MIAMI-DADE COUNTY
Carlos A. Gimenez, Mayor

Department of Regulatory and Economic Resources
Environmental Resources Management
701 NW 1st Court, 4th Floor
Miami, Florida 33136-3912
T 305-372-6700 F 305-372-6982

miamidade.gov

September 29, 2016

CERTIFIED MAIL NO. 7013 2630 0001 2419 4052
RETURN RECEIPT REQUESTED

Matthew J. Raffenberg
Director of Environmental Licensing and Permitting
Environmental Services Department
Florida Power & Light Company
700 Universe Blvd (JES/JB)
Juno Beach, FL 33408

Re: Proposed Groundwater Water Recovery System and Supporting Groundwater Model for the FPL Turkey Point power plant facility and Cooling Canal System (CCS) located at, near or in the vicinity of 9700 SW 344 Street, Miami-Dade County, Florida (DERM HWR-821, IW-3 & IW-16).

Dear Mr. Raffenberg :

On May 16, 2016, FPL submitted a three-dimensional, variable density dependent transient groundwater flow and transport Model (the Model) and a proposal for a groundwater recovery well system in fulfillment of paragraph 17.b. of the October 7, 2015 Consent Agreement (CA) between Miami-Dade County and FPL. On May 23, 2016, June 10, 2016, and July 14, 2016, FLP submitted supplemental information in support of the May 16, 2016 submittal.

Miami-Dade County, through the Department of Regulatory and Economic Resources' Division of Environmental Resources Management (DERM), with technical assistance from Miami-Dade County Water and Sewer Department and the University of Florida's School of Civil and Coastal Engineering (MDC Technical team), has reviewed the above mentioned submittal along with the supplemental information and provides the attached report along with the following comments:

1. Groundwater Flow and Transport Model

A. The Model and codes developed by FPL's team are appropriate for the intended application of supporting the design of a recovery well system to address the hypersaline plume (the Plume) west and north of the FPL property. Notwithstanding the appropriateness of the Model, the technical team finds that a reevaluation of the following Model assumptions and approaches is required to allow for a better understanding of the hydrogeology of the study area, inform Model revision, and improve the Model's ability as a predictive tool with respect to the Plume's response to the groundwater recovery system, and therefore guide modifications to the groundwater remediation system.

   (i) The Model shall incorporate the surface water routing package developed by USGS (Surface-Water Routing (SWR) Process for Modeling Surface-Water Flow with the USGS Modular Groundwater Flow Model (MODFLOW) SWR1: http://water.usgs.gov/ogw/swr/).

(ii) The Model design shall incorporate significant water features such as quarries as well as significant recreational (e.g. golf courses) and other water users located within the Model domain.

(iii) Given the aquifer heterogeneity described in various local and regional studies relating to the Biscayne Aquifer in Miami-Dade County, the assumption of aquifer homogeneity with respect to hydraulic parameters across the Model domain shall be reevaluated. Available data (e.g. data from the WASD's Newton and Everglades Labor Camp Wellfields (copies attached) and the Florida Keys Aqueduct Authority's Wellfield) shall be utilized to evaluate and refine assumptions regarding hydraulic parameters within the Model domain.

(iv) Until the SWR package (referenced in Item 1.A.(i) above) is incorporated into the Model, the Model simulations using the River package shall properly account for the construction of the L-31E canal; specifically, the discontinuity between the northern and southern portions of the canal at the canal's intersection with the Florida City Canal.

(v) Re-evaluate the Model representation of net recharge, especially during the dry seasons, to properly account for evaporative losses.

(vi) Until the SWR package is incorporated into the Model, given that the Card Sound Canal is simulated as a drain, address how the Model accounts for the canal's contribution to the movement of the salt water interface.

(vii) Sensitivity runs shall be conducted to test the magnitude of the Model's responses on the range of simulated outputs to check changes in stresses, aquifer parameters, surface-groundwater interactions, and subsequent performance of the recommended remedial alternatives.

B. Other Review Comments

In addition to the above, the Model re-evaluation shall incorporate the applicable comments provided by the South Florida Water Management District (SFWMD) during the groundwater Modelling review meeting held at the DERM office on July 21, 2016, along with the comments provided by the Florida Keys Aqueduct Authority, included as an attachment to this correspondence.

2. Evaluation of Remedial Alternatives

The May 16, 2016 submittal and supplemental information described two different objectives for the recovery well system. Seven of the eight alternatives presented in the May 16, 2016 report targeted one or the other of the two objectives. The application of the same criteria to evaluate each option regardless of the target remedial objective results in an inherently biased screening procedure. Therefore, DERM does not concur with the matrix, ranking, and conclusions provided in the Applications Simulations Ranking Matrix.

3. Proposed Groundwater Monitoring Network

DERM has no objection to the monitoring network provided in the May 16, 2016 submittal - Turkey Point Recovery Well System Proposed Monitoring Network- and the revised proposal received on August 12, 2016 with the following modifications.

a. In addition to the new groundwater monitoring well clusters proposed FPL shall install additional well clusters within the Model Lands; specifically:

   i. An intermediate depth monitoring well located west of the proposed TPGW-17 Alt3 within the most western portion of the Plume.
   ii. A monitoring well cluster north-northwest of TPGW-12 to evaluate and monitor the behavior of the northern reaches of the Plume.
   iii. A monitoring well cluster located within the Plume west of the southernmost portion of the CCS and east-southeast of TPGW-4

   The additional wells shall be similar in design and function to the existing monitoring wells in the area.

b. Based on the location of the existing USGS wells G-3976 and G-3966 located NE and NW (well depths 107 feet) respectively of the proposed TPGW-20, DERM does not require the installation of the proposed TPGW-20 as a part of the groundwater recovery system monitoring network.

c. Based on the proposed location of the recovery well system monitoring wells L-3 and L-5 are not required to be included as a part of the monitoring program.

d. In addition, FPL shall propose a minimum number of surface water gauges within the Model Lands to evaluate potential impacts to the surrounding wetlands (i.e. hydroperiod, drawdown, stage) resulting from the operation of the groundwater recovery system.

4. Groundwater Recovery System

The information provided in the above mentioned reports indicate that the Model predicts that in the shallow and intermediate layers of the aquifer the proposed groundwater recovery system, represented by Alternative 3D, is capable of achieving the goals of interception, capture, containment and retraction of the Plume to the property boundary within the timeframe provided in the Model simulation. However, the Model simulation indicates that the eastern retraction of the Plume in the deep layers of the aquifer is not achieved under any of the contemplated alternatives.

Regardless of the above observations, DERM finds that the remedial system design proposed as Alternative 3D is a necessary component to any groundwater system to address the requirements of intercepting, capturing, containing and retracting the plume to the Property boundary pursuant to paragraph 17.b. of the CA. Based on the above, and given the urgency to initiate actions to address the Plume, while recognizing the need to collect additional data to conduct additional analysis and to refine the groundwater model for the purposes provided in Item 1.A. above, DERM hereby approves the conceptual design for the implementation of a Phase 1 groundwater recovery system as described in Alternative 3D, subject to the following conditions:

A. This approval is not intended to limit FPL's ability to initiate, prior to the implementation of the recovery system to be located west the FLP property boundary, one year of extraction from the base of Biscayne aquifer beneath CCS and adjacent to the Underground Injection Control (UIC) via the installation of a recovery well associated with the construction of the UIC well. FPL shall provide diagrams and construction details for the recover well and associated equipment along with copies of all applicable permits or authorization obtained for the construction of the recovery well, pumping and discharge.

B. Within 120 days of receipt of this correspondence FPL shall submit to DERM for review and approval a Phase I Remedial Action Plan which shall provide:

(i) A revised Model report which incorporates the elements provided above in Items 1.A. (ii), 1.A. (iii) (as feasible), Item 1.A. (iv), Item 1.A. (v), and Item 1.A. (vi), along with applicable comments from Item 1.B.. In addition, the Model shall demonstrate, pursuant to Section 24-48 and Section 24-48.3 of the Code of Miami-Dade County, Florida and paragraph 17.b.i. of the CA, that the proposed groundwater recovery system will not create potential adverse environmental impacts on the surrounding wetland areas (hydroperiod or water stage).

(ii) Copies of any permit, approval, or letter of no objection from SFWMD, Florida Department of Environmental Protection (FDEP) or any other regulatory agency with jurisdiction over the activities related to the design, construction, or operation of any component of the groundwater recovery system.

(iii) Design details and construction plans of the proposed groundwater recovery system which incorporates the revised groundwater Model required in 4.B.(i) above and which includes:

a. Recovery well construction details
b. Recovery well spacing and location with supporting justification
c. Flow rate per recovery well
d. Pumps specifications and supporting calculations, ancillary equipment, etc.
e. Piping specifications and layout

C. Subsequent to DERM approval of the Phase I Remedial Action Plan, and no more that sixty days prior to the start up of the recovery system, FPL shall conduct a baseline groundwater assessment, which shall include:

(i) Sampling of all designated wells (as specified in the DERM Phase I RAP approval) for chlorides, conductivity, and collection of groundwater and surface water elevation measurements.

(ii) A new Continuous Surface Electromagnetic (CSEM) survey which mimic the area of interest evaluated during the January to April 2016 survey adjusted such that it provides definition of the extent of the hypersaline plume to the north and northwest of the CCS. Correlation evaluation for range of chloride concentrations encountered within the entire area of interest (i.e. not limited to the hypersaline plume) shall be provided.

A baseline assessment report shall be included in the Phase I Remedial Action Status Report described below and shall include the CSEM survey calibration and supporting data, Excel file(s) with the chloride concentrations from the groundwater monitoring wells for each interval, along with the estimated chloride concentration based on the CSEM. Additionally, chloride contours, developed using the CSEM estimation, as well as groundwater monitoring data, shall be provided for each interval of interest and encompassing the range of (1000 mg/L to max. concentration) and which depicts the extent of the 19,000 ppm chloride shall be provided. The report shall also provide an estimate of the volume and aerial extent of the hypersaline plume located west and north of the FPL property boundary.

D. Within 15 months of the implementation and start up of the groundwater recovery system and annually thereafter, FPL shall submit a Phase I Remedial Action Annual Status Report that shall include without limitation:

(i) A refined groundwater Model, which shall incorporate the elements described in Item 1.A.(i) and 1.A.(vii) above, the data collected during the first year of the recovery system operation, along with geologic information obtained during the installation of the groundwater recovery system (including the newly installed monitoring wells) to facilitate a better understanding of the hydrogeology within the study area especially with respect to the deeper layers of the aquifer beneath the Lower High Flow Zone and to improve the Model simulation of saltwater conditions throughout the full aquifer vertical profile, and the Model's capability to predict the Plume's response to the groundwater recovery system.

(ii) The first annual CSEM survey.

(iii) Groundwater quality monitoring data from each designated well and screen interval, performance statistics, mass removal calculations per recovery well, cumulative volume of hypersaline water recovered, trends in water level elevations within the Model lands, chloride concentration trends per designated monitoring well and screen interval, along with the appropriate excel tables.

(iv) Groundwater contours utilizing both CSEM and laboratory data providing chloride contours per each interval (shallow, intermediate, and deep) encompassing the range of (1000 mg/L to max. concentration) and depicting the extent of the 19,000 ppm chloride contour.

(v) Estimates of the percent reduction of the aerial extent of the plume (baseline vs. end of the year of groundwater recovery) as well as the percent reduction of the volume of the plume (baseline vs. end of the year of groundwater recovery).

(vi) Groundwater elevation and drawdown contours along with a map depicting the cone of influence of the recovery wells.

(vii) An evaluation of the correlation between chloride concentrations from the groundwater monitoring wells for each interval versus the estimated chloride concentration based on the CSEM Model predictions.

(viii) An evaluation of the performance of the groundwater recovery system related to achieving the objectives of intercepting, capturing, containing and documentation of the extent of retraction of the plume.

(ix) Based on the evaluation and conclusions of the first year of data FLP shall provide recommendations for modification(s) to optimize the groundwater recovery system (as necessary, e.g. changes to extraction rates, modification to recovery well configuration in specific sub areas) to ensure that the system will achieve the goals of interception, capture, containment and ultimate retraction of the Plume, throughout the vertical extent of the aquifer. Any recommendations for modification shall be submitted to DERM for review and approval prior to implementation.

(x) Revised 5 and 10 year Model predictions and milestones developed for years 2 through 10 to evaluate the systems performance with respect to achieving the objectives as provided by paragraph 17.b. of the CA.

The information and evaluations required pursuant to Items D.(i) through D.(x) above shall include data tables (excel format), maps and graphs as appropriate.

E. Within 90 days of the completion of the first three years of the operation of the groundwater recovery system, FPL shall submit to DERM for review and approval a Performance and Compliance Report. The report shall evaluate the performance of the groundwater recovery system with respect to achieving the objectives of intercepting, capturing, containing and documentation of the extent of retraction of the plume, and achieving milestones developed pursuant to Item 4.D.(x) above and approved by DERM. The evaluation shall be supported by the cumulative annual status reports and groundwater monitoring data along with the yearly CSEM surveys and a refined Model.

If the evaluation indicates that the recovery system has failed to accomplish the above goals, then FPL shall propose a Remedial Action Plan modification which shall contemplate without limitation; injection wells, additional recovery wells to the west, additional disposal wells, or a combination thereof, to ensure the ability of the system to accomplish the objectives of the CA. Any proposed system modification shall be supported by a refined/recalibrated Model (which shall incorporate the review comments provided pursuant to Item 1 above and any additional Model review comments submitted as provided in Item 1 above and which shall utilize all the data collected to reduce uncertainty in the Model and improve the Model abilities as a predictive tool with respect to the Plume's response to the groundwater recovery system. The Model shall provide assurance that the proposed modified system will be effective in accomplishing the objectives provided by paragraph 17.b. of the CA.

F. FPL shall submit a Performance and Compliance Report at the end of 5 year and after 10 years of system operation. The report shall demonstrate the effectiveness of the recovery well system in achieving the objectives of intercepting, capturing, containing and retracting the plume to the Property boundary, as required by paragraph 17.b. of the CA, and consistent with the approved milestones. The demonstration that the objectives have been achieved shall be supported by the cumulative annual status reports and groundwater monitoring data, along with the yearly continuous surface electromagnetic (CSEM) surveys.

The report shall be submitted to DERM for review and approval within 90 days of the specified time period.

If the Year 5 and 10 evaluation indicates that recovery system has failed to accomplish the above objectives provided by the CA then FPL shall propose a comprehensive system modification which shall include changes to the recovery system which shall contemplate without limitation; injection wells, additional recovery wells to the west, additional disposal wells, or a combination thereof, to ensure the ability of the system to accomplish the objective of the CA. Any proposed system modification shall be supported by a refined/recalibrated Model and which shall utilize all the data collected to reduce uncertainty in the Model and improve the Model abilities as a predictive tool with respect to the Plume's response to the groundwater recovery system. The Model shall provide assurance that the proposed modified system will be effective in accomplishing the objectives provided by paragraph 17.b. of the CA.

Any person aggrieved by any action or decision of the DERM Director may appeal said action or decision to the Environmental Quality Control Board (EQCB) by filing a written notice of appeal along with submittal of the applicable fee, to the Code Coordination and Public Hearings Section of DERM within fifteen (15) days of the date of the action or decision by DERM.

If you have any questions concerning the above please contact me via email at mayorw@miamidade.gov or via telephone at (305) 372 -6700.

Sincerely,

Wilbur Mayorga, P.E. Chief
Environmental Monitoring and Restoration Division

pc: Scott Burns, FPL - Scott.Burns@fpl.com
Alan Katz, FPL - Alan.Katz@fpl.com
Pete Andersen, P.E. Tetra Tech - Pete.Andersen@tetratech.com
James Ross Ph.D. Tetra Tech - James.Ross@tetratech.com
John Truitt, FDEP - John.Truitt@dep.state.fl.us
Jonathan Shaw, SFWMD - jshaw@sfwmd.gov
Jefferson Giddings, SFWMD - jgidding@sfwmd.gov
Lee Hefty, DERM Director – heftyl@miamidade.gov
Virginia Walsh, Ph.D., MDWASD – walschv@miamidade.gov
Barbara Brown, DERM – brownb@miamidade.gov
Craig Grossenbacher, DERM – grossc@miamidade.gov

Review of Florida Power & Light Turkey Point Groundwater Model

FINAL REPORT

By

Louis H. Motz, Ph.D., P.E., D.WRE
Department of Civil and Coastal Engineering
University of Florida
Gainesville, Florida, USA 32611

For

Department of Regulatory and Economic Resources
Miami-Dade County, Florida

September 2016

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1.0 BACKGROUND

Florida Power and Light (FPL) has operated the cooling canal system (CCS) at the Turkey Point Plant in southern Miami-Dade County since the 1970's (written communication, Miami-Dade County Department of Regulatory and Economic Resources, February 23, 2016). The CCS, which consists of a 5,900-acre network of unlined canals, serves as a heat exchange for the power plant units at Turkey Point. An 18-foot deep ditch [the interceptor ditch (ID)] located west of the cooling canal system was constructed and designed to provide a shallow hydraulic barrier to prevent the inland westward migration of water from the CCS. As part of the regulatory requirements, FPL is required to conduct groundwater and surface-water monitoring to evaluate the impact of the CCS on the surrounding environment. This monitoring has documented that saline water, with chloride concentrations that exceed regulatory standards and criteria, has migrated westward from the CCS resulting in a groundwater plume that extends several miles inland and that within the deeper portions of the Biscayne Aquifer, a plume of hypersaline groundwater [>19,000 milligrams per liter (mg/L) of chlorides] attributable to the CCS operations extends approximately two miles inland (see Figure 1).

On October 7, 2015, FPL entered into an Administrative Consent Agreement (CA) with Miami-Dade County. The CA required FPL among other items to develop a three-dimensional transient variable-density groundwater-surface-water model to simulate the behavior of the aquifer and surface water system within the study area, particularly as it relates to the response of the hypersaline plume to groundwater extraction, and to utilize the model to guide the design of an aquifer recovery (ARS) to intercept, capture, contain, and retract the hypersaline groundwater to their property boundary while minimizing negative impacts to the ecological resources in the area (e.g., hydro-period changes in the surrounding wetlands). As part of the CA, FPL agreed to conduct an aquifer performance test (APT) to obtain aquifer characteristic data to aid in the model development.

2.0 SCOPE OF THIS INVESTIGATION

In support of Dade County's regulatory activities and investigations, the University of Florida (UF) was authorized on May 11, 2016 to review FPL's groundwater model and related aspects of the hypersaline plume. Specifically, UF's investigation included reviewing previous reports relevant to the hydrogeologic characteristics of the underlying Biscayne Aquifer, evaluating FPL's APT, reviewing the groundwater model to determine its appropriateness and accuracy with respect to simulating site-specific conditions and interactions as well as predicting the timeframe to retract the hypersaline plume to the property boundary, and evaluating the model's ability to support the design of FPL's proposed groundwater recovery system. Also, UF's investigation included reviewing FPL's proposed

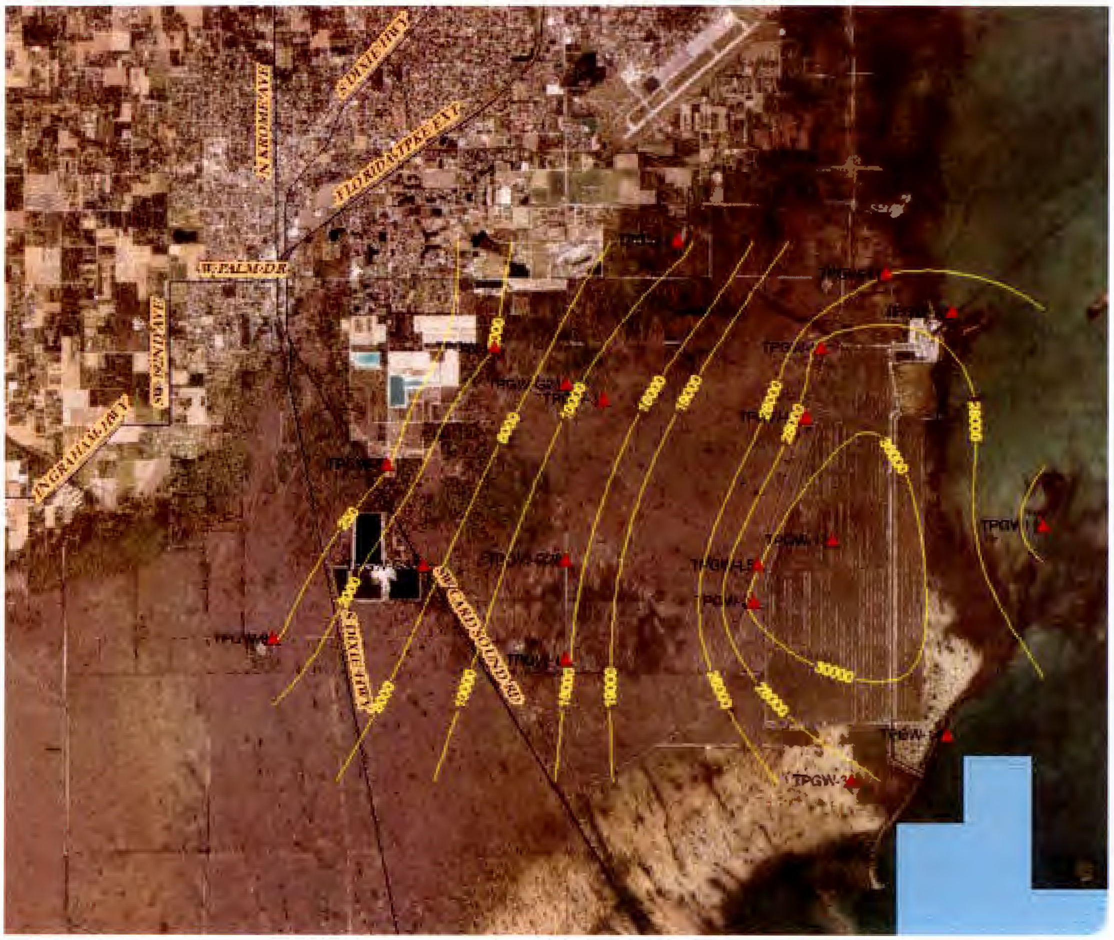

Figure 1. – Turkey Point Groundwater Chloride Contours in Deep Wells in March 2015
(source: DERM 2016)

ARS with respect to meeting the specific remedial objective of intercepting, capturing, containing, and retracting the hypersaline plume to the property boundary and also evaluating FPL's associated groundwater and surface-water monitoring program with regard to the adequacy of the monitoring program (data gaps, number and location of monitoring sites, etc.).

3.0 MODEL REVIEW

During this investigation, a number of reports, documents, and computer files were reviewed, reflecting an ongoing process by FPL and its contractors to conduct required testing and monitoring and make adjustments and improvements in the groundwater model as new information became available and improved analyses were performed. This material included presentations, reports, and data files prepared by Anderson and Ross (2016a and b), Chin (2016), Enercon Services (2016a and b), FPL (2016a, b, and c), JLA Geosciences (2010), SDI Environmental Services (2016), and Tetra Tech (2016a, b, and c). For this review, these sources were used to describe and review the groundwater model prepared by Tetra Tech for FPL, including the evolution of four versions of the groundwater model during this investigation. As described in the following sections, a summary of the groundwater model and the four versions developed during calibration by FPL and Tetra Tech was prepared, along with the results of selected simulations that were run to verify results reported by FPL and Tetra Tech. An editorial and technical review of the two principal reports prepared by FPL (2016c) and Tetra Tech (2016b and c) is included, along with a review of the groundwater monitoring proposed by FPL and a set of conclusions and recommendations resulting from this investigation.

3.1 SUMMARY OF GROUNDWATER MODEL (FOUR VERSIONS)

3.1.1 Hydrogeology and Groundwater Quality

The CCS and surrounding area at Turkey Point are underlain by the Biscayne Aquifer, which is composed of porous, very permeable limestone that consists of two primary water-bearing units (Tetra Tech 2016b). The upper water-bearing unit is the near-surface Miami Oolite, and the underlying unit is the Fort Thompson Formation. The base of the Fort Thompson Formation slopes to the east and south resulting in a wedge-shaped aquifer (HDR 2009), which is thickest in the southeast and thinner to the north and west. Well logs in the vicinity of Turkey Point indicate that the Miami Oolite and Fort Thompson Formation both contain areas with extensive tubes, channels, and voids (HDR 2009) that likely act as preferential subsurface flow paths.

The transmissivity of the Biscayne Aquifer generally is quite large based on aquifer tests that have been conducted in the vicinity of the CCS (Tetra Tech 2016b). A transmissivity of 203,256 ft^2/day was determined from an APT that was conducted near the northwest corner of the CCS (Enercon 2016a and SDI 2016), and transmissivities ranging from 700,000 to 1,200,000 ft^2/day were determined from an aquifer test conducted on Turkey Point east of the CCS (HDR 2009). Also, results from aquifer tests in the Biscayne Aquifer in southeastern Dade County have yielded transmissivity values ranging from 600,000 ft^2/day to more than 1,000,000 ft^2/day (Fish and Stewart 1991).

The distribution of saltwater in the Biscayne Aquifer beneath and in the vicinity of the CCS is determined by the presence of Biscayne Bay, which has a salinity similar to seawater, the presence of hypersaline water with a greater salinity than natural seawater in the unlined CCS canals; the interceptor ditch (ID) to the west, which contains water with variable salinity; and various water management canals in the area, which generally contain freshwater (Tetra Tech 2016b). Salinity in the CCS has ranged from approximately 34 to 95 parts per thousand (ppt) over the past 10 years. In the years since the CCS began operations, denser hypersaline water from the unlined CCS canals has migrated vertically downward and horizontally westward away from the CCS at depth within the Biscayne Aquifer.

3.1.2 Selection of Computer Code

The U.S. Geological Survey groundwater code SEAWAT version 4 (Langevin et al. 2008) is a three-dimensional variable-density groundwater flow and transport code that can accommodate the variable density of groundwater as a function of both salinity and temperature. This code was used as the basis for constructing a groundwater model of the Biscayne Aquifer and related surface-water features in the vicinity of the CCS (Tetra Tech 2016b). The USGS code was modified in order to allow the model to continue running even if an internal constraint related to the pre-conjugate gradient (PCG) package was not satisfied, with the result that a modified executable file was used to run the model (email correspondence, Scott Burns, FPL, to Richard Hall, EPA Region 4, June 17, 2016). According to FPL, this modification has been employed in other modeling analyses, and FPL "...does not believe that it [the modification] affects the results of the model solution." (email correspondence, Scott Burns, FPL, to Richard Hall, EPA Region 4, June 17, 2016).

3.1.3 Model Description

3.1.3.1 Discretization - The groundwater model simulates hydraulic heads, salinity, and temperature in a 276-square-mile area bounded on the north by the C-103/Mowry Canal, on the west and south by the C-111 Canal, and on the east by the eastern portion of Biscayne Bay (Figures 1 and 2 in Tetra Tech 2016b). Salinity values are expressed in terms of relative salinities, where one relative salinity unit is equal to an assumed seawater concentration of 35,000 mg/L salinity. The model domain is subdivided into 274 columns from west to east and 295 rows from north to south. The width of the rows and columns varies from 200 feet (ft) to 500 ft with the smaller grid cell dimensions located near the CCS.

Vertically, the Biscayne Aquifer is represented by 11 layers, the thickness of which varies from approximately 50 ft in the west to approximately 100 ft in the east (Figure 3 in Tetra Tech 2016b). The hydrostratigraphic layering for the groundwater model was defined based on 41 well boring logs, including Turkey Point groundwater wells TPGW-1 through TPGW-14 (JLA Geosciences 2010) (see Figure 2) and additional boring logs interpreted and reported by Fish and Stewart (1991) and Parker et al. (1955). The upper surface elevation of the Biscayne Aquifer was defined using digital elevation maps. The uppermost model layer represents unconsolidated surficial sediments, layers 2 through 4 represent the Miami Oolite, and layers 5 through 11 represent the thicker Fort Thompson Formation. Layers 4 and 8 represent two zones of high hydraulic conductivity that were assumed to be continuous throughout the entire model domain. The upper high flow zone (Layer 4) occurs at the base of the Miami Oolite, and the lower high flow zone (Layer 8) is located in the approximate middle of the Fort Thompson Formation.

3.1.3.2 Boundary Conditions - Surface-water features in layer 1 in the model are represented by MODFLOW River and Drain packages, and groundwater flow between the surficial aquifer and Biscayne Bay is simulated using specified head boundary conditions to represent the bay (Figure 4 in Tetra Tech 2016b). Groundwater flow under the canals forming the perimeter of the model is simulated using general head boundary conditions (Figure 6 in Tetra Tech 2016b). Municipal, industrial, and agricultural groundwater pumping is simulated using the MODFLOW well package (Figure 5 in Tetra Tech 2016b). Spatial and temporal distributions of rainfall and reference evapotranspiration and estimates of runoff from low-density, medium-density, and high-density urban areas were used to calculate net recharge to the groundwater system, defined as rainfall minus runoff and evapotranspiration.

Temperature and salinity values were assigned at the three boundary types that can act as sources to the groundwater system, i.e., at the river, specified-head, and general head boundaries. Temperatures were assigned based on temperature data collected by FPL and by interpolating between locations where measured data were available. The Biscayne Bay specified head cells were assigned relative salinity values of 1.0 throughout all of the model simulations. Salinity values in the river cells representing the CCS were varied temporally throughout the simulations based on the operating history of the CCS (Figure 7 in Tetra Tech 2016b). Salinities in the other river cells were varied during the simulations based on canal configurations and the presence and/or effectiveness of flow structures in preventing inland migration of seawater.

3.1.4 Calibration and Remedial Alternatives Using Manually Calibrated Model (Versions One and Two, June 10, 2016 Report)

Figure 2. – Groundwater Monitoring Well Locations (source: Wacker 2011)

3.1.4.1 Calibration - Calibration for the manually-calibrated groundwater model described in the June 10, 2016 report (Tetra Tech 2016b) was divided into four timeframes:

- Pre-development steady-state flow model (prior to 1940);
- Steady-state flow and transient transport calibration model (1940-1968);
- Seasonal transit flow and transport calibration model (1968-2010); and
- Monthly transient flow and transport calibration model (2010-2015).

The goals of the calibration process were to meet simultaneously the following criteria:

- Minimize the mean error (ME) of the seasonal and monthly transient models;
- Reduce the mean absolute error (MAE) of the seasonal and monthly transient models until the ratio of the MAE and the range of observed values was less than 0.10 (10%);
- Simulate a good approximation of the 1968 saltwater-freshwater interface at the base of the Biscayne Aquifer (layer 11); and
- Simulate the breakthrough of the saltwater-freshwater interface at monitoring wells G-21 and G-28 during the seasonal transient model period (1968-2010).

Calibration of the groundwater model included making changes in both aquifer parameters and boundary conditions. The sequence of steady-state and transient groundwater models was calibrated to match measured groundwater levels and salinities at locations in the model area (Figure 8 in Tetra Tech 2016b). The calibration was performed manually instead of using an automated procedure such as PEST (Doherty 2004) to estimate the aquifer parameters. Initially, a preliminarily calibrated model, which is considered version one for the purpose of this review, generally under-simulated the extent of saltwater intrusion to the west. This result led to version two of the groundwater model, in which the hydraulic conductivity values in the high flow zones (layers 4 and 8) were increased, effectively doubling the modeled aquifer transmissivity, which resulted in a better simulation of the extent of saltwater intrusion to the west of the CCS (Figure 9 in Tetra Tech 2016b). In version two of the groundwater model, horizontal hydraulic conductivities range from 100 ft/day in layer 1 to 20,000 ft/day in the upper high flow zone (layer 4) and 60,000 ft/day in the lower high flow zone (layer 8) (Table 1 in Tetra Tech 2016b). Vertical hydraulic conductivities range from 10 ft/day in layers 1 and 2 to 2,000 ft/day in layer 4 and 6,000 ft/day in layer 8. The hydraulic conductivities generally vary from layer to layer, but within each layer, the hydraulic conductivities are held constant. Thus, each layer is treated as a homogeneous layer with respect to hydraulic conductivity throughout the model domain. Each of the other calibration parameters (specific storage, specific yield, porosity, and longitudinal, horizontal transverse, and vertical transverse dispersivity) generally has the same value from layer to layer and also within each layer.

The freshwater-saltwater interface (relative salinity = 1,000 mg/L / 35,000 mg/L = 0.0286, Tetra Tech 2016a) simulated for 1968 by the steady-state model at the base of the Biscayne Aquifer generally matches prior estimates made by Parker et al. (1995) and Klein and Hull (1978) (Figure 10 in Tetra Tech 2016b). The calibration goals for the seasonal and monthly transient models were met except for the calibration metric of a 10% ratio of the mean absolute error (MAE) and the range of observed values for the salinities in the seasonal (1968-2010) transient model (Table 2 in Tetra Tech 2016b). Scatter plots of observed versus water levels and relative salinities for the monthly model (2010-2015) (Figures 11-12 in Tetra Tech 2016b) indicate that the simulated water levels and relative salinities match the observed water levels and relative salinities for this timeframe reasonably well. Transient plots of water levels and relative salinities at a subset of monitoring wells indicate that the simulated and observed values are in reasonably good agreement (Figures 13-14 in Tetra Tech 2016b). However, the simulated salinity at well TPGW-7D (Figure 14 in Tetra Tech 2016b) is less than the observed salinity at this well, which indicates that version two of the groundwater model may not accurately simulate the breakthrough of the saltwater-freshwater interface at this well. Similarly, the simulated salinity at well G-28 is also less than the observed salinity (Figure 15 in Tetra Tech 2016b). In contrast, the simulated salinity in well G-21 is greater than the observed salinity, which indicates that the breakthrough of the saltwater-freshwater interface is simulated to occur too early at this well (Figure 16 in Tetra Tech 2016b).

Salinities observed from the results of a Controlled Source Electromagnetic Survey (CSEM) (Enercon 2016b) provide an additional source of salinity data (Tetra Tech 2016b). The CSEM survey indicates that the most westward extent of the saltwater plume west of the CCS is located in the lower high flow zone (model layer 8), not in the deepest part of the Biscayne Aquifer (model layer 11). The simulated hypersaline interface is generally consistent with the CSEM-based interface location (Figures 17a and 17b, Tetra Tech 2016b).

3.1.4.2 Remedial Alternatives - Seven remediation scenarios were designed and evaluated using version two of the groundwater model (Tetra Tech 2016b). The hydrologic stresses and model boundary conditions in the 5-year timeframe (2010-2015) of the calibrated monthly transient flow and transport model were repeated to simulate a 10-year (2016-2025) predictive timeframe. As described in detail by Tetra Tech (2016b), alternative 1 is a no-action alternative with no CCS salinity abatement, alternatives 2 – 5 are designed to retract the hypersaline plume to the western boundary of the CCS with minimal impacts to groundwater, wetland, and other environmental resources, and alternatives 6 – 7 are designed to stabilize or retract the toe of the saltwater-freshwater interface in the Biscayne Aquifer. Alternative 2 involves the addition of Floridan Aquifer water to the CCS, the reduction of CCS salinity to 34,000 mg/L, and an associated increase in stage relative to historical conditions, without groundwater extraction. Alternatives 3 – 7 involve the use of vertical or horizontal extraction wells or vertical injection wells generally along the western boundary of the CCS or to the west of the CCS in an area designated the Model Control Boundary (Figure 18 in Tetra Tech 2016b). An additional alternative, designated as Alternative 8, which consists of extraction wells used in Alternative 3D and injection wells used in Alternative 7C (FPL 2016b).

A set of criteria for evaluating and ranking the remedial alternatives was established based on the ability of each alternative to ameliorate salt concentrations and the westward movement of the saltwater and hypersaline interfaces in the Biscayne Aquifer without adversely impacting wetlands and seepage from surface-water features such as canal L-31W (Table 3 in Tetra Tech 2016b). Additional criteria were used to evaluate the ease with which the different remedial scenarios can be implemented relative to such management factors as construction time, permitting, legal control, and public perception. Based on these criteria and ranking, Alternative 3D is the highest ranked alternative (Table 4 in Tetra Tech 2016b). This alternative consists of CCS salinity abatement and one year of extraction from the base of the Biscayne Aquifer adjacent to an Underground Injection Control (UIC) well located within the boundary of the CCS followed by 9 years of pumping 15 million gallons per day (MGD) from 10 wells screened at the base of the aquifer (model layers 10 and 11) spaced approximately 2,000 ft apart along the western boundary of the CCS (Figures 18 and 19 in Tetra Tech 2016b). For this alternative, the simulated hypersaline interface in the lower high flow zone (model layer 8) moves eastward from its initial location west of the CCS, nearly reaching the western boundary of the CCS after 5 years of pumping and is retracted beneath the CCS after 10 years of pumping (Figures 20 and 21 in Tetra Tech 2016b). Also, alternative 3D extracts more salt mass from the Biscayne Aquifer than the other alternatives without inducing drawdowns of 0.2 ft or greater west of L-31E (Figures 22 and 23 in Tetra Tech 2016b). However, common to all of the alternatives evaluated, changes in the location of the hypersaline plume at the base of the aquifer (model layer 11) are negligible after 10 years of pumping (Figure 24 in Tetra Tech 2016b).

3.1.5 Calibration and Remedial Alternatives Using Automatic-Calibrated Model (Versions Three and Four, July 20, 2016 Report)

3.1.5.1 PEST Calibration (Version Three) - Subsequent to the June 10 (Tetra Tech 2016b) report and a telephone conference call on June 27, 2016, automated parameter estimation software PEST (Doherty 2004) (Figure 1 in Tetra Tech 2016c) was used to re-calibrate the APT and regional groundwater models to evaluate whether the manually calibrated model of the site-specific APT and the existing manually calibrated regional model were optimal. Data from the Controlled Source Electromagnetic Survey (CSEM) (Enercon 2016b) were used to supplement the re-calibration of the regional groundwater model.

The objectives of re-calibrating the APT manual calibration were to:

- Improve the ability of the uniform zone APT model to reproduce the drawdowns observed during the APT;
- Use the updated parameters from the re-calibration of the APT model to improve the re-calibration of the regional groundwater model; and
- Use the updated parameters from the re-calibration of the APT model to confirm findings of other studies and make any necessary revisions to the conceptual understanding of the hydrogeologic system.

The automated calibration of the uniform zone sequence of the APT groundwater model reduced the APT model error by 60% and obtained a better match than the manual calibration to the drawdowns observed during the APT (Tables 1 and 2 and Figures 2–6 in Tetra Tech 2016c). The results of this calibration indicate that the lower zone, represented by model layers 7 and 8, has a lower overall hydraulic conductivity than the manually-calibrated APT analysis yielded. The calibration also indicates that the two upper zones, represented by model layers 2 and 3, are more conductive than previously estimated. These findings were used to improve the calibration of the regional groundwater flow model and also provided support for revisions in the conceptual model of the hydrogeologic system.

After submission of the manually-calibrated regional groundwater model (Tetra Tech 2016b), elements of the groundwater model were identified that warranted further attention (Tetra Tech 2016c):

- Simulated salt breakthrough at wells G-21 and G-28;
- Apparent over-simulation of salt concentration in the deep aquifer relative to the CSEM survey;
- Confirmation of the optimality of the manual calibration; and
- Sensitivity of simulated water levels and salinities to variations in model parameter values.

The PEST suite of model utilities was used to evaluate the manually calibrated groundwater model. In the PEST calibration, horizontal and vertical hydraulic conductivities and porosities for the four main hydrogeologic formations (Miami Limestone, Upper and Lower High Flow Zones, and the Fort Thompson Formation) and marine sediments were adjusted to improve model calibration (Table 3 in Tetra Tech 2016c). The PEST calibration was divided into the same three simulation periods as the manual calibrations, and, similarly, the same 9,435 water level and salinity targets were used in the PEST calibration as in the manual calibrations (Table 4 in Tetra Tech 2016c). The PEST calibrated model parameters (Table 5 in Tetra Tech 2016c) are generally similar to the manually calibrated model parameters. The high flow zones remain the most conductive formations in the aquifer, and the lower high flow zone is more conductive than the upper high flow zone. Normalized mean absolute errors (MAE's) for the PEST calibration for three categories (seasonal water levels, seasonal salt concentrations, and monthly salt concentrations) are slightly less than corresponding categories for the manual calibration, and the normalized MAE in the PEST calibration for monthly salt concentrations is slightly greater than the corresponding mean absolute error for monthly salt concentrations for the manual calibration (Table 6 in Tetra Tech 2016c). Also, scatter plots of simulated water levels and salinities obtained in the manual and PEST calibrations are very similar (Figures 7 and 8 in Tetra Tech 2016c). In addition, the calculated transmissivities in the vicinity of observation well TPGW-1 for the manually calibrated model and the PEST-calibrated model are very similar, approximately 380,000 and 330,000 ft^2/day, respectively. These results indicate that the PEST calibration is slightly better yet very similar to the results obtained with the manual calibration (Tetra Tech 2016b). At wells G-21 and G-28, both calibrated models simulate the breakthrough of salt concentrations observed in the shallow screen at well G-21 and in both the shallow and deep screens at well G-28 (Figure 9 in Tetra Tech 2016c).

Based on the calibration statistics and visual comparison of model results, it is clear that the PEST-calibrated model is very similar to (and validates) the manually calibrated model (Tetra Tech 2016c). Model predictions of the remedial alternative 3D illustrate further similarities. Simulation results for salt concentrations in the lower high flow zone (model layer 8) for one years, five years, and ten years are very similar for both the manually calibrated model and the PEST-calibrated model (Figures 10-12 in Tetra Tech 2016c). Also, simulation results for salt concentrations in the lower Fort Thompson Formation (model layer 11) for one year, five years, and ten years are very similar for both the manually calibrated model and the PEST-calibrated model (Figures 13-15 in Tetra Tech 2016c). However, in both models, the hypersaline interface in the deep aquifer (model layer 11) is considerably farther west than the CSEM data indicate, and eastward movement of the hypersaline interface is not achieved in the deeper part of the aquifer by means of this remedial alternative in either model (Tetra Tech 2016c).

3.1.5.2 PEST with CSEM Targets Calibration (Version Four) - A second PEST calibration, referred to as the PEST with CSEM Targets calibration, was conceived and executed (Tetra Tech 2016c). In this calibration, aquifer salinity concentrations obtained from the CSEM survey were incorporated as calibration targets in addition to the static water-level and salinity observations used in the prior manual and PEST calibrations. In this calibration, the hydraulic conductivity and porosity of the Fort Thompson Formation below the Lower High Flow Zone were allowed to vary independently of the hydraulic conductivity and porosity of the Fort Thompson Formation above the Lower High Flow Zone. In addition, the conductances of the RIV river cells that represent the CCS were allowed to vary during the

PEST with CSEM calibration. An additional 17,802 salinity concentration targets from the CSEM data were added for this calibration. The data were subdivided into layers and/or sets of layers (layers 1-3, layer 4, layers 5 to 7, layer 8, and layers 9-11) and assigned varying weights in order to achieve the following outcomes:

- Maintain good calibration to historic static water-level and salinity concentration targets;
- Improve the modeled match to saltwater breakthrough at wells G-21, G-28, and TPGW-7D;
- Match the overall characteristics of the CSEM-derived hypersaline concentrations immediately west of the CCS where monitoring wells are relatively sparse; and
- Match the salinity concentrations in the deeper part of the aquifer where the hypersaline interface is farther west in the Lower High Flow Zone that it is in the aquifer layers below the Lower High Flow Zone.

Three significant changes to the model parameters occurred as a result of the PEST with CSEM data calibration (Table 7 in Tetra Tech 2016c):

- The horizontal hydraulic conductivity of the deep Fort Thompson Formation was reduced by nearly an order of magnitude:
- The longitudinal dispersivity of the model was reduced by a factor of approximately 2; and
- The conductance values representing the CCS canal sediments were reduced by approximately 10 percent.

All three changes are consistent with the goal of reducing the westward extent of the simulated saltwater and hypersaline interfaces, particularly in the deepest part of the aquifer. Comparison of scatter plots of the CSEM data before and after the PEST with CSEM data calibration indicates that the calibration using PEST with the CSEM data improved the match between simulated and observed salt concentration in the deepest layers (Figure 16 in Tetra Tech 2016c). Statistical results show reductions in normalized MAE values in eight out of nine categories (Table 8 in Tetra Tech 2016c). However, there are still many Layer 9 to 11 data points in which the simulated concentrations are greater than observed concentrations, indicating the model still exaggerates the westward extent of the hypersaline interface with respect to the CSEM data. Also, emphasis upon the G-21 and G-28 targets via target weighting results in improved matches at wells G-21 and G-28 (Figure 17 in Tetra Tech 2016c), but a worse match at well TPGW-7D (Figure 18 in Tetra Tech 2016c).

Predictions made for Remedial Alternative 3D using the PEST with CSEM targets calibrated model (version four) reduced the westward extent of the saltwater-freshwater and hypersaline interfaces in the lower part of the Biscayne Aquifer compared to the results obtained for versions one, two, and three. In this simulation (Tetra Tech 2016c), the locations of the extraction wells were changed slightly from those simulated in earlier versions of the model such that the wells, which are immediately west of the CCS, more closely follow the path of the Interceptor Ditch instead of the path of L-31. Comparison of simulated salinity concentrations at time = 1 year for model layers 8 and 11 for the PEST calibrated model and the PEST with CSEM targets calibrated model indicate that the westward extent of the saltwater-freshwater and hypersaline interfaces is reduced in both layers in the PEST with CSEM targets calibrated model (Figures 19 and 20 in Tetra Tech, 2016c). The westward extent of hypersaline interface is greater in model layer 8 than model layer 11, which is consistent with the CSEM survey data. After 10 years, the hypersaline interface is retracted to L31-E in the Lower High Flow Zone (model layer 8) (Figure 21 in Tetra Tech 2016c) and in layers above, but the hypersaline interface is not retracted in model layer 11 (Figure 22 in Tetra Tech 2016c) or in layer 10.

3.1.5.3 FPL and Tetra Tech Conclusions - The PEST with CSEM data included in the calibration (groundwater model version four) simulates conditions that are more consistent with those observed via static water levels and salt concentrations as well as the CSEM survey data (Tetra Tech 2016c). This result was achieved in part by reducing the horizontal hydraulic conductivity of the deep Fort Thompson Formation, which is consistent with the PEST-calibrated APT model. However, this reduction in the hydraulic conductivity in the deepest model layers reduces the capture zone of the extraction wells screened in those layers. As such, capture of hypersaline water in these layers is not achieved in the model. Also, simulated salinity concentrations in this part of the aquifer are still greater than observed salinity concentrations based on the CSEM data. Additional work including geophysical logging was recommended to achieve a better understanding of the hydrogeology below the Lower High Flow Zone (model layer 8) and to improve the model simulation of saltwater conditions throughout the full aquifer vertical profile.

3.2 SIMULATIONS RUN TO VERIFY RESULTS

3.2.1 Model Versions Two and Four

Input files provided by FPL for the revised manually-calibrated model (version two) and the PEST with CSEM target data calibration (version four) were run as part of this review to simulate selected remedial alternatives to compare with results reported by Tetra Tech (2016b and c). Input files for alternatives 1, 3D, and 8 that had been run by Tetra Tech (2016a) using version two of the groundwater model with FPL's modified SEAWAT code sw_Trans_monthly.EXE were re-run using version four of the USGS (unmodified) SEAWAT code, and the output files were opened and reviewed using Groundwater Vistas (Environmental Simulations 2011). Groundwater Vistas files for alternatives 1 and 3D that had been run by Tetra Tech using version four of the groundwater model in Groundwater Vistas with FPL's modified SEAWAT code sw_Trans_monthly.EXE were re-run using the USGS unmodified SEAWAT code, and the output files were opened and reviewed using Groundwater Vistas. The simulations run for this review for alternatives 1, 3D, and 8 using the unmodified USGS SEAWAT code yielded the same results for predicted salinity concentrations as results obtained with FPL's modified SEAWAT code, indicating that the modifications made to SEAWAT did not affect calculated salinities for these alternatives.

3.2.2 Revised Manually-Calibrated Model (Version Two)

3.2.2.1 Alternative 1 - Alternative 1 is the no-action alternative with no CCS salinity abatement, and the results should indicate what the groundwater model predicts if no remedial action is taken. Using version two of the groundwater model, the maximum concentration of salinity in layer 8 is predicted to increase from c = 1.840 at time = 1 year to c = 1.977 at time = 10 years (see Figure 3), which is the expected result. However, the hypersaline interface (c = 1.0) moves westward a very short, almost imperceptible, distance; similarly, the saltwater-freshwater interface (c = 0.0286) moves westward only a very short distance (see Figure 3).

3.2.2.2 Alternative 3D - Alternative 3D is indicated to be the best alternative considered based on the result that the hypersaline interface in the lower high flow zone (model layer 8) is moved eastward to the western boundary of the CCS at the end of the 10-year simulation period (Figure 21 in Tetra Tech, 2016b). The simulation performed as part of this review confirms Tetra Tech's model prediction that the hypersaline interface is moved eastward to the western boundary of the CCS at the end of the 10-year simulation (see Figure 4). Also, similar to what is reported by Tetra Tech (2016b), the model predicts that the hypersaline interface in the lower zone (model layer 11) does not respond to Alternative 3D and remains essentially in the same location after 10 years (see Figure 5).

3.2.2.3 Alternative 8 – According to FPL (2016b), the results for Alternative 8, the combined alternative consisting of the extraction wells in Alternative 3D and the injection wells in Alternative 7, indicate that retraction of the hypersaline plume north and west of the CCS is achieved and that the saltwater-freshwater interface is more effectively moved back to the east. A simulation run using the model input files provided for Alternative 8 by FPL on May 15, 2016 confirms that version two of the model predicts the retraction of the hypersaline interface to the western boundary of the CCS in model layer 8 (see Figure 6). However, in this simulation, the location of the saltwater-freshwater interface predicted for Alternative 8 is essentially unchanged from time = 1 year to 10 years in model layer 8 (see Figure 6), and the result is very similar to the result for the saltwater-freshwater interface location in model layer 8 for Alternative 3D, which consists only of extraction wells (see Figure 4).

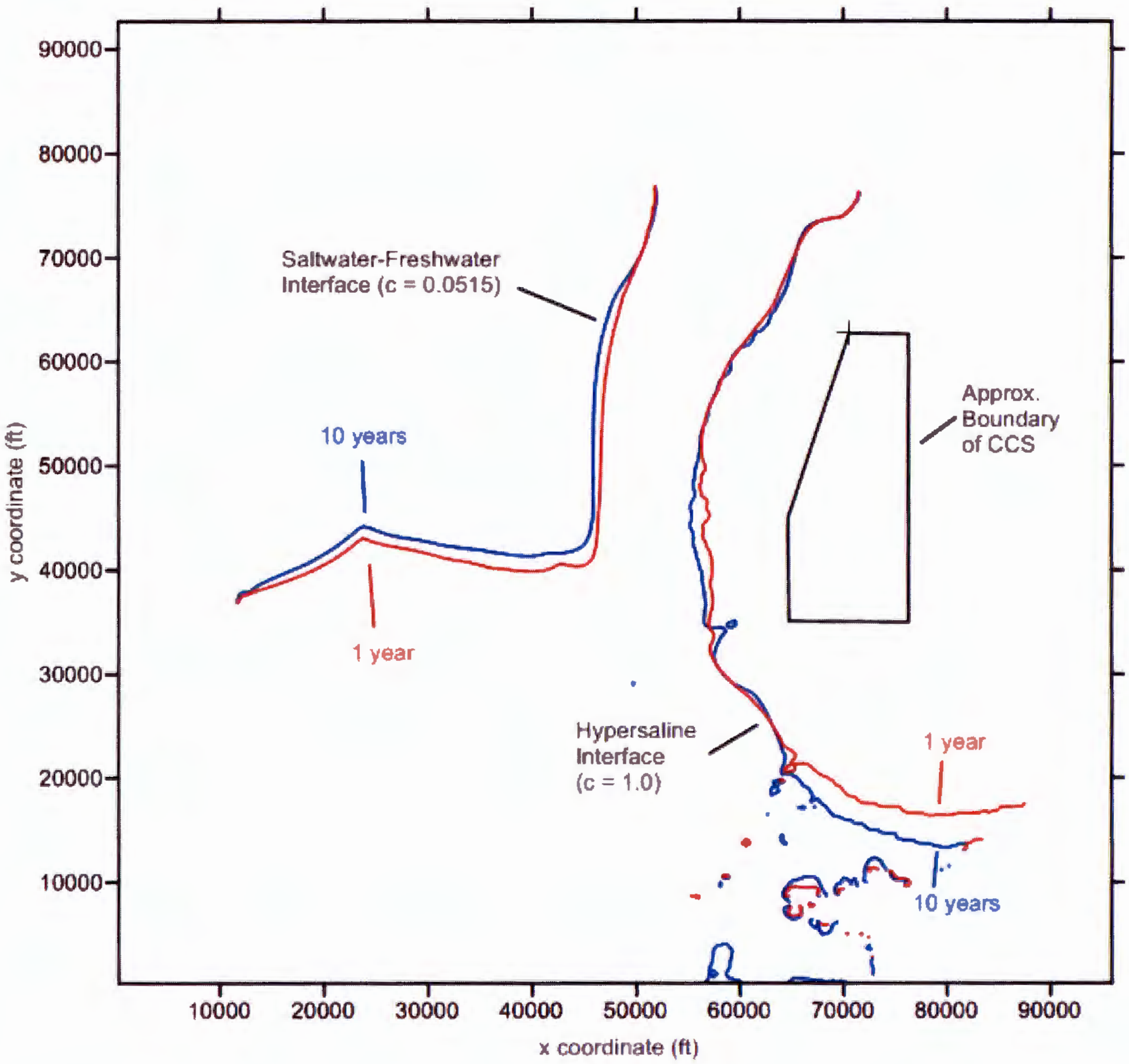

Figure 3. – Alternative 1: Manual Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 8

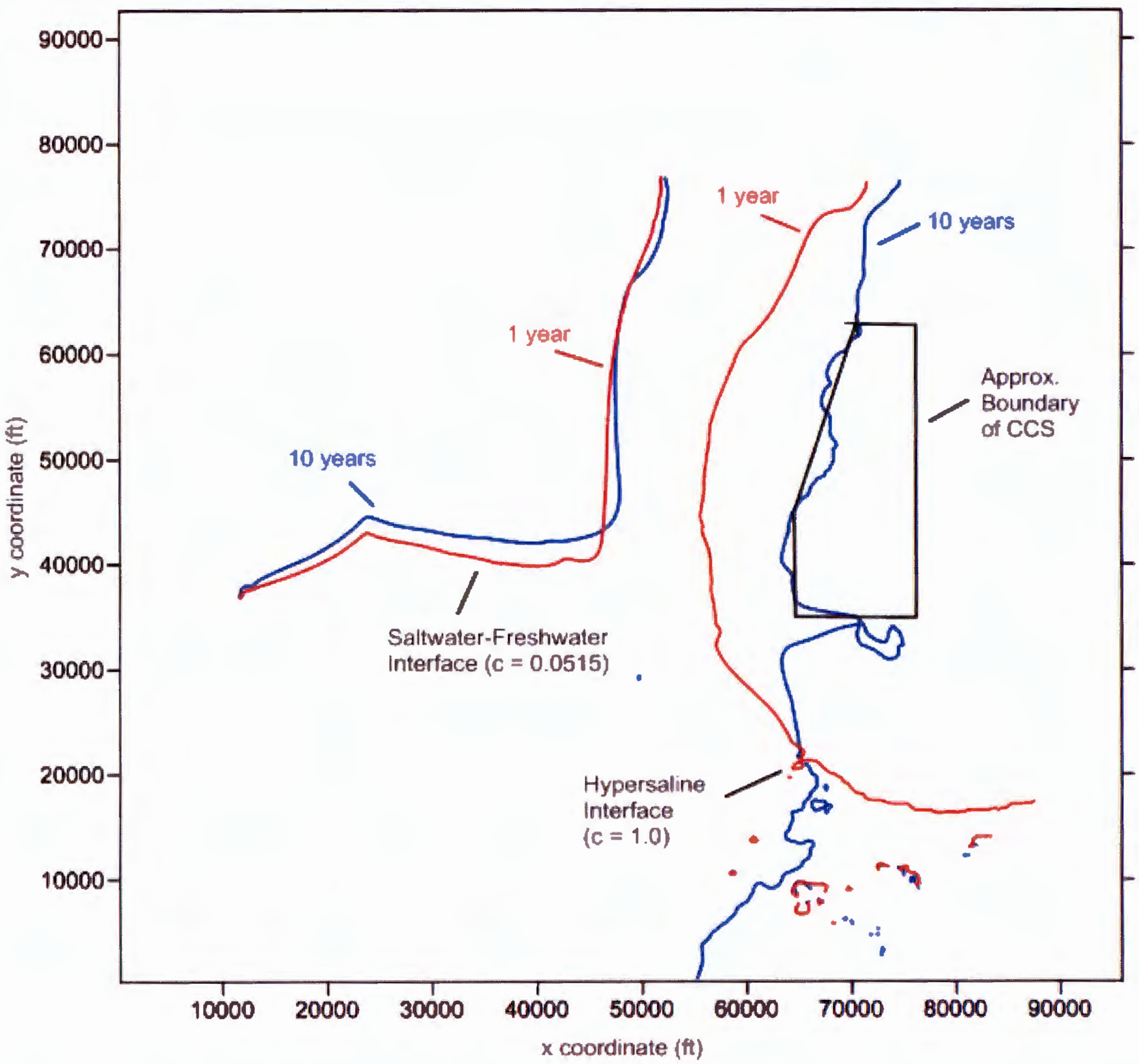

Figure 4. – Alternative 3D: Manual Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 8

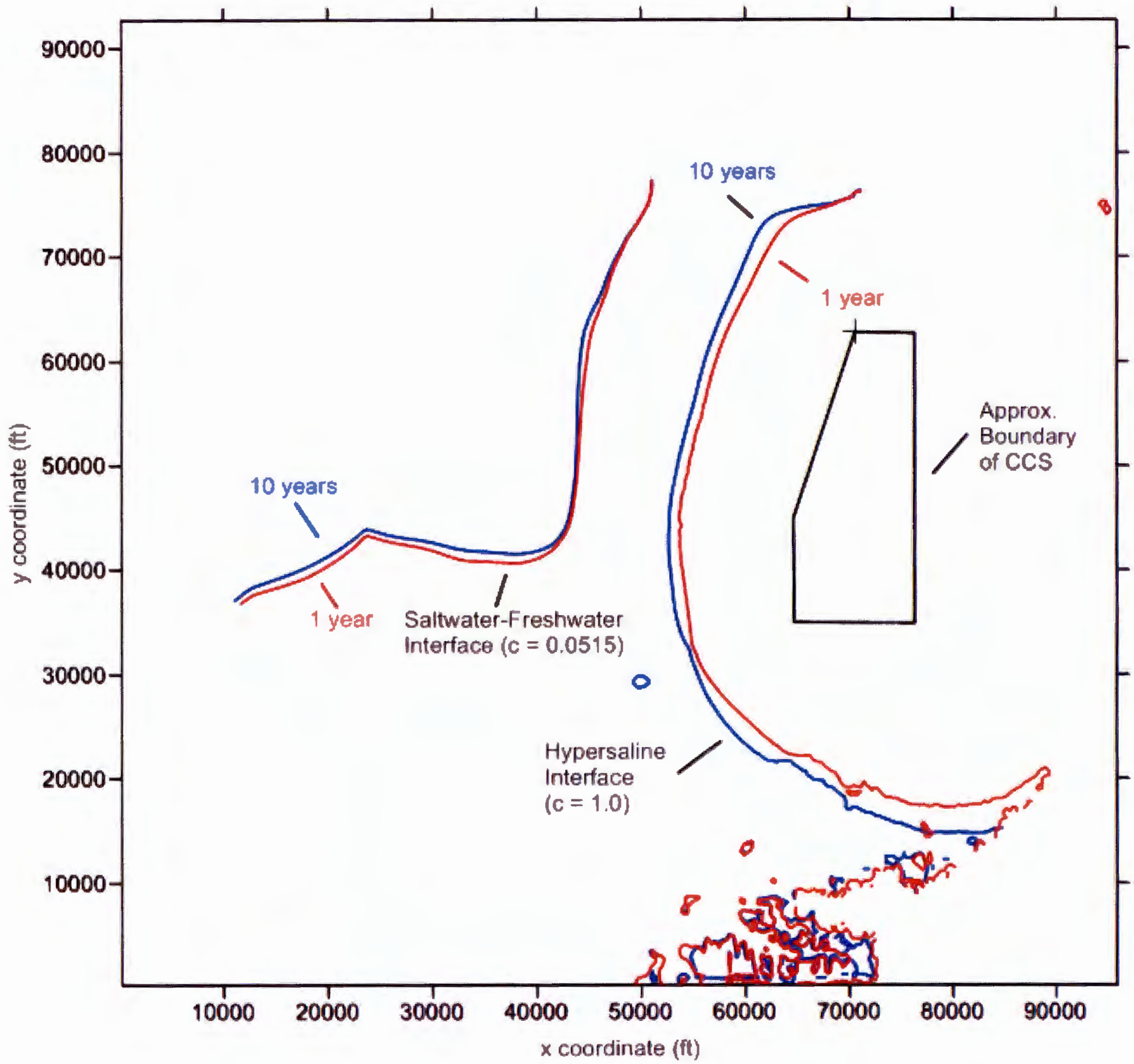

Figure 5. – Alternative 3D: Manual Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 11

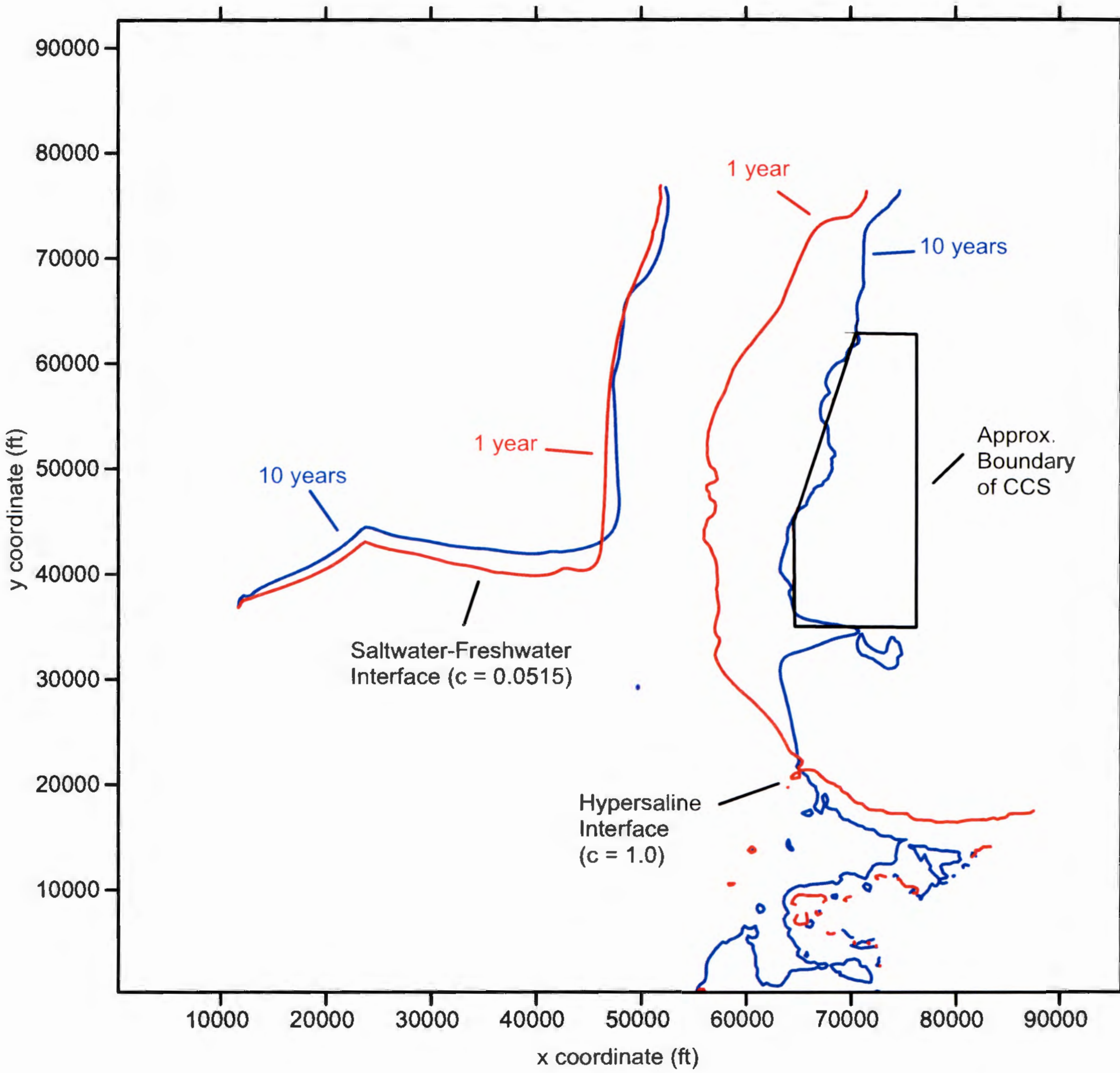

Figure 6. – Alternative 8: Manual Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 8

3.2.3 Pest with CSEM Target Data Calibrated Model (Version Four)

3.2.3.1 Alternative 1 - The results obtained for alternative 1, the no-action alternative, using version four of the groundwater model are similar to the results obtained using version two of the model. The maximum concentration of salinity in layer 8 is predicted to increase from c = 1.840 at time = 1 year to c = 1.977 at time = 10 years (see Figure 7), but the hypersaline interface (c = 1.0) and the saltwater-freshwater interface (c = 0.0515) move westward only short, almost imperceptible, distances (see Figure 7).

3.2.3.2 Alternative 3D - For alternative 3D, the simulation performed using version four of the model is similar to the results obtained using version two. This simulation confirms Tetra Tech's model prediction that the hypersaline interface is moved eastward to the western boundary of the CCS at the end of the 10-year simulation (see Figure 8). Also, similar to what is reported by Tetra Tech (2016c), this version of the model predicts that the hypersaline interface in the lower zone (model layer 11) does not respond to Alternative 3D and remains essentially in the same location after 10 years (see Figure 9).

3.3 TECHNICAL REVIEW COMMENTS

Technical review comments were prepared for the two principal reports that document the groundwater model. The manually-calibrated second version of the model is described in detail in the June 10, 2016 report (Tetra Tech 2016b) with reference to the manually-calibrated first version as a "preliminarily-calibrated" version. The third version of the model, calibrated automatically using PEST, and the fourth version of the model, calibrated automatically using PEST with the CSEM target data, are described in the July 22, 2016 report (Tetra Tech 2016c). As previously noted (email correspondence, Louis H. Motz, UF, to Wilbur Mayorga and Lorna Bucknor, DERM, June 27, 2016), these reports represent a remarkably large body of work accomplished by Tetra Tech in a very short period of time. As suggested in the review comments below, however, more details and explanations need to be provided in order for these reports to be independently reviewed by other parties and stakeholders.

3.3.1 June 10, 2016 Tetra Tech (2016b) Report

Please note: Page numbers were not included in the June 10, 2016 report. For the purpose of this review, pages numbers starting with the title and introduction page (designated p. 1) were added consecutively ending with Figure 24 numbered as p. 53. Accordingly, the page numbers referred to in the technical review comments in this section refer to these page numbers that were added to the June 10, 2016 report.

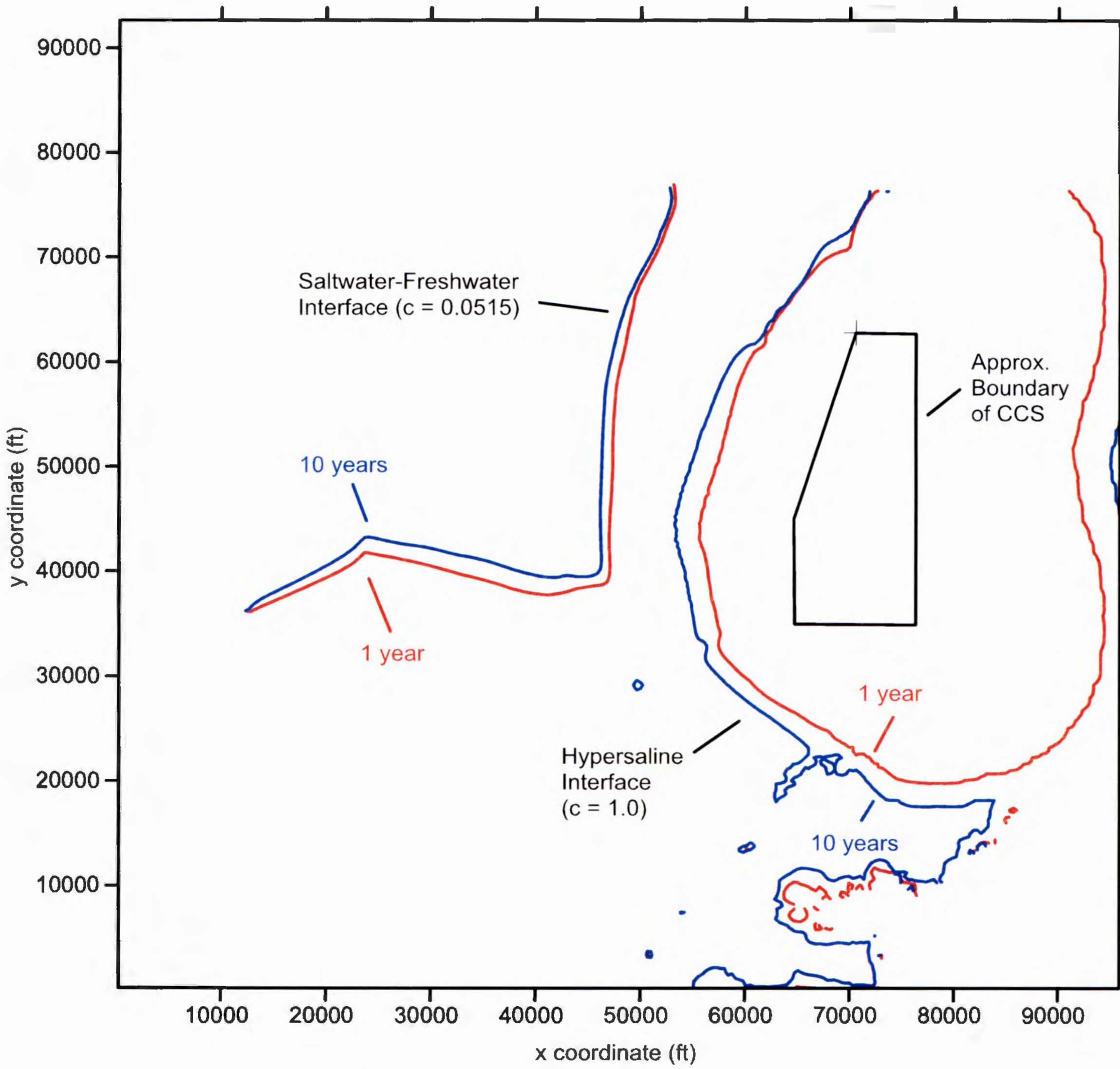

Figure 7. – Alternative 1: PEST with CSEM Targets Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 8

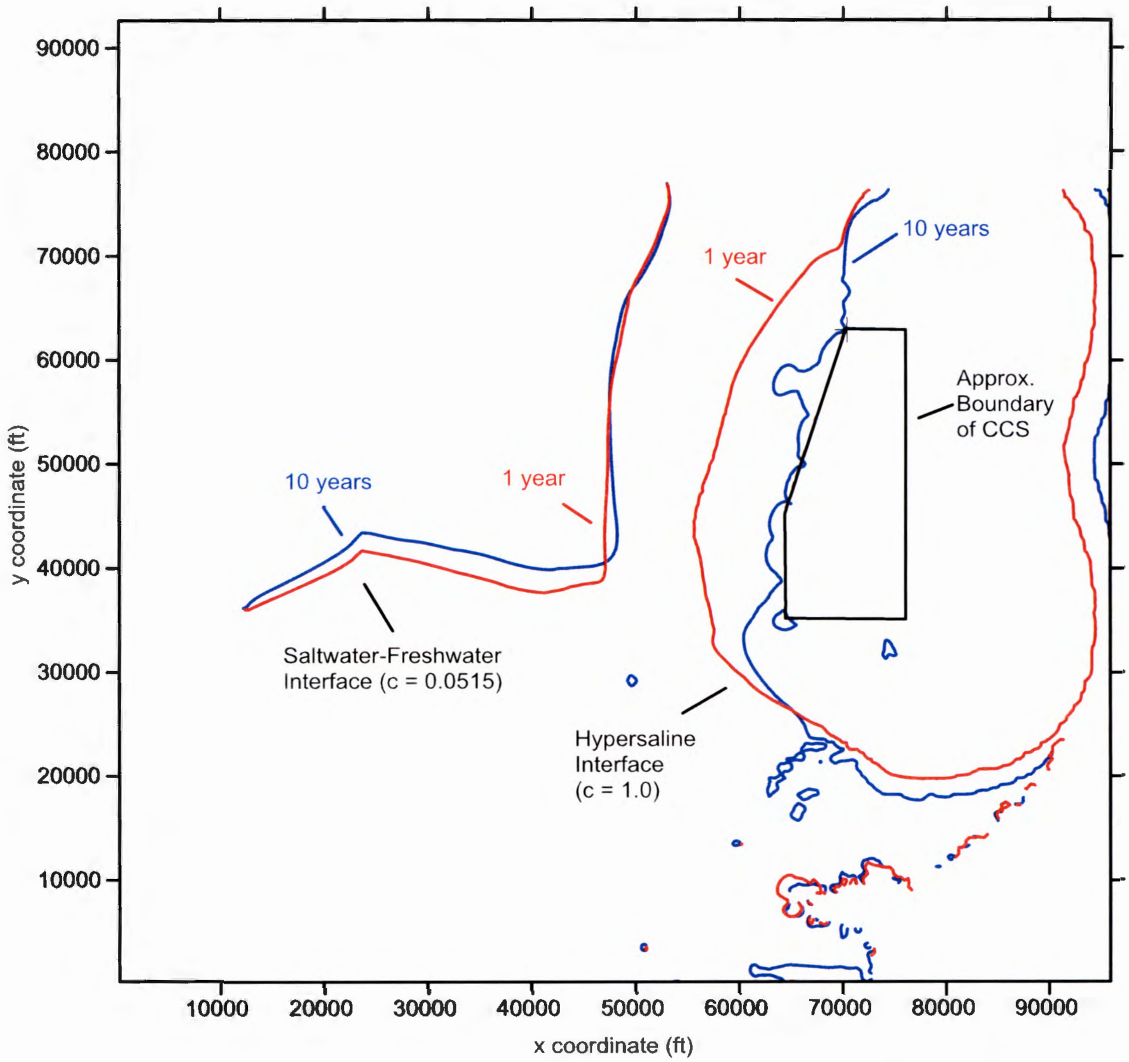

Figure 8. – Alternative 3D: PEST with CSEM Targets Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 8

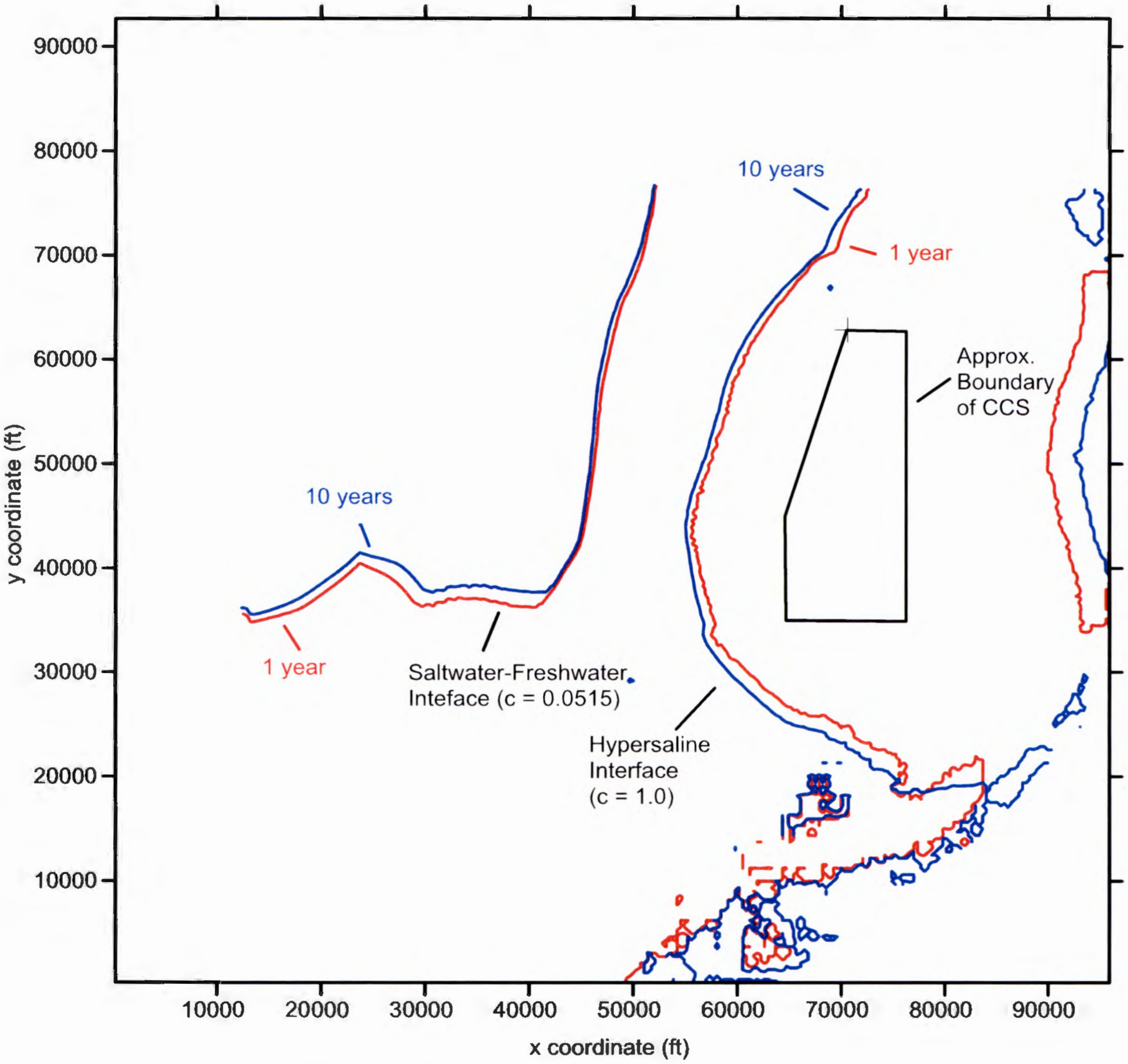

Figure 9. – Alternative 3D: PEST with CSEM Targets Calibration Simulation for Saltwater-Freshwater and Hypersaline Interfaces at Time = 1 and 10 Years for Model Layer 11

1. pp. 2 and 3: Model Code (and Supplemental Coding Required)
"Potential GUIs include Groundwater Vistas…."
The model output files provided by FPL on May 15, 2016 can be opened and processed with Groundwater Vistas, but the model input files cannot be loaded into and run using Groundwater Vistas.

2. p. 3: Review of Existing Published Models and Justification for Development of a New Model
"Earthfx Inc. (2012) developed a …model to support permitting of water withdrawals for dewatering a rock mine near the Turkey Point CCS."
Is this rock mine and its impacts included in the Tetra Tech model?

3. p. 6: "The USGS groundwater flow and solute transport modeling tool (Langevin et al. 2008) was used in this analysis."
The USGS code was modified in order to allow the model to continue running even if an internal constraint related to the pre-conjugate gradient (PCG) package was not satisfied, with the result that a modified executable was used to run the model (email correspondence, Scott Burns, FPL, to Richard Hall, EPA Region 4, June 17, 2016). According to FPL, this modification has been employed in other modeling analyses, and FPL does not believe that the modification affects the results of a model solution. In spite of this assurance, the use of the modified SEAWAT code could be of some concern if the modified code has not been properly benchmarked.

4. p. 8: "A localized groundwater model was developed and calibrated by SDI Environmental Services (Enercon 2016a) to match local changes in water levels and salinities measured during the APT which was conducted near TPGW-1. This local-scale model used three comparatively low-conductivity isotropic layers interspersed within the Biscayne aquifer to represent observed geology."
How do the eight layers in the APT model correspond to the eleven layers in the groundwater model? How were the results of the APT used in the regional groundwater model? Please provide a table in the report that shows how layers in the APT model correspond to layers in the groundwater model.

5. p. 9: Specified-Head Boundaries
"Groundwater flow between the surficial aquifer and Biscayne Bay is simulated using specified head boundary conditions to represent the Bay."
Were equivalent freshwater heads at this boundary calculated internally by SEAWAT based on the specified concentration and depth?

6. p. 12: "These salinities were estimated based on the Ghyben-Herzberg approximation." Please explain how the Ghyben-Herzberg approximation was used to calculate salinity.

7. p. 14: "The goals of the model calibration process were to simultaneously meet the following criteria: ...Simulate a good approximation of the 1968 freshwater-salt water interface at the base of the Biscayne aquifer (model layer 11)...."
Please define what salinity concentration contour in the model results was used to represent the freshwater-salt water interface, i.e., $c/c_0 = 1.0/35 = 0.0285$ or $1.804/35 = 0.0515$, or some other value? Is this value used consistently throughout the report to report the location of the saltwater-freshwater interface in the model results?

8. p. 16: Aquifer Remediation Scenarios
"Seven remediation scenarios were broadly designed and evaluated."
Who designed the scenarios? Please provide a reference (or references) to the development and design of the remediation scenarios.

9. p. 18: Scenario Selection Criteria
"Of these alternatives, Alternative 3D...performed best in retracting the hypersaline plume eastward to the eastern edge of the CCS to a large degree in 5 years and completely within 10 years....After 10 years (Figure 21), the hypersaline interface in the lower high flow zone [model layer 8?] has moved to beneath the CCS, and the groundwater concentrations beneath the CCS have nearly universally been reduced to seawater or less."
Is this correct? Examination of Figure 21 indicates that the hypersaline interface (relative salinity contour = 1.0) in the lower high flow zone (model layer 8) at time = 10 years is still generally located along the ***western*** boundary of the CCS and that the maximum concentration of relative salinity in the area to the east of the CCS is approximately 1.4. Examination of the salinity output file for Alternative 3D indicates that the maximum salinity concentration east of the CCS in model layer 8 is reduced from 1.77 at time = 1 year to 1.42 at time = 10 years, which is still significantly greater that the salinity concentration of seawater (relative concentration = 1.0).

10. p. 18: Scenario Selection Criteria
"...Alternative 3D extracts more salt mass from the aquifer (Figure 22) without inducing drawdowns of 0.2 ft or greater west of L-31E (Figure 23)."
How was Figure 23 plotted? There does not appear to be a drawdown file (*.ddn) in the model output files provided by FPL.

11. p. 18: Scenario Selection Criteria
"Figure 24 shows the initial and tenth year groundwater salt concentrations at the base of the aquifer (model layer 11). Note that the changes to the interface locations and overall salt

concentrations are minor after 10 years of extraction, even though the extraction wells are screened at the bottom of the aquifer, within model layers 10 and 11."

Yes, the salinity output file for Alternative 3D confirms this. Was pumping from the lower high flow zone (model layer 8) instead of pumping from model layers 10 and 11 investigated as an alternative? Would pumping from the lower high flow zone (model layer 8) yield better results than pumping from the less transmissive model layers 10 and 11?

12. p. 19: Conclusions:

"The two versions of the model (pre and post hydraulic conductivity revision) [versions one and two] employed to simulate remedial alternatives can be viewed as a sensitivity analysis on the impact of aquifer transmissivity on the historical and predicted movement of the saltwater wedge."

Comparing the impact of aquifer transmissivity on the historical and predicted movement of the saltwater wedge is only one part of a sensitivity analysis, and a more complete sensitivity analysis for the manually-calibrated model (versions one and two) is recommended. The automatic-calibration using PEST for versions three and four of the groundwater model (Tetra Tech 2016c) satisfies this requirement for a sensitivity analysis.

13. pp. 19 and 20: Conclusions

"Based on the suite of results from these two versions of the model, more work is necessary to reduce uncertainty in the definition of hydraulic conductivities in the hydrogeologic formations that comprise the Biscayne aquifer."

A reference to the July 20, 2016 report (Tetra Tech 2016c) describing versions three and four of the groundwater model would provide a link to the additional work that has already been accomplished.

14. p. 24: Tables

A new Table 1 of all relevant input values should be presented preceding what is now numbered as Table 1.

15. p. 25: Table 1. Calibrated Groundwater Flow Model Parameters

In columns 3 and 4, are the horizontal and vertical hydraulic conductivities uniform in each layer or should ranges of hydraulic conductivity be reported in columns 3 and 4?

16. p. 26: Table 2. Calibration Statistics

Which figures represent each of these results? The statistics should also be shown on the corresponding figures.

17. p. 39: Figure 10: Comparison of simulated freshwater-saltwater interface position in 1968 with prior estimates.
Please indicate what concentration of salinity in the model results represents the saltwater-fresh-water interface.

18. pp. 40-41, Figures 11 – 12:
Calibration statistics such as correlation coefficients should be shown on each plot.

19. pp. 42-44: Figures 13 – 16:
Please indicate in the report text and on the figures the row, column, and layer locations in the model that were used to represent each of the monitoring wells in Figures 13 – 16.

3.3.2 July 20, 2016 Tetra Tech (2016c) Report

1. p. 3: "Target weighting…."; p. 12: "These targets…were attributed varying weights in order to achieve the following outcomes…."
Please provide details of the various weights that were used to achieve the calibration. Also, please see similar comment below for p. 12.

2. p. 6: "Hydraulic conductivities in the specified-head boundary cells representing the L-31E canal, the interceptor ditch (ID) and the cooling canal system were also allowed to vary during calibration [of the APT results]."
This statement seems to contradict the description of these boundary conditions in versions one and two of the regional groundwater model in the June 10, 2016 report (Tetra Tech 2016b) and in version four (Tetra Tech 2016c). In the June 10, 2016 report (p. 11), it is stated that FPL's CCS and L-31E are represented by river cells in the regional groundwater model, and the ID is represented by drain cells. Are the boundary conditions in the analysis of the APT results different from the boundary conditions in versions one and two [and presumably versions three and four also] of the regional groundwater model? If so, why are they different?

3. p. 6: "A comparison of the simulated and corrected drawdown targets after two days (Figure 6) [p. 27] shows that a majority of the drawdown values predicted by the recalibrated model fall closer to the diagonal (perfect match) line than the original calibrated model's results."
This statement needs to be substantiated by some statistical means, i.e., comparing correlation coefficients and/or mean absolute errors. The statistical results should be in the text and shown on Figure 6.

4. p. 7: "The hydraulic conductivities of the specified-head boundary cells representing surface water bodies were all reduced from their original values of 2000 ft/day (Table 2)."
Were surface-water bodies such as the CCS treated as specified-head boundary conditions in analysis of the APT test results? This contradicts how surface-water bodies were treated in versions one - four of the regional groundwater model, i.e., as river and drain cells (TetraTech 2016

a, b, and c). Are the boundary conditions in the analysis of the APT results different from the boundary conditions in versions one and two [and versions three and four also] of the regional groundwater model? If so, why are they different?

5. p. 8: "In this calibration, horizontal and vertical conductivities and porosities for the four main hydrogeologic formations (Miami Limestone, Upper and Lower High Flow Zones, Fort Thompson Formation) and marine sediments were adjusted to improve model calibration."
Please indicate the corresponding model layers for the formations and marine sediments. It is suggested that this be done throughout the June 10 and July reports (Tetra Tech 2016b and c) or at least clearly and consistently presented in tables that are introduced when the formations and sediments are first described in these reports.

6. p. 10: "...a reviewer for MDC requested the 'use of a sensitivity analysis to demonstrate that the best (practical) calibration was achieved'...(email communication from Dr. Louis Motz to Wilber Mayorga, 2016)....FPL believes that the PEST calibration satisfies requests for a sensitivity analysis of the Regional Biscayne Aquifer Model."
The suggestion to conduct a sensitivity analysis was made relative to the manually-calibrated groundwater model (version two) described in the June 10, 2016 report (Tetra Tech 2016b). The PEST calibration used for the automatic calibrations (versions three and four) in the July 20, 2016 report (Tetra Tech 2016c) satisfies this suggestion.

7. p. 12: "These targets...were attributed varying weights in order to achieve the following outcomes during the PEST with CSEM Targets calibration...."
Please provide details of the weighting factors that were used in the calibration. Are the values the same or different for Layers 1 through 3, Layer 4, Layers 5 to 7, Layer 8, Layers 9 through 11, and wells G-21, G-28, and TPGW-7D? How were they selected?

8. PEST calibration."
In column 1, what do "Model Layers 1-8" refer to? How do these layers correspond to model layers 1-11 in the regional groundwater flow model?

9. p. 18: Table 3: A column indicating the corresponding layers in the regional groundwater model should be added to the table.

10. p. 19: Table 5: A column indicating the corresponding layers in the regional groundwater model should be added to the table.

11. p. 23-26: Figures 2–5: Which cells (row, column, and layer) in the regional groundwater model are used to represent these monitor wells?

12. p. 28: Figures 7 and 8: Statistical results for each scatter plot should be plotted on the figures to compare and demonstrate the improvements in calibration.

13. p. 29: Figure 9: Row, column, and layer locations should be indicated for wells G-21 (shallow and deep) and G-28 (shallow and deep).

3.4 REVIEW OF PROPOSED GROUNDWATER MONITORING NETWORK

FPL's proposed groundwater monitoring network consists of ten existing wells, four new wells, and CSEM mapping (Turkey Point Recovery Well System Proposed Monitoring Network, FPL, May 15, 2016) (see Figure 10). Six of the existing wells (TPGW-1, TPGW-2, TPGW-4, TPGW-5, TPGW-7, and TPGW-12 are three-well cluster wells that sample shallow, middle, and deep zones (JLA Geosciences 2010), and four of the existing wells (L-3, L-5, G-21, and G-28) are called "historic wells" that sample 28-ft and 58-ft depths and are described in the 2010 Annual Report: Groundwater Monitoring Program (Golder Associates 2010). Three of the new wells (TPGW-17, TPGW-18, and TPGW-19) will be three-well clusters that will sample shallow, middle, and deep zones) and the fourth new well (TPGW-20) is a single well that will sample the deep zone (JLA Geosciences 2016). FPL proposes to measure cations and anions and tritium quarterly in the monitoring wells and conduct CSEM mapping over the continuous vertical thickness of the Biscayne Aquifer west and north of the CCS on an annual basis (Turkey Point Recovery Well System Proposed Monitoring Network, FPL 2016a).

More information and detail need to be provided in the description of the proposed groundwater monitoring network. The latitude-longitude locations for the proposed new wells (TPGW-17, TPGW-18, TPGW-19, and TPGW-20) need to be expressed also in the same easting and northing 1983 datum coordinates as the 14 existing monitoring well locations described in Table 1 in JLA Geosciences (2010). Latitude-longitude and coordinate locations for existing wells L-3, L-5, G-21, and G-28 also need to be provided in the proposed monitoring plan. Six of the existing monitoring wells (TPGW-1, TPGW-2, TPGW-4, TPGW-5, TPGW-7, and TPGW-12) described by JLA Geosciences (2010) are included in the proposed monitoring plan, but eight of the existing monitoring wells (TPGW-3, TPGW-6, TPGW-8, TPGW-9, TPGW-10, TPGW-11, TPGW-13, and TPGW-14) described by JLA Geosciences (2010) are not. A discussion and explanation for this should be provided. The quarterly sampling frequency proposed for cations and anions and tritium should be adequate

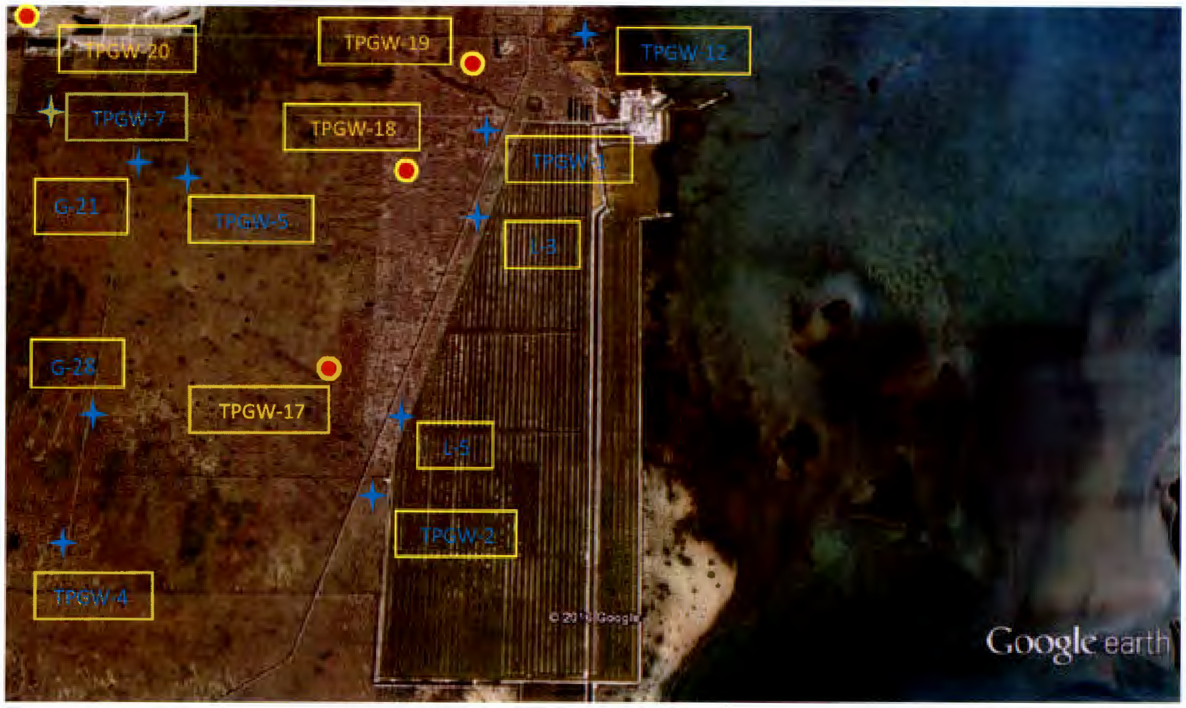

Figure 10. – Proposed Turkey Point Recovery Well System Monitoring Network (source: FPL 2016)

to monitor the movement of the hypersaline plume. However, in order to determine whether the proposed remediation is successful in retracting the hypersaline interface eastward to the western CCS boundary, two additional monitoring well locations should be considered, one cluster-well location approximately midway between monitoring wells TPGW-1 and TPGW-2 and a second cluster-well location in the vicinity of the southwest corner of the CCS between monitoring wells TPGW-2 and TPGW-3.

4.0 CONCLUSIONS AND RECOMMENDATIONS

In response to specific questions from DERM, the following conclusions and recommendations have been developed:

4.1 EVALUATION OF APT

Aquifer test results reported by Enercon (2016a) and SDI (2016) delineated eight layers at the test site with layers 1-3 representing the upper (shallow) permeable zone of the Biscayne Aquifer, layer 5 representing the middle permeable zone, and the layer 7 representing the lower permeable zone. In a uniform parameter APT SEAWAT model that was manually calibrated, it was determined that the hydraulic conductivities of layers 2 and 3 were each 2,000 ft/day, the hydraulic conductivity of layer 5 was 4,500 ft/day, and the hydraulic conductivity of layer 7 was 1,000 ft/day. Also, it was determined that the transmissivity of layer 2 was 26,000 ft^2/day, the transmissivity of layer 3 was 24,000 ft^2/day, the transmissivity of layer 5 was 126,000 ft^2/day, and the transmissivity of layer 7 was 22,500 ft^2/day. For the uniform parameter model, the total transmissivity of the Biscayne Aquifer was 203,256 ft^2/day. In an APT SEAWAT multi-zone model that was manually calibrated, it was determined that the total transmissivity of the Biscayne Aquifer ranged from 203,256 to 410,204 ft^2/day, with the majority of the values of transmissivity equal to the lower value from the uniform parameter model. The hydraulic conductivity results from the manually-calibrated APT uniform parameter model were used as the initial parameter set in the preliminarily-calibrated groundwater model (version one) (Tetra Tech 2016b). It was determined that the total transmissivity from the APT was much lower than transmissivities that have been typically assigned to the Biscayne Aquifer in south Florida. As a result, the hydraulic conductivities in the preliminarily-calibrated model (version one) were increased, effectively doubling the aquifer transmissivity in version two of the groundwater model. This change proved effective for the simulation of saltwater intrusion to the west of the CCS. Subsequently, the automatic parameter estimation software PEST (Doherty 2004) was used to recalibrate the uniform zone APT results, which resulted in increased values of horizontal hydraulic conductivities in the upper zones and reduced values in the lower zones of the Biscayne Aquifer in version three of the groundwater model (Tetra Tech 2016c). The total transmissivity in the Biscayne Aquifer in version four of the groundwater model, which was calibrated with PEST including the CSEM data as targets, is 257,000 ft^2/day, which is in close agreement with the total transmissivity of the Biscayne Aquifer determined in the manually-calibrated uniform parameter APT SEAWAT model (203,256 ft^2/day).

4.2 APPROPRIATENESS OF THE GROUNDWATER MODEL TO SIMULATE SITE CONDITIONS AND PREDICT TRANSIENT RESPONSE OF HYPERSALINE PLUME

As described in this report, a detailed summary of the four versions of the groundwater model developed by Tetra Tech has been prepared, and a technical review of the two principal reports (Tetra Tech 2016a and b) describing the model has been performed. In addition, input files for selected remedial alternatives that had been run by Tetra Tech using versions two and four of the groundwater model were re-run, and predicted simulations were obtained that yielded the same results as results reported by Tetra Tech (2016a and b). As a result of this investigation, it is concluded that the groundwater model developed by Tetra Tech (2016b and c), which is based on the USGS three-dimensional variable-density groundwater flow and transport code SEAWAT version 4 (Langevin et al. 2008), is an appropriate choice to describe the complex site and water-quality conditions at FPL's Turkey Point Power Plant and to simulate the impacts that the CCS has on the groundwater and related surface-water systems at this site. The groundwater model also has been appropriately used by Tetra Tech to predict the transient response of the hypersaline plume to various remedial alternatives that were evaluated to retract the plume to the western boundary of the CCS.

4.3 MODEL'S ABILITY TO SUPPORT DESIGN OF AQUIFER RECOVERY SYSTEM

Seven remedial alternatives were designed and evaluated using version two of the groundwater model (Tetra Tech 2016b). Also, predictive simulations for Alternative 3D were performed using version four of the groundwater model (Tetra Tech 2016c). The hydrologic stresses and model boundary conditions in the 5-year timeframe (2010-2015) of the calibrated monthly transient groundwater model were repeated to simulate a 10-year (2016-2025) predictive framework that is based on actual hydrologic conditions that occurred during the timeframe 2010-2015. The groundwater model adequately supports the conceptualization and evaluation of the seven alternatives, and the model should be able to support the design of the number and location of extraction wells, the zone to be pumped, and the proposed pumping rate for Alternative 3D, which is considered to be the best alternative (Tetra Tech 2016b).

4.4 ABILITY OF ARS AND MONITORING PLAN TO MEET REMEDIAL OBJECTIVES

The simulations run for Aquifer Recovery System (ARS) Alternative 3D using versions two and four of the groundwater model (Tetra Tech 2016b and c) predict that this alternative will retract the hypersaline interface eastward to the western boundary of the CCS within 10 years, and the scenario run for Alternative 3D using version two of the groundwater model (Tetra Tech 2016b) predicts that the drawdowns in the water-table in the upper part of the Biscayne Aquifer will be less than 0.2 ft west of L-31E. As discussed in this report, more information concerning coordinate locations for monitoring wells and choices of monitoring wells needs to be provided in the proposed monitoring plan (Turkey Point Recovery Well System Proposed Monitoring Network, FPL, May 15, 2016). Also, consideration needs to be given to locating two additional monitoring wells to the proposed network, one cluster well approximately midway between monitoring wells TPGW-1 and TPGW-2 and a second cluster well in the vicinity of the southwest corner of the CCS between monitoring wells TPGW-2 and TPGW-3.

4.5 RECOMMENDATIONS FOR ADDITIONAL DATA COLLECTION AND MODEL REFINEMENT

The calibrated groundwater model successfully reproduces the observed groundwater salinities in nearly all of the Biscayne Aquifer, and the predictive simulations for Alternative 3D appear to yield reasonable hydrogeologic results. However, a somewhat major issue that is still unresolved in all four versions of the groundwater model is the simulated salinity in the part of the Biscayne Aquifer below the lower high flow zone (model layer 8) and the response of the salinity in this part of the aquifer to the extraction wells simulated in Alternative 3D (Tetra Tech 2016c). In this part of the aquifer, simulated salinities are greater than observed salinities, and capture and extraction of the hypersaline plume is not achieved. Tetra Tech (2016c) recommends additional data collection and analyses, including geophysical logging, should be pursued to improve the model simulation of saltwater conditions though the full aquifer vertical profile. We concur with this recommendation and urge FPL to conduct additional data collection and model refinement to resolve this salinity issue in the part of the Biscayne Aquifer below the lower high flow zone.

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Aquifer Performance Test (APT) Report

Everglades Labor Camp Wellfield

Miami-Dade County, Florida

Miami-Dade Water and Sewer Department

Water Resources Section

August 2010

MIAMI-DADE COUNTY

Delivering Excellence Every Day

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Aquifer Performance Test (APT) Report

Everglades Labor Camp Wellfield

Miami-Dade County, Florida

ABSTRACT

An Aquifer Performance Test (APT) was conducted by Miami-Dade Water And Sewer Department (MDWASD) at the Everglades Labor Camp (ELC) Wellfield to determine the hydrologic characteristics of the Biscayne Aquifer there. The test results indicate an aquifer transmissivity (T) between 11,600,000 gpd/ft and 15,800,000 gpd/ft. and a storage coefficient (S) of 0.2 at the site. These T values are similar to the T value previously reported by the United States Geological Survey (USGS) for the Florida Keys Aqueduct Authority (FKAA) Wellfield located approximately one mile north of the ELC Wellfield. In 1972 the USGS conducted APT tests and calculated a T value of 15,000,000 gpd/ft for the FKAA Wellfield which at the time was known as the Navy Wellfield (Meyer, F.W., 1974). In 1991, the USGS again reported a T of 14,960,000 gpd/ft at the FKAA Wellfield (Fish and Stewart, 1991).

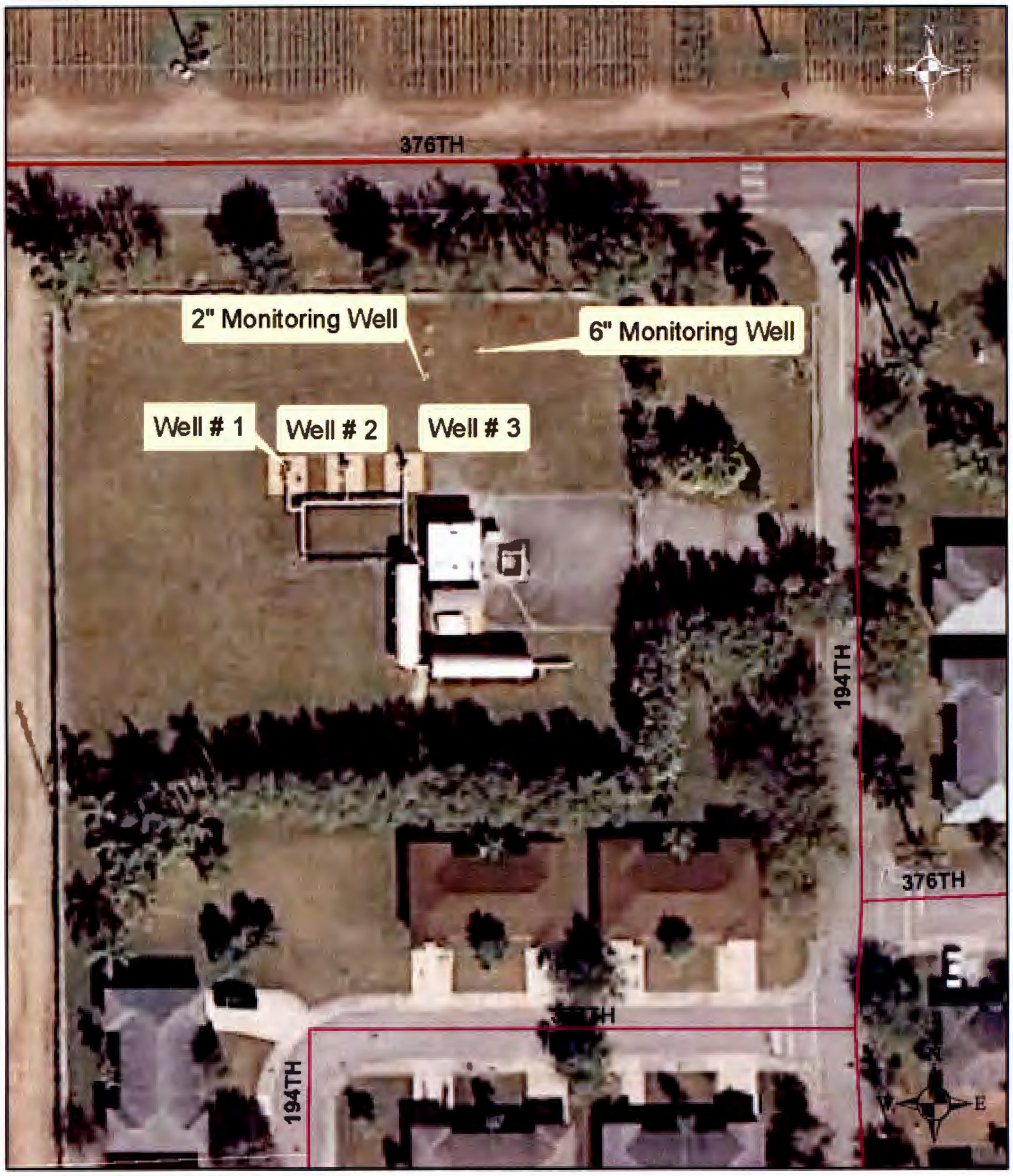
Based on the lower and more conservative T value of 11,600,000 gpd/ft, it is calculated that the drawdown expected from the installation of another 1,500 gpm pump at the ELC Wellfield will result in a drawdown of approximately 5 feet at the pumped well during a typical 12-hour continuous operation day; or a drawdown of approximately 8.5 ft for a 180-day continuous operation period. These drawdown levels will have no significant effect on the current setting depth of the pump intakes of the other two production wells, nor will it require any special modification of the wells. However, because of apparent down-hole restrictions in the open hole of the westernmost of the three production wells, it is recommended that installation of a new 1,500 gpm pump be done in the middle production well (Production Well No.2).

1.0 BACKGROUND

The population growth in southern areas of Miami-Dade County west of the City of Homestead, is creating a demand for additional water supplies to satisfy that growth. The Miami-Dade Water and Sewer Department (MDWASD) has completed an aquifer performance test (APT) at the wellfield that serves that area of the County (Figure 1). The APT was conducted to investigate the feasibility of obtaining those additionally required water supplies from the Everglades Labor Camp Wellfield (ELCW). This wellfield taps the Biscayne Aquifer with three production wells. The wells are cased with 18-inch OD steel casing to a depth below land surface of approximately 50 feet and are open-holed to approximately 65 feet below land surface. The wells are located in a west to east direction, starting with westernmost Well No. 1, Well No. 2 in the middle, and Well No. 3 to the east of Well No. 2 (Figure 2). Additionally, there are four shallow monitor wells on site, two of which were used to monitor water levels in the aquifer during the APT test.

Everglades Labor Camp Water Treatment Plant
19500 S.W. 376 Street

Figure 1. Location of the Everglades Labor Camp Wellfield and Water Treatment Plant



Everglades Labor Camp Water Treatment Plant
Well Location

0 30 60 120 180 240 Feet

Figure 2. Wellfield Layout

2.0 PURPOSE AND SCOPE

2.1 Purpose

The purpose of this report is dual: First it presents the procedures, data, analyses, results, and recommendation derived form the APT in support of an increased water production from the ELCW. Second, and perhaps more important, the test results in this report provide estimates of transmissivity and specific yield for the Biscayne Aquifer in this area of Miami-Dade County. The estimated values of those aquifer characteristics are used to help MDWASD determine the best setting depths for pump intakes and to help calculate the TDH that must be used for the pump selections. Currently two of the three production wells at the ELC Wellfield are equipped with 500 gpm turbine pumps and the third well (Well No. 3 is equipped with a 1,500 gpm turbine pump. The scope of this investigation includes calculation of the effects on groundwater levels caused by the installation of a new 1,500 gpm pump to replace one of the 500 gpm pump on one of the other two wells. Installation of that higher capacity (1,500 gpm) pump at one of the other two water supply wells is needed if the projected water demands in the area are to be met. The APT test was conducted in the late evening of December 17, 2009 and the early morning of December 18, 2009. The calculation of T and S were completed in March 2010 and the preliminary results and conclusions of the investigations were submitted for internal use on April 20, 2010. This report represents the formal and final record of this APT investigation.

2.2 Scope

The scope of this report includes the presentation of the range of values for the hydrologic characteristics T and S calculated from the test data. The scope also includes the selection of the most representative of those calculated values for T and S, but keeping in mind that these calculated values were derived from a very short and highly restricted pumping test.

The APT test had to be performed under less than ideal conditions. It had to be performed using the existing production wells as the test wells. That required keeping the production wells fully connected and on continuous-standby. The production wells had to be ready, at a moment's notice, to supply the full water demands of the community should the volumes available in the storage tanks be depleted by unexpected demands during the time period of the APT.

The test wells could not be disconnected from the water production system, nor was it possible to pump the wells at rates higher than the installed pumps could produce. Consequently, the aquifer was not ideally stressed. In fact, the aquifer was not stressed sufficiently volumetrically, nor was it stressed long enough. Neither were the monitor wells located at the ideal distances from the pumping wells, nor would it have been practical to drill new monitor wells at the ideal distances because higher pumping rates with the existing pumps would not have been possible.

Also, because it was necessary to maintain a possitive pressure on the water supply system all throughout the test (a fire-flow ordinance requirement of 40 psi), the APT discharge had to be made against a constant pressure and consequently the discharge was not a free flow. Additionally, an operational requirement that the water supply system be fully operational for the high water demand periods that start early in the morning and throughout the day, made it impossible to conduct more extensive APT tests on the system. The system can only be taken out of service during the nighttime period from 11 PM to about 4 AM and then it can only be taken partially out of service because back pressure on the lines can never drop below 40 psi.

3.0 PHYSICAL SETTING

3.1 Hydrogeology

The area investigated is underlayed by the highly productive Biscayne Aquifer of southeast Florida. This water table aquifer is the principal supplier of potable water to Miami-Dade County. The aquifer is wedge shaped, increasing in thickness towards the coast. It is about 60 feet thick at the ELC Wellfield and feathers out towards the western reaches of the county.
At the ELCW site the geologic strata are composed entirely of Late Quaternary Pleistocene deposits. The original surface formation (now lying approximately 4 feet below man-made soils—fill) is the Lake Flirt Marl. The Lake Flirt Marl is approximately 2 feet thick and overlies approximately 16 feet of Miami Oolite. Immediately below the oolite is the Fort Thompson Formation. At this site the upper 32 feet of the Fort Thompson is a medium to hard limestone with numerous marine shells and rock fragments. The lower 12 feet of the Fort Thompson is a very permeable sandy limestone. At a depth of approximately 66 feet below land surface (-60 ft. MSL) the Fort Thompson grades into the contact with the Tamiami Formation. The Tamiami Formation is generally considered to formally indicate the bottom of the Biscayne Aquifer. However, previous investigators (Causaras, 1987 and Fish and Stewart, 1991) have identified additional permeable zones below that contact.

Hydraulically, the most productive section of the aquifer is the lower 12 feet of the Fort Thompson Formation from -48 ft MSL to -60 ft. MSL, and the production wells at the ELC Wellfield tap exactly that interval with the open-holes open to the formation from -44 to -59 ft MSL.

At the ELC Wellfield site, the average high water table for September is 3.4 feet MSL and the average low water table for April is 1.4 feet MSL.

3.2 Production Wells

Five wells in the area are important to this investigation (Figure 2). The three production wells, including the two that were pumped during the test, and two observation wells.

SUMMARY			
WELLFIELD	EVERGLADES		
WELL NO.	1	2	3
GROUND ELEVATION	6.0	6.0	5.9
PUMP 16' SQ. BASE ELEV.	6.25*	6.25*	6.15*
CASING BOTTOM ELEVATION	(-) 44.0	(-) 44.0	(-) 44.1
OPEN HOLE BOTTOM ELEV.	(-) 59.0	(-) 59.0	(-) 59.1
DISCHARGE CONN. DIAM.	6"	6"	10"
TOP OF CASING ELEV.	8.25	8.46	8.46
℄ PUMP DISCHARGE ELEV.	9.21	9.21	9.21
PUMP RATING-GPM/TDH	500/155		1500/155
MOTOR H.P.	30	30	75

NOTE:
ELEVATIONS REFER TO M.S.L. U.S.C. & G.S. DATUM
* ELEVATIONS AT THE LOWEST POINT OF SLAB

Table 1. Production Wells Construction Details

The construction design details of the three production wells and of the pumps installed on them are shown in Table 1. Production Wells No. 1 and No. 2 are equipped with 500 gpm electric turbine pumps designed to discharge against a TDH of 155 feet through 6-inch connections. Each of those two pumps is powered with a 30 horsepower motor. Production Well No. 3 is equipped with a 1,500 gpm turbine pump with a 10" discharge and it too is rated for a 155 ft. TDH. The pump in Production Well No. 3 is powered by a 75 horsepower electric motor. The installation of the pumps is similar in all three wells and is typically shown in Figure 3.

For the current water demands from the ELC Wellfield, normal operations only require that one of the two 500 gpm wells be operating at a given time. The second 500 gpm well is needed for standby service only; although the use of these wells is regularly alternated to better protect the life of the pumps, and when servicing the equipment. Production Well No. 3 is also a standby well. Its primary function is as a fire flow well. Miami-Dade County's Fire Department requirements within the service area of the ELC Wellfield cannot be met with just the two 500 gpm wells.

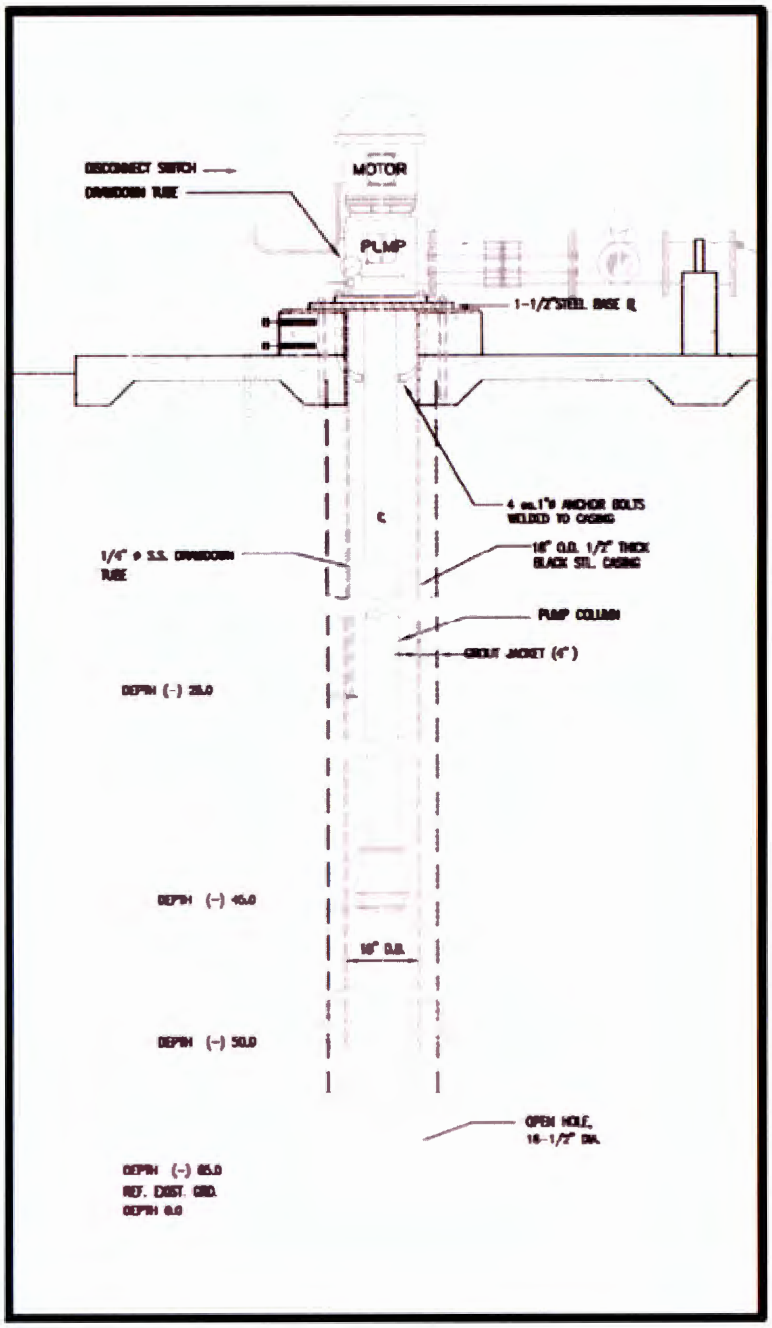


Figure 3. Typical Pump Installation Details

3.3 Observation (Monitoring) Wells

Observation well #1 is a 2" water-quality monitoring well that is part of a well cluster consisting of three monitoring wells installed at various depths. This well, is cased with PVC pipe and the measuring point used for water level measurement was the top of the casing. The well, shown in Figure 2, is the deepest of the three wells in the cluster. Observation well #2 is a 6-inch diameter well originally drilled as a test well and later converted into a water quality monitoring well. It is also cased with PVC pipe and the measuring point selected from which to measure the distance down to the water level was the highest point at the top of that casing.

The horizontal distances between the wells used for the APT test is shown in the table below

Distances between wells (in feet)	Production Well No.1	Production Well No. 2	Production Well No. 3	2" Observation Well	6" Observation Well
Production Well No 1.	-	25'	50'	71'	97'
Production Well No. 2	25'	-	25'	52'	75'
Production Well No. 3	50'	25'	-	38'	58'
2" Observation Well	71'	52'	38'	-	21'
6" Observation Well	97'	75'	58'	21'	-

Table 2. Distances Between Wells

4.0 Aquifer Performance Test Program

4.1 Test Procedures

The full APT test consisted of three separate APT pumping events. Each event included a pumping phase and its corresponding recovery phase after each pumping phase. Each of the three pumping events relate to which of the three production wells was being pumped at the time. However, because Production Well No. 2 had been operating as the single production well in the ELC Wellfield before the APT, the first event of the APT did not include an actual pumping phase; it only involved the recovery phase after Production Well No. 2 was shut down. This first recovery phase was a 1 hour observation of the recovery that occurred when Production Well No. 2 was shut down at 11:00 PM on December 17, 2009 after having been in operation for at least 1 hour pumping at a rate of between 400 and 500 gpm. Recovery data indicated full water level recovery had been reached in all the wells within minutes of shut down.

The next event of the APT test included both the pumping phase and the recovery phase for the APT of Production Well No. 1. The well was pumped at a rate of approximately 500 gpm for 2 ½ hours during which time the pumps on the other two production wells remained locked-out. After the pump on Production Well No.1 was shut down, the recovery was measured for the next ½ hour, by which time full recovery had been achieved (as determined by constant water levels) in all the wells..

The third event was the APT test of Production Well No. 3. This APT also included both the pumping phase and the recovery phase. The pumping phase was a ½ hour pumping phase at a rate of approximately 1,500 gpm from Productrion Well No. 3 while the other two production wells were locked-out. The recovery phase was observed for ½ hour, by which time the water levels in all the wells had fully recovered.

4.2 Electronic Testing Equipment

Each of the two observation wells and each of the three production wells were equipped with electronic water level (pressure) transducers. The transducers used are self contained "diver" transducers capable of measuring pressure changes at pre-selected time intervals and then recording those readings into the diver's down-loadable memory The transducers were installed on the wells by the United States Geological Survey (USGS) on December 16, 2009 and were calibrated by USGS that same day. The afternoon of December 17, 2009 several hours before the APT, the calibration was checked again, this time by MDWASD. Both hand-held electric-taped and chalked-taped readings were used to measure depth to water from the measuring point (MP) previously selected for each well.

During the actual APT testing, the diver recorders were scaled to record water levels at fractions of a second interval; but as a backup, and to provide a more visual and tangible level of confidence in those test data, the water levels in the wells were also measured at between two and five minute intervals (during both pumping and recovery) using had held tapes (electronic and chalked). The diver water level data from all five wells are on file and available in CD format. The backup hand-held tape readings are also on file. Plots of the water level measurement data have been developed from the data and are presented in the Appendix.

The discharge measurements made during the test were made electronically using magnetic meters that are part of the ELC Wellfield piping and distribution system. The discharge meters and the pressure gauge data is recorded on paper charts at the wellfield office and during the APT test all the discharge and gauge data was taken from those gages and charts and also recorded by hand . The water produced during the pumping phases was discharged on the ground through the regular piping system using a fire hydrant located nearly ¼ mile from the pumping test site. The discharged water did not contribute to the recharge of the aquifer at the test site during the time interval of the tests.

5.0 DATA ANALYSIS

The APT test was in reality a three event test and each event was of very short duration. Because of the short duration, correction for long-term seasonal trends in water level and for changes in barometric pressures were not required. Neither was there any rainfall during the duration of the test that would have required data correction. Extremely heavy rainfall reported in the area on December 18, 2009 occurred late in the morning after the APT test had been completed. Also, since the pumping wells were for all practical purposes fully penetrating, no corrections were needed for partial penetration. Transmissivity was calculated using both the equilibrium (Theim's) and the modified non-equilibrium (Theis') equations.

At the completion of the APT test, the transmissivity of the Biscayne Aquifer at the ELC Wellfield site was calculated and confirmed to be very large. Even before the planning process for the APT test had begun, this was already suspected, but now it was confirmed. Because of that high transmissivity, the values of drawdown developed during the test were very small and it became clear that applying that data to the Theim's equation would be difficult. The failure to stress the aquifer enough to cause significant drawdown at distant points from the pumping well was the main problem that made it impossible to perform accurate calculations of transmissivity using the Theim's approach. By using the pumping rates produced by the existing pumps it was not possible to stress the aquifer sufficiently. This meant that a drawdown vs. distance analysis (which is the basis of the Thiem solution) would result in extremely low values that would not represent real conditions. For that reason the Theim solution was not selected for valid calculation of T. The analysis using the Theim graphic solution is presented in this report but it is not accurate and was therefore disregarded. It is presented only to illustrate and highlight the need to use a much higher pumping rate in any future APT tests conducted in this area of the County.

The approach selected for the determination of the value of T was the Theis solution. For the Theis equation the graphic solution was divided into two reaches, one reach showing the very early stages of the test and the other reach including the later stages of the test. The two reaches plot with different slopes, with the first reach showing a steeper slope and the second reach showing a more moderate slope. Because of the high slope of the early part of the test, it appears that the earlier reach probably included water stored in the casing as well, and not much water coming from the formations. This problem that often occurs with pumping tests was recognized by Papadopulus and Cooper in 1967 and was discussed in detail by Schafer in 1978. Schafer's paper (Appendix C.) includes several figures that illustrate the change in slope of the two reaches and the analysis that affirms that the second reach is the more accurate one. This investigation has found findings similar to Schafer's. Consequently the second reach is considered more accurate and was therefore selected as the better reach for the analysis of T; although as had been discussed earlier and for design purposes only, the lower and more conservative value obtained from the analysis of the first reach was selected.

5.1 Theis' Analysis

$T = 264\ Q\ (\log_{10} t_2/t_1) / \Delta s$

Where:

T = Transmissivity in gpd/ft

Q = Rate of discharge from pumped well in gpm.

t_1 = time from start of pumping to time of drawdown measurement in measured well.

t_2 = time from start of pumping to time of drawdown measurement in measured well.

s = Drawdown in feet at pumped well.

1. Because the drawdown is a small fraction of the saturated thickness of the aquifer, there is no need to correct for drawdown deatering.
2. No corrections were made for the wells not being fully penetrating of the aquifer. It was assumed the wells are fully penetrating, as it seems to be the case.
3. The aquifer was assumed homogeneous.

The Theis analysis was performed using the data developed while pumping Production Well No.1 at 500 gpm and using the 6-inch Observation well #2 to record drawdown vs. time from the start of pumping. The combination of these two wells was used because that combination represents the use of the two wells furthest apart and showing the least disturbance from variations in pump rpm fluctuation and fire-hydrant discharge adjustments These data are presented in the graph of Figure 4 as a plot of drawdown versus time over the 90 minute pumping interval. The solution points used for the Theis formula were selected over the logarithmic cycle between the two-minute and the twenty-minute interval. This interval, from 2 to 20 minutes over the whole 90 minute length of the test, yielded the best results for the drawdown vs. time analysis and was used for the 500 gpm and for the 1,500 gpm analyses. Additionally, for both the 500 gpm and the 1,500 gpm tests, the drawdown curves were divided into two reaches. The first reach applies to the early part of the tests during which casing water was being pumped out and the discharge rates were being adjusted by throttling the flow in the fire hydrant. The second reach encompasses the later part of the test when the discharge was steadier . While the analyses using the second reach are deemed more accurate, the results of the analysis of the first reach yields a lower value for T and is therefore more conservative. Keeping in mind that for values of T as high as were found at the ELC Wellfield, a difference of 20 % between results is within the margin of error that can be expected from the very restricted APT test that was conducted; therefore, it is considered that the analyses of both reaches yielded acceptable results. The analysis of the 1,500 gpm test also yielded equally high values of T, but well within the acceptable range of variation. The graphic plots of the 500 gpm test data is shown in Figure 4. The 1,500 gpm data plot is shown in Figure 5.

The data presented in graphic form in Figures 4 and 5 shows the two reaches discussed earlier for the 90-minute 500 gpm pumping phase and for the 30-minute 1,500 gpm pumping phase. Erring on the conservative side, the lower value of T, of the three shown in Figures 4 and 5, has been selected to represent the final T value from this test. The 1,500 gpm test was considered to be less accurate because of the proximity of the monitor well to the pumping well and because of the increased pressure restraining the free discharge through the fire hydrant during the 1,500 gpm discharge rate.

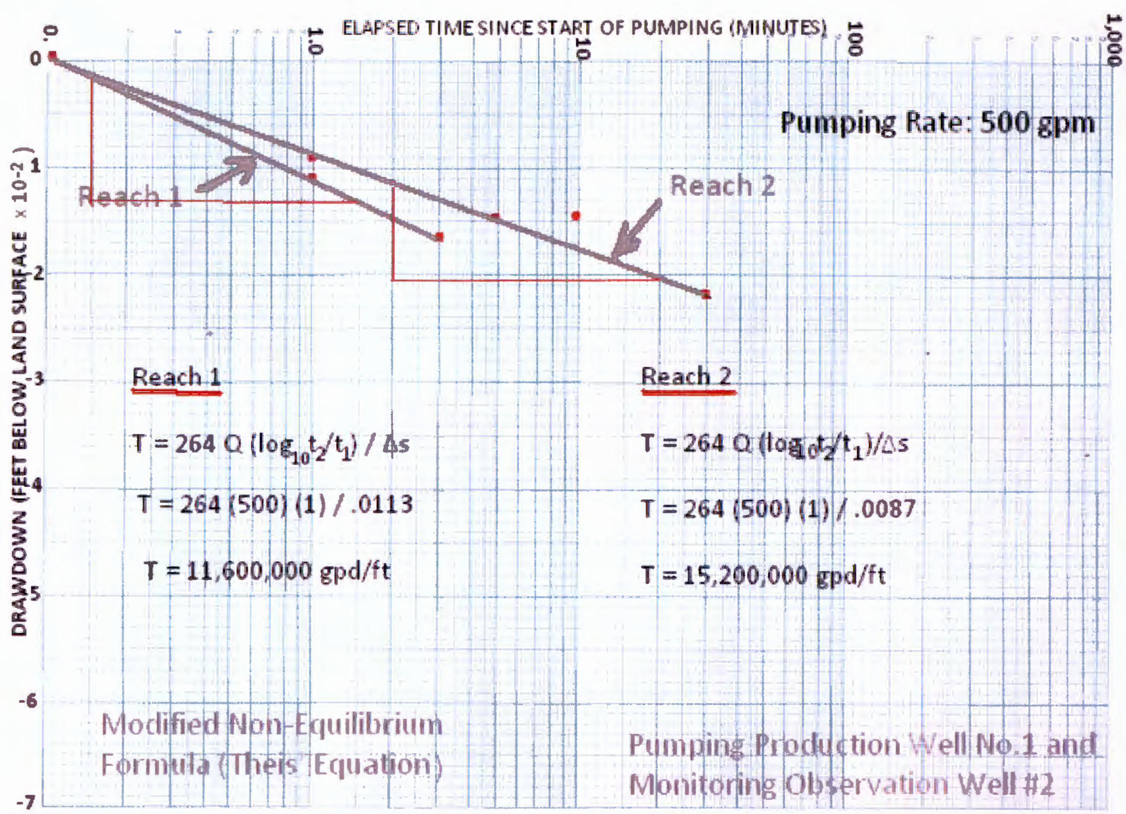


Figure 4. Logarithmic Plot of Time vs. Drawdown for 500 gpm test (Theis' Equation)

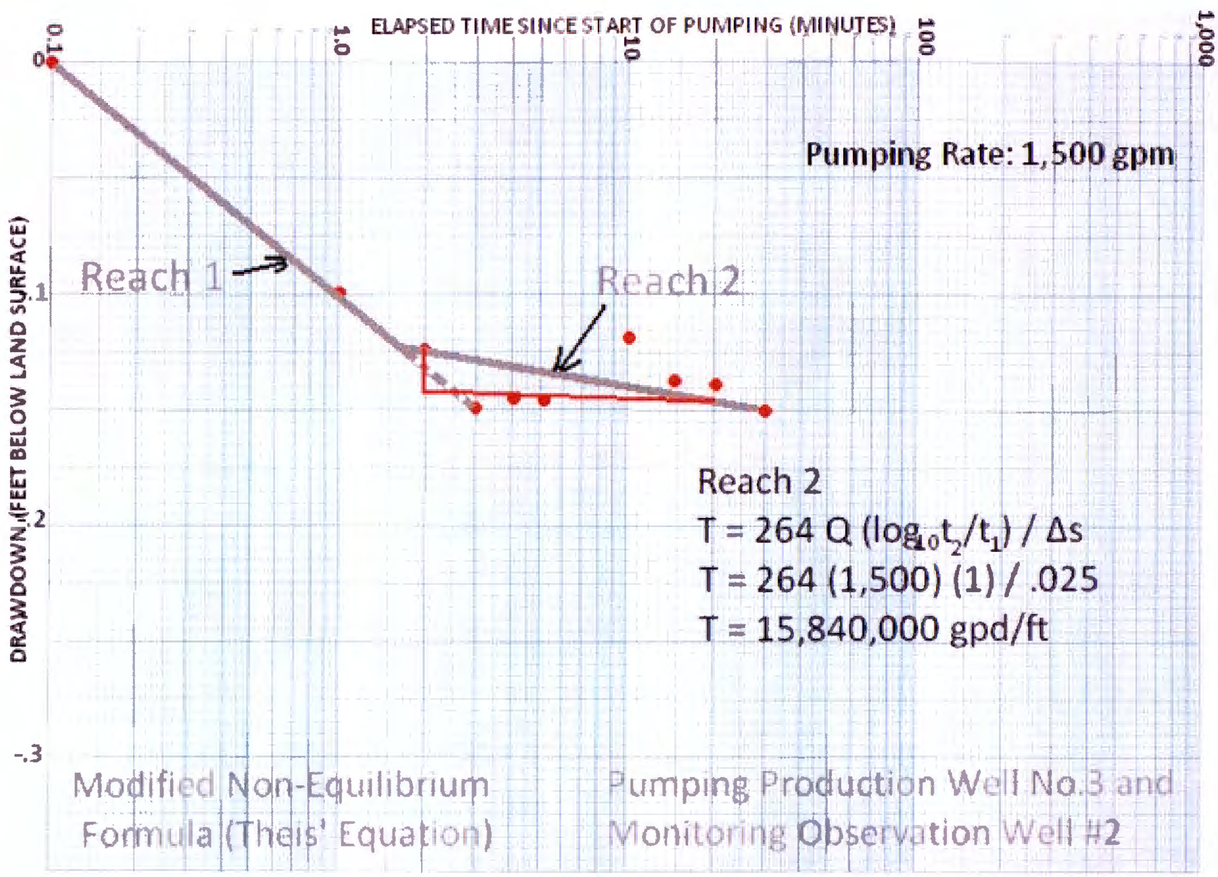


Figure 5. Logarithmic Plot of Time vs. Drawdown for 1,500 gpm test (Theis' Equation)

5.2 Theim's Analysis

This analysis is presented in the interest of completeness but it does not represent an accurate solution. However the extension of the drawdown line in the graph is useful in determining the zero drawdown distance that can then be used to calculate specific yield S.

Transmissivity was estimated by using the Theim's equilibrium equation. Drawdown versus distance from the pumped well was plotted (Figure 6) and values for the equation were then obtained from the graph.

Equilibrium Formula (Theim's Equation)

$T = 527.7\ Q\ \log_{10} (r_2/r_1) / (s_1 - s_2)$

Where:

T = Transmissivity in gpd/ft

Q = Rate of discharge from pumped well in gpm.

r_1 = Distance in feet from pumped well to first observation well.

r_2 = Distance in feet from pumped well to second observation well.

s_1= Drawdown in feet at the first observation well.

s_2 =Drawdown in feet at the second observation well.

Or, using for s_2 the zero drawdown extension of the graph and for s_1 the face of the borehole of the pumping well the Theim's Equilibrium Equation becomes:

$T = 1060\ Q\ m\ \log_{10}(r_2/r_1) / s\ (2m-s)$

Where:

T = Transmissivity in gpd/ft

Q = Rate of discharge from pumped well in gpm.

r_1 = Distance in feet from pumped well to first observation well.

r_2 = Distance in feet from pumped well to second observation well.

s = Drawdown in feet at pumped well.

m = Aquifer thickness in feet (54 feet saturated thickness)

1. Because the drawdown is a small fraction of the saturated thickness of the aquifer, there is no need to correct for drawdown.
2. No corrections were made for the wells not being fully penetrating of the aquifer it was assumed to be so as it seems to be.
3. The aquifer was assumed homogeneous

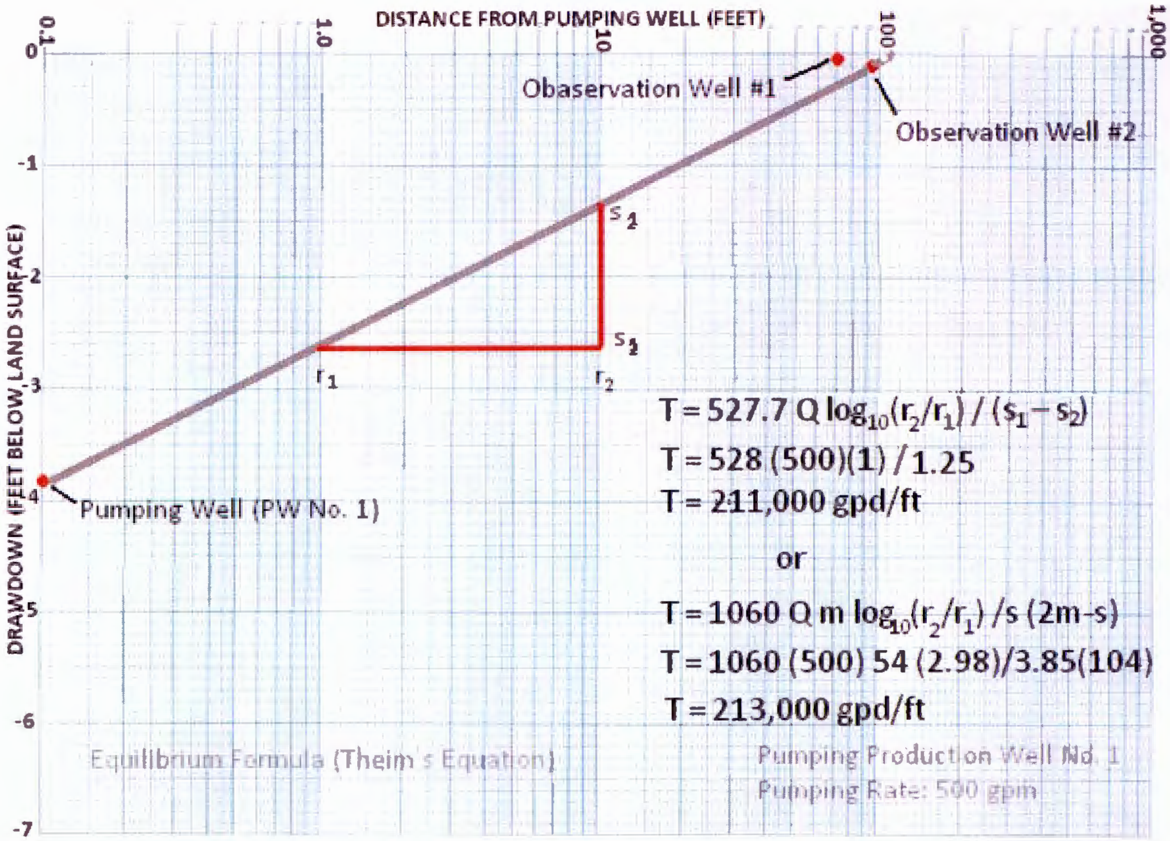


Figure 6. Logarithmic Plot of Distance from Pumping Well vs. Drawdown (Theim's Equation)

5.3 Specific Yield (S) Analysis

Specific yield was determined from the extrapolation of the 500 gpm drawdown vs. distance curve for the Theim's solution (Figure 6), and using the recovery period of one minute that it took for the drawn-down water levels to return to pre-pumping levels. The extrapolation of the drawdown vs. distance curve beyond the 97 foot distance that Observation Well No. 2 is from the pumping well shows that the point of zero drawdown is reached at a distance of 110 feet from the pumping well. That is the theoretical radius of zero drawdown from the pumped well.

Using these values and the value for transmissivity previously estimated from the Theis Solution (Figure 4), the specific yield (S) was determined.

$S = 2.09 \times 10^{-4}\ T\ t_m / r_e^2$

Where: T = 11,600,000 gpd/ft (from Theis equation)

t_m = 1 minute

r_e = 110 feet (radius of zero drawdown from Figure 6)

$S = 2.09 \times 10^{-4} \times 11{,}600{,}000 \times 1 \div 110^2 = 0.2$

6.0 RESULTS

An Aquifer Performance Test ("the pumping test") was conducted for the ELC Wellfield on December 17-18, 2009 to determine T (transmissivity) and S (specific yield) values at a wellfield that is going to be serving future additional service areas in southern Miami-Dade, where the county proposes to approve new developments requiring additional water supplies.

The calculations of these aquifer hydraulic characteristics indicate that Biscayne Aquifer at the site has a very high transmissivity value (11,600,000 gpd/ft using one method of calculating it, and 15,200,000 gpd/ft using another method). These values result in a very high degree of confidence in the test results because the Navy Wellfield (FKAA Wellfield) located about a mile and just to the north of the ELC Wellfield has a reported transmissivity of 14,900,000 gpd/ft. Using the lowest transmissivity value obtained from the APT test and the specific capacity calculated from it, as well as from the known drawdown level for the wells at the Everglades Labor Camp Wellfield, it is calculated that adding another 1,500 gpm discharge from the Everglades Labor Camp Wellfield for additional supplies will only drawdown the existing water levels in the other two wells by another 0.3 feet. Therefore the additional withdrawal of 1,500 gpm will not require lowering the drop pipes in the other two wells.

Analysis of the data shows an estimated value of 11,600,000 (gallons per day per foot) for the transmissivity, and 0.2 for the specific yield. In effect, because the aquifer is unconfined, by definition, this is really specific yield and strictly should not be called storage coefficient (Lohman, 1972).

Total drawdown in the 16 ½ -inch Production Well No. 3 while pumping at 1,500 gpm was recorded as 4.1 feet and so the setting depth for a similar pump in Production Well No. 2. at a depth of -45 feet below land surface will be adequate.

However, to err on the side of caution, some leeway is recommended and it should be assumed that the drawdown that would result from adding an additional 1,500 gpm pump to the well could be more than the 0.3 feet we have calculated. It is recommend to round up to 0.5 feet the expected drawdown.

Production Well No. 1 appears to have a restriction in the open hole. The cause of that is not positively known, but it is suspected that annular cement may have fallen in the open hole. It is therefore suggested that if a 1,500 gpm pump is to be installed, it should be on Production Well No.2 or else repairing Production Well No. 1 should be done if the pump is to be installed on Production Well No. 1. Well No. 3 is not available since it already has a 1,500 gpm pump on it.

Installation of another 1,500 gpm pump and withdrawal of additional volumes in excess of the current permitted levels will require a permit change to the South Florida Water management District (SFWMD) Water Use Permit (WUP) and a construction change permit with the Health Department.

7.0 MDWASD STAFF'S CONCLUSIONS AND RECOMMENDATIONS

7.1 The conclusions derived from the pumping test results are:

1) From the pumping test data, we have calculated very high aquifer transmissivity values. We used two different methods of calculating transmissivlty. We obtained a value of 11,600,000 gpd/ft using one method of calculating it, and 15,200,000 gpd/ft using another method of calculating it. A calculation using the 1,500 gpm pumping test data suggest a T of 15,800,000 gpd/ ft. Although we feel comfortable with the higher values, we feel more confident with the lower one; and to be safe, we should use the lower of the three values (11,600,000 gpd/ft).

The old Navy Wellfield (FKAA Wellfield) located just to the north of our ELC Wellfield has a reported transmissivity of 14,900,000 gpd/ft. and that gives us additional reassurance in our results because our calculations are in the same general ball park. Using a T of 11,600,000 gpd/ft at the ELCW will be a safe assumption.

2) We also recorded a specific capacity of approximately 300 gpm per foot of drawdown at the ELCW from a single well.

3) We have also estimated a specific yield (S) of 0.2

4) Using the lower transmissivity value of 11,600,000 gpd/ft and the specific capacity of 300 gpm per foot of drawdown level for the wells at the Everglades Labor Camp Wellfield, we calculate that changing the pump on Well No 2 to enable us to increase the discharge form that

well to 1,500 gpm will only drawdown that well by a little more than 5 feet based on a typical daily operational period of 12 hours,

5) Based on the assumption of continuous operation to be 180 days, the drawdown inside the pumping well would be no more than 8.5 feet for continuous non-stop operation.

6) The water levels of the other two existing wells (Wells No. 1 and No. 3) will be lowered by no more than another 0.5 feet during 180-day nonstop operation and less than that during 12 hours of continuous operation.

7.2 Recommendations include:

1) Installing a pump to provide a withdrawal of 1,500 gpm from Well No. 2 will not require changing the depth of the pump intakes in the other two wells. Pump intakes set at -45 feet below land surface should be used in all three wells.

2) It is noticed that no mention has been made of the alternative of placing the 1,500 gpm pump on Well No. 1. That alternative has not been discussed because Well No. 1 has an obstruction in the open hole, and pumping Well No. 1 at 1,500 gpm without first removing the obstruction (apparently cement from the annulus around the casing has apparently fallen into the open hole) is likely to create excessive drawdown and would require more horsepower to overcome the increased head loss.

3) Finally, permitting issues must be addressed separately. Prior to installing another 1,500 gpm pump in a well to pump additional water permission from the Health Department and water use permit modifications from the SFWMD may be required. DERM and SFWMD may also require that potential saltwater intrusion effects be modeled, and DERM may require that the wellfield expansion include a redrawing of the wellfield zones of protection.

8.0 REFERENCES

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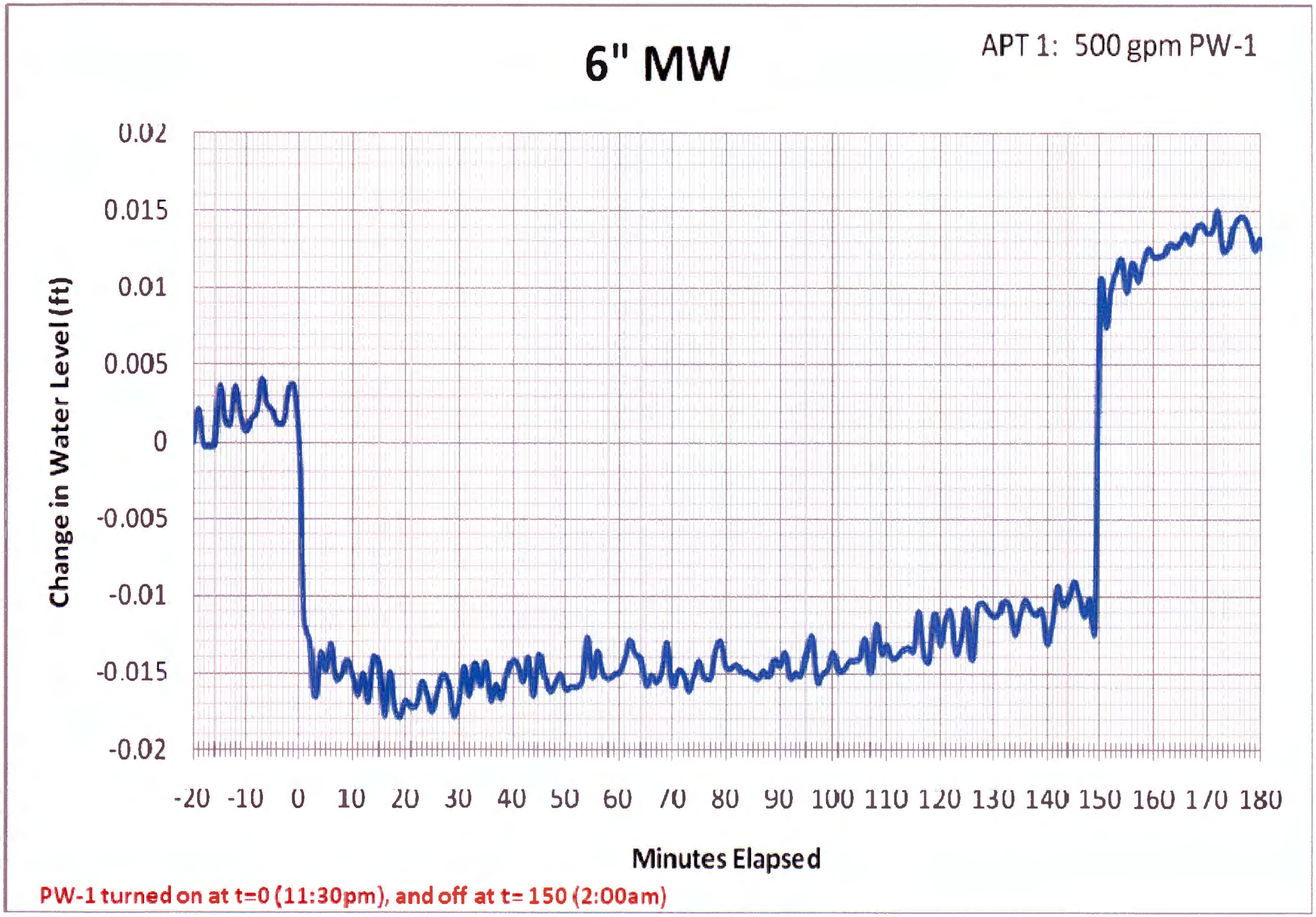
APPENDICES

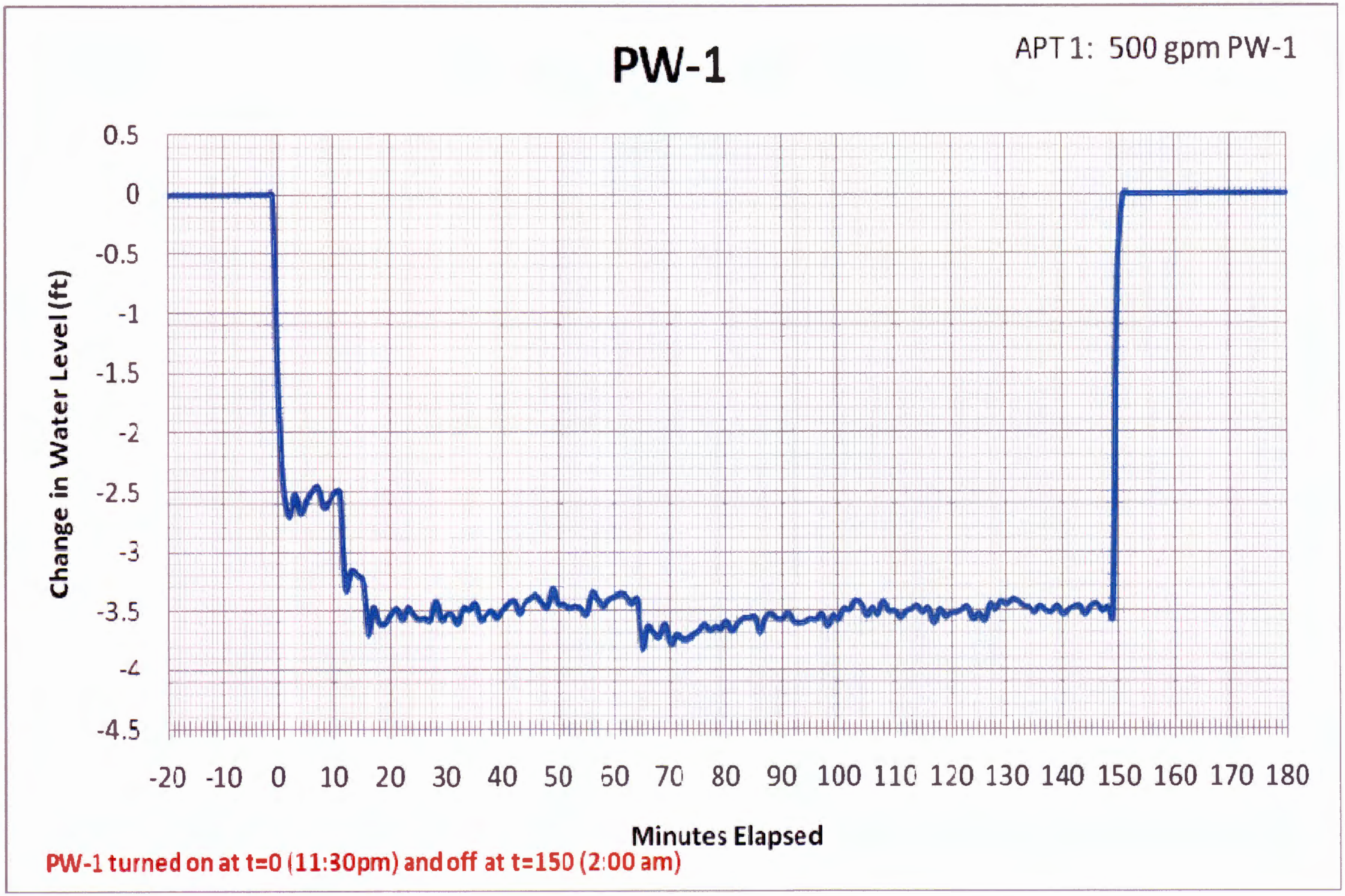
Appendix A. Test Data for the 500 gpm APT

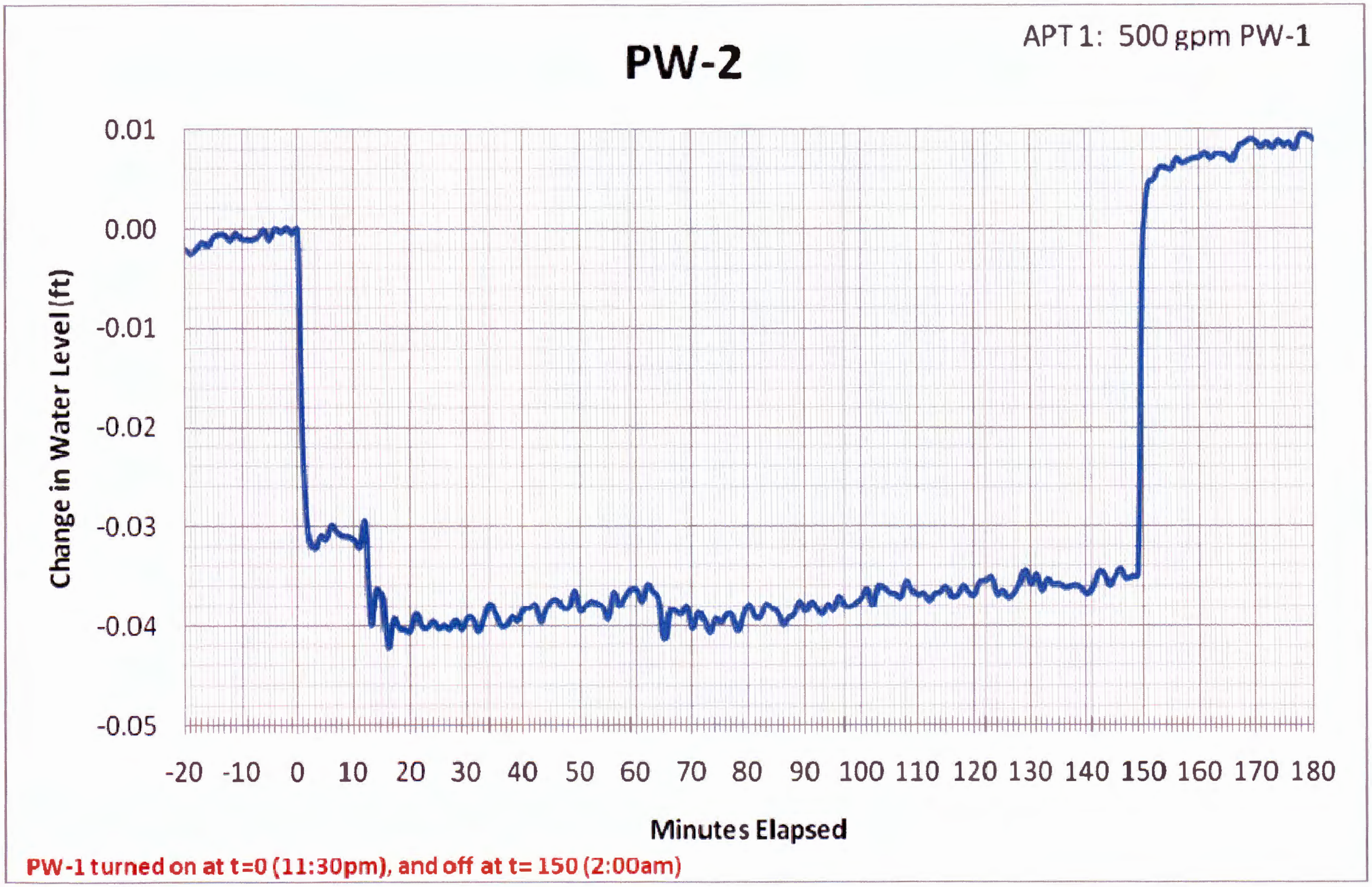
Appendix B. Test Data for the 1,500 gpm APT

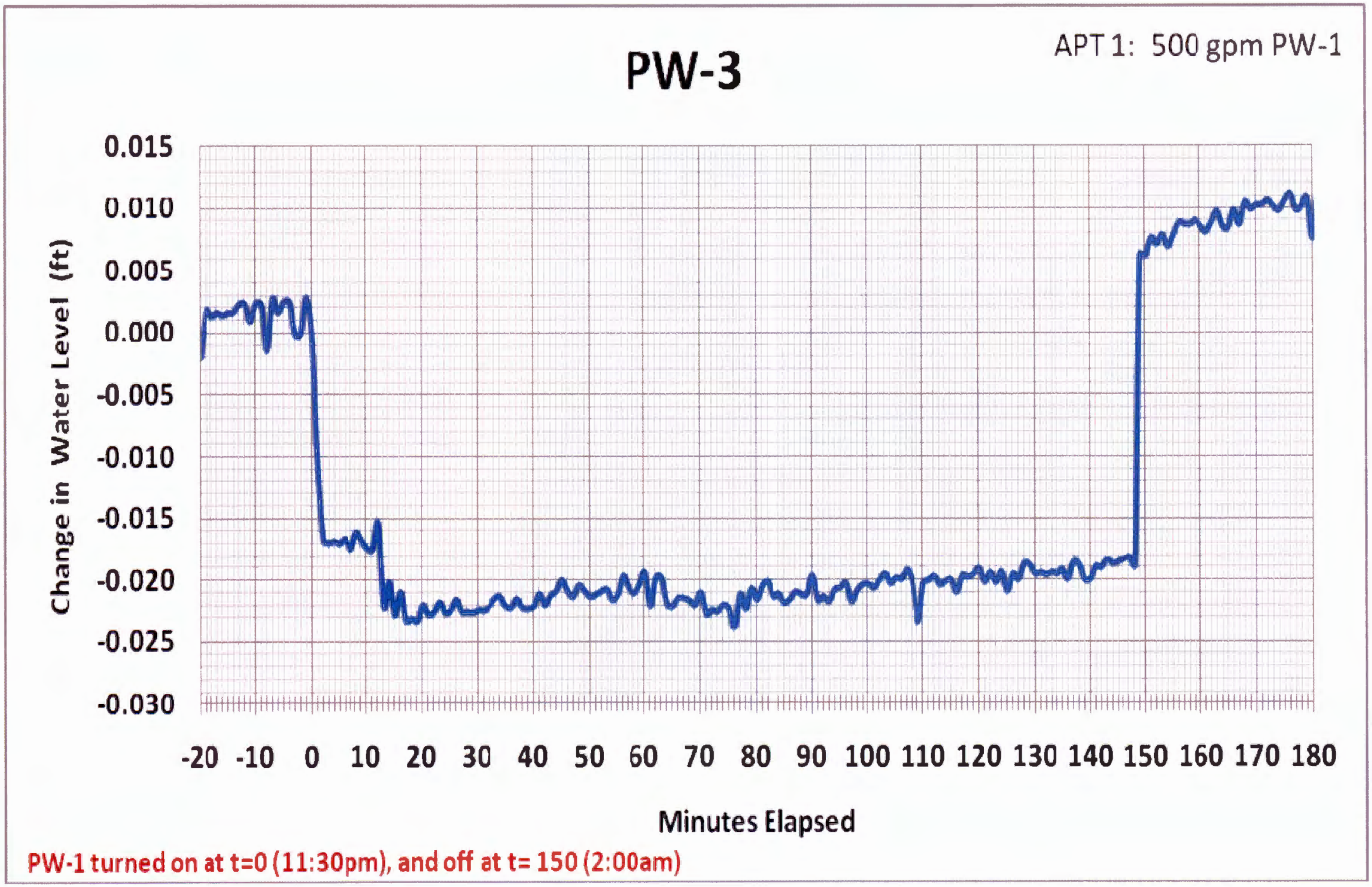
Appendix C. Casing Storage Effect

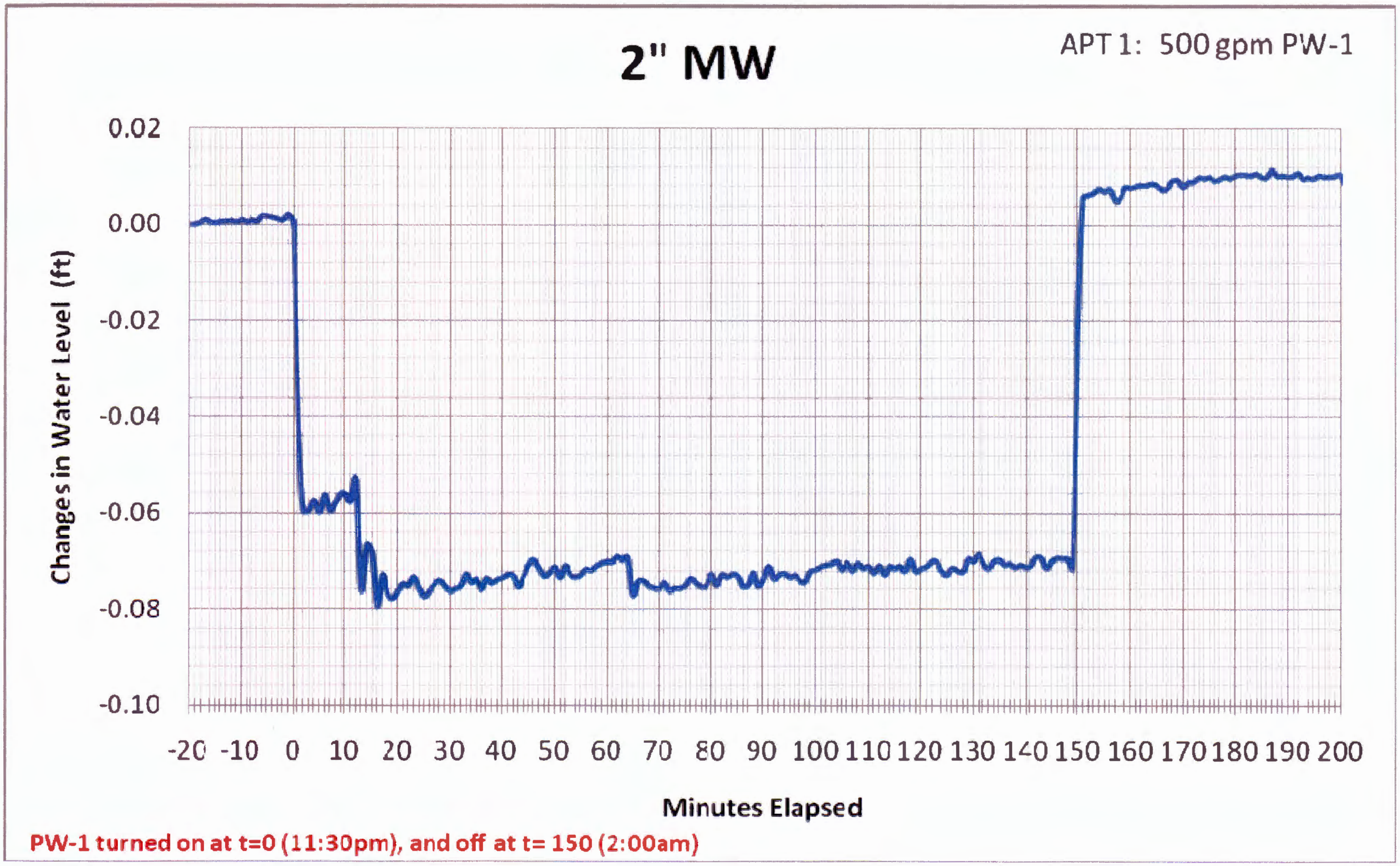
Appendix A. Test Data for the 500 gpm APT


6" MW
APT 1: 500 gpm PW-1
Change in Water Level (ft)
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Minutes Elapsed
PW-1 turned on at t=0 (11:30pm), and off at t= 150 (2:00am)

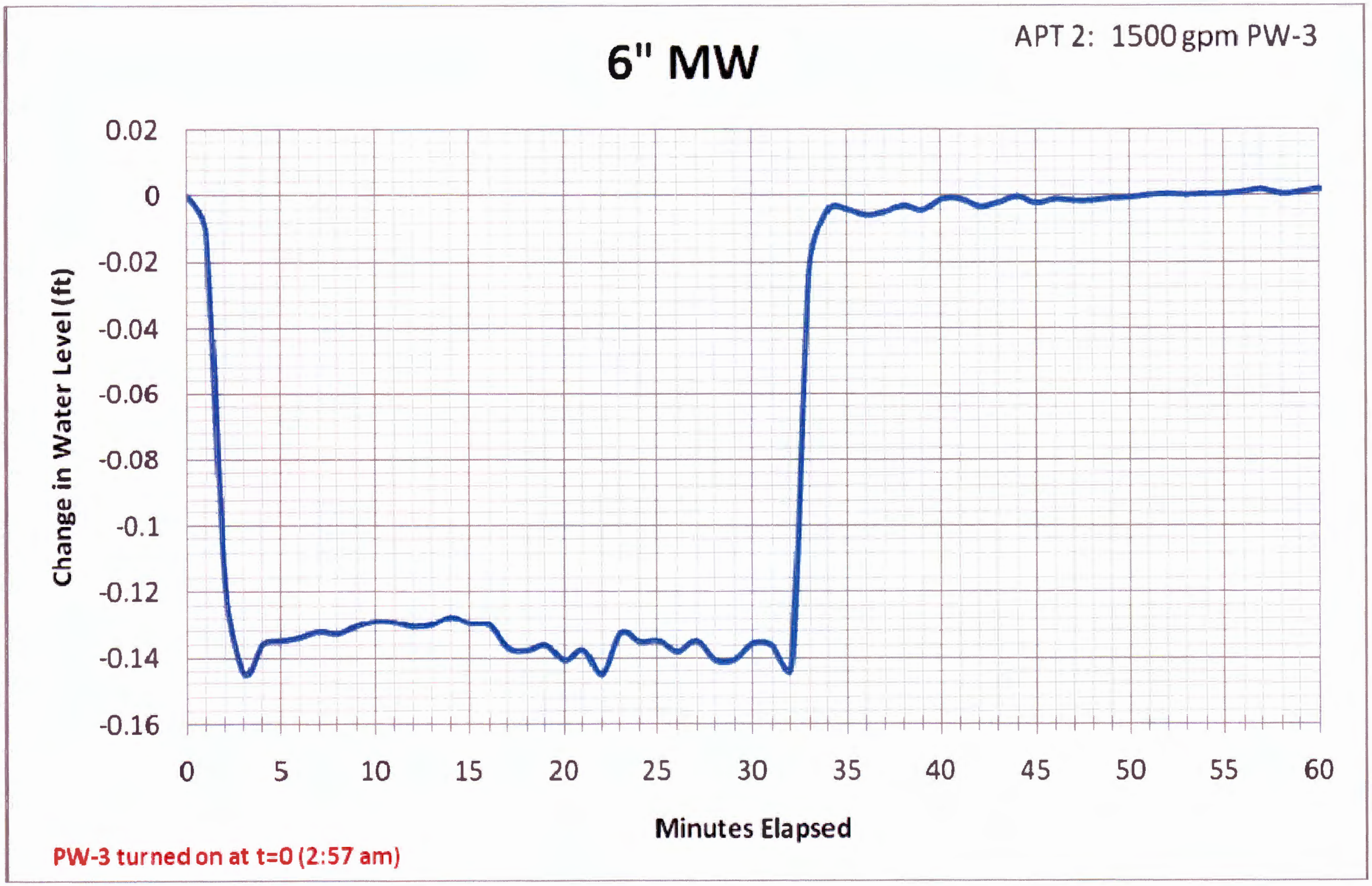

PW-1
APT 1: 500 gpm PW-1
Change in Water Level (ft)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Minutes Elapsed
PW-1 turned on at t=0 (11:30pm) and off at t=150 (2:00 am)


PW-2
APT 1: 500 gpm PW-1
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
Change in Water Level (ft)
-20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Minutes Elapsed
PW-1 turned on at t=0 (11:30pm), and off at t= 150 (2:00am)

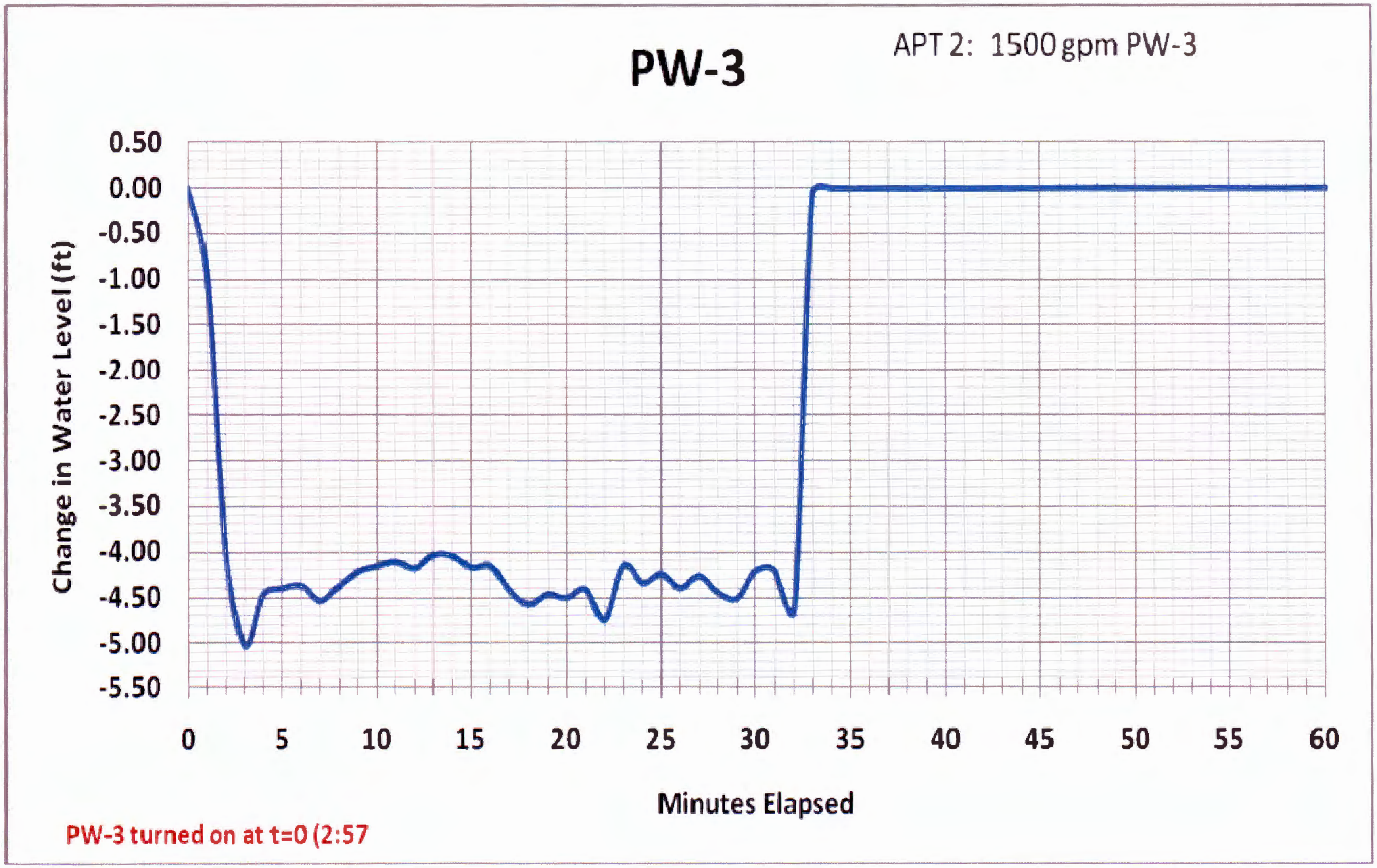

PW-3
APT 1: 500 gpm PW-1
Change in Water Level (ft)
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Minutes Elapsed
PW-1 turned on at t=0 (11:30pm), and off at t= 150 (2:00am)


2" MW
APT 1: 500 gpm PW-1
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
Changes in Water Level (ft)
-20 -10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Minutes Elapsed
PW-1 turned on at t=0 (11:30pm), and off at t= 150 (2:00am)

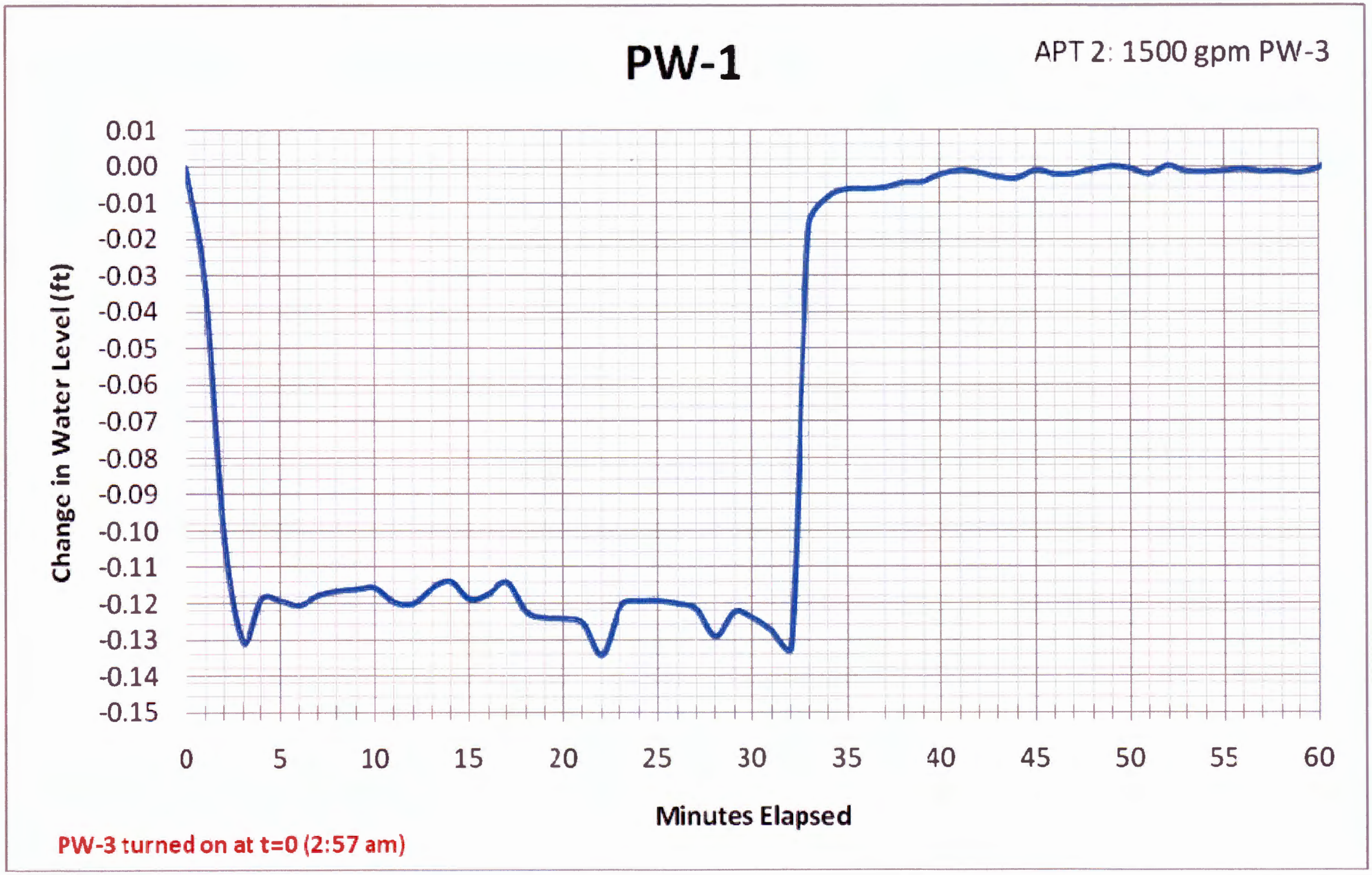
Appendix B. Test Data for the 1,500 gpm APT



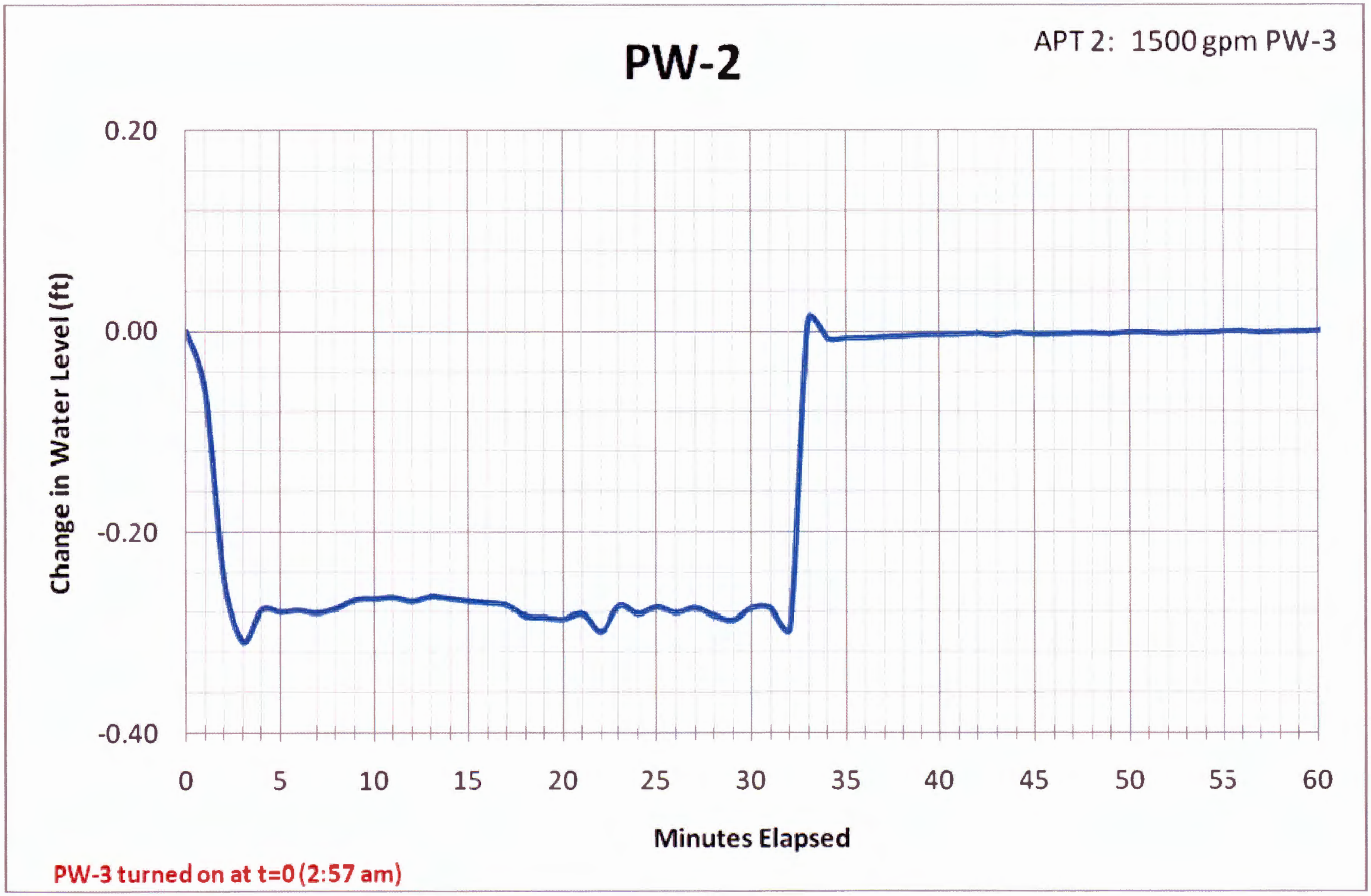
6" MW
APT 2: 1500 gpm PW-3
Change in Water Level (ft)
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
0
5
10
15
20
25
30
35
40
45
50
55
60
Minutes Elapsed
PW-3 turned on at t=0 (2:57 am)



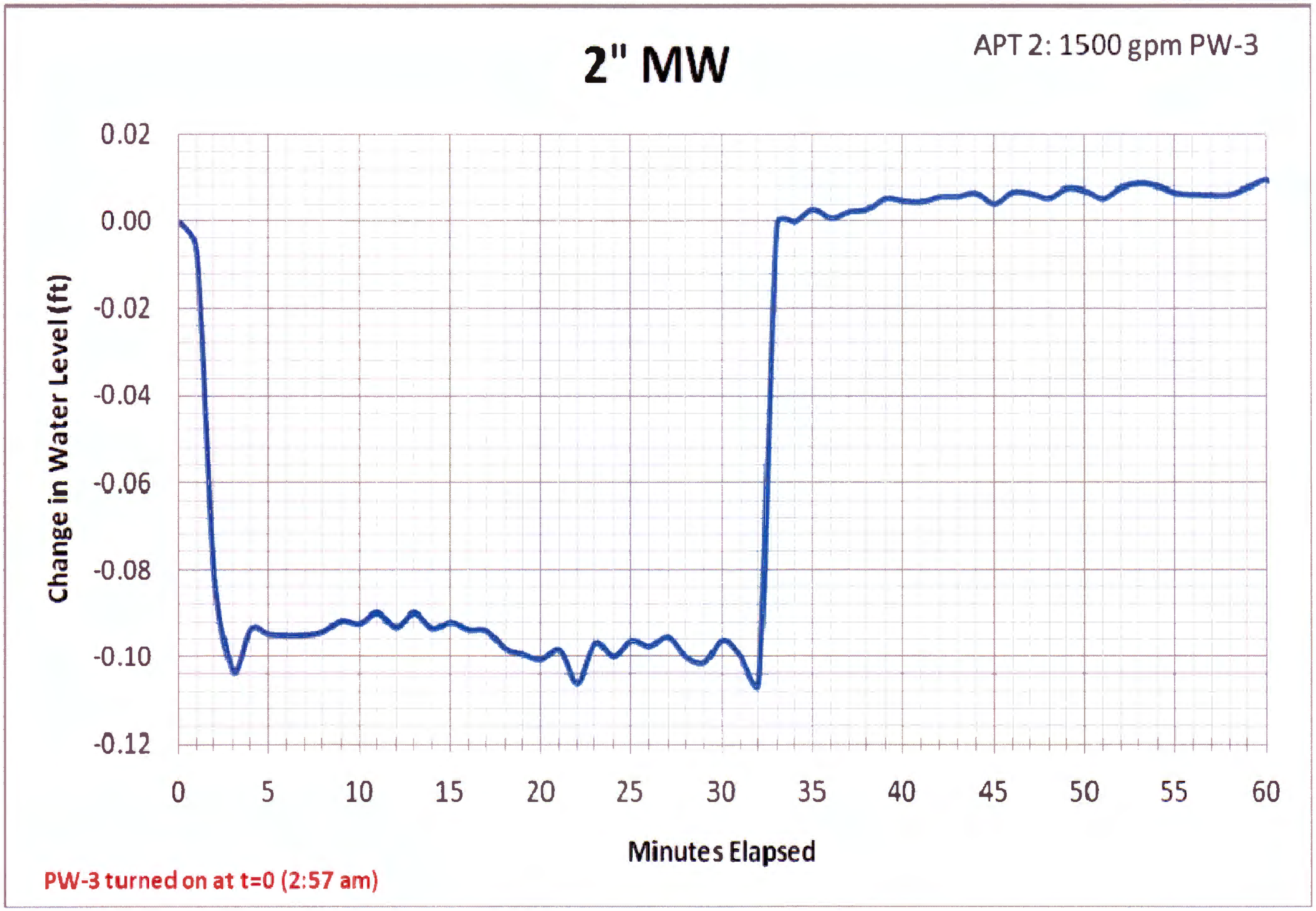
PW-3
APT 2: 1500 gpm PW-3
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
-3.50
-4.00
-4.50
-5.00
-5.50
Change in Water Level (ft)
0
5
10
15
20
25
30
35
40
45
50
55
60
Minutes Elapsed
PW-3 turned on at t=0 (2:57



PW-1
APT 2: 1500 gpm PW-3
Change in Water Level (ft)
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.10
-0.11
-0.12
-0.13
-0.14
-0.15
0
5
10
15
20
25
30
35
40
45
50
55
60
Minutes Elapsed
PW-3 turned on at t=0 (2:57 am)



PW-2
APT 2: 1500 gpm PW-3
0.20
0.00
-0.20
-0.40
Change in Water Level (ft)
0
5
10
15
20
25
30
35
40
45
50
55
60
Minutes Elapsed
PW-3 turned on at t=0 (2:57 am)


2" MW
APT 2: 1500 gpm PW-3
Change in Water Level (ft)
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-0.12
0
5
10
15
20
25
30
35
40
45
50
55
60
Minutes Elapsed
PW-3 turned on at t=0 (2:57 am)

Appendix C. Casing Storage Effect

The Johnson Drillers Journal

January-February, 1978

Casing Storage Can Affect Pumping Test Data

BY DAVID C. SCHAFER

This article examines one of the shortcomings of conventional pumping test analysis techniques which can lead to errors in data interpretation and suggests a guide to use in obtaining proper interpretation of the data.

THE MODIFIED non-equilibrium formula of Jacob derived from the Theis equation is often used by hydrologists to compute aquifer characteristics from pumping tests. This well known method of analysis (described in detail in the March-April and May-June 1977 JOHNSON DRILLERS JOURNAL) generally provides useful and accurate information.

Many pumping tests, however, have been observed where the early data do not fit Jacob's theory precisely. Often this lack of agreement between Jacob's predictions and the actual data results from the removal of water from casing storage during the pumping test.

One of the basic assumptions made in deriving Theis's (and subsequently Jacob's) equation is that all of the water pumped from a well during a pumping test comes from the aquifer and none from storage within the well. Since this condition is not fulfilled in practice, Theis's and Jacob's equations are somewhat inaccurate and a different theory is required to properly describe the behavior of the water level in a pumping well.

In 1967, Papadopulos and Cooper presented an equation describing the discharge from a pumping well which takes into account the volume of water removed from casing storage.* Drawdown values calculated from their equation differ significantly from Theis's and Jacob's equations during the early portion of the pumping test when a relatively high percentage of the discharge comes from casing storage. During the later stages of the pumping test when only a negligible quantity of water is obtained from casing storage, the equations produce equal results.

Difference in Drawdown Values

This can be seen in Figure 1 which shows time drawdown graphs in the generalized form for both the Papadopulos-Cooper and Theis equation. Notice that for early values of time the graphs differ. As time increases they converge and at time t_c become virtually identical. (The time at which the two curves appear to coincide, t_c, has arbitrarily been selected in this article to be the time at which the difference in drawdown values becomes one per cent. This criterion has proved satisfactory for practical problem solving.)

Figure 2 shows another comparison of time drawdown graphs predicted by Papadopulos-Cooper and Jacob or Theis. These graphs were constructed from theoretical calculations based on the specific aquifer parameters and well geometry indicated. Data from an actual pumping test would follow the Papadopulos-Cooper curve shown on this graph.

Jacob's method has been used in Figure 2 to

Mr. Schafer is a regional hydrologist at the headquarters office of Johnson Division, UOP Inc.

determine formation transmissivity (T) using the following equation:

$$T = \frac{264\,Q}{\Delta s}$$

where

- T = transmissivity in gpd/ft
- Q = pumping rate in gpm
- Δs = slope of the line of best fit drawn through the data points (change in drawdown per log cycle of time)

Two distinct values of transmissivity, T_1 and T_2, have been calculated from the Papadopulos-Cooper curve. T_1, determined from the early portion of the pumping test, has a value of 3,360 gpd/ft. T_2, determined from the later stages of the pumping test, has a value of 10,000 gpd/ft. Clearly, the calculated value of T_1 is correct because of the exaggerated slope of the early time drawdown data. This is caused by the influence of casing storage. T_2, however, provides the correct transmissivity value since it has been calculated from data which are no longer affected by casing storage.

As a result of the effect of the casing storage on the time drawdown graph, it is possible to misinterpret the data and assume the erroneous T value to be the correct one. For instance, the early data (steep slope) could be interpreted as indicating the correct transmissivity and the later data (flatter slope) could be interpreted as indicating recharge. Furthermore, it might be possible to have a pumping test of such short duration that only the casing storage-sensitive data are seen and the "correct" slope never appears.

In order to avoid misinterpretation of the data in cases like these, it is necessary to have some method of determing how much of the pumping test data is affected by casing

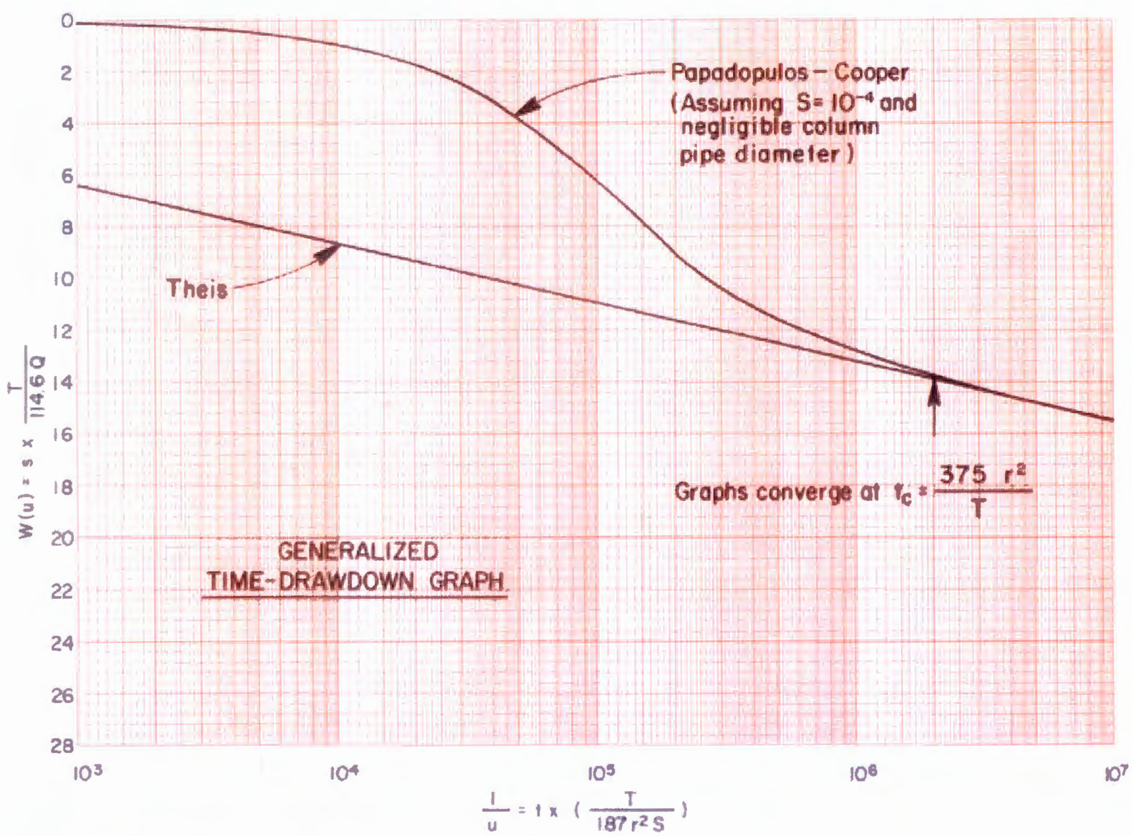


Fig. 1. When the Papadopolous and Cooper equation is applied to pumping test data, drawdown values for the early stages differ significantly from those obtained by the Theis equation.

storage. To accomplish this, Papadopulos and Cooper developed an equation for calculating t_c, the time at which the correct slope is observed on the time drawdown graph. The following is a slight modification of their formula:

$$t_c = \frac{375\,(r_c^2 - r_p^2)}{T} \quad (1)$$

where

- t_c = time in days after which the effect of casing storage can be ignored (assuming a one per cent error in drawdown values as mentioned earlier)
- r_c = radius (in feet) of well casing (inside dimension) over which the water level changes are occurring
- r_p = radius (in feet) of pump column pipe (outside dimension)
- T = transmissivity in gpd/ft

The form of equation (1) shows that t_c is directly proportional to the annular space between the well casing and column pipe and inversely proportional to the formation transmissivity. In general, then, t_c will be large when either the well radius is large or the T value is small.

Equation (1) has two limitations, however, which restrict its use in practical problem solving. First of all, it is necessary to already know the correct T value in order to calculate t_c. Second, the formula is valid only for wells which are 100 per cent efficient.

For inefficient wells, a solution obtained by H. J. Ramey provides a more accurate estimate of t_c than equation (1).†‡ In fact, evidence suggests that Ramey's equation is the most accurate one available for estimating t_c. An approximation of Ramey's equation is as follows:

$$t_c = \left[\frac{375\,(r_c^2 - r_p^2)}{T}\right]\left[\frac{2E + 1}{3E}\right] \quad (2)$$

where t_c, r_c, r_p and T are as stated for equation

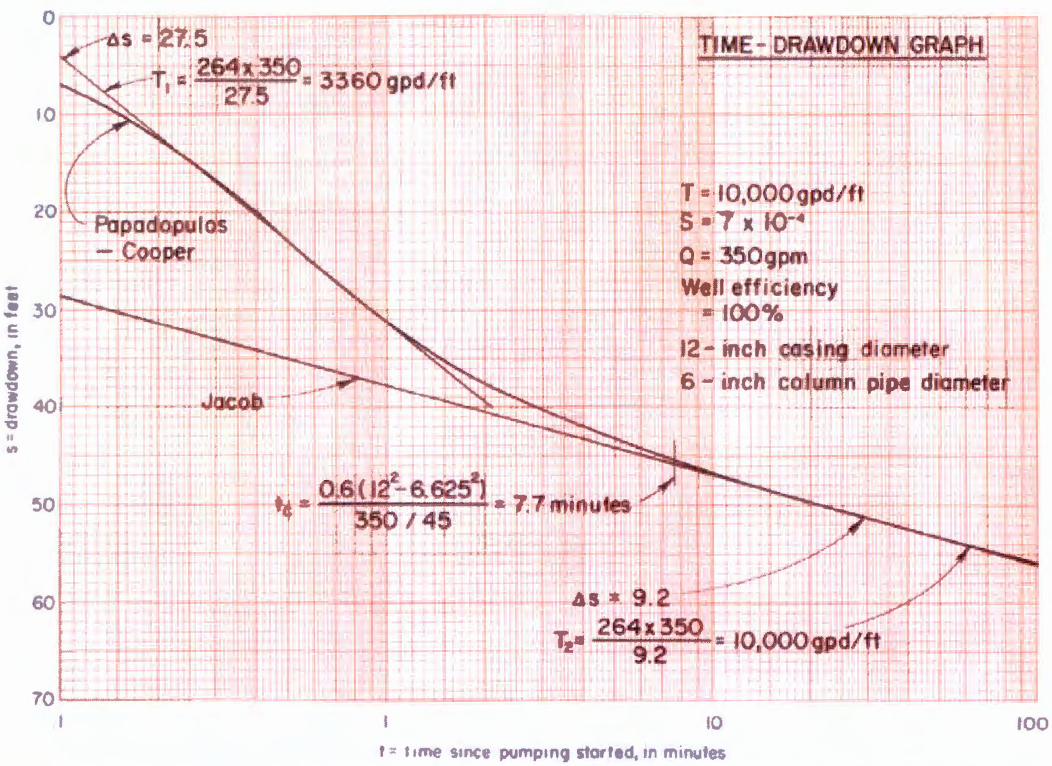


Fig. 2. The influence of casing storage on the transmissivity, T_1, is considerable, whereas transmissivity, T_2, is no longer affected by casing storage and thus it provides the correct value.

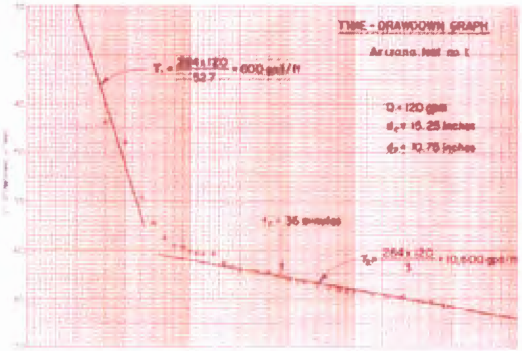


FIG 4 t = time since pumping started, in minutes

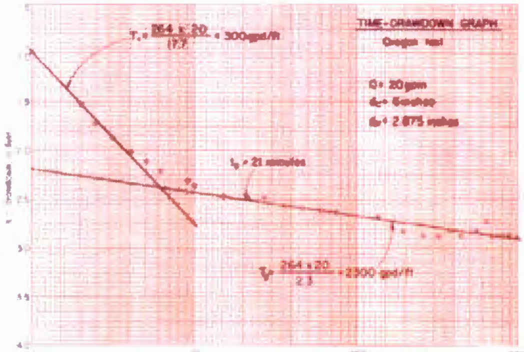


FIG 3 t = time since pumping started, in minutes

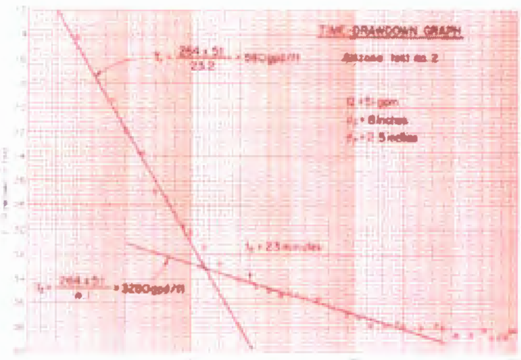


FIG 5 t = time since pumping started, in minutes

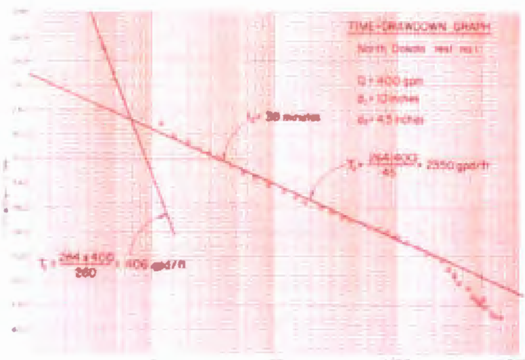


FIG 6 t = time since pumping started, in minutes

Figures 3-7. The time drawdown graphs above illustrate the effect that casing storage has on pumping test data. The values of T_1 shown on each graph are all incorrect because of the exaggerated slope of the early time drawdown data caused by casing storage. The secondary slope on the graphs leads to the calculated values of T_2 which indicate the correct formation transmissivites.

(1), and E = well efficiency at time t_c.

In order to use equation (2), however, it is still necessary to know the correct T value and well efficiency.

In order to provide an estimate of t_c which compensates for well efficiency and which does not require prior knowledge of formation and well characteristics, the following equation is suggested:

$$t_c = \frac{0.6\,(d_c^2 - d_p^2)}{Q/s} \qquad (3)\,\S$$

where

- t_c = time in minutes when casing storage effect becomes negligible
- d_c = inside diameter of well casing in inches
- d_p = outside diameter of pump column pipe in inches
- Q/s = specific capacity of the well in gpm/ft of drawdown at time t_c

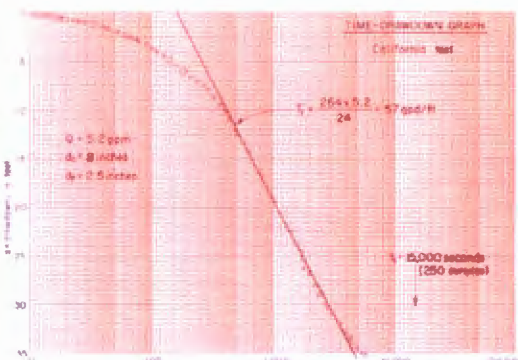


FIG 7 t = time since pump started, in seconds

All of the parameters in equation (3) are readily obtainable from any pumping test. Thus t_c can always be determined.

In order to investigate the validity of the casing storage theory, and in particular equation (3), a number of pumping tests were analyzed. Figures 3 through 10 show either time drawdown or recovery graphs for eight different pumping tests along with calculated values of T_1, T_2, and t_c based on equation (3).

Note that T_2 could not be determined for the California test in Figure 7 because the pumping period was not long enough. The test duration was only 90 minutes compared to a required pumping time (t_c) of 250 minutes to reach the beginning of the correct straight line slope.

Casing Storage Phenomenon

Based upon supporting data from each pumping test (not included here) it has been determined that without exception the T_1 values shown are incorrect, i.e., not indicative of true formation characteristics, whereas the T_2 values shown are correct. In other words, the steep slope on each graph is a result of the casing storage phenomenon.

In addition, it can be seen that the values of t_c are reasonably reliable (though perhaps somewhat conservative) in determining the start of the correct straight line slope.

Thus, pumping test data that heretofore were considered anomalous or were simply misinterpreted altogether now appear explainable. In addition, equation (3) provides a useful guide in determining where the "anomalous" data end and the reliable data begin.

A question arises then concerning the potential usefulness of early data gathered from a pumping test. That these data are still useful can be seen as follows.

Evidence suggests that for wells in which the efficiency E is greater than about 20 or 30 per cent, the following relationship exists between T_1 and T_2:

$$T_2 = \frac{4\,T_1}{E} \quad (4)$$

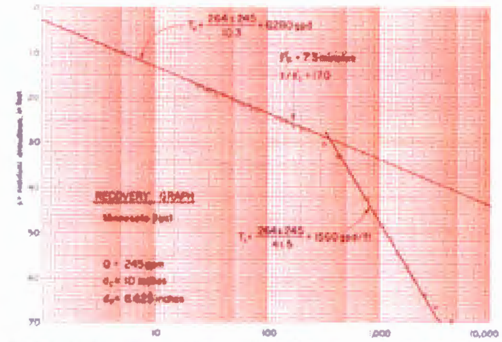


FIG. 8 t/t' = time since pumping started divided by time since pumping stopped

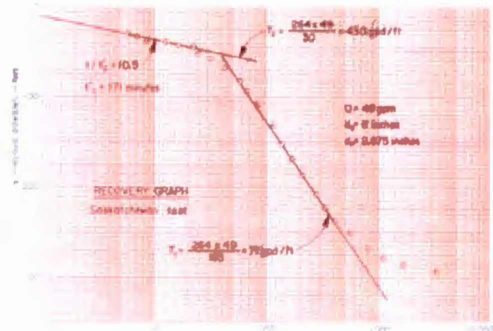


FIG. 9 t/t' = time since pumping started divided by time since pumping stopped

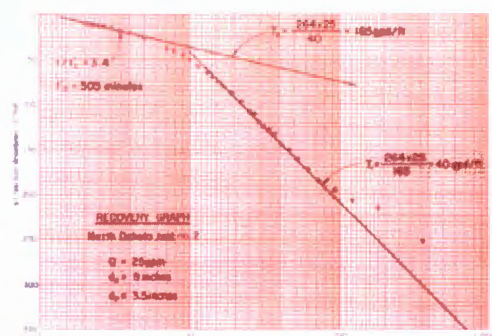


FIG. 10 t/t' = time since pumping started divided by time since pumping stopped

Figures 8-10. These recovery graphs show how the pumping test data have been affected by casing storage. The T_1 values calculated from the casing storage sensitive data are in error. The T_2 values, however, are correct, since they have been determined from data which are no longer affected by casing storage.

Feet
0 50 100 200 300 400

Figure 3

MIAMI DADE WATER AND SEWER DEPARTMENT
NEWTON WELLFIELD

MIAMI DADE WATER AND SEWER DEPARTMENT NEWTON WELLFIELD WATER LEVELS (ft)				
Station ID	Collection date	Top of Casing Elevation (ft) NGVD 1929	Measured Depth To Water (Ft)	Groundwater Elevation (Water Level = TOC elevation - DTW)
G-3900 (Newton MW-1)	11/13/2009	7.63		2.54*
G-3900 (Newton MW-1)	2/1/2010	7.63		2.25*
G-3900 (Newton MW-1)	4/6/2010	7.63		1.98*
G-3900 (Newton MW-1)	1/20/2011	7.63	5.05	2.61*
G-3900 (Newton MW-1)	4/14/2011	7.63	6.1	1.53*
G-3900 (Newton MW-1)	9/5/2013	7.63	5.06	2.57*
G-3900 (Newton MW-1)	2/7/2014	7.63	5.64	1.99*
G-3900 (Newton MW-1)	5/23/2014	7.63		1.50*
G-3900 (Newton MW-1)	10/9/2014	7.63	5.4	2.23
G-3900 (Newton MW-1)	2/13/2015	7.6		1.7*
G-3900 (Newton MW-1)	6/3/2015	7.63	5.82	1.81
G-3900 (Newton MW-1)	10/23/2015	7.63	5.24	2.39
G-3900 (Newton MW-1)	2/18/2016	7.63	6.84	0.79
Newton MW-2	11/12/2009	5.33	3	2.33
Newton MW-2	1/28/2010	5.33	3.75	1.58
Newton MW-2	4/6/2010	5.33	3.3	2.03
Newton MW-2	1/19/2011	5.33	2.56	2.77
Newton MW-2	4/14/2011	5.33	3.88	1.45
Newton MW-2	8/26/2013	5.33	2.98	2.35
Newton MW-2	2/6/2014	5.33	3.3	2.03
Newton MW-2	3/5/2014	5.33	3.47	1.86
Newton MW-2	4/29/2014	5.33	3.8	1.53
Newton MW-2	5/22/2014	5.33	3.8	1.53
Newton MW-2	10/8/2014	5.33	3.05	2.28
Newton MW-2	2/12/2015	5.33	3.55	1.78
Newton MW-2	6/2/2015	5.33	3.5	1.83
Newton MW-2	10/21/2015	5.33	2.78	2.55

MIAMI DADE WATER AND SEWER DEPARTMENT NEWTON WELLFIELD WATER LEVELS (ft)				
Station ID	Collection date	Top of Casing Elevation (ft) NGVD 1929	Measured Depth To Water (Ft)	Groundwater Elevation (Water Level = TOC elevation - DTW)
Newton MW-2	2/17/2016	5.33	3.23	2.1
Newton MW-3	11/12/2009	5.67	3.25	2.42
Newton MW-3	1/28/2010	5.67	3.5	2.17
Newton MW-3	4/6/2010	5.67	3.65	2.02
Newton MW-3	1/19/2011	5.67	2.9	2.77
Newton MW-3	4/14/2011	5.67	4.22	1.45
Newton MW-3	8/26/2013	5.67	3.23	2.44
Newton MW-3	2/6/2014	5.67	3.62	2.05
Newton MW-3	3/5/2014	5.67	3.86	1.81
Newton MW-3	4/29/2014	5.67	4.1	1.57
Newton MW-3	5/22/2014	5.67	3.95	1.72
Newton MW-3	10/8/2014	5.67	3.3	2.37
Newton MW-3	2/12/2015	5.67	3.87	1.8
Newton MW-3	6/2/2015	5.67	3.85	1.82
Newton MW-3	10/21/2015	5.67	3.1	2.57
Newton MW-3	2/17/2016	5.67	3.6	2.07
Newton MW-4	11/12/2009	6.15	3.71	2.44
Newton MW-4	1/28/2010	6.15	3.45	2.7
Newton MW-4	4/6/2010	6.15	4.18	1.97
Newton MW-4	1/19/2011	6.15	3.4	2.75
Newton MW-4	4/14/2011	6.15	4.7	1.45
Newton MW-4	8/26/2013	6.15	3.82	2.33
Newton MW-4	2/6/2014	6.15	4.13	2.02
Newton MW-4	5/22/2014	6.15	4.45	1.7
Newton MW-4	10/8/2014	6.15	3.92	2.23
Newton MW-4	2/1/2015	6.15	4.45	1.7
Newton MW-4	6/2/2015	6.15	4.33	1.82

MIAMI DADE WATER AND SEWER DEPARTMENT NEWTON WELLFIELD WATER LEVELS (ft)				
Station ID	Collection date	Top of Casing Elevation (ft) NGVD 1929	Measured Depth To Water (Ft)	Groundwater Elevation (Water Level = TOC elevation - DTW)
Newton MW-4	10/23/2015	6.15	4.73	1.42
Newton MW-4	2/17/2016	6.15	4.04	2.11
Newton MW-5	11/13/2009	6.66	4.33	2.33
Newton MW-5	2/1/2010	6.66	4.38	2.28
Newton MW-5	4/6/2010	6.66	4.68	1.98
Newton MW-5	1/19/2011	6.66	3.9	2.76
Newton MW-5	4/14/2011	6.66	5.2	1.46
Newton MW-5	9/5/2013	6.66	4.1	2.56
Newton MW-5	2/6/2014	6.66	4.64	2.02
Newton MW-5	5/22/2014	6.66	4.95	1.71
Newton MW-5	10/8/2014	6.66	4.4	2.26
Newton MW-5	2/12/2015	6.66	5.95	0.71
Newton MW-5	6/2/2015	6.66	4.85	1.81
Newton MW-5	10/21/2015	6.66	3.21	3.45
Newton MW-5	2/18/2016	6.66	4.65	2.01
Newton MW-6	11/12/2009	5.09	2.5	2.59
Newton MW-6	1/28/2010	5.09	2.95	2.14
Newton MW-6	4/6/2010	5.09	3.05	2.04
Newton MW-6	4/14/2011	5.09	3.64	1.45
Newton MW-6	9/5/2013	5.09	2.45	2.64
Newton MW-6	2/6/2014	5.09	3.03	2.06
Newton MW-6	5/23/2014	5.09	3.75	1.34
Newton MW-6	10/8/2014	5.09	2.8	2.29
Newton MW-6	2/12/2015	5.09	3.4	1.69
Newton MW-6	6/3/2015	5.09	3.25	1.84
Newton MW-6	10/21/2014	5.09	3.55	1.54
Newton MW-6	2/18/2016	5.09	3.03	2.06

MIAMI DADE WATER AND SEWER DEPARTMENT NEWTON WELLFIELD WATER LEVELS (ft)				
Station ID	Collection date	Top of Casing Elevation (ft) NGVD 1929	Measured Depth To Water (Ft)	Groundwater Elevation (Water Level = TOC elevation - DTW)
Newton MW-7	9/6/2011	7.07	4.39	2.68
Newton MW-7	9/5/2013	7.07	4.52	2.55
Newton MW-7	2/6/2014	7.07	5	2.07
Newton MW-7	5/23/2014	7.07	5.4	1.67
Newton MW-7	10/8/2014	7.07	4.8	2.27
Newton MW-7	2/12/2015	7.07	5.33	1.74
Newton MW-7	6/2/2015	7.07	5.24	1.83
Newton MW-7	10/21/2015	7.07	4.6	2.47
Newton MW-7	2/18/2016	7.07	5.05	2.02
Newton MW-8	6/28/2012	6.8	4.25	2.55
Newton MW-8	11/9/2012	6.8	4.6	2.2
Newton MW-8	2/7/2014	6.8	4.82	1.98
Newton MW-8	5/23/2014	6.85	5.15	1.7
Newton MW-8	10/9/2014	6.85	4.8	2.05
Newton MW-8	2/12/2015	6.85	5.05	1.8
Newton MW-8	6/3/2015	6.85	4.95	1.9
Newton MW-8	10/23/2015	6.85	4.35	2.5
Newton MW-8	2/18/2016	6.85	4.77	2.08

*-From USGS on site water level recorder

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.

Seasonal Model: Net Recharge at R155 C21

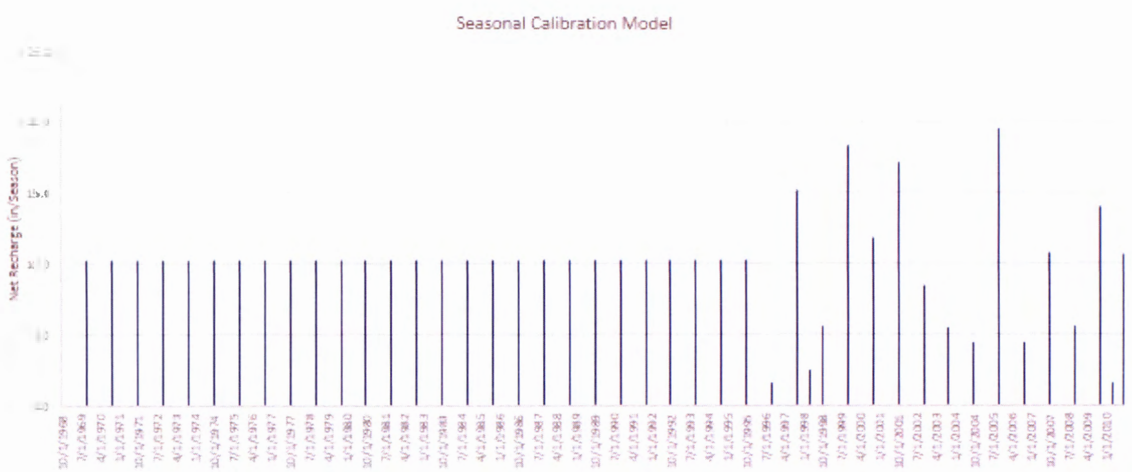


Figure 1. Net recharge (inches/season) applied in the seasonal calibration model.

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).

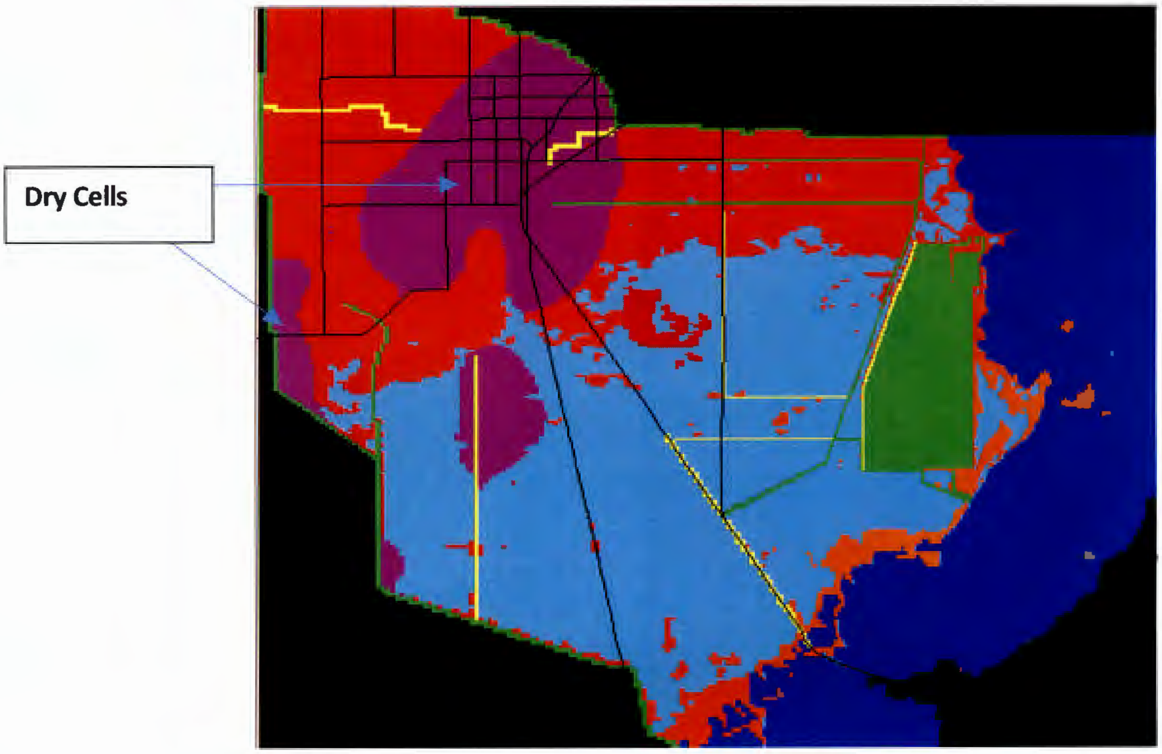


Figure 2. Dry cells in model Layer 1 at the end of stress period 1 in the monthly calibration model.

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.

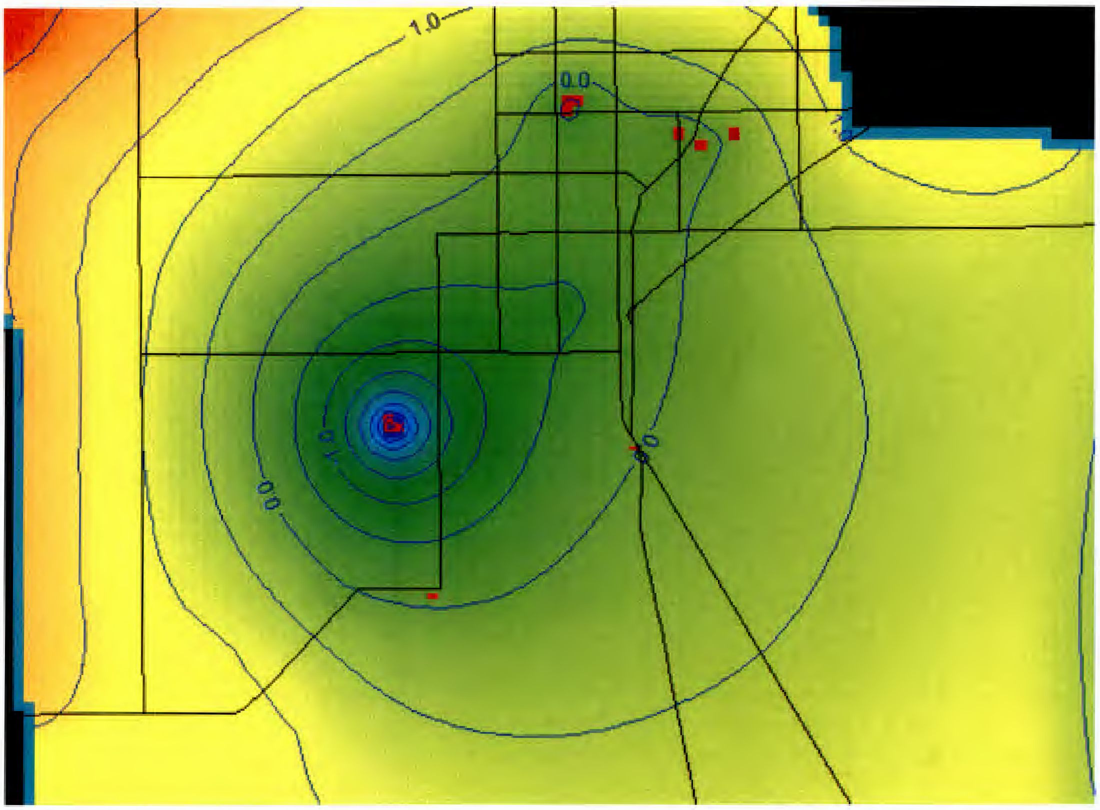


Figure 3. Simulated water levels (ft, NGVD) for December 2015, in Layer 8.

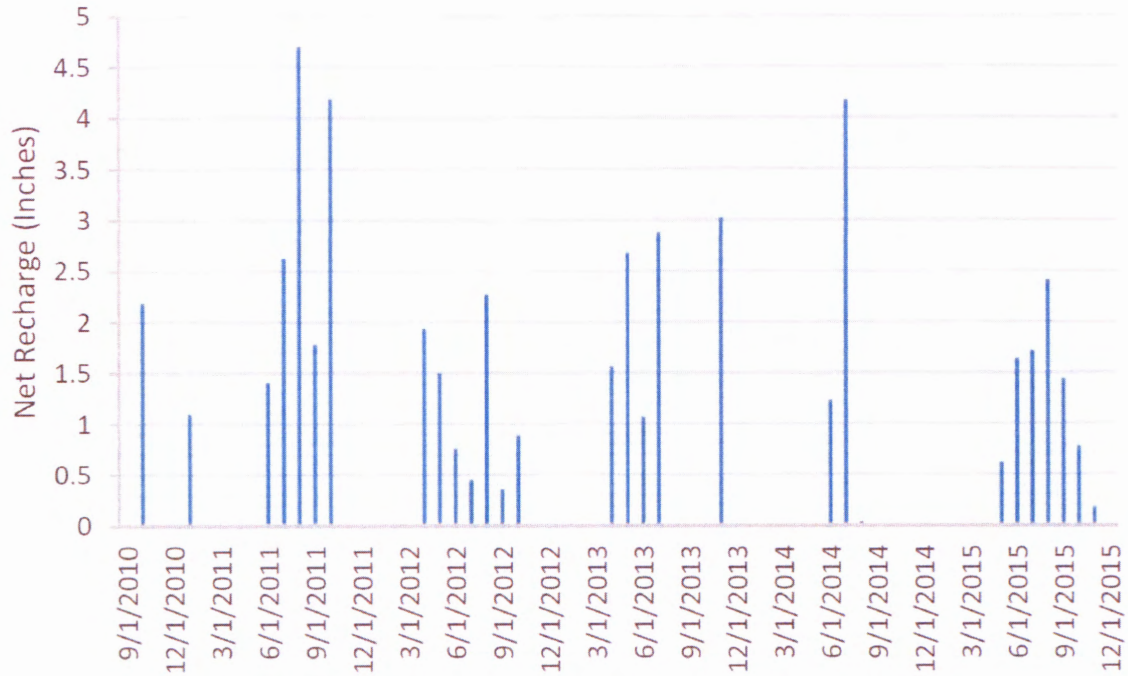


Figure 4. Net recharge (inches/season) applied in monthly calibration model.

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.

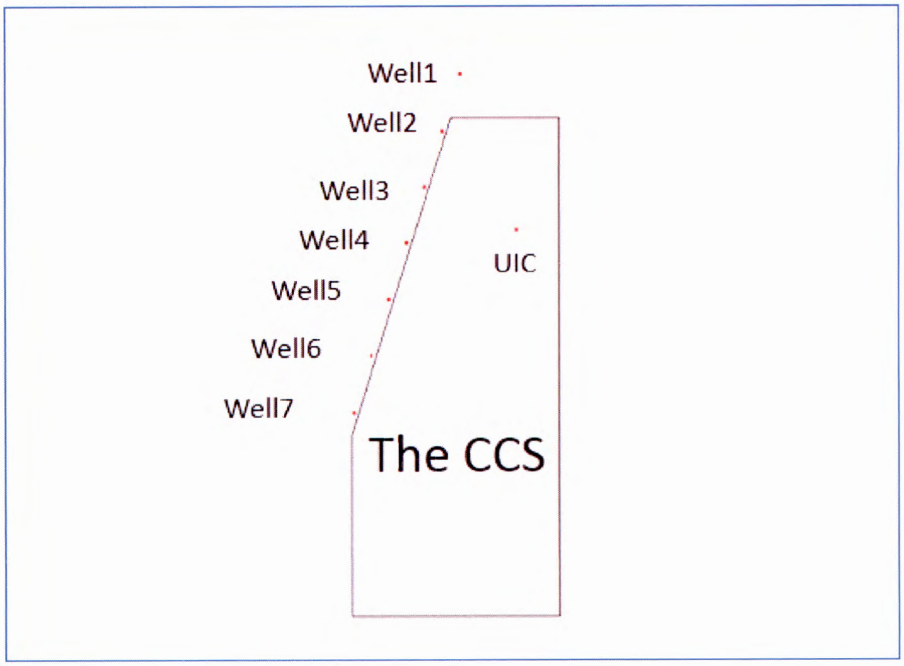


Figure 5. Location of proposed extraction wells in ALT3B.

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.

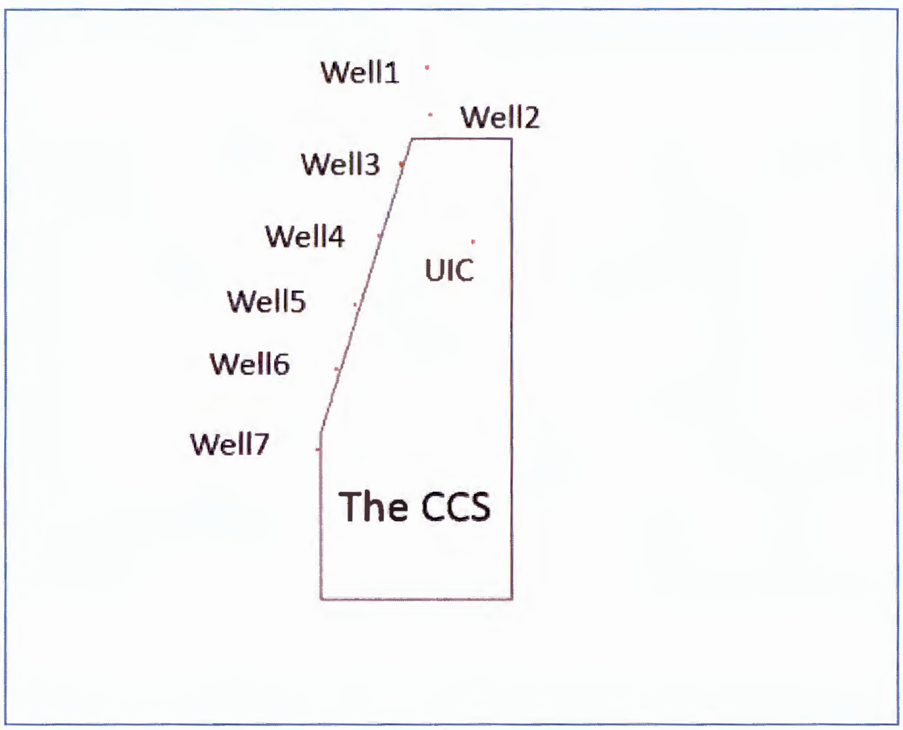


Figure 6. Location of proposed extraction wells in ALT3C.

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.

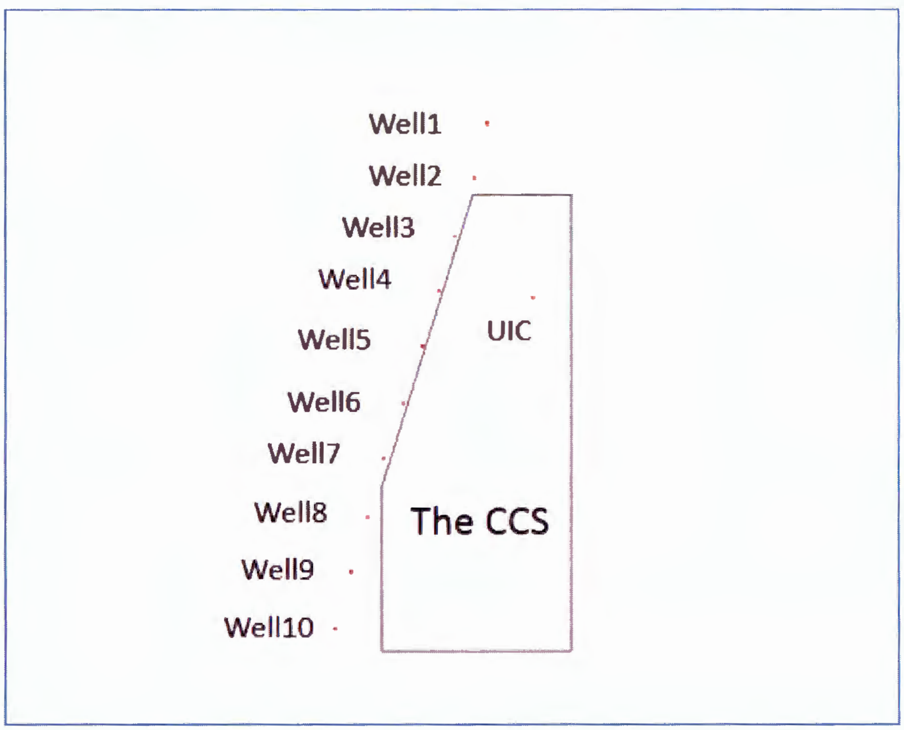


Figure 7. Location of proposed extraction wells in ALT3D.

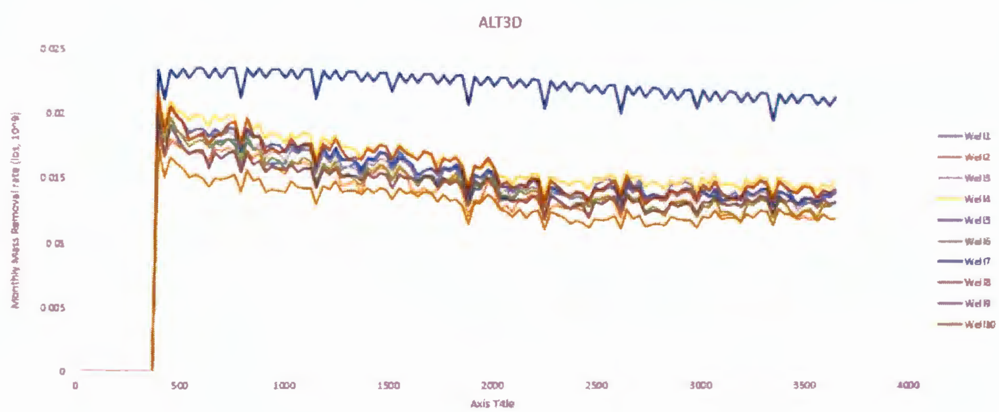
The performance of individual extractions (except the near UIC well), at the monthly mass removal rate, is shown on Figure 8. The proposed extraction rates for ALT3D scenario is provided in Table 4. It seems most of these proposed extraction wells behave similarly except for Well 7. The reason for better 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.

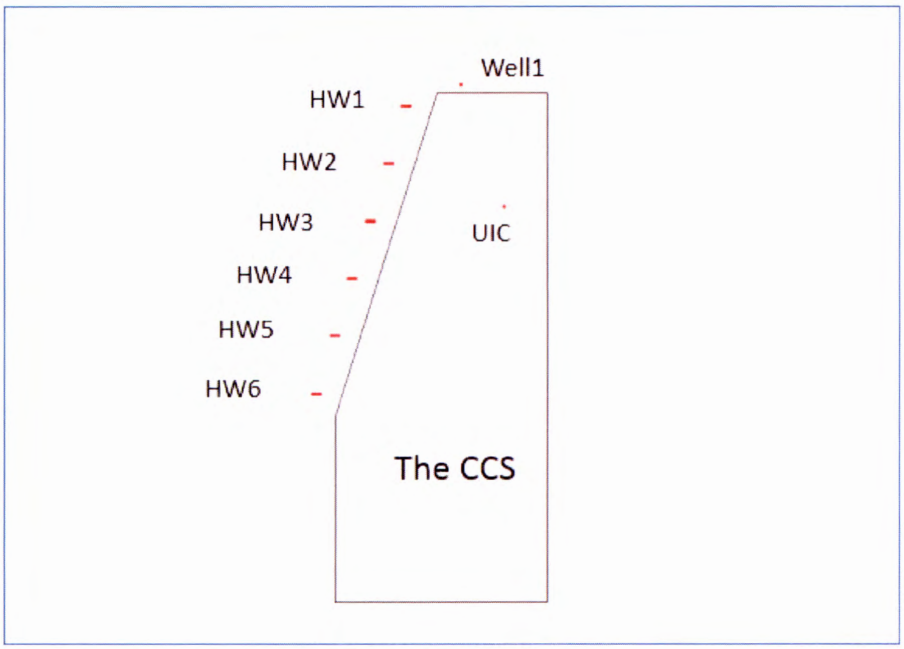


Figure 9. Location of proposed extraction wells in ALT4.

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.

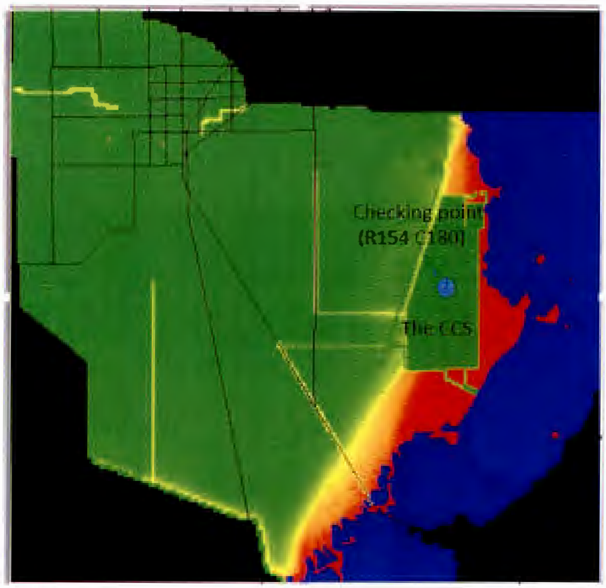


Figure 10. Location of checking point.

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

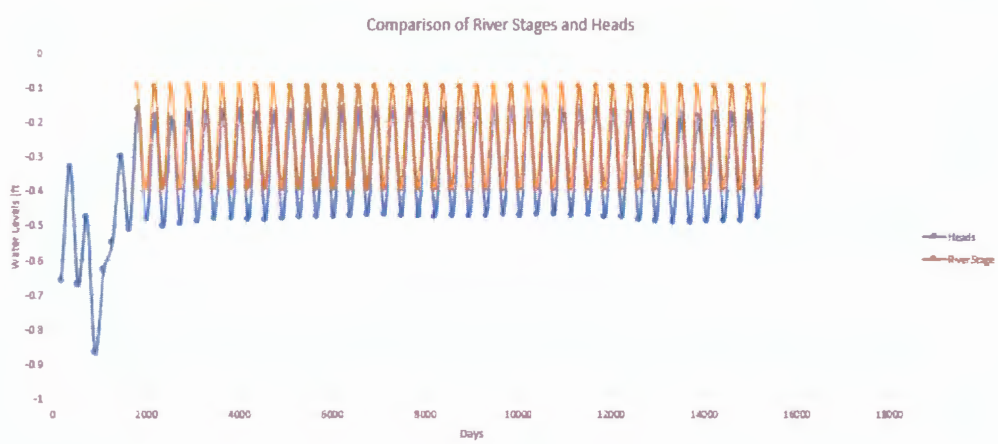


Figure 11. Simulated head changes in model Layers 1-4 in seasonal calibration model.

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.

Seasonal Model: Head Changes (L1-L4)

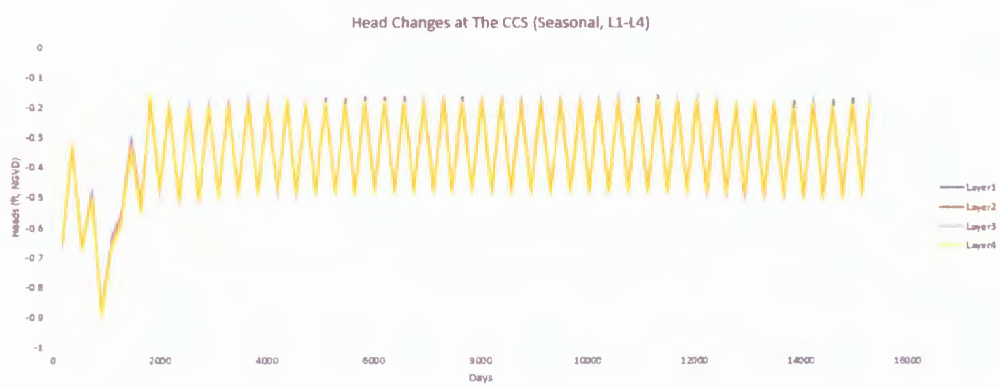


Figure 12. Simulated head changes in model Layers 1-4 in seasonal calibration model.

Seasonal Model: Head Changes (L5-L11)

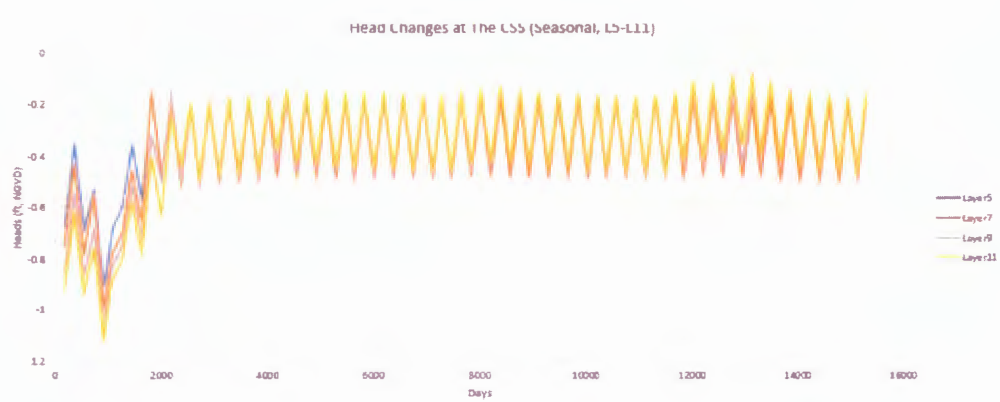


Figure 13. Simulated head changes in model Layers 5-11 in seasonal calibration model

Seasonal Model: Salt Concentration in CCS Canal vs. Aquifer

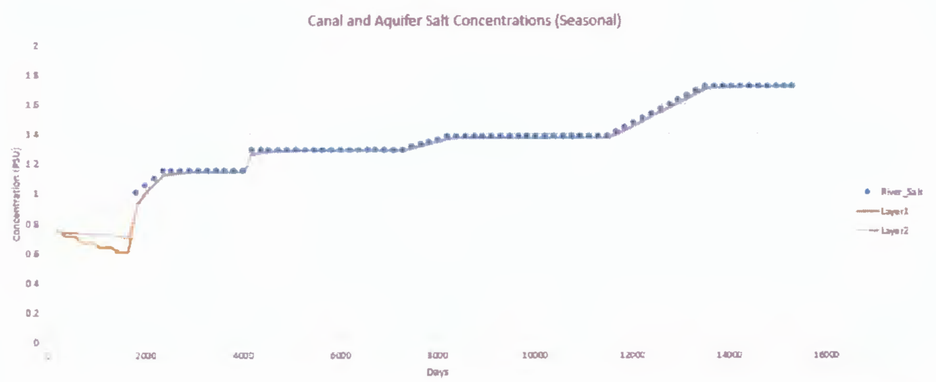


Figure 14. Simulated salt concentration changes in the CCS and model Layers 1 and 2 in seasonal calibration model.

Seasonal Model: Salt Concentration Changes (L5-L11)

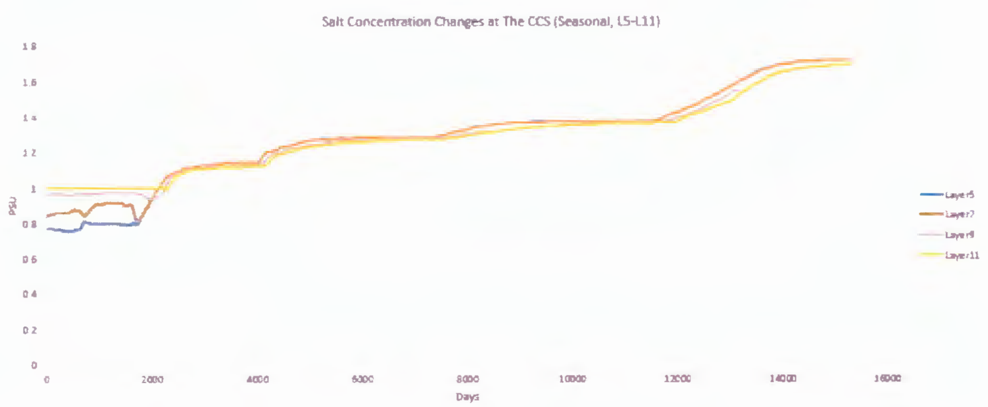


Figure 15. Simulated salt concentration changes in model Layers 5, 7, 9, and 11 in the seasonal calibration model.

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.

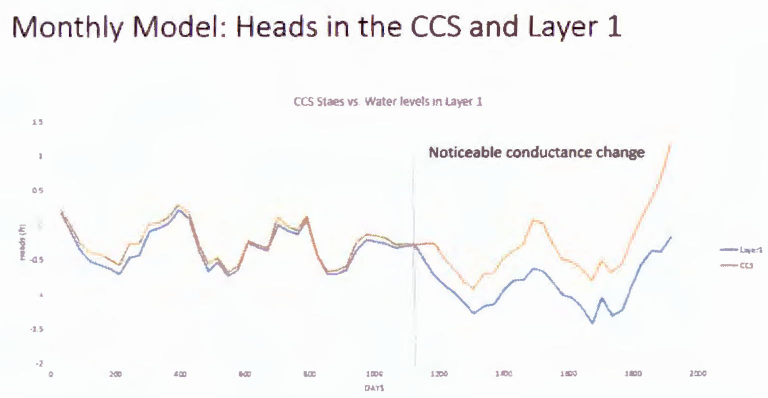


Figure 16. Simulated water levels in the CCS canal and model Layer 1 in monthly calibration model.

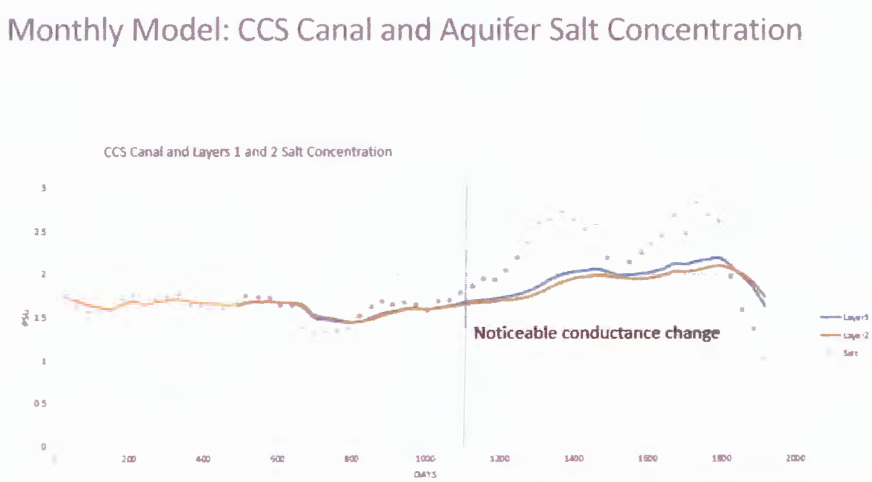


Figure 17. Simulated salt concentration changes in the CCS canal and model Layers 1 and 2 in the monthly calibration model.

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).

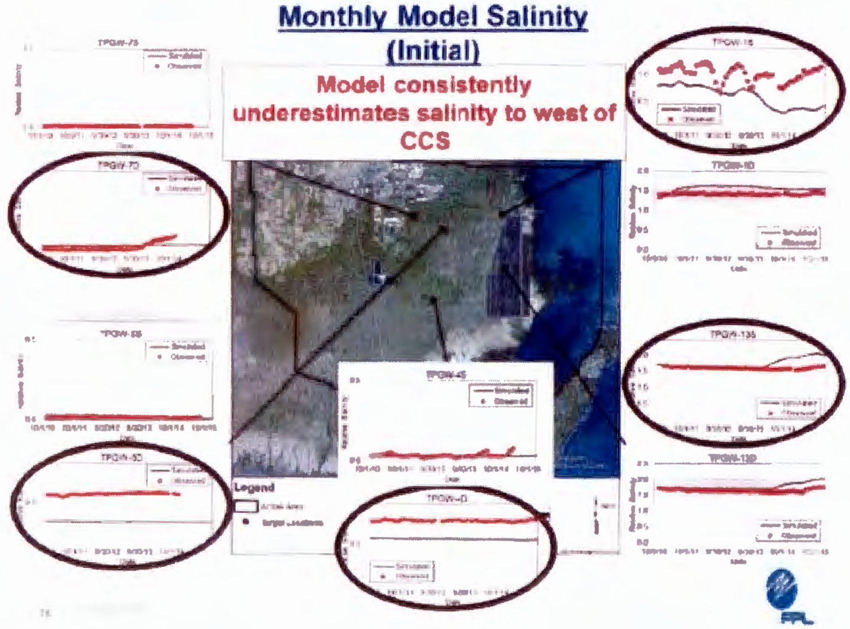


Figure 18. Salinity calibration results of the monthly model (Tetra Tech, 2016).

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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