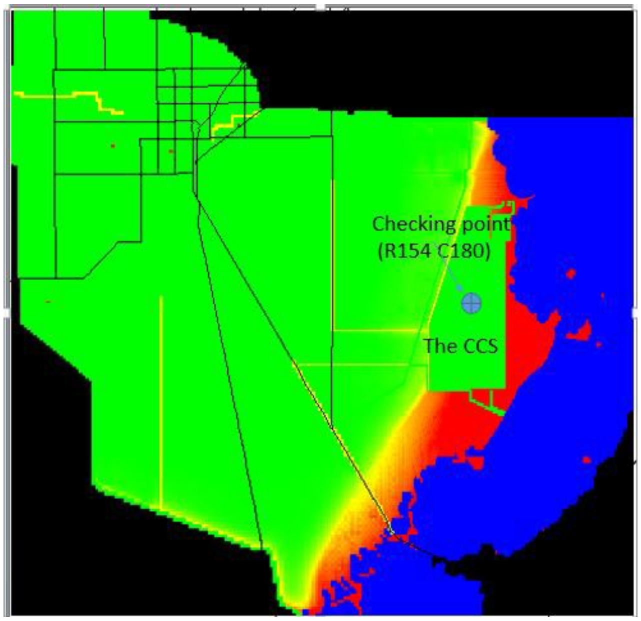


Figure 10. Location of checking point.

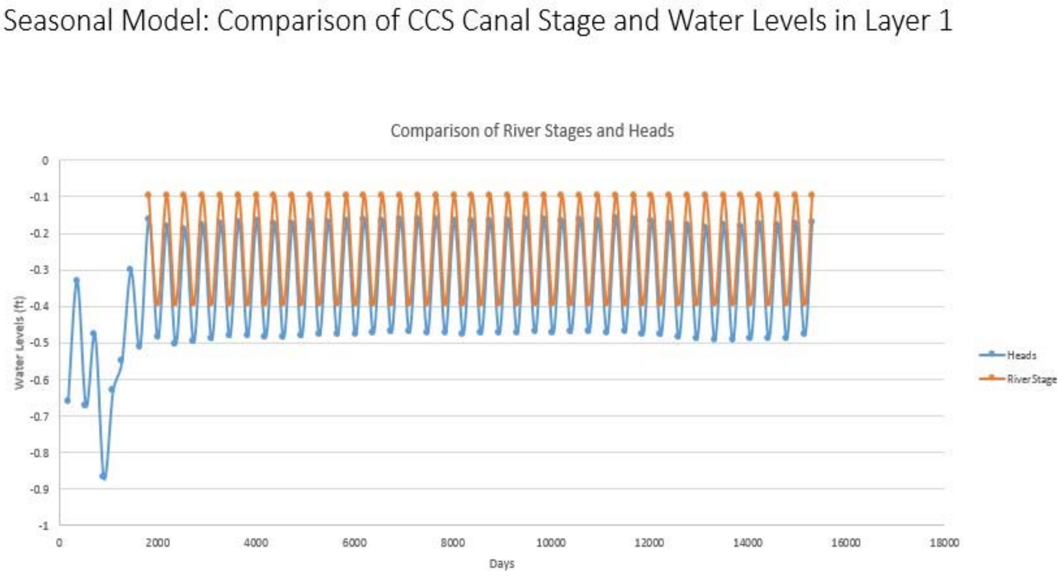

Seasonal Model: Comparison of CCS Canal Stage and Water Levels in Layer 1

Figure 11. Simulated head changes in model Layers 1-4 in seasonal calibration model.

For most of the calibration period, the river conductance at the selected location is 16,667 ft^2/day and the water levels in the aquifer below the CCS show a close synchronized pattern with the stages assigned for the CCS. It is noted that

Layers 1 through 11 are hydraulically well connected and water levels in these layers fluctuate in a similar fashion. As indicated on Figure 11, a slight offset of about 0.05 feet is noted between the simulated water level in Layer 1 and stage values in the canal. The salinity in the aquifer is also very similar to the salinity specified in the CCS at the selected location as indicated on Figures 14 and 15.

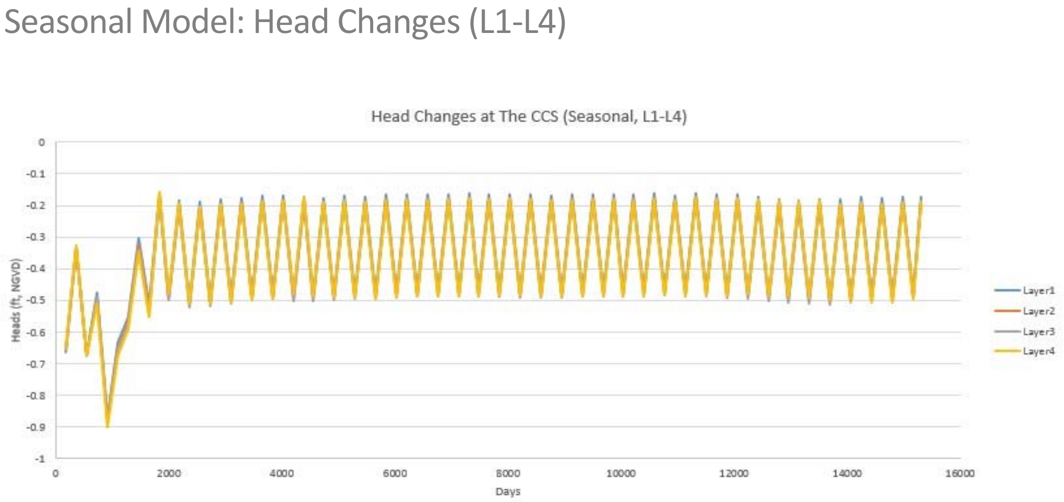


Figure 12. Simulated head changes in model Layers 1-4 in seasonal calibration model.

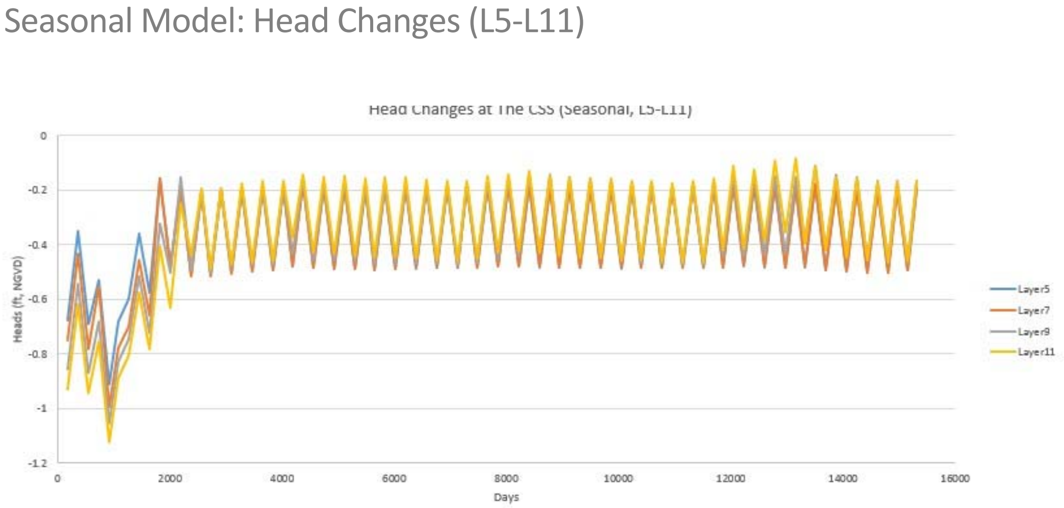


Figure 13. Simulated head changes in model Layers 5-11 in seasonal calibration model

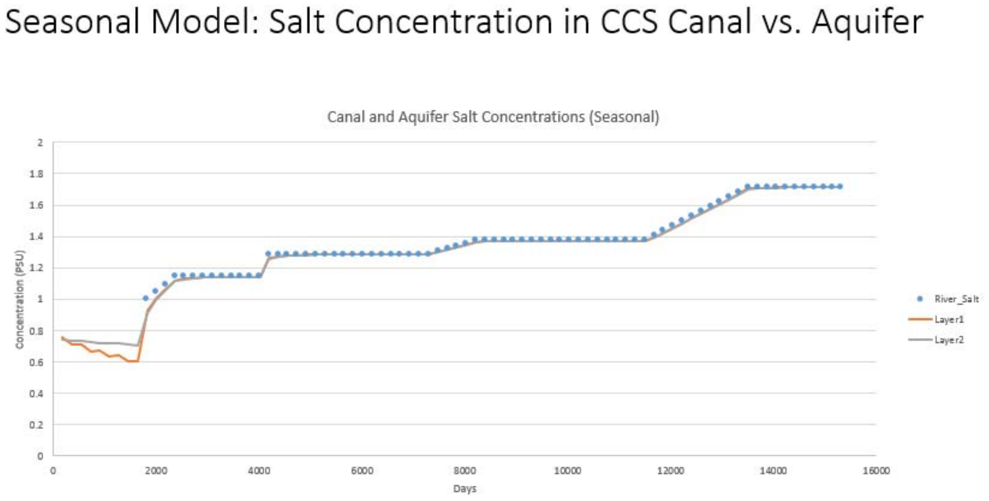


Figure 14. Simulated salt concentration changes in the CCS and model Layers 1 and 2 in seasonal calibration model.

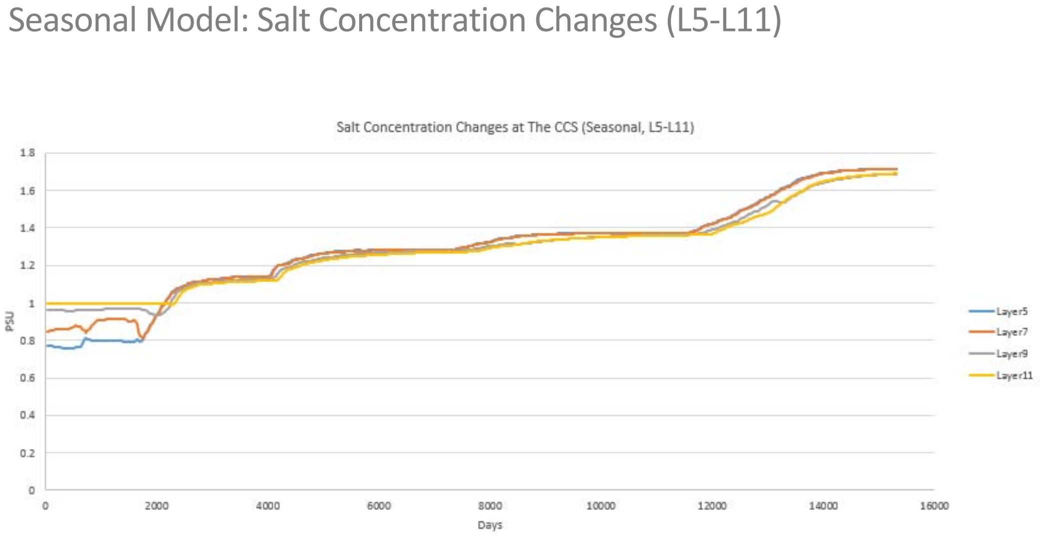


Figure 15. Simulated salt concentration changes in model Layers 5, 7, 9, and 11 in the seasonal calibration model.

According to the technical memorandum, the river conductance in the CCS were "calculated using the appropriate layer hydraulic conductivities and either the GIS-based surface area of the surface water feature (for the canal bottoms) or the lateral exposed area (for the vertical canal-aquifer interfaces)." Review of the CCS river cells, shows that the river conductance values specified for the CCS are, in general, quite high, on the order of 1X10^{-3} to 1X10^{-4} ft^2/day. However, for reasons not indicated in the report, the river conductance values for the CCS were reduced significantly toward the end of the monthly calibration period during Stress Period 38, corresponding to November, 2013. The sudden change in river conductance value, at the randomly selected check point (R154, C180) is shown in Table 6.

Table 6. River conductance for the CCS canal at R154 C180

Stress Period	Row	Col	Stage (ft)	Conductance (ft2/d)	Bottom Elev. (ft)
31	154	180	-0.26876	16667	-3.77
32	154	180	-0.13292	16667	-3.77
33	154	180	-0.15232	16667	-3.77
34	154	180	-0.19454	16667	-3.77
35	154	180	-0.28552	16667	-3.77
36	154	180	-0.27359	16667	-3.77
37	154	180	-0.2862	16667	-3.77
38	154	180	-0.27312	667	-3.77
39	154	180	-0.27745	667	-3.77
40	154	180	-0.49713	667	-3.77
41	154	180	-0.64699	667	-3.77
42	154	180	-0.81633	667	-3.77
43	154	180	-0.94633	667	-3.77
44	154	180	-0.70736	667	-3.77
45	154	180	-0.69858	667	-3.77
46	154	180	-0.49237	667	-3.77

The river conductance at this location was reduced by approximately 96%. The change from 16,667 ft^2/day to 667 ft^2/day may suggest a possible data processing error or change in model assumptions for the remediation simulations. The conductance for most of the river cells representing the CCS, if not all, seem to have a similar reduction. The large change in river conductance for the CCS may not have significantly affected the overall model calibration statistics since the change was made towards the end of the calibration period, and it seems to have occurred only at the CCS area. However, the change indicates a very different set of conditions for the remediation simulations as compared to the model calibration efforts. The impact of this change may also significantly affect the simulation results as shown in Figures 16 and 17.

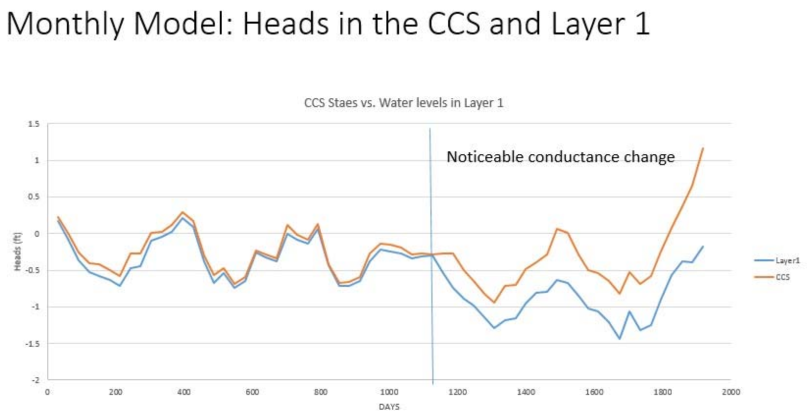


Figure 16. Simulated water levels in the CCS canal and model Layer 1 in monthly calibration model.

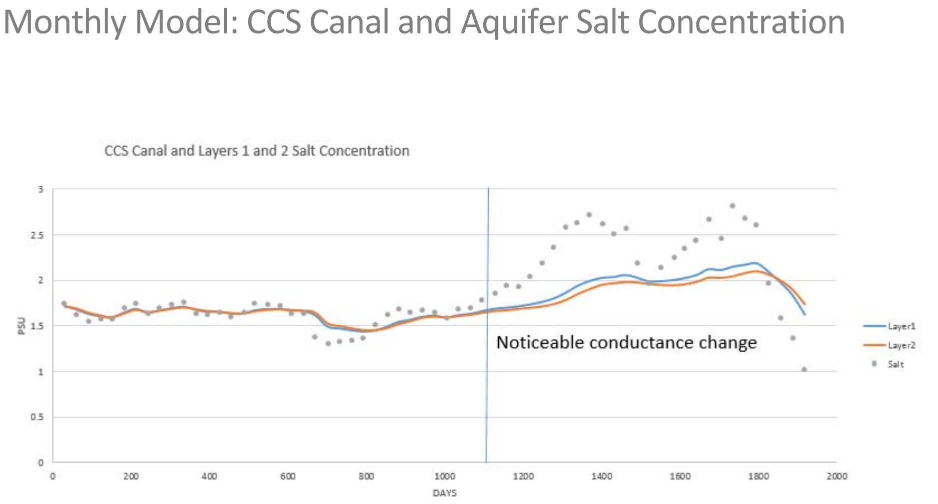
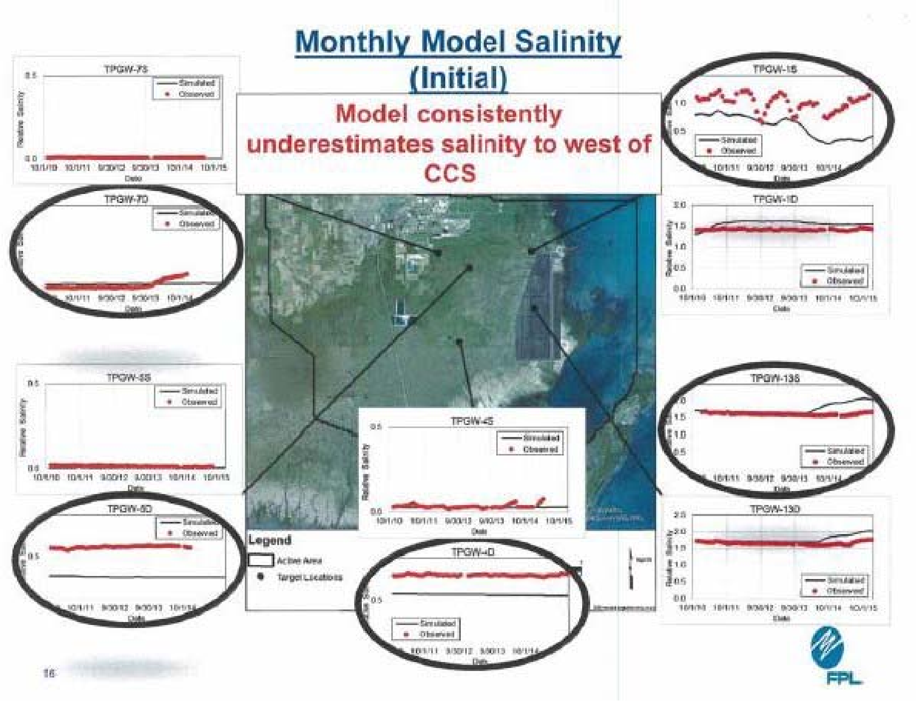


Figure 17. Simulated salt concentration changes in the CCS canal and model Layers 1 and 2 in the monthly calibration model.

Review of the figures indicates that the simulated heads and salinity start to deviate from the values specified in the CCS after the river conductance values are reduced. This impact is also observed in the model calibration time series (from the Tetra Tech PowerPoint presentation presented as Figure 18).



Monthly Model Salinity (Initial)

Model consistently underestimates salinity to west of CCS

Figure 18. Salinity calibration results of the monthly model (Tetra Tech, 2016).

As shown above, simulated salinity values in the calibration target monitor wells, TPGW-13S and TPGW-13D, started moving away from observed values at approximately the end of 2013. Another monitoring well, TPGW-7D, located a significant distance away from the CCS, also showed a similar pattern change. The revised river conductance values for the CCS were used in all of the predictive models. This is a concern. The change of the river conductance beneath the CCS was significant and made at a very late stage of the model calibration period. The reduced river conductance may not be representative of actual field conditions and was not considered during most of the model calibration period. The validity of the prediction scenarios are therefore placed in question because of the significance of the change and the late stage of the change in the area most critical for performance evaluation of the proposed remediation measures.

B. Constant Hydraulic Properties

Vertically, the model has 11 layers to represent the Biscayne Aquifer. Constant values of hydraulic parameters (horizontal and vertical hydraulic conductivity and specific yield/storativity) were used for each of the model layers. However, much data has been collected within the Biscayne Aquifer showing high degrees of variability across Miami-Dade County. It is not clear why the spatial variations of hydraulic parameters were not represented in this model considering aquifer heterogeneity could significantly affect the groundwater flow and solute transport processes especially in local scales.

C. Inactive Areas, Dry cells and Flooded Cells

A large area of dry cells is present at the west side of the model. When the cells become dry, no flow or solute transport will be simulated in the cells for subsequent time steps. In addition, a large portion of model area is flooded. These dry cells or flooded cells may not be critical for the purpose of this modeling study, but they may indicate more serious issues, such as issues with the net recharge approach and/or poorly calibrated hydraulic parameters.

D. Pumping Rate and Locations

In all of the alternatives reviewed, an extraction rate of 15 MGD was proposed from one well completed near the UIC well within the base of the Biscayne Aquifer for the first year of remediation. Although it is simple to have a well with such a pumping rate built into a numerical model, it may not be practical to install a well with such a capacity. Fish and Stewart (1991) showed the highest pumping rate reported for wells tapping the Biscayne Aquifer is approximately 10 MGD, and in practice, individual well withdrawal rates are typically limited to 5 MGD from the Biscayne Aquifer. In addition, the groundwater under the CCS has a much higher salinity (about 1.8 PSU or 63,000 mg/l) thus a higher fluid density (1045 kg/m3) than freshwater, so it would be more difficult to pump the saline water at this rate from one well.

Additionally, all of the extraction scenarios had an approximate total pumping rate of 15 MGD, which correlates to the permitted capacity of the existing injection well at the facility. While a limitation of 15 MGD has practical value in utilizing existing infrastructure for disposal of the extracted hypersaline fluids, it would be of interest to see if other extraction rates not restricted to existing disposal limitations yield better remedial results.

It would be of interest to see if a higher efficiency of extraction of the hypersaline plume and seaward movement of the saline water interface could be achieved with the location of the extraction wells more towards the middle of the hypersaline plume. It would also be beneficial to look at the mass removal rate of each extraction well, as shown in Figure 8 for ALT3D, to optimize the remediation system design.

E. Salinity in CCS

As shown on Figure 15, the maximum salinity in the CCS simulated in the seasonal model is about 1.8 PSU. It is relevant to note that salinity as high as 3.0 PSU has been reported for CCS (Chin, 2015). Higher salinity, up to about 2.7 PSU as shown in Figure 17, was applied to the CCS in the monthly model. However, due to change in canal conductance at that time, the salinity in deeper layers appears to not be impacted by the salinity in the CCS. It needs to be understood why the simulated salinity does not match the observed peak salinity values in the canal and how the low conductance in canal post 2013 is affecting the salinity in lower model layers.

F. Flow from GHB Cells

General head boundary (GHB) was applied along the model active area in most model layers to represent the hydraulic connection between the model domain and its surrounding hydrogeological units. The flow in and out these GHB cells should be checked as part of mass balance analysis to ensure the amount of water entering into the model is realistic.

G. Canal Representation using Drain Package

The Card Sound Canal was represented in the model using the Drain package. Drain cells allow water to move from aquifer to the drain cells but not vice versa. Use of the Drain cell approach does not allow the model to simulate saltwater intrusion that may occur in the area surrounding the Card Sound Canal.

H. Net recharge Approach

A net recharge approach was carried out for representation of the major water balance elements of rainfall, runoff, evaporation, and transpiration. A positive recharge means the recharge reaches the water table and a "negative recharge" indicates the aquifer is losing water (ET is greater than the natural recharge). Negative recharge rates were “ignored” by assigning the recharge rate as zero with the assumption that under a negative recharge scenario, “the maximum ET rates would not be realized due to insufficient rainfall.” The approach is generally used when the parameters for MODFLOW EVT (evapotranspiration) package and or the surface runoff are difficult to quantify. However, the approach may underestimate water losses due to ET in the dry season.

5. CONCLUSIONS AND RECOMMENDATIONS

Overall, it appears that a significant amount of work was conducted to develop these data-intensive, variable-density models. Most assumptions and approaches used during model development seem to be reasonable and the model development followed the general standard procedures. The model calibration seems reasonable. The calibration results indicate that the model-calculated water levels and salinity are in general agreement with the field data.

However, the following concerns need to be addressed or resolved before the model can be used for remedial design purposes.

- Assigning spatially varying hydraulic parameters to model layers should be considered since it could affect the flow and transport significantly.

- The varying rates of net recharge part way through the calibration period is not clearly tied to calibration efforts. Some explanation for these changes are required.

- The occurrence of "dry cells" and "flooded cells" over large portions of the model domain raise concerns about the appropriateness of model assumptions and/or inputs and could be an issue for overall model accuracy and reliability for predictive application.

- The change of river conductance at the CCS is a major concern. The changes are significant, late in the simulation period. The issue is identified at locations most critical for the performance evaluation of the various remedial alternatives. The change of river conductance may require the model to be recalibrated or the proposed remediation scenarios be reevaluated if the change is not supported by actual field data.

- It is recommended to consider practical well capacities for the proposed extraction wells in the remediation scenarios. To optimize the remediation designs, the performance of individual extraction wells may be assessed by checking the mass removal rates or particle tracking methods.

- Using the MODFLOW Drain package to simulate Card Sound canal should be reconsidered.

One of the objectives for the model development was to "ameliorate the westward movement of the saltwater and hypersaline water interface in the Biscayne aquifer." Proposed extraction wells in the scenarios reviewed indicated removal of salt from the aquifer and some mitigation of the westward extent of the hypersaline plume. However, none of the analyses indicated if these proposed remediation systems would sufficiently prevent the further westward migration of the saltwater interface west of the hypersaline water plume.

6. REFERENCES

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