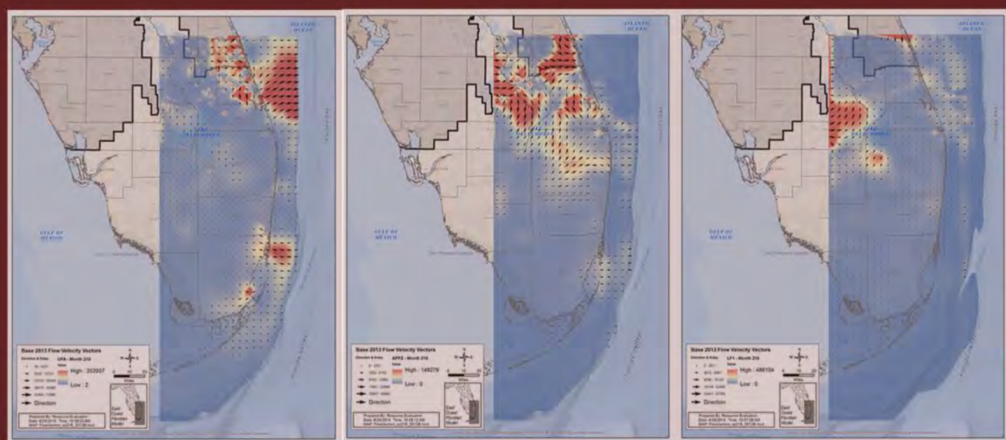
SOUTH FLORIDA WATER MANAGEMENT DISTRICT

East Coast Floridan Model



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Jefferson B. Giddings, Angela Montoya and Ligia J. Jurado
Resource Evaluation Section
Water Supply Bureau

South Florida Water Management District
West Palm Beach, Florida

sfwmd.gov

Contents

Appendices

Tables

Figures

Selected Acronyms and Abbreviations

AFSIRS	Agricultural Fields Scale Irrigation Requirement Simulation
APPZ	Avon Park permeable zone
APT	aquifer performance test
ASR	aquifer storage and recovery
BZ	Boulder Zone
cfd	cubic feet per day
DBHYDRO	the South Florida Water Management District's hydrometeorologic, water quality, and hydrogeologic data retrieval system
District	South Florida Water Management District
ECFM	East Coast Floridan Model
FAS	Floridan aquifer system
FDEP	Florida Department of Environmental Protection
GHB	general head boundary
GSA	global sensitivity analysis
ICU	intermediate confining unit
K_h	horizontal hydraulic conductivity
K_v	vertical hydraulic conductivity
LC	lower confining unit
LEC	Lower East Coast Planning Area
LFA	Lower Floridan aquifer
LF1	Lower Floridan aquifer– first permeable zone
MC1	Middle confining unit 1
MC2	Middle confining unit 2
MCU	Middle confining unit
MGD	million gallons per day
mg/L	milligrams per liter
MODFLOW	Modular 3D Finite-Difference Groundwater Flow Model (USGS)
MT3DMS	a new version of the Modular 3-D Transport model, where MS denotes the Multi- Species structure for accommodating add-on reaction packages
NAD	North American Datum
NGVD29	North Geodetic Vertical Datum of 1929
OAT	one (factor) at a Time
PEST	Parameter Estimation; also a USGS computer program that can be used to aid model calibration
QA/QC	quality assurance/quality control
RMSE	root mean square error
SAS	surficial aquifer system
SEAWAT	a generic MODFLOW/MT3DMS-based computer program designed to simulate three-dimensional variable-density groundwater flow coupled with multi-species solute and heat transport (USGS)
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
Ss	specific storage
SWFWMD	Southwest Florida Water Management District
TDS	total dissolved solids
UCODE	a USGS computer program that can be used to aid in model calibration

UEC	Upper East Coast Planning Area
UFA	Upper Floridan aquifer
UIC	Underground Injection Control (Program)
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

Executive Summary

The Lower East Coast and Upper East Coast Planning Areas of the South Florida Water Management District face numerous water management challenges. Growing freshwater demands, dwindling traditional water sources, increased levels of environmental protection, changing water quality, and sea level rise need to be addressed and managed to protect the areas' water resources and provide an adequate water supply. Regional water supply plans are the District's primary tools to address these issues. In general, the water supply plans recommend shifting future demands away from traditional water sources, such as surface water and shallow aquifers, to alternative sources, including brackish water from the Floridan aquifer system.

To evaluate the potential impacts of this strategy, a density-dependent groundwater flow and transport model of the Floridan aquifer system (FAS) covering the east coast of the District was developed. This East Coast Floridan Model (ECFM) can simulate the response of the aquifers to stresses such as proposed wellfield pumpage, aquifer storage and recovery systems, reductions in recharge, and increasing sea level. Results of the model applications can provide guidance in developing water management strategies, support periodic updates to the regional water supply plans, and be used in regulatory applications.

The three-dimensional coupled groundwater flow and solute transport model was developed using the United States Geological Survey's SEAWAT model code. The model covers a large area extending from central Florida to the Florida Keys and from the approximate central line of the Florida peninsula to the Florida Straits and Atlantic Ocean. This area was divided into a uniform grid with spacing of 2,400 feet. The model has seven primary layers representing the Upper Floridan aquifer, Middle confining unit 1, Avon Park permeable zone, Middle confining unit 2, Lower Floridan aquifer – first permeable zone, lower confining unit, and the Boulder Zone. The model is a refinement of previous modeling projects, including models developed by HydroGeoLogic in 2006 and later refined by Golder Associates in 2008. The model was peer reviewed in 2011 and the panel's comments and suggestions have been incorporated into the present version of the model.

The model was calibrated to both steady-state and transient conditions. A quasi steady-state run was also completed as an additional check of the model. A number of water level and water quality targets (total dissolved solids) were used for model calibration. The transient model was calibrated to the period from January 1989 through December 2012. Both manual and automatic calibration methods were used iteratively during the model calibration process. The results of model calibration indicate that the simulated water levels and water quality values are in general agreement with field-observed data at most monitoring wells (targets). Simulated flow patterns and concentration distributions in major aquifers generally match the observed conditions.

The steady-state represents conditions of the late 1980s, which was a period of minimal Floridan aquifer groundwater use in the southern half of the study area and a period of increased monitoring that provided the initial conditions for the transient model. The primary purpose of the transient model is to evaluate long-term (20 to 50 years) planning and water quality issues. To support regulatory decisions,

another version of the model is proposed, which will consist of model runs representing a two-year period, as required by the District's water use permitting rules.

The model was designed to provide an evaluation of regional conditions for the FAS in southern Florida. The model reasonably simulates groundwater and water quality conditions in the FAS. One should be cautious when attempting to utilize this tool for evaluations of withdrawal impacts at a local scale or where the water quality in the aquifers beneath a wellfield is unknown. Predictions of water quality changes at an existing or future wellfield will require a more detailed representation of the local hydrogeology and initial water level and quality distributions. These data would support creation of a local scale model using the ECFM for boundary conditions or the revision on the water quality and hydrologic properties in the ECFM model prior to evaluation of a proposed withdrawal.

1.0 Introduction

1.1 Background

The South Florida Water Management District (SFWMD or District) is divided into five regions for water supply planning purposes. Two of these regions comprise the east coast of the District (Figure 1.1-1). The Upper East Coast Planning Area (UEC) includes all of St. Lucie and Martin counties and a portion of eastern Okeechobee County. The Lower East Coast Planning Area (LEC) includes all of Palm Beach, Broward, and Miami-Dade counties and portions of Monroe, Hendry, and Collier counties. Both of these regions face numerous challenges maintaining adequate water supply for growing urban and agricultural demands while simultaneously meeting the needs of the environment. Detailed information on historic and projected demands for these planning areas can be found in their respective water supply plans (SFWMD 2011, SFWMD 2013).

Historically, demands in these two planning regions were met using surface and groundwater. The primary sources of surface water have been the regional flood control/water management system canals, Lake Okeechobee, and the water conservation areas. Major sources of groundwater include the surficial aquifer system (SAS), primarily the Biscayne aquifer in Broward and Miami-Dade counties, and the Floridan aquifer system (FAS), primarily in St. Lucie, Okeechobee, and sections of Martin County. However, increased withdrawals from these traditional sources are limited. The need for ecosystem restoration and water quality improvement limits the use of surface water from the regional system to meet future demands. These needs also limit increased withdrawals of groundwater from the SAS where there is a strong connection between the surface water and groundwater systems. Another potential challenge to future withdrawals from the SAS is saltwater intrusion as (1) the freshwater head pressure is reduced due to increasing groundwater withdrawals and reduced surface water levels, and (2) the seawater head increases due to sea level rise. Saltwater intrusion can pose a significant threat to public supply wells and the coastal ecosystem. Finally, increased withdrawals from the SAS are limited by potential impacts to wetlands.

To reduce the potential impacts to traditional freshwater sources, future increased demands are proposed to be gradually shifted to alternative water sources such as brackish aquifers in the FAS that are not currently heavily utilized as major water supply sources in large parts of the two planning areas. The FAS is a regional resource, underlying portions of Georgia, South Carolina, Alabama, and the entire Florida peninsula. In southeast Florida, the water quality of the FAS contains water of brackish to seawater concentrations. Both the LEC (SFWMD 2013) and the UEC (SFWMD 2011) Water Supply Plans recommended the development of a comprehensive FAS groundwater model in the planning areas to allow the District and the public to evaluate potential impacts of both water withdrawals and storage via aquifer storage and recovery (ASR) wells utilizing the FAS.

Better understanding of the FAS will provide essential information for the future management of this important resource. This report documents the development of the East Coast Floridan Model, which is a regional density-dependent flow model using the United States Geologic Survey (USGS) SEAWAT code covering both the UEC and LEC planning regions.

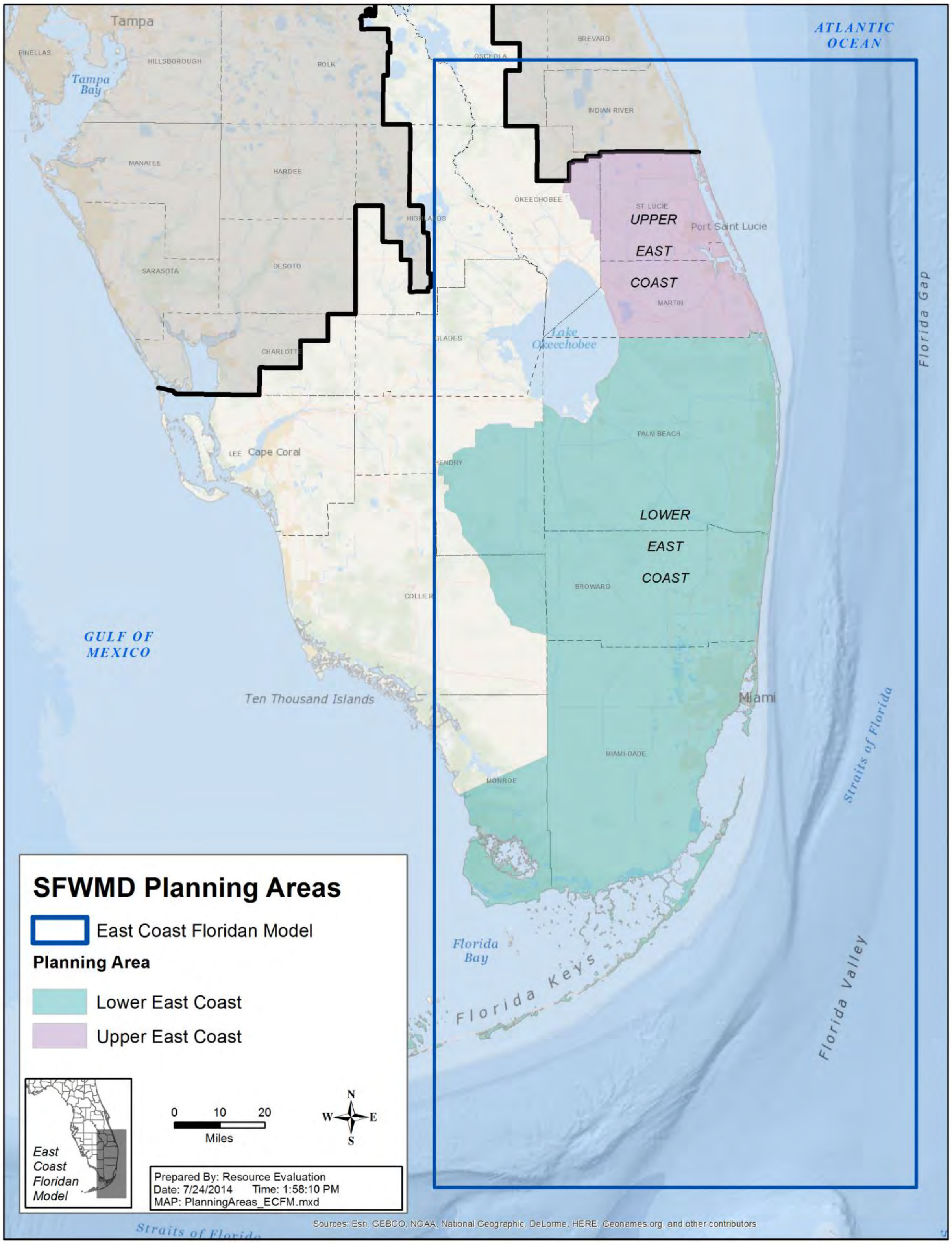

Figure 1.1-1. Location of LEC and UEC Planning Areas

1.2 Previous Studies

The FAS has been the focus of many previous studies (Hickey 1982, Miller 1986, Bush and Johnson 1988, Meyer 1989, Tibbals 1990) due to its importance as a major water source for parts of Georgia and Florida. Several numerical models were developed in recent years by different agencies. Those developed by or for the SFWMD are reviewed as part of this study. The previous studies discussed in this section include mainly the regional studies within the SFWMD area.

In the early 1990s, the SFWMD undertook the development of countywide groundwater flow models for most counties under its jurisdiction. Most of these early models focused on the SAS, but one addressed the upper Floridan aquifer (UFA) in the UEC (Lukasiewicz 1992). Although sufficient at the time, this model did not address water quality issues nor capture the total groundwater flow regime within the FAS. Problems with understanding FAS groundwater flow in the region continued until Reese and Richardson (2008) developed a unified hydrogeologic framework that combined existing works into a single description of the upper three most productive zones of the FAS in south Florida.

The first density-dependent solute transport model of the FAS developed for the District was completed by HydroGeoLogic (2006). This was the first phase of FAS model development and covered Miami-Dade, Broward, and Palm Beach counties. Phase II was completed by Golder (2008) and expanded the model northward to include the UEC. An independent peer review panel reviewed both of these models and published their findings in 2011 (Jacobs et al. 2011), which are discussed in Section 1.3. The United States Army Corps of Engineers (USACE) also recently developed an FAS model as part of a regional ASR modeling study for the Comprehensive Everglades Restoration Plan (USACE 2010).

1.3 Scope of Work

The recommendations and findings from the peer review panel provided the direction for enhancements and modifications to an updated version of the model, now referred to as the East Coast Floridan Model (ECFM). The peer review panel provided numerous short- and long-term recommendations. The primary short-term recommendations and how they were addressed in this revised version of the model are as follows:

Peer Review Comment Number 1: The panel is not confident in the model calibration for the reasons enumerated in the peer review report and recommends that the model be recalibrated. The panel recommends that the model first be calibrated to pre-development quasi steady-state conditions and this then be used as initial conditions for the calibration of the transient model. As a goal, the panel recommends that the pre-development model be calibrated to measured 1980 water quality and potentiometric head values. The use of 1980 conditions is contingent on the availability of sufficient data and the achievement of significant reductions in execution time that would allow for the calibration of a 20-year transient simulation.

SFWMD Response:

1. The District reviewed and collected water quality and water level data from all FAS wells within the model domain from both USGS and SFWMD databases. This information was added to the

existing data bases developed by Golder (2008). Additional water quality data was also assembled from the Florida Department of Environmental Protection's (FDEP) Underground Injection Control (UIC) and the SFWMD's Water Use Regulation databases. All data were reviewed for quality and erroneous or questionable data; and if found, they were removed from the final model database. A third source of data was generally single point-in-time water quality values collected during initial aquifer testing at various wellfields, or data collected in support of a short-term project or publication. An evaluation of the available data suggests that water quality and water level availability fell within two distinct time frames, although data at some wells occurred outside these dates. The first period generally occurred from 1989 through the early 1990s and corresponded to a severe drought. The second period of available data generally begins in the early 2000s and continued through 2012. This second period corresponds to the introduction of telemetry and other methods for automatic measurements. There are approximately 150 wells with water level readings useful for model calibration and more than 300 water quality wells of which approximately half have single or several water quality observations. Water level readings from the FDEP UIC monitoring wells were not used because of concerns with the methods of data collection and reporting and the pressure influence from the injecting on monitoring well data.

2. The recommendation to develop a steady-state model to approximately 1980 conditions was slightly adjusted after a review of available water level and water quality data. The assumption that 1980 represents predevelopment conditions is valid in Palm Beach, Broward, Miami-Dade, and Monroe counties where development of the FAS as a water supply source was restricted to a few barrier island golf courses and other smaller uses, primarily in the Florida Keys. More widespread use of the FAS in southeastern Florida generally began in the 1990s in the Jupiter area and in the 2000s in Broward and Miami-Dade counties. The early 1980s did see an increase in use of the deeper Boulder Zone of the FAS for disposal of secondary effluent from wastewater treatment plants via deep injection wells, but this use has minimal impact on the upper portions of the FAS at the regional level. For Martin and St. Lucie counties, the assumption that 1980 represents predevelopment conditions is less rigorous due to agricultural users that utilized both surface water and FAS groundwater for irrigation demands dating back to at least the 1950s, if not significantly earlier. The exact date for when these groves became operational and the acres and water supply source used to irrigate them is unclear although some records suggest wells were constructed in the 1940s and 1950s. Meyer's (1989) predevelopment map of the FAS was also reviewed as a potential target for the steady-state run but was determined to be insufficient because of the lack of monitoring data used to construct the map south of Martin County. In addition, there was no corresponding estimate of the predevelopment water levels for either the Avon Park permeable zone (APPZ) or the Lower Floridan aquifer (LFA), nor was predevelopment water quality available. The seasonal USGS potentiometric maps were also used but they also lacked data from the southern counties. Meyer's (1989) work was valuable for determining the estimated position of the groundwater divide of the UFA and the general trend of flow within the aquifer. As a result, it was determined that 1989 represents a reasonable steady-state period for model development based upon the availability of water

level and water quality data. The use of 1989 over 1980 remains in agreement with the peer review panel recommendations since it still allows for a full 20-year transient simulation period and also incorporates an earlier period when FAS users can be more readily identified and their demands reasonably estimated. The steady-state model includes estimated groundwater withdrawals for the users identified utilizing the SFWMD permit data base active in 1989. The calibrated steady-state water levels and total dissolved solids (TDS) concentration data were then used as initial conditions for transient model calibration.

3. Upon completion of the steady-state model, an interim coupled transient flow and transport model was developed to evaluate changes in water quality during a 400-year period. The development of this version was used to assess the stability of water quality and, to a lesser extent, water levels over a significant period of time. For this simulation, all production wells were inactivated. Although this tool may represent the predevelopment model suggested by the peer review panel, it could not be completed as the initial step because the aquifer parameters, boundary conditions, and other model properties had to be developed spatially across the model domain from observed data and recorded system responses before implementation. The properties reflected the response of the groundwater system to stresses imposed.

4. The transient model was then developed and extended for a 24-year period from 1989 through 2012. Due to the method of reporting historical pumpage use, pumpage data for the year 2013 were not available and therefore not used in the simulation; however, the simulation period extends beyond the recommended 20 year period suggested by the peer review panel. The model was simulated using monthly stress periods, time steps, and solute transport time steps. The monthly solute transport time steps were computed by SEAWAT; in testing different lengths of transport time steps, it was found that weekly or shorter transport steps did not change the solution but added considerable computational time.

Peer Review Comment Number 2: Recalibration should employ automated calibration procedures to the extent possible, with use made of the parameter uncertainty estimates resulting from those methods. The panel anticipates that this will result in less variability in hydraulic conductivity since deviations in hydraulic conductivity from measured values can be included as part of the objective function that is minimized in calibrating the model. Commonly used calibration codes for this purpose are PEST and UCODE. Either may be used for model calibration; however, the code selection should consider the capability of the calibration code to make use of parallel processing or cloud-based computation.

SFWMD Response: The SFWMD used a combination of manual and automated calibration methods using PEST (Doherty and Hunt 2010) as the automated calibration model code. To minimize computational time during the PEST simulations, the PEST runs were conducted in the Linux environment using a series of over 150 processors, which is relatively equivalent to a cloud-based approach. Automated calibration was conducted using pilot points and was done for both the steady-state and the 24-year transient model simulations. Standard manual calibration and predictive simulations use the SEAWAT code, which was compiled in 64-bit mode for the Windows environment, also improved computational speed.

Peer Review Comment Number 3: Calibration of water quality at individual wells is neither realistic nor desirable for a regional model such as the one reviewed here. It would be preferable to revise goals utilized in calibration of water quality to use broad categories of water quality such as potable, brackish, and saline as had been used in the Phase I modeling project.

SFWMD Response: Water quality distributions and trends were generated and used to calibrate the steady-state and transient models. For water quality trends, however, it is understood that the model may not respond to local changes in water quality due to local heterogeneity since the data taken from an aquifer performance test (APT) or longer-term monitor well may not be screened or open across an entire model layer. TDS distribution maps were generated following the panel's recommendation for four broad zones: potable (less than 1,000 mg/L), brackish (1,000 mg/L to 10,000 mg/L), moderately saline (10,000 mg/L to 19,000 mg/L), and saline (greater than 19,000 mg/L). Calibration at individual wells followed a general calibration criterion with the fresher portions of the aquifers having tighter calibration criteria (± 500 mg/L) than the more saline monitor wells (± 4000 mg/L).

Peer Review Comment Number 4: Calibration indicators, such as scatter plots of measured versus simulated potentiometric head should be generated independently for each major aquifer unit to provide more information on the effectiveness of the calibration within each unit. Mapped residual values should also be used that are generated on a unit-by-unit basis to further assist in understanding the success of the model in representing measured field parameters.

SFWMD Response: Scatter plots of observed versus simulated heads and TDS values have been generated for each individual production unit. Maps of the spatial residuals have also been developed on an aquifer basis. In addition, a set of statistics is presented for each well and categorized by production zone to provide a clearer picture and better understanding of the model's response.

Peer Review Comment Number 5: Volumetric flow targets should be used in calibration instead of relying only on water level measurements. For example, the upward flow rate into the surficial aquifer could be a target. It would better constrain the hydraulic properties of the various zones since computed flow rates are more sensitive to hydraulic conductivity than computed hydraulic heads. The freshwater inflow to the model could also be compared to the estimated recharge entering the ECFM in Polk County.

SFWMD Response: The primary recharge to the FAS occurs in the central part of the state along the Lake Wales Ridge and Polk Uplands. The model domain was expanded westerly and northerly in comparison to the previous versions to include the southern recharge areas of the Lake Wales Ridge (as shown in Figure 1.1-1). Boundary conditions for this area were defined using the SEAWAT/MODFLOW General Head Boundary package to control the magnitude of recharge entering the model from the recharge area from the north and west. This is because the specified heads along boundaries in the FAS (i.e., from observed wells) reflect a function of subregional recharge from Polk and Highlands counties and a sink area along the Kissimmee River. The northwestern edge of the model was extended to Lake

Kissimmee on the north and the Lake Wales/Avon Park Ridge on the west. Moving the western boundary into Polk and Highlands counties also allowed the inclusion of Collier and Hendry counties in the south, thus minimizing boundary effects from several large existing and proposed FAS users.

Flux into the model domain can be estimated from a number of studies conducted along the Lake Wales Ridge area. These studies attempted to estimate recharge from the SAS into the UFA as a result of rainfall and local stresses. These reports have primarily been produced by the USGS, the Southwest Florida Water Management District (SWFWMD), and the St. Johns River Water Management District (SJRWMD). Estimated recharge rates from these reports were used as calibration targets during model calibration.

Horizontal flow into the model and offshore discharge to the ocean are harder to quantify. Available literature was reviewed to provide a general framework of the relative contribution of each aquifer into the model and location of the offshore aquifer outcrops and submerged solution features that help governing discharge locations and rates. Hydraulic conductivity values were also determined from free-flowing wells and used to define the range of aquifer properties during calibration.

Peer Review Comment Number 6: In light of limited information on dispersivity and porosity, efforts should be made to justify the choice of these parameter values. The literature on dispersivity should be consulted. We anticipate that this will result in a dispersivity value set based on the regional transport scale. Effective porosity values should be determined based on calibration of the transient water quality simulation.

SFWMD Response: The SFWMD collected bulk porosity estimates from several APT sites and used them as reference values to define the upper limit of the effective porosity for each hydrogeologic unit. The District also conducted a thorough literature review and compared the model calibrated values of dispersivity for previously calibrated models with similar hydrogeologic conditions or generalized literature values to determine reasonableness.

Peer Review Comment Number 7: The model domain might be rotated so that the western boundary is aligned with the north-south trending groundwater divide. This will reduce the dependence of the model on potentiometric head values along this boundary and is a good standard practice. Some portion of the northern model boundary should remain as a specified head boundary. Flow from the recharge area in Polk County will largely enter through this portion of the northern boundary, with some contribution directly from the surficial aquifer in the northwest corner of the model.

SFWMD Response: There are significant and proposed groundwater demands near the current location of the groundwater divide that may cause serious boundary condition problems should the grid be rotated in a northwest/southeast direction. In addition, the estimated position of the groundwater flow divide generally runs in a north-south direction south of Lake Okeechobee resulting in minimal benefits from grid rotation in that area of the model.

As noted in the response to peer review comment number 5, the model was expanded to the north and west into Polk County. This allows the western portion of the revised grid to more adequately simulate influxes into the FAS from the Polk, Highland, and Osceola county ridge recharge areas. This approach is consistent with the panel's recommendation in that in the main body of the report that addresses this specific concern, the panel indicated that keeping the orientation of the grid in a north-south direction and expanding the grid further west and north would also be satisfactory.

Peer Review Comment Number 8: Efforts should be made in the next model phase to reduce model execution time without compromising model solution accuracy. Explicit coupling is recommended for the SEAWAT transport solution. Under explicit coupling, the density matrix is updated at the completion of each time step of the flow solution and is a reasonable compromise between the more intensive implicit coupling and uncoupled solutions. Other means of reducing model execution should be evaluated, including the lengthening of stress periods and flow model time steps and increasing grid size in cells that lie seaward of the coastline. Analysis of simulation error introduced by these efforts should be evaluated by comparative simulations and sensitivity analysis that evaluate deviations from the base case solution based on the existing temporal discretization.

SFWMD Response: The model is calibrated to a steady-state condition, and a coupled, transient flow and transport model on a monthly basis. Options to reduce execution time were discussed and implemented, resulting in a transient model with reasonable execution time. Because of the improvements observed in simulation time from these changes, there was no need to modify stress period lengths or grid dimensions.

While explicit coupling of the flow and transport simulation may result in some accuracy being lost compared to the implicit coupling technique, it is generally much more computationally efficient and allows for faster run times. Therefore, during the calibration process, both uncoupled and explicit coupling were utilized. However, the transient model statistics presented in this report are from a final implicit coupled simulation.

Peer Review Comment Number 9: Ideally, additional wells would be installed to obtain water quality and potentiometric head data in the Boulder Zone and Lower Floridan aquifer. Given the installation costs of these wells, the panel hesitates to make this recommendation. We do however recommend that the SFWMD continue to work with utilities in collecting additional water quality and potentiometric head information from deep regional aquifers at existing and newly installed wells. We also recommend that the SFWMD utilize underground injection control borehole logging criteria within deep wells installed in this area in order to gain the most possible information about the units' hydraulic properties.

SFWMD Response: SFWMD used all available data that met our data quality standards. As noted in the recommendation, the cost for installation of additional wells into the lower units is prohibitive for a large-scale investigation; however, the District continues to explore the FAS with limited funding. The District has also been working with the existing public water supply utilities, other FAS users including agricultural and industrial/commercial users, and other water management districts to continue to expand our knowledge and data collection efforts of the FAS. The District is actively engaged with the Southeast Florida Utility Council and this relationship, in conjunction with the District's water use permitting authority, helps the District remain aware of ongoing FAS well projects. The District actively seeks this data on the FAS for uploading to DBHYDRO, the SFWMD corporate database.

Peer Review Number 10: Future model users should be proficient in modeling, but might still benefit from a user's manual given the complexity of using a transient, density-dependent model. Important material to be included in the manual would be documentation of flow and transport properties, selection of stress periods, time step duration, and solution algorithms, information on the assignment of pumping stresses and transient and fixed boundary conditions, recommendations for construction of subregional models, and a description of model limitations.

SFWMD Response: This documentation of the ECFM revisions follows general standards utilized by past authors and conforms to the *Standard Guide for Documenting a Groundwater Flow Model Application* (ASTM 2006). It is the District's intention to develop a user's manual when a regulatory version of the tool is developed in the next step. The regulatory version of the model is anticipated to be a two-year monthly stress period uncoupled transient model to be used as an aid for permit applications and review. However, this document does address the important material identified by the peer review panel with the exception of the construction of a subregional model from this tool. Construction of a subregional tool from the ECFM may be included in additional reports by the SFWMD for site-specific applications.

The peer review panel also provided additional suggestions addressing longer-term issues such as monitoring and data collection, which are not part of the model revisions. The District's focus was on the 10 previously identified issues. To provide assistance during this process, the District contracted with Schlumberger Water Services to provide technical oversight and consultation during the process of addressing the panel's ten main comments. The Schlumberger Water Services report (Guo 2014) is available in Appendix E. This report provides an independent expert analysis summarizing if District staff adequately addressed the peer review comments during model development. Guo (2014) concludes that "the District has implemented all the Panel's pertinent recommendations with one contingency condition that the District will finish the User's manual as suggested by the Review Panel and promised by the District". In addition, the report includes three additional comments and suggestions. These include several editorial comments and a recommendation to include a sensitivity analysis on the dispersivity values in the model, and a contour map of the steady-state heads versus transient calculated heads.

2.0 Geological and Hydrogeologic Frameworks of the Floridan Aquifer System

2.1 Geological Framework

The geological framework of south Florida has been studied by a number of investigators including Miller (1990), Meyer (1989), and Reese and Richardson (2008). Most of the following is summarized directly from Reese and Richardson (2008). Florida is underlain by a thick sequence of carbonate and clastic sedimentary rocks ranging in age from Paleocene to recent. The geologic units that compose the Floridan aquifer system generally include the Cedar Keys Formation of Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Suwannee Limestone of Oligocene age when present, and the base of the Hawthorn Group, which ranges in age from late Oligocene to Miocene. A generalized geologic/hydrogeologic framework of south Florida is shown in Figure 2.1-1.

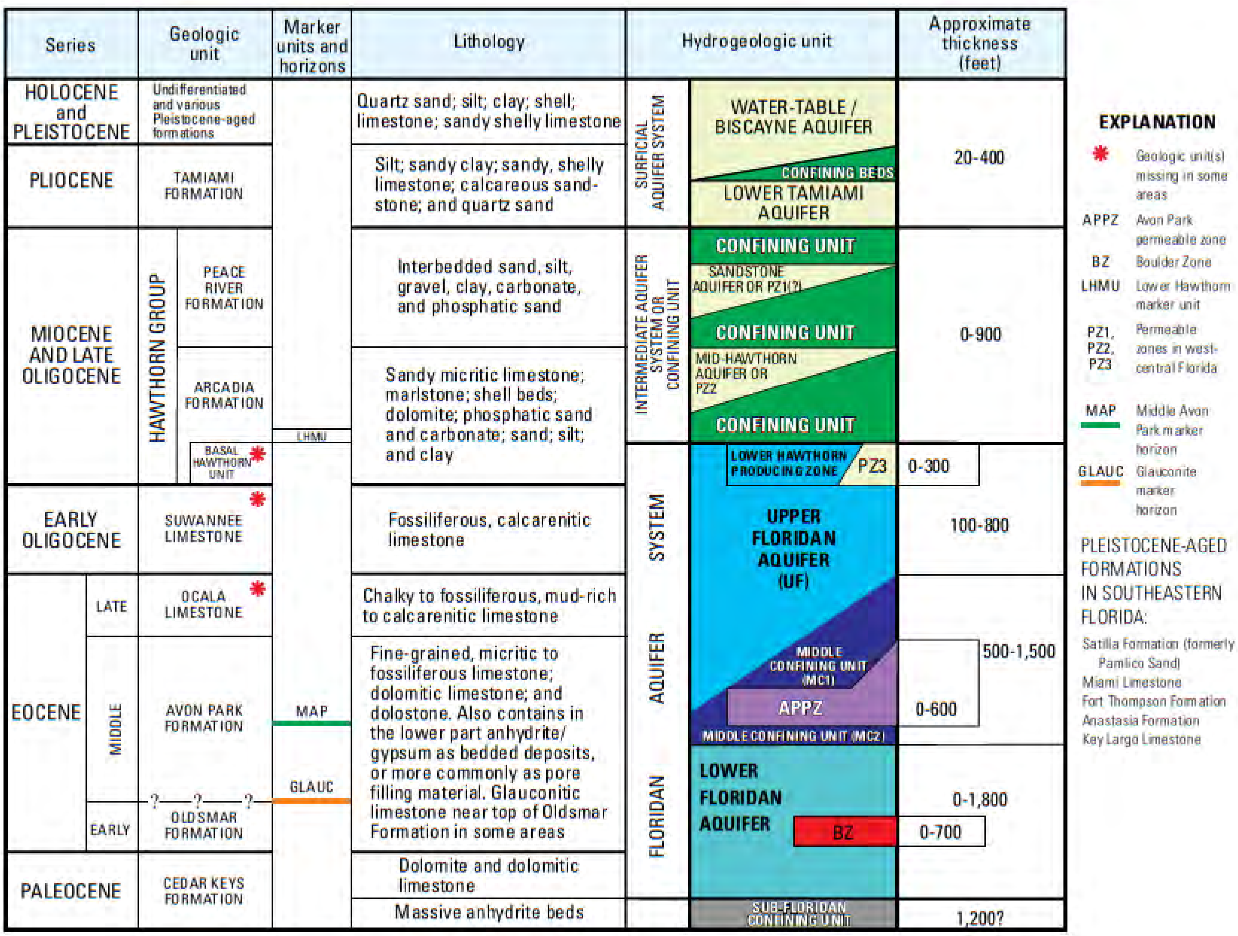

Figure 2.1-1. Generalized Geologic and Hydrogeologic Framework of South Florida (from Reese and Richardson 2008)

The Cedar Keys Formation consists of dolomite, dolomitic limestone, and anhydrite. The anhydrite exists as massive beds in the lower part of the formation and forms the base of the FAS. The Oldsmar Formation, which includes the Boulder Zone, consists primarily of interbedded micritic limestone and dolomite. The Avon Park Formation consists of micritic and fossiliferous limestone, dolomitic limestone, and dolostone or dense dolomite. The Ocala Limestone consists of micritic or chalky limestone, calcarenitic limestone, and coquinoid limestone. Miller (1986) maps the Ocala Formation as absent in the extreme southeastern area of Florida. The Hawthorn Group, which includes the Arcadia and Peace River formations, consists of varying lithologies including limestone, mudstone, dolomite, dolosilt, shell, and quartz sand, existing as both as an interbedded sequence and mixtures of all these materials. Geologic units that overlie the Hawthorn Group are not relevant to this study and are not discussed here.

2.2 Hydrogeologic Framework

There are three principal hydrogeologic units present in the study area: the surficial, intermediate, and Floridan aquifer systems. While the SAS is not actively simulated in the model, it provides recharge to the upper Floridan aquifer in the extreme northwest portion of the model. In this area, characterized by the Lake Wales and Avon Park ridges, the SAS consists of fine- to medium-grain quartz sand with varying amounts of silt, clay, and shell deposits. It is unconfined and produces small quantities of good- to fair-quality water. The intermediate aquifer system generally consists of the fine-grain sediments of the Hawthorn Group. While there are some aquifers within the Hawthorn Group that have been developed to a reasonable degree (mainly in southwestern, west-central, and north Florida), the Hawthorn Group generally acts as a regionally extensive confining unit over the underlying FAS. This confining zone, hereafter referred to as the intermediate confining unit (ICU) varies in thickness from several feet in the extreme northwestern portion of the study area to approximately 900 feet in the southern portions of the study area.

The FAS is the main focus of this study. It consists of the Upper Floridan aquifer, the Middle confining unit (MCU), and the Lower Floridan aquifer (Miller 1990). Reese and Richardson (2008) refined these units and provide a more consistent hydrogeologic framework for groundwater model development. The framework they developed uses multiple methods for identifying hydrostratigraphic units, including lithologic and geophysical methods. The results of their work are adhered to in this study (supplemented with data that became available after their report was published), and most of the following is summarized directly from their 2008 report.

The UFA occurs at the base of the Hawthorn Group and includes the upper portions of the Avon Park Formation and the Ocala Limestone. In the study area, it generally consists of several thin, highly permeable water bearing zones interbedded with thicker zones of lower permeability. The transmissivity of the UFA ranges from 10,000 to over 100,000 feet^2/day throughout the study area. The elevation of the top of the UFA in the study area varies from above sea level to more than 1,100 feet below NGVD 1929 in extreme southeastern Florida. The thickness of the UFA varies between less than 100 feet in central Florida to more than 700 feet in some areas of southern Florida. The bottom of the UFA tends to be gradational in nature and its elevation is difficult to define precisely. The UFA is semi confined in the northwest portions of the study area and more fully confined throughout the remainder of the area.

The Middle confining unit of Miller (1986) is subdivided into three units: an upper Middle confining unit (MC1), the APPZ, and a lower Middle confining unit (MC2). The APPZ is a major producer of water in portions of the study area. As stated above, the boundary between the UFA and MCU is gradational and difficult to define precisely; therefore, the altitude of the top of the MC1 shows a significant degree of variability. The thickness of the MC1 varies between less than 100 feet to greater than 800 feet. The APPZ is present throughout most of the study area, although it thins and may pinch out along the southeast coast of Florida, and may be absent in portions of Collier and Monroe counties. In other portions of the study area, it can be up to 500 feet thick. The elevation of the top of the APPZ is also quite variable, but generally occurs 750 to 1,500 feet below NGVD 1929. Permeability of the APPZ is mainly associated with fracturing. Transmissivity of the APPZ ranges from less than 100,000 feet^2/day in the southern portions of the study area to 1,600,000 feet^2/day in west-central Florida. MC1 provides only poor to moderate confinement between the APPZ and the UFA. In areas where the APPZ is absent, the MC1 and MC2 merge to form a single confining unit.

The Lower Floridan aquifer consists of a sequence of permeable zones separated by semiconfining units. The first permeable zone (LF1) is somewhat contiguous throughout the study area. It is located near the base of the Avon Park Formation at elevations between 1,400 and 2,600 feet below NGVD 1929. Its thickness ranges between near absent to over 150 feet. Reported transmissivities generally range between 10,000 and 50,000 feet^2/day with some localized higher values. Water quality within the LF1 is generally saline throughout the area but can become brackish to marginally potable in the extreme northwestern portion of the model domain. LF1 is located in the Lower Floridan aquifer shown in Figure 2.1-1 generally above the glauconitic limestone marker bed. Below the LF1 is a series of confining units with localized permeable zones at the upper portion of this deeper unit. The spatial extent of the thin permeable zones have not been fully mapped or identified in the deeper wells that penetrate this unit and would be difficult to treat as distinct hydrostratigraphic units. As a result, these lower confining units and the thin permeable zones within them are treated as a single semiconfining unit that is referred to in this document as the Lower Floridan Confining Unit (LC). Below the LC is an extremely transmissive zone of cavernous and fractured dolomites and limestones of the Oldsmar Formation locally referred to as the Boulder Zone (BZ). The BZ occurs at elevations of approximately 2,100 to 3,500 feet below NGVD 1929 and can be several hundred feet thick in some areas (Reese and Richardson 2008) with extremely high transmissivities values. The BZ represents the base of the FAS in south Florida as it is underlain by the massive impermeable anhydrite beds of the Cedar Keys Formation (Figure 2.1-1).

2.3 Conceptualized Groundwater Flow

Groundwater flow in the UFA, within Florida, generally radiates outward from four prominent high water level areas observed on the potentiometric map for the state (Miller 1990). Two of these exist in the Panhandle (northwest Florida) near the Georgia border, one northeast of Gainesville, and the other around Polk City in central Florida. The Polk City high generally dictates the direction of flow within the aquifer for central and southern Florida. The high is oblong in shape and trends north/south from northern Polk County southward into Highlands County generally following the Lake Wales Ridge. Although not as pronounced, this local high feature in the potentiometric surface continues southward into western Palm Beach and eastern Hendry counties as shown in Figure 2.3-1.

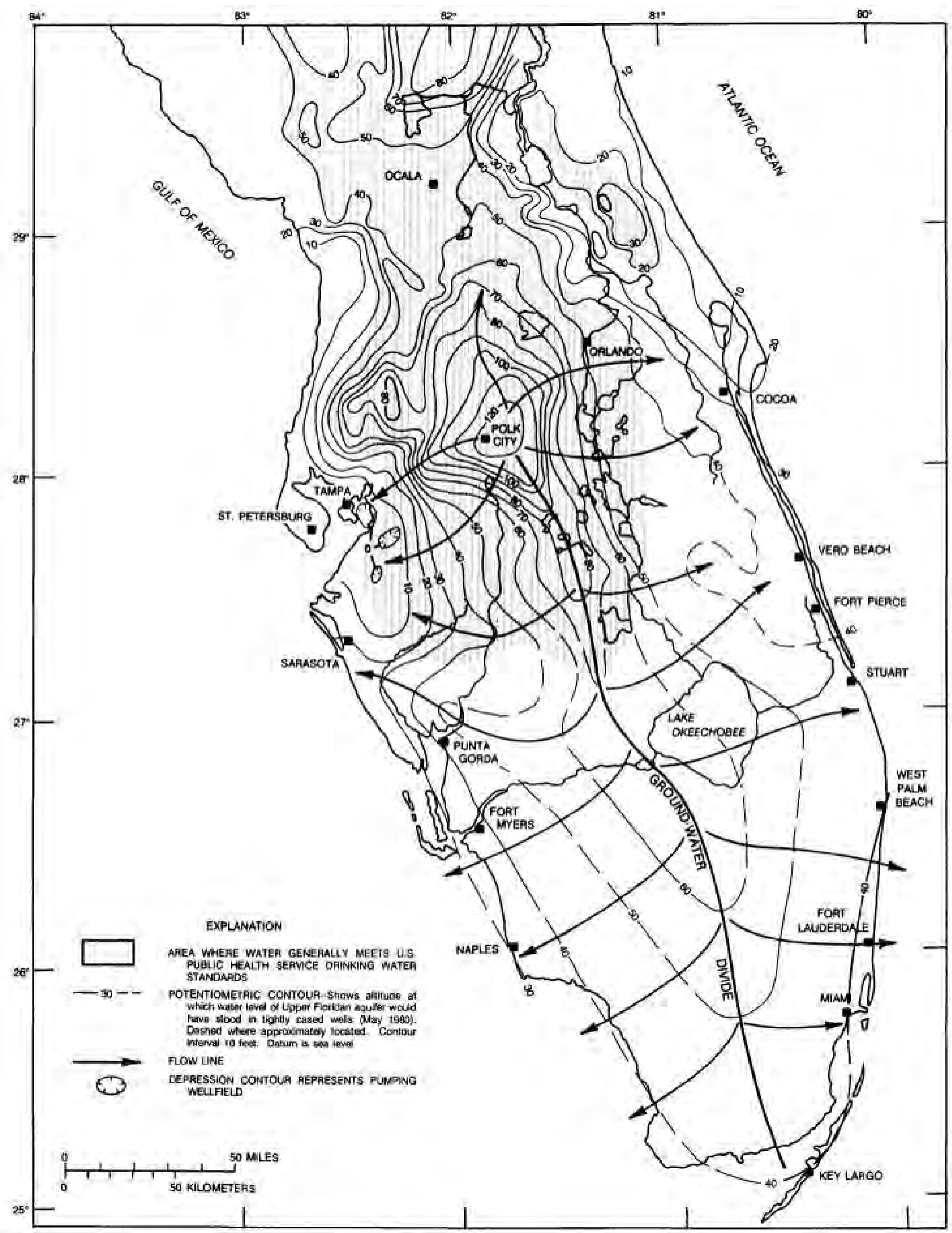

Figure 2.3-1. Flow Patterns in the Upper Floridan Aquifer (Meyer 1989)

Freshwater recharge into the FAS occurs primarily in the northwest portions of the study area in Polk and Highlands counties, and to a lesser extent, Osceola County. The SAS is an important component of the overall water budget for the FAS because it provides temporary storage of freshwater that can eventually reach the UFA. The Lake Wales and Avon Park ridges are characterized by thick permeable deposits of sand and shell with deep water tables. This area allows for greater downward percolation of rainfall that would otherwise be lost to evapotranspiration compared to most areas of the state where the water table is closer to the surface. Surface water drainage networks are also poorly developed along the ridges, restricting runoff and allowing the potential for additional recharge. In addition, several areas along the ridges are closed basins where no runoff occurs. Recharge to the UFA beneath these ridges takes place where the ICU is thin or permeable or where the overlying confining unit may have been partially or totally breached by sinkhole development (Spechler 2010).

Topographically, the Avon Park and Lake Wales ridges are areas of higher elevation than the surrounding regions. The water table elevation beneath the associated ridges is also higher than the adjacent flatlands. These higher SAS water level elevations provide a potential driving mechanism for downward leakance of rainfall into the UFA. The rate of leakance then becomes a function of the head difference between the SAS and the UFA along the ridges, and the vertical hydraulic conductivity and thickness of the ICU. This only occurs in the northwestern portion of the study area. Elsewhere, the ICU is thicker and restricts interaction between the SAS and the UFA, and the head of the UFA is higher than the SAS, further reducing the possibility of downward leakance from rainfall into the UFA.

While rainfall provides some limited direct recharge into the FAS within the study area, additional influxes occur in the northwestern portion of the study area as horizontal flow into the UFA, APPZ, and LFA. Water levels in the FAS can exceed 120 feet NGVD29 around the Polk City high while water levels within the study area rarely exceed 75 feet NGVD29. This results in a noticeable head gradient that can potentially supply horizontal flow into the study area. Few studies have quantified the spatial distribution and volume of water moving eastward from the Lake Wales Ridge. Water budget calculations from the East Central Florida Transient MODFLOW model (CFWI 2014) suggests that eastward flow across the Lake Wales Ridge in the FAS occurs predominately in the APPS and the LF1 with a lessor percentage occurring in the UFA.

Discharge from the FAS in the study area occurs via three primary mechanisms: offshore discharge, groundwater withdrawals, and upward seepage into the SAS. The ICU overlays the FAS throughout the study area and effectively restricts the interaction of water between the SAS and UFA over most of the study area. As previously discussed, the northwest area receives some downward percolation of rainwater. The Kissimmee River flows through a topographic low in this area were the SAS water levels are at or below the water levels in the UFA, potentially creating a means for upward movement of water from the FAS into the SAS or to the river itself. In 1999, a network of SAS groundwater monitoring wells, in-river piezometers, seepage meters, and stage recorders were installed to support a groundwater/surface water interaction study in Pools A and C of the Kissimmee River. Existing FAS wells were also monitored during the study. The investigation was conducted during the pre- and post-restoration efforts for this section of the Kissimmee River. Observed data indicated that the FAS water levels were higher than the SAS water levels at both Pool A in the north but lower than the river stages.

At Pool C further south, the FAS water levels were higher than the both SAS water levels and the river stages. Water level, water quality, and isotope data in the groundwater wells, combined with seepage meters placed in the Kissimmee River bottom sediments to monitor fluxes across the river bottom, revealed several anomalies that can be partially explained by introducing an SAS/UFA interaction variable.

Groundwater withdrawals are another source of loss from the FAS. Figure 2.3-2 shows a low water level area at the northeastern portion of the model domain in Indian River and Brevard counties. Flow moves eastward from the Lake Wales Ridge towards Indian River and St. Lucie counties. Crain et al. (1975) estimated the irrigation demands for Indian River County to be approximately 132 million gallons per day (MGD) in 1970, of which the majority was obtained from the FAS. The estimated demands from the FAS for Okeechobee County in the year 2000 were approximately 20 MGD (SFWMD 2006) and approximately 20 MGD in St. Lucie County (SFWMD 2011) in 2005. FAS withdrawals have been occurring in Okeechobee, Indian River, and St. Lucie counties for at least the last 50 years and is a key anthropogenic factor governing the groundwater flow patterns in the study area for the period of concern. Elsewhere in the study area, which is not influenced by significant groundwater withdrawals, flow patterns are more indicative of predevelopment conditions with a general east-to-southeast direction radiating outward from the Lake Wales Ridge high.

Discharges from the FAS into the Atlantic Ocean occur along outcrops in the Straits of Florida and along the Miami Terrace. The Miami Terrace is composed of a series of offshore linear features ranging in bathymetric depth from approximately 650 to more than 2,000 feet below sea level (Mullins and Neumann 1979) extending from southern Palm Beach County southward to the Florida Keys. It is generally composed of a series of exposed underwater limestone ridges of the Avon Park Formation and Ocala Limestone. The upper terrace is capped with phosphorites and phosphatic limestones suggesting submarine exposure of the Hawthorn Group sediments. Collapsed sinkholes are also prevalent along the shallow portions of the terrace, allowing for additional discharge points into the ocean from the UFA.

Besides the movement of water into and out of the FAS, significant flow is theorized to occur within the FAS. Kohout (1965) speculated that cold and dense salt water moves into the Boulder Zone from the Straits of Florida and Atlantic Ocean in southern Florida. This saltwater then migrates upward into the LFA, the APPZ, and UFA due to density differences caused by geothermal and salinity gradients. Meyer (1989) expanded upon this concept and developed a conceptual model of groundwater flow in the FAS for south Florida based on geochemical, temperature, pressure, and geologic data. Figure 2.3-3 provides a cross section of Meyer's conceptual model across the state from Naples to Feet. Lauderdale. Seawater enters the Boulder Zone through outcrops in the Straits of Florida off the Florida Keys, the Tongue of the Atlantic Ocean in the Bahamas, and through a series of collapsed features along the Miami Terrace offshore of the Feet. Lauderdale/Miami area. This conceptualized flow system suggests that upward flow from the Boulder Zone and the LFA is a key component of the overall water budget of the FAS.

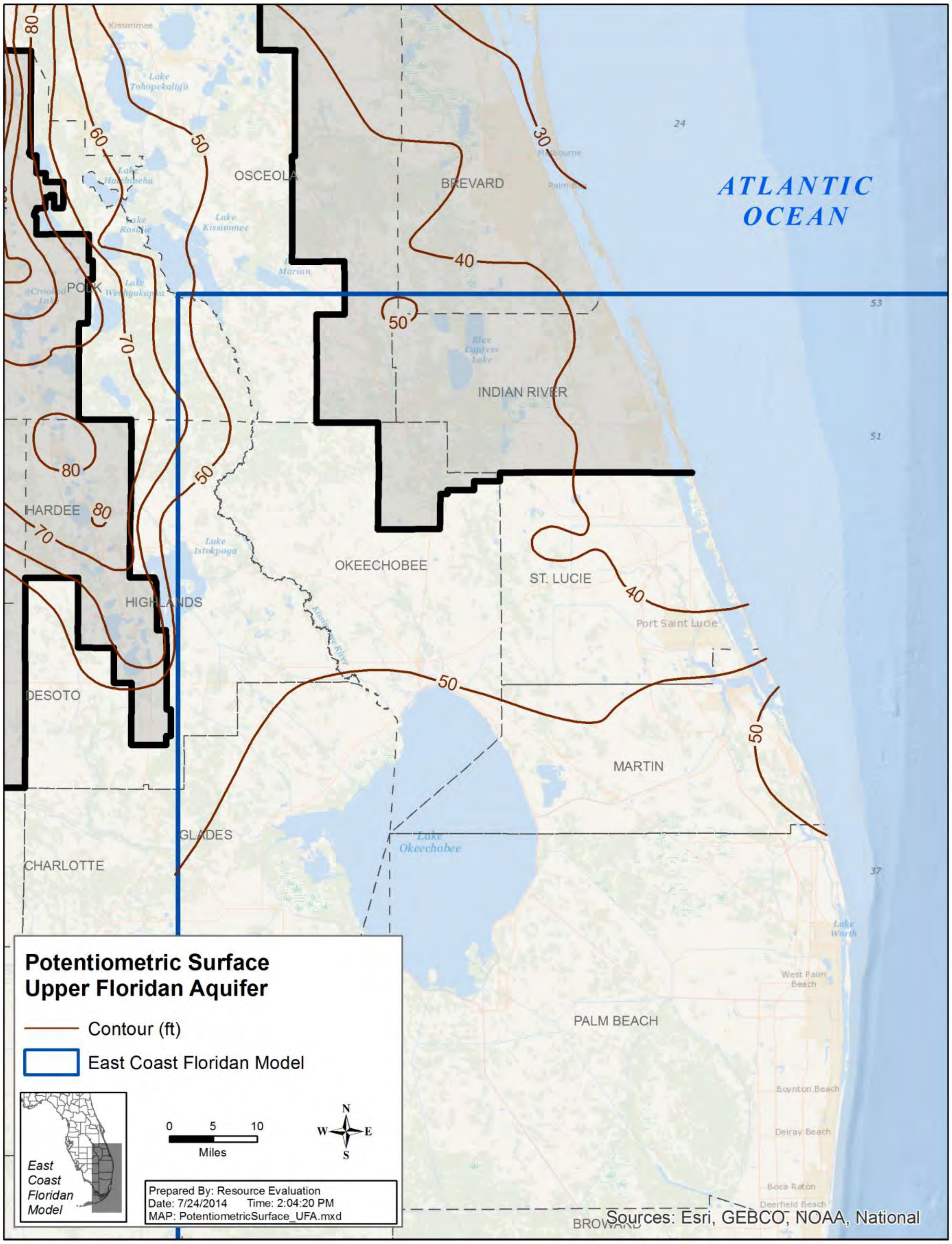

Figure 2.3-2. Potentiometric Surface of the Upper Floridan aquifer, May 2005

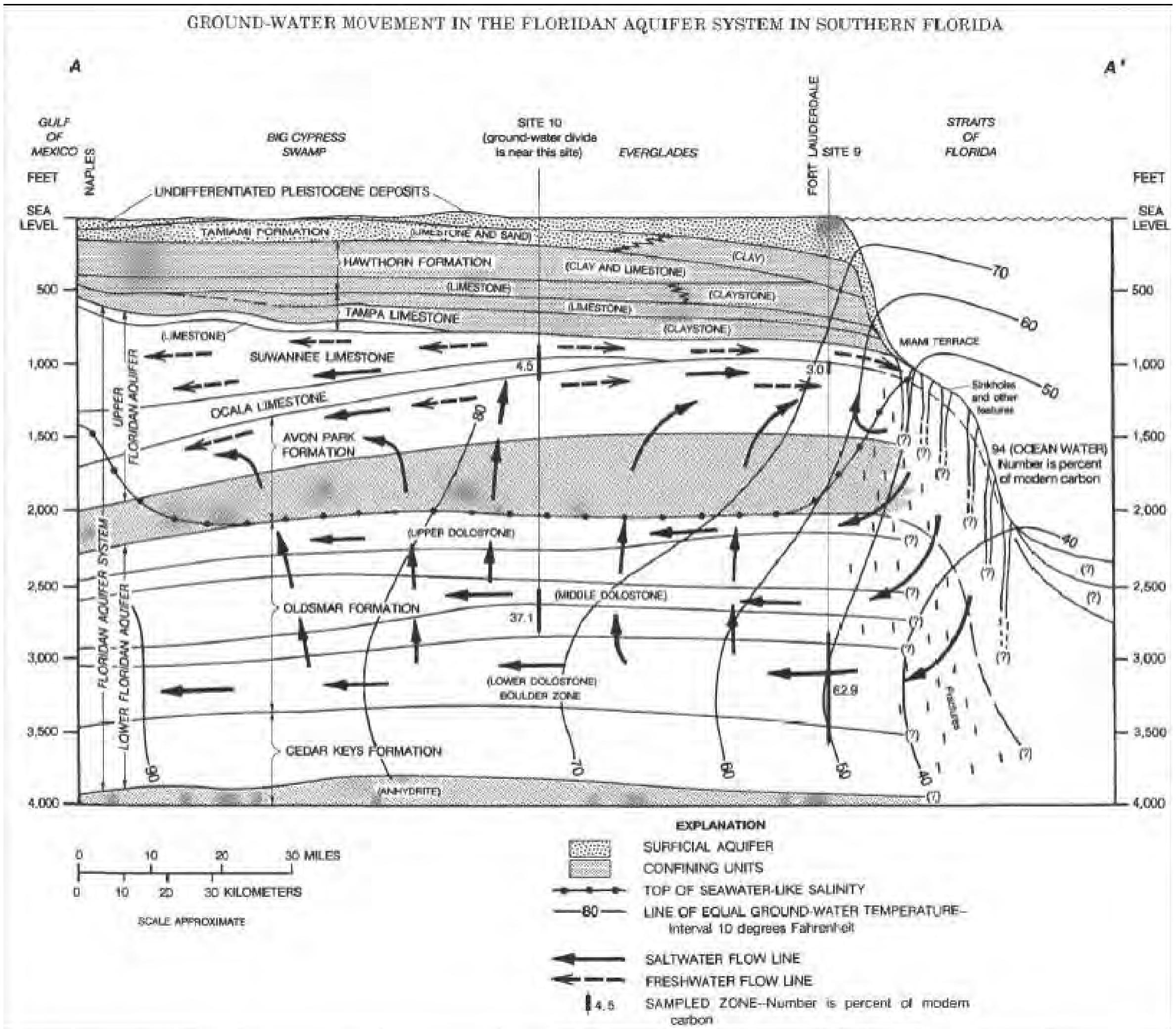

Figure 2.3-3. Conceptual Vertical Flow Patterns in the Floridan Aquifer System (Meyer 1989)

In summary, the conceptual groundwater flow model has water entering the FAS either as horizontal inflow into the study area from the Polk City high or from downward percolation of rainfall along the ridge systems in the northwest portion of the model area. Flow generally moves east/southeastward toward the ocean except for the northeastern portion of the model where it takes a more eastwardly direction in response to groundwater withdrawals. Discharges from the FAS occur as groundwater withdrawals, flow into the Atlantic Ocean along the eastern outcrops, and to a minor extent flow into the Kissimmee River valley (see Section 5.4). Flow within the FAS generally has an upward component because of density, pressure, and temperature differentials between the aquifers.

3.0 Data Collection and Analysis

The collection of data and the assembly of input data sets is one of the most important and time-consuming parts of model development, particularly for a model with a large geographic extent and complex hydrostratigraphy, such as the ECFM.

3.1 Hydrostratigraphic Data

The conceptual numerical groundwater model was initially divided into similar hydrostratigraphic units following the primary water producing units and confining units identified in Reese and Richardson (2008). Data from that work and the District's DBHYDRO database provided the majority of information used to construct the conceptual model. The groundwater flow and transport model was then constructed based upon hydrostratigraphic units and may not necessarily follow geological formation contacts. Additional data points from wells constructed post 2008 were also obtained. These newly obtained sites were checked against the existing database and corrected as necessary to meet the conceptual model specifications.

Once all data were assimilated and checked for quality assurances, they were combined into a single dataset for development of the model layers. The hydrostratigraphic layers were then created by kriging the surfaces of each of the major hydrostratigraphic units. In areas where data were missing, additional control points from the surfaces created by Reese and Richardson (2008) were used to control the drift and ensure consistency. In general, a maximum difference of 50 feet between the Reese and Richardson (2008) report and the model-generated hydrostratigraphic surfaces was allowed except in areas were new control wells were added or offshore where data were lacking and the two different interpolations schemes diverged.

The conceptual hydrostratigraphic model originally included all control wells throughout southern Florida from roughly the Tampa/Cocoa Beach line southward into the Florida Keys. This ensured that general trends and features were preserved along the model boundaries. A subset was then developed and kriged that only included the model domain. Figures 3.1-1 through 3.1-7 show the top elevation contours for the UFA, MC1, APPZ, MC2, LF1, LC, and the BZ for the model. To facilitate comparison, each of these figures has a contour interval of 100 feet.

Most layers show a southerly dip from the Polk County portion of the model to Miami-Dade County. The degree and extent of this dip varies between hydrologic units. The UFA shows a relatively consistent increase in depth of the top of the unit in a southerly direction. The higher areas in Hendry County can be attributed to the basal portion of the ICU showing productivity and therefore included in the UFA. North of Lake Okeechobee, the APPZ exhibits a southerly trend but develops a more southwestwardly trend south of Lake Okeechobee. The reason for this directional change can be partially attributed to the APPZ pinching out in eastern Collier and mainland Monroe counties.

Hydrostratigraphic control points may indicate that a unit may be extremely thin or absent as is the case for the APPZ in Collier, eastern Hendry, and mainland Monroe Counties. To solve the flow and transport equations, with the exception of specific storage for steady-state model simulations, aquifer properties should to be greater than zero. This includes aquifer thickness, which is a function of transmissivity, and determined from the layer surfaces. To ensure numerical stability during model execution, a minimum thickness of 10 feet was assigned to all areas and model layers when the thickness of any unit was less than 10 feet by comparing the kriged surface to the over- and underlying units. A similar approach was used for the hydraulic conductivity and storage arrays.

Cross-sectional views through the system aid in the general understanding of the hydrostratigraphic units. Figure 3.1-8 provides two north-south cross-sections and Figure 3.1-9 provides two in the west-east direction. Cross-section A-A' in Figure 3.1-8 shows the issue with the APPZ pinching out. The middle portion of the cross-section is the general location of the Collier County/Broward County line. In this area, APPZ thickness is sporadic and was manually adjusted to meet the 10 foot minimum criteria.

The LC surface represents the base of the LF1 hydrostratigraphic unit, which may differ from other authors. LF1 is reasonably contiguous across the study area and therefore treated as a single unit. For this report, the discontinuous and localized production zones of LF2 and LF3 were incorporated into the LC and treated as a single model layer. Similar to the APPZ, the surface of the LF1 has a slight southwestward dip in the southern portion of the study area. The base of the model is represented by the BZ. Wells penetrating this unit are concentrated along the coastal cities with few wells inland. The top of the BZ generally slopes southward. The base of the BZ is not included because the model simulates this unit as a constant head/concentration boundary and therefore an estimated depth to base is not required.

Appendix A provides the well names and aquifer top elevations used in the model construction. Bathymetric data from the offshore regions of the model domain were also used to estimate the outcrop positions of the aquifers and confining units and to assign general head boundaries. Because of the density and distribution of the existing data (both spatially and vertically), the upper units of the FAS are relatively better defined than the deeper units, in general.

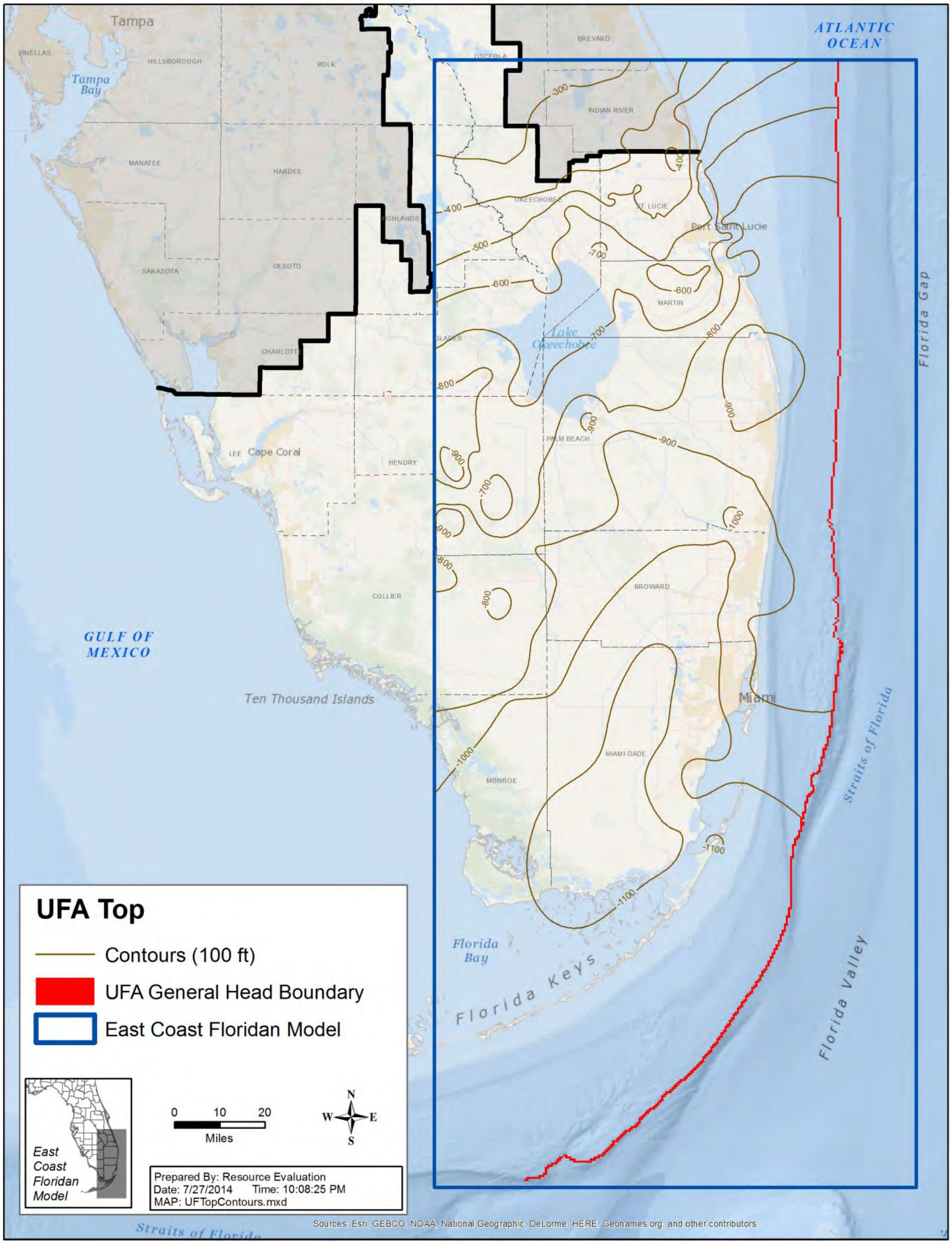

Figure 3.1-1. Top Surface of Upper Floridan aquifer

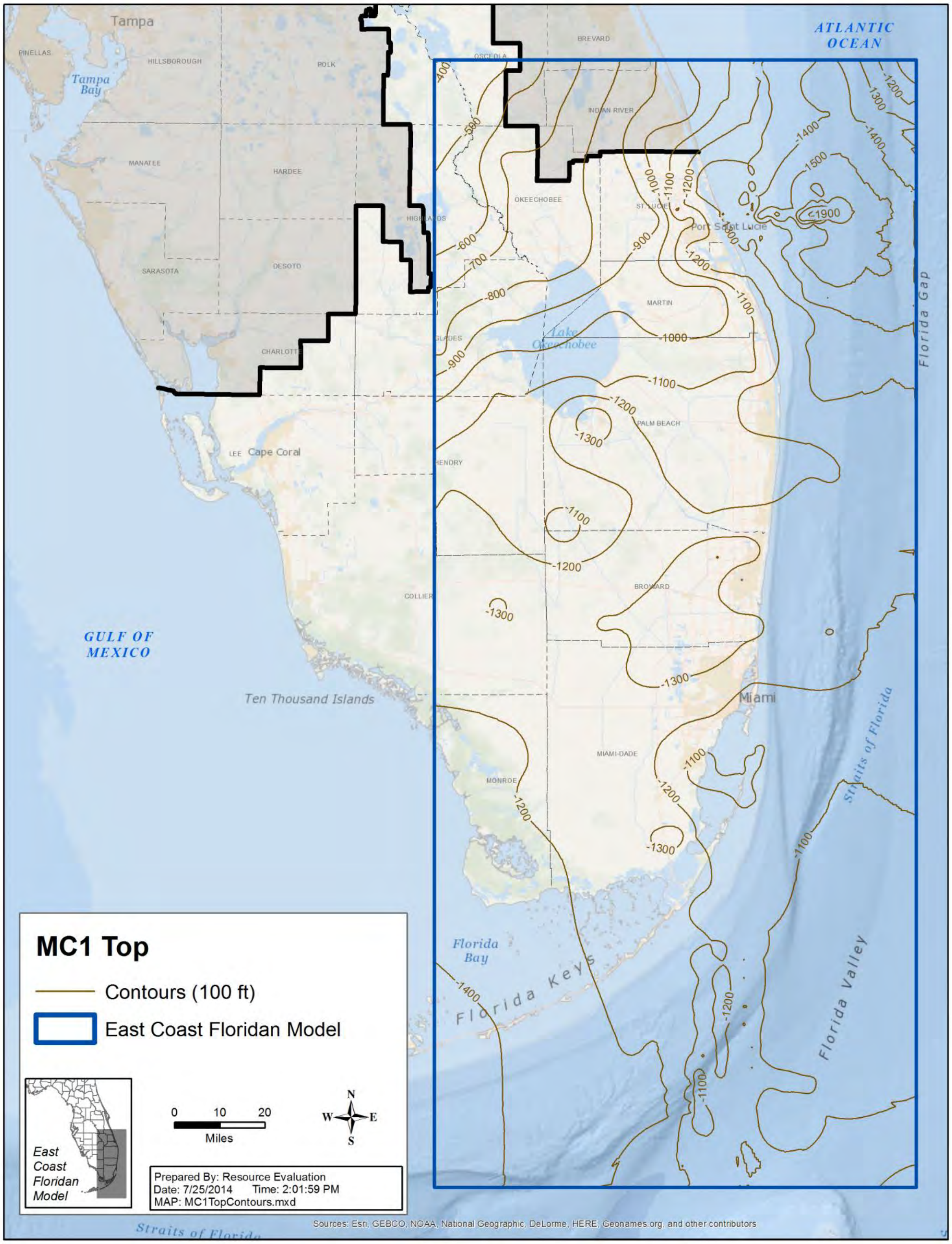

Figure 3.1-2. Top Surface of Middle Confining Unit 1

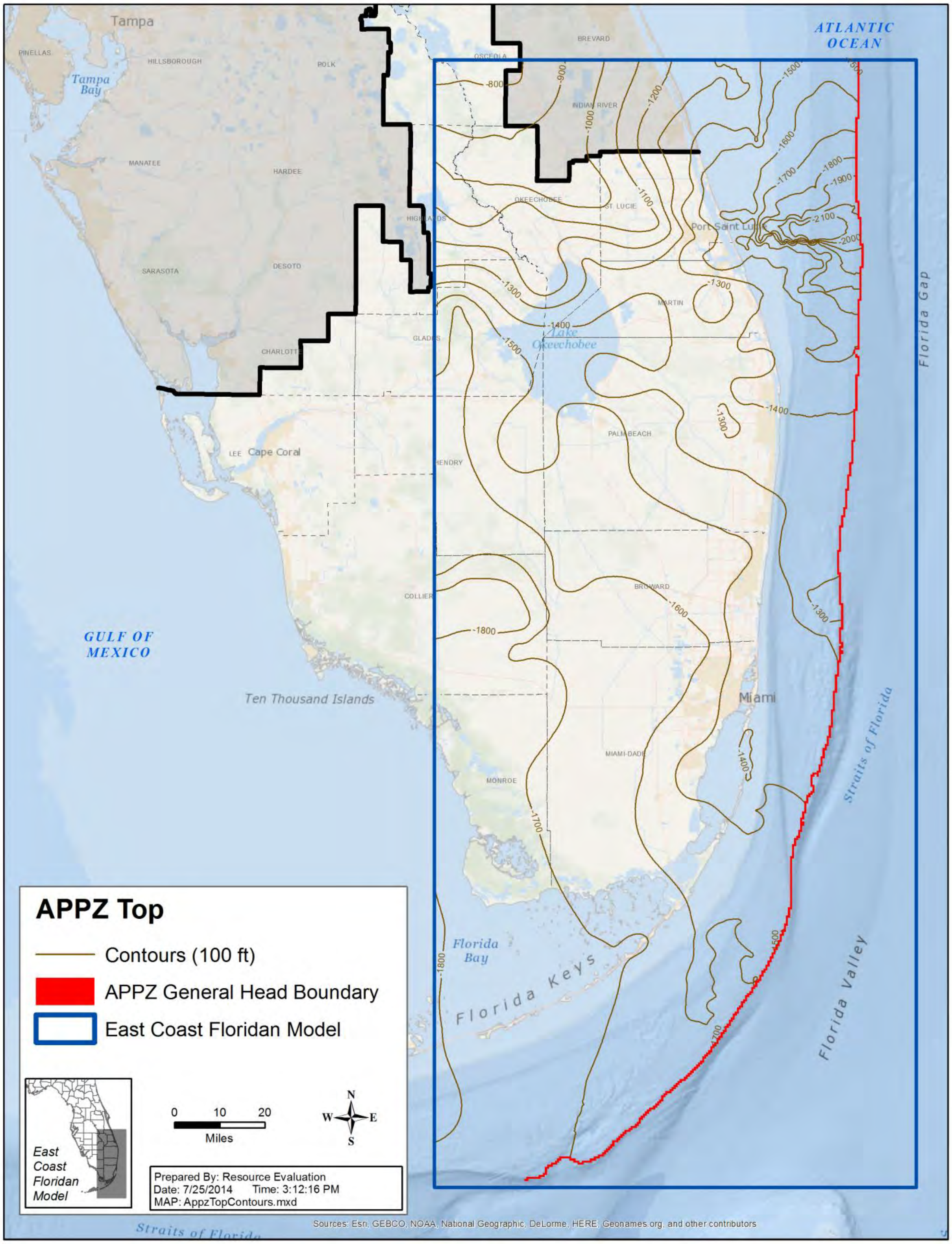

Figure 3.1-3. Top Surface of Avon Park Permeable Zone

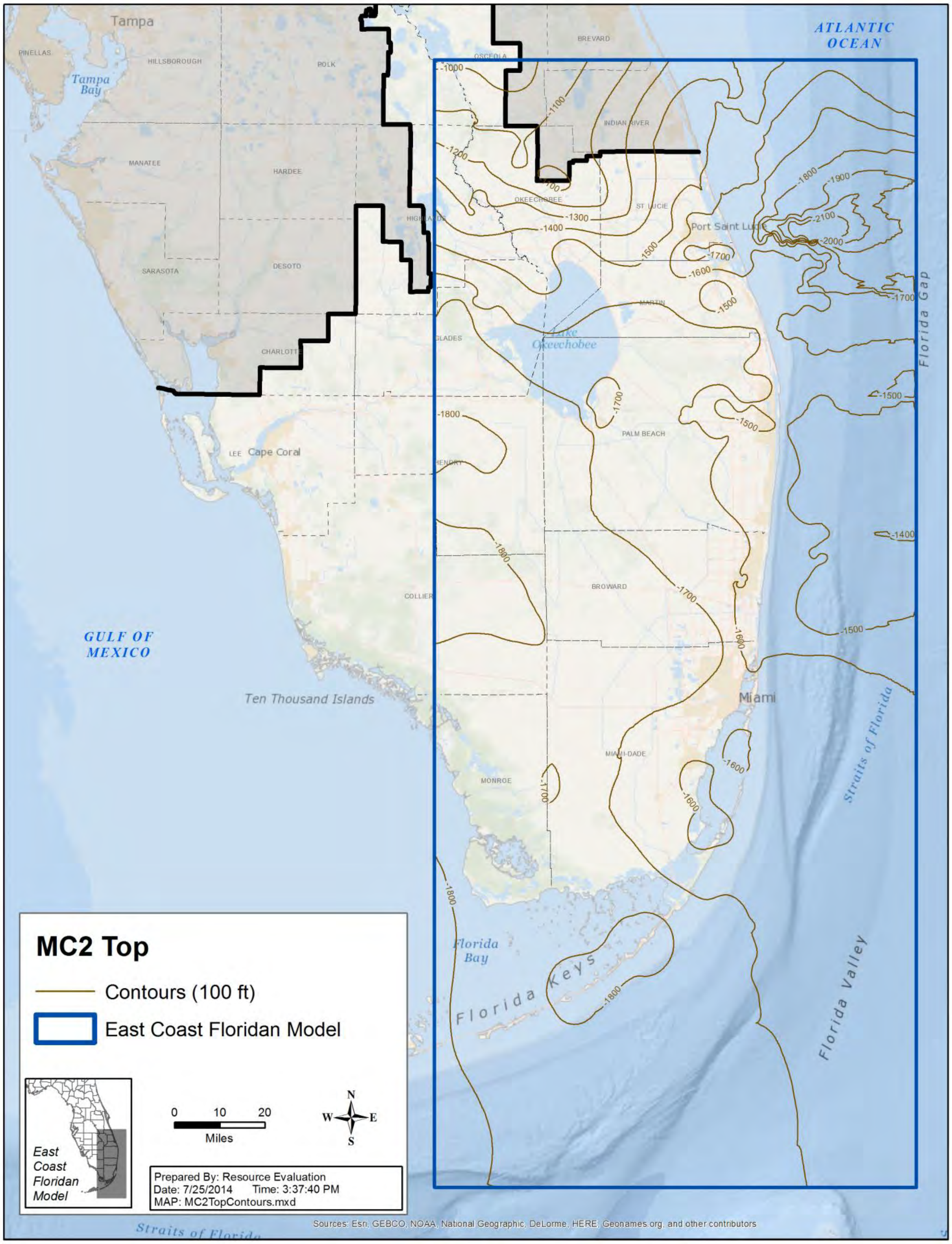

Figure 3.1-4. Top Surface of Middle Confining Unit 2

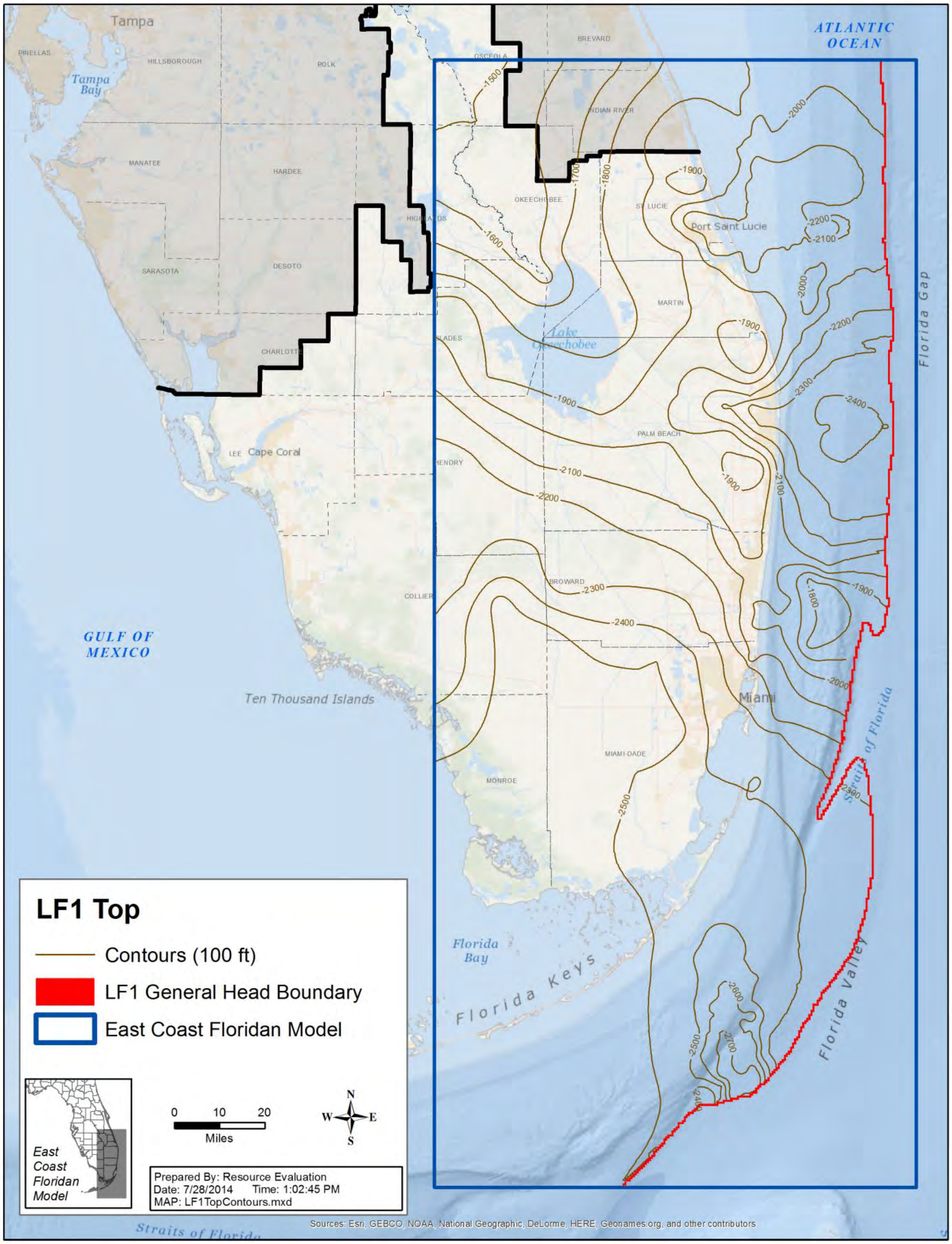

Figure 3.1-5. Top Surface of Lower Floridan aquifer – First Permeable Zone

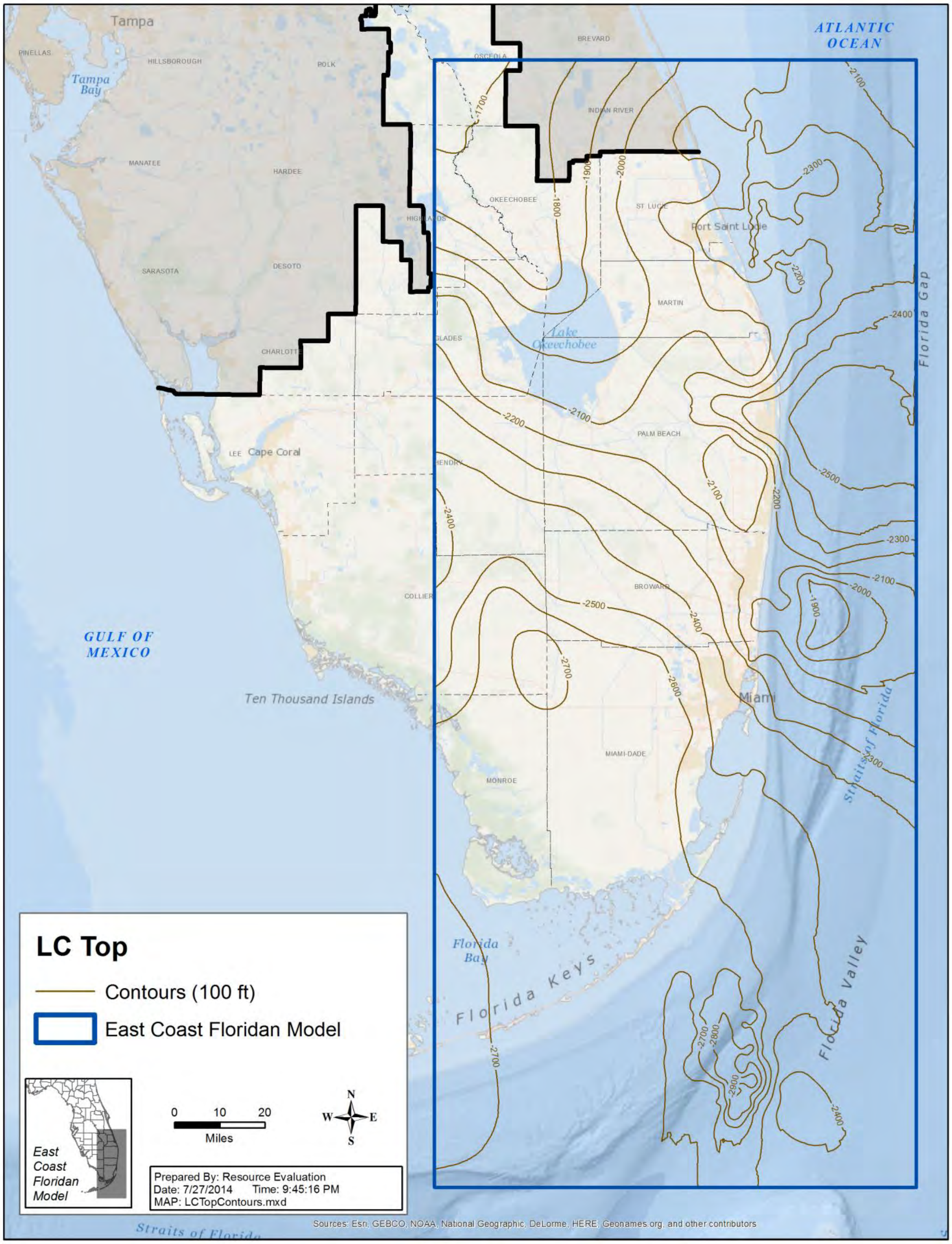

Figure 3.1-6. Top Surface of Lower Confining Unit

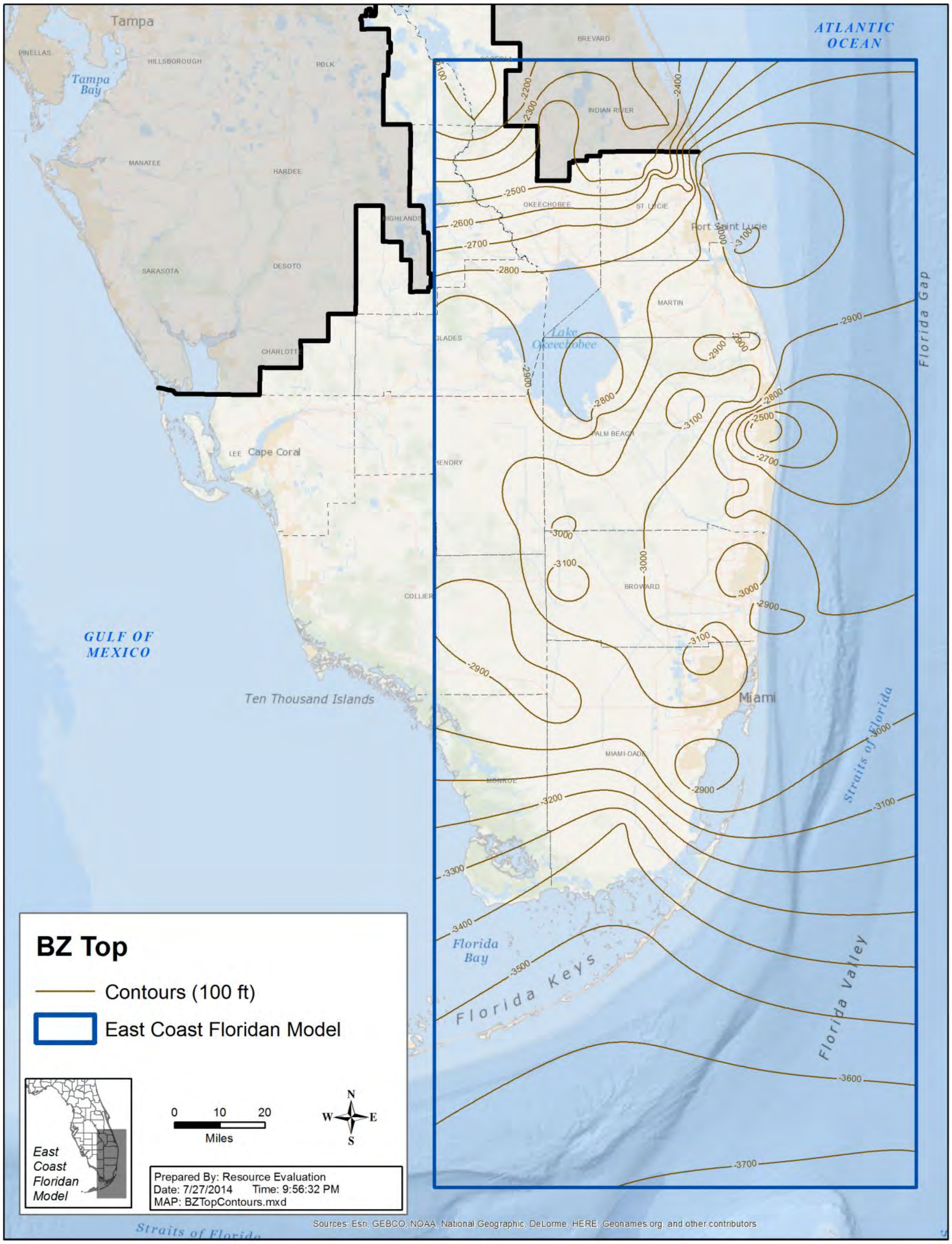

Figure 3.1-7. Top Surface of Boulder Zone

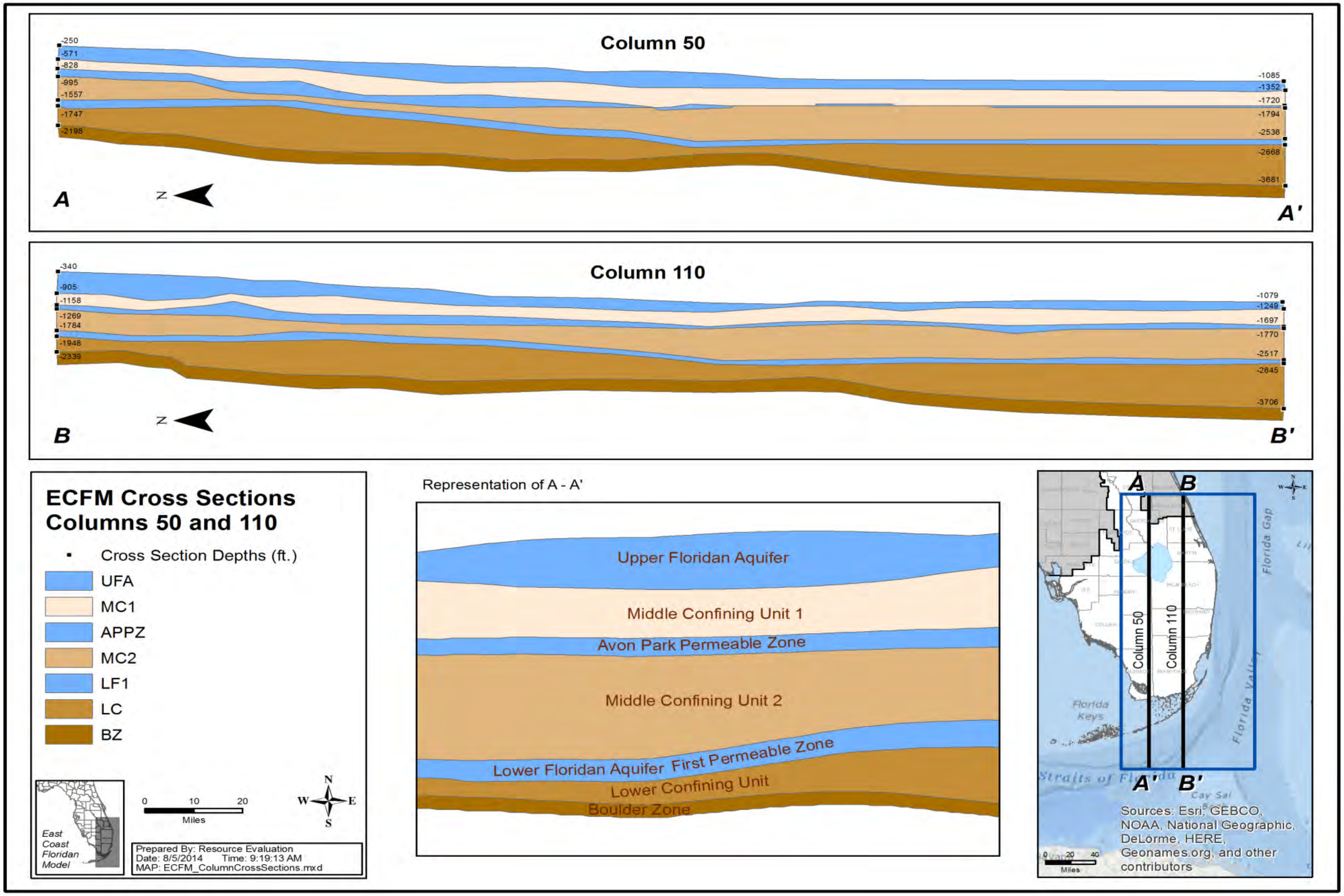

Figure 3.1-8. Column Cross Sections

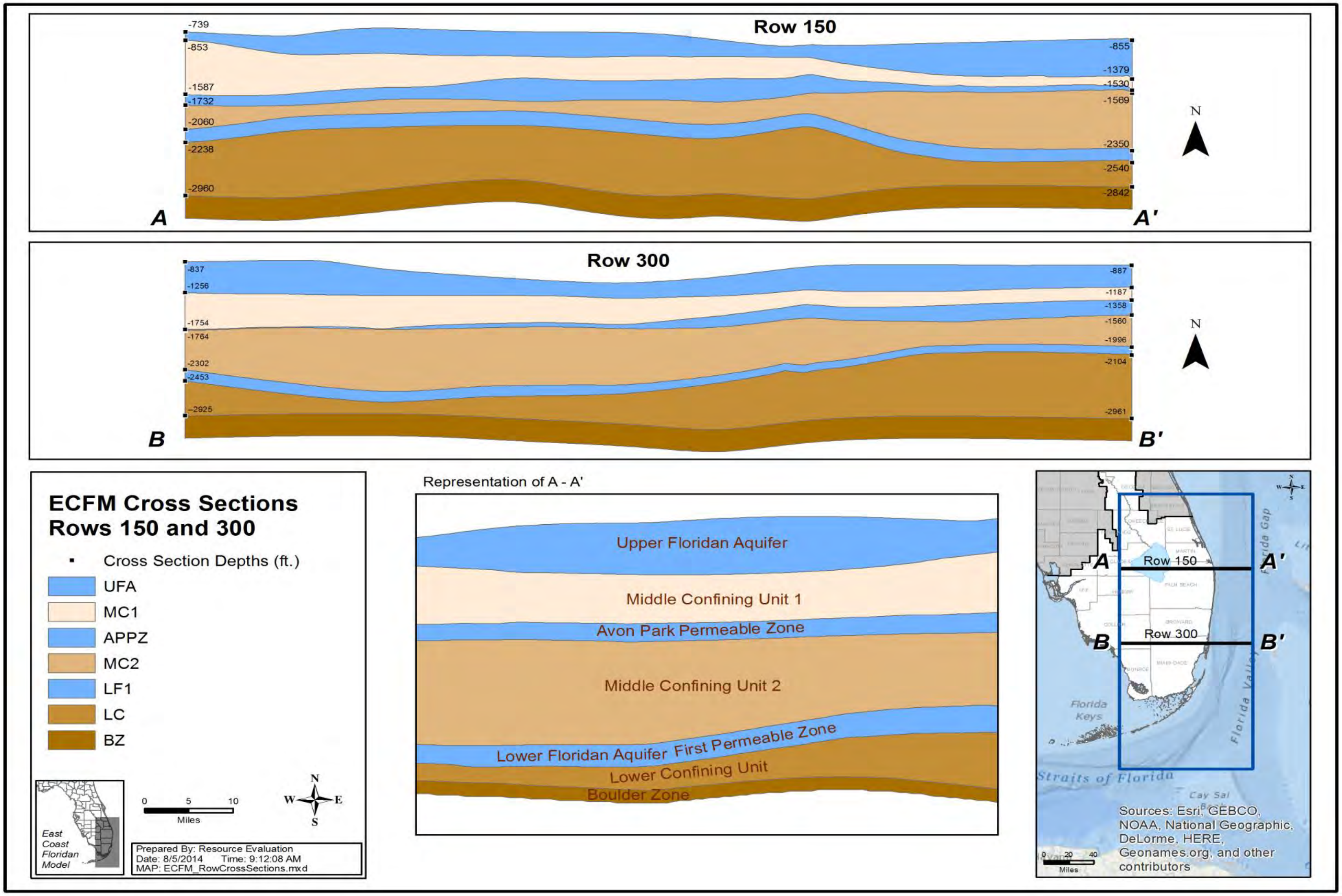

Figure 3.1-9. Row Cross Sections

3.2 Hydraulic Data

Numerous types of hydraulic data are required to develop a density-dependent solute transport model. For this section of the model development discussion, the data are divided into the following six categories:

- Hydraulic conductivities and storage coefficients
- Solute transport parameters
- Pumpage rates
- Recharge rates
- Boundary conditions
- Initial conditions

The first two categories are directly related to aquifer properties and hydraulic data, while the remaining four represent aquifer stresses and observed conditions.

Data collection procedures generally require that data be collected both from within and outside the model area to define conditions along the model boundaries as accurately as possible. The discussion that follows focuses on the data collected within the model boundaries unless specifically stated otherwise.

3.2.1 Hydraulic Conductivities/Storage Coefficients

Hydraulic conductivity was one of the most important parameters used to develop the model. It represents the aquifer's ability to transmit water under a hydraulic gradient. When multiplied by the aquifer thickness, the resulting term is called transmissivity, which can be readily obtained from aquifer performance tests (APTs). In developing this model, aquifer and confining unit tops and bottoms are static input parameters. The thickness of the aquifer, and consequently the transmissivity of the aquifer, was calculated internally by the model code. Therefore, vertical and horizontal hydraulic conductivities were used in place of transmissivity values.

Another important parameter needed for the transient simulations was the storage coefficient of the aquifer. Storage coefficients can also be readily obtained from the tests. Similar to the relationship between hydraulic conductivity and transmissivity, the model code requires a specific storage value, which is the quotient of the storativity of the aquifer divided by the aquifer thickness.

A large number of APT results were available for incorporation into the model. Most of these data were available for the UFA, which is the principal aquifer used throughout much of the state. This database was compiled from multiple sources including the SFWMD, the SWFWMD, the SJRWMD, the USGS, the USACE, various county governments, and numerous consultant reports. Horizontal hydraulic conductivity (K_h) values and specific storage (S_s) values for the three major aquifers (UFA, APPZ, and LF1) were calculated. There were 121 K_h and 48 S_s data values for the UFA, 26 K_h and 26 S_s values for the APPZ, and 7 K_h values for the LF1 within the active model domain. In general, the APT sites covered most of the study area but were poorly distributed in the Everglades area and the Florida Keys.

Figures 3.2-1 through 3.2-3 show the K_h values and their distributions for the UFA, APPZ and LF1. The K_h in the UFA range from 3.0 feet/day to over 500 feet/day; in the APPZ, they range from 3.0 feet/day to 11,000 feet/day; and in the LF1, they range from 3.0 feet/day to 1,000 feet/day. The K_h of the BZ is extremely high, but is not required for the model because the BZ is treated as a constant head/constant concentration boundary and the K_h values assigned for the BZ do not affect the model results. However, a uniform K_h value of 10,000 feet/day was assigned for this layer. Specific storage values for the three aquifers generally range from 10^{-3} to 10^{-8}. Vertical hydraulic conductivity (K_v) was calculated either from laboratory tests or from the leakance values for the confining units. Values of K_v can be calculated from the APTs by dividing the leakance value by the thickness of the overlying confining unit. The calculated K_v values for the confining units are shown in Table 3.2-1. The S_s values for the confining units were assumed to be low and a constant value of 10^{-5} was assigned uniformly for all confining units. Considering the large degree of uncertainty with the K_v and S_s values in the confining units, these parameters were adjusted during the calibration process.

A secondary feature that affects the K_v values is the Miami Terrace, a seafloor feature along the southeastern margin of the Florida peninsula north of the Florida Keys. This narrow carbonate platform interrupts the smooth profile of the Florida-Hatteras slope between Delray Beach and northern Key Largo, where it disappears north and south under prograding sediments. This feature can be divided into an upper and lower terrace. The upper terrace, which extends from 600 to 1,200 feet below sea level, is characterized by irregular, mostly sediment-free, karst-like topography. The shallower portions of the upper terrace reveal exposed surfaces of dense, dark gray to black, conglomeratic phosphatic limestones suggesting exposure of the Hawthorn Group (Mallow and Hurley, 1970). A similar exposure of the Hawthorn Group occurs off the Florida Keys and is referred to as the Pourtales Terrace. At depths greater than 1,000 feet below sea level, the exposed surfaces change to include hard substrates, moderate- to high-relief slabs, outcrops, boulders, ledges, steep slopes, and escarpments suggesting the outcrop of the Ocala Limestone. The narrower, discontinuous lower terrace from 1,900 to 2,200 feet below sea level apparently formed as a result of submarine erosion due to the intensification of the Gulf Stream associated with closure of the Isthmus of Panama.

Seismic reflection across the terrace indicates deep karst features penetrating hundreds of feet. These collapse features suggest that the K_v values used for the onshore areas in the model need to be increased to account for the discontinuous nature of the confining units in the area of these outcrops. These localized collapse features may provide a conduit for movement of water between the BZ upwards into the UFA. Similar collapse features in the FAS have also been observed in seismic profiles conducted in the freshwater canals of Broward County (Reese and Cunningham 2013). Therefore, K_v values offshore from Palm Beach County southward where initially increased by a factor of 100, above what has been observed on land, and further adjusted during calibration.

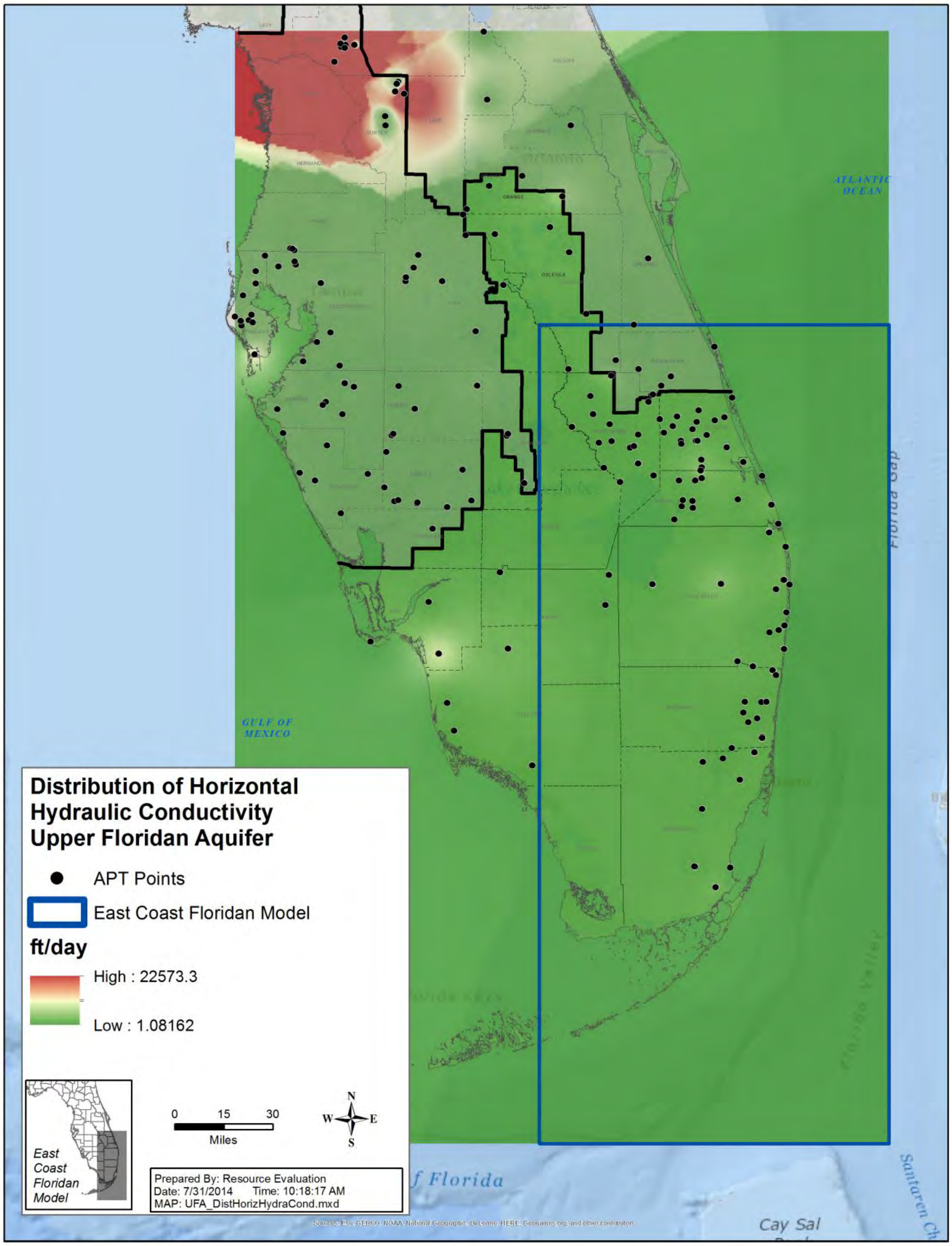

Figure 3.2-1. Distribution of Horizontal Hydraulic Conductivity in the UFA

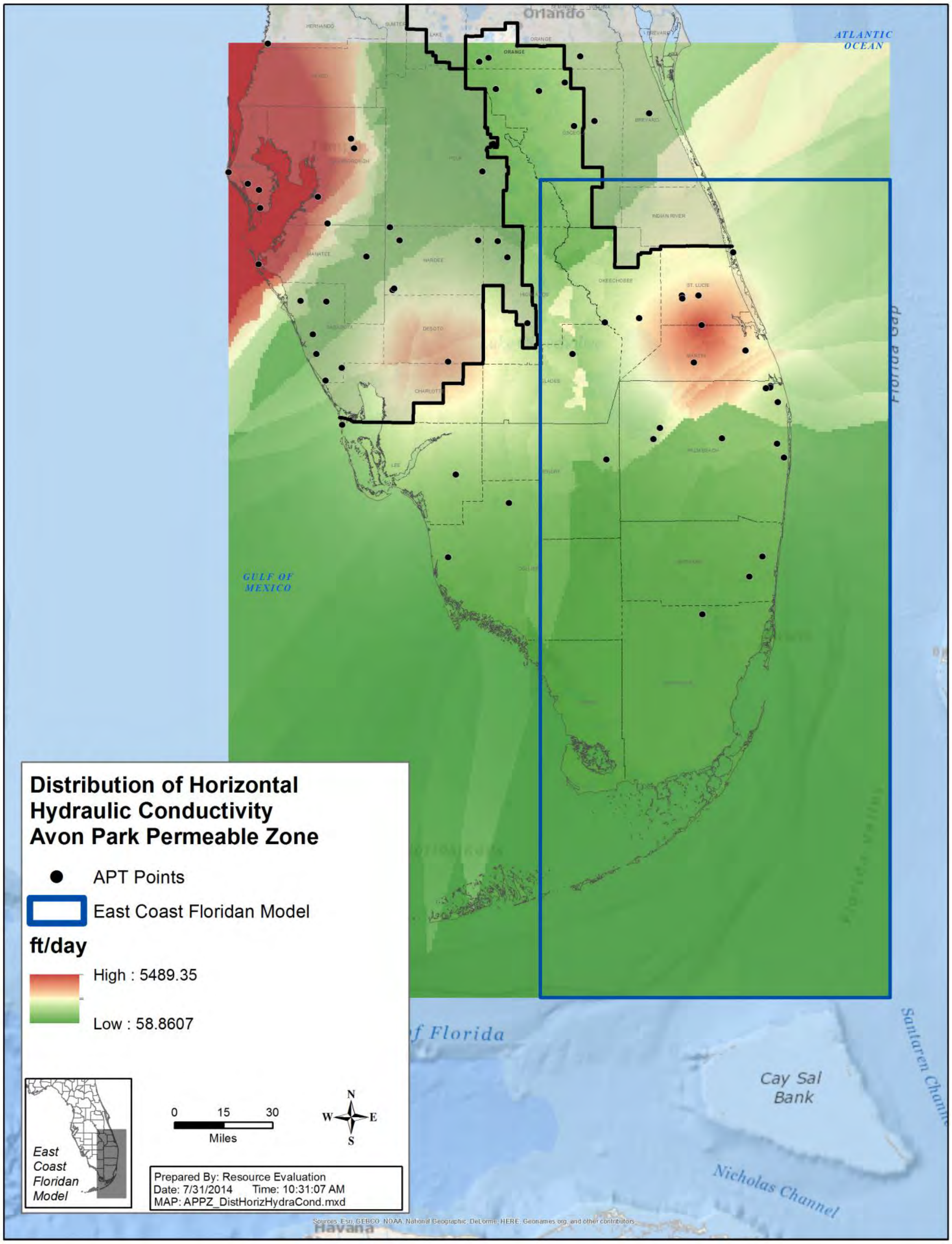

Figure 3.2-2. Distribution of Horizontal Hydraulic Conductivity in APPZ

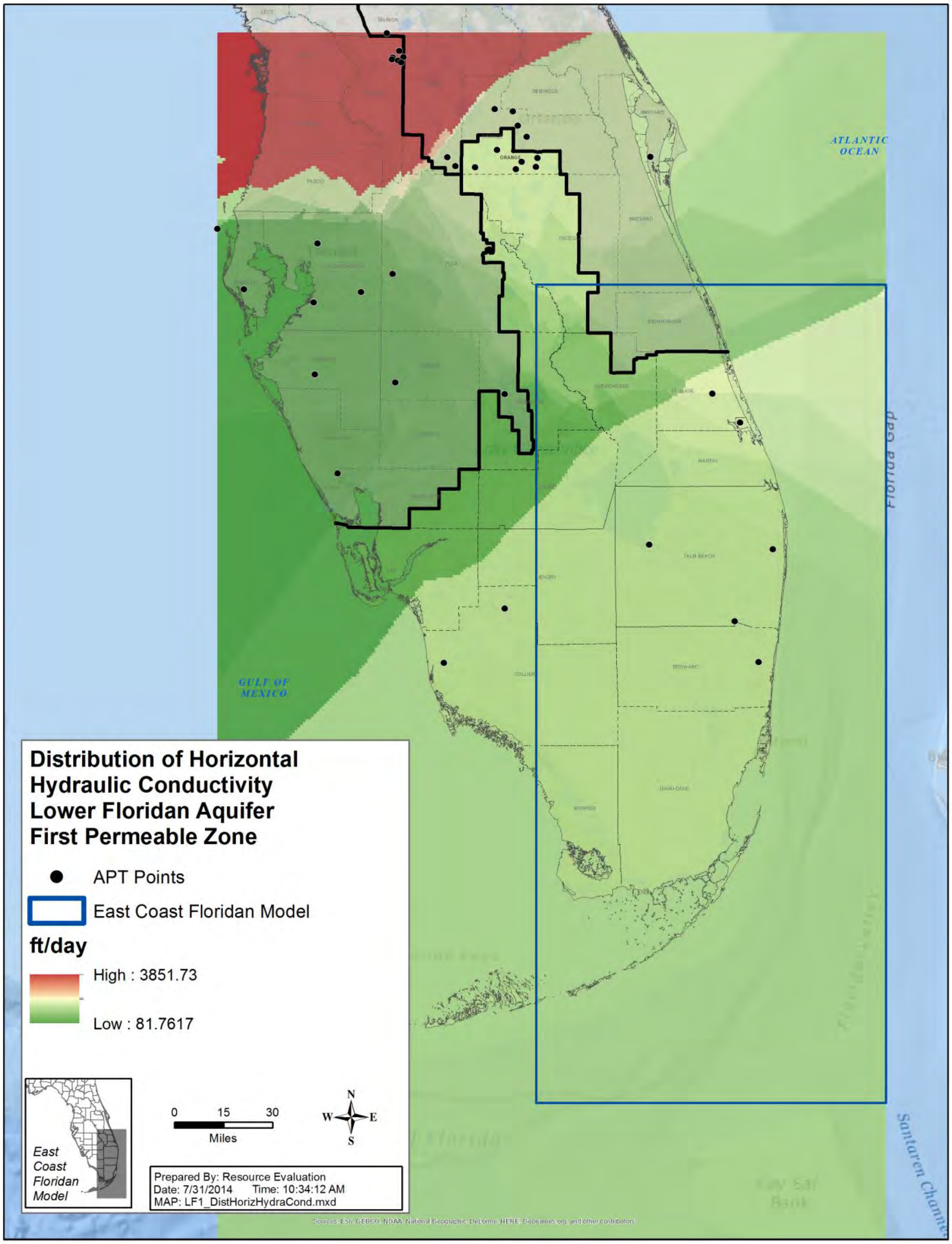

Figure 3.2-3. Distribution of Horizontal Hydraulic Conductivity in the LF1

Table 3.2-1. Calculated K_v Values for the Confining Units

Well Name (APT)	X Coordinate	Y Coordinate	Parameter (hydraulic conductivity, layer)	Calculated Value (feet/day)
BF-2	925546	669572	k_v2	0.087
DF-2	830645	573066	k_v2	0.6228
BF-3	925364	669470	k_v2	0.0601
SLF-74	821841	1092293	k_v2	0.3137
PBF-9	748906	860074	k_v2	0.1409
W-12295	851079	370735	k_v2	0.0011
DF-1	828433	575983	k_v2	0.0177
COHWTP_TW	926387	611661	k_v2	0.0087
W-17095	724745	1055176	k_v2	0.5523
G-3706	829113	497139	k_v2	0.299
ICW-2	814120	983804	k_v2	1.7498
L2-PW1	672709	826685	k_v2	0.0186
PB-1197	931130	942241	k_v2	0.2796
L2-TW	672741	826627	k_v2	0.1211
PBF-9	748906	860074	k_v4	0.9896
W-16067	895855	1057464	k_v4	0.624
W-16039	866992	1091917	k_v4	0.1265
W-15886	917036	749287	k_v4	0.0584
PB-1689	938655	874131	k_v4	0.0004
PSLWPT-IW1	866387	1055241	k_v4	0.0222
HOL-IW1	941045	616691	k_v4	1.8257
PSLLTC-IW1	850609	1104256	k_v4	0.0888
W-16067	895855	1057464	k_v6	0.4707
W-16039	866992	1091917	k_v6	0.5927
W-16897	878265	1135537	k_v6	0.248
W-15886	917036	749287	k_v6	0.0271
W-16882	943434	798936	k_v6	0.0431
W-17052	764969	896738	k_v6	0.074
PB-1170	936561	942379	k_v6	0.1042
PB-1186	757542	858553	k_v6	0.5628
PB-1689	938655	874131	k_v6	0.0223
PB-1190	928897	785409	k_v6	0.0723
PSLWPT-IW1	866387	1055241	k_v6	1.0576
PSLLTC-IW1	850609	1104256	k_v6	0.073

3.2.2 Solute Transport Parameters

Solute transport parameters such as porosity and dispersivity, both horizontal and transverse, are difficult to quantify, especially at the regional modeling scale but are essential to solve solute transport equations. Molecular diffusion occurs gradually over long periods and is assumed to be negligible during the study's time range. Porosity is the ratio of pore volume to total volume of a sample, whereas effective porosity is the ratio of the pore volume that water can circulate through, to the total volume. Therefore, effective porosity cannot exceed porosity. Porosity values can then be used in the original design of the model as an upward bounding limit.

Several geophysical log types, including compensated neutron, sonic, and Z-density, can be used to provide a general understanding of the porosity down hole. Core samples are also used to determine porosity using the helium method, which is based on Boyle's law ($P_1V_1 = P_2V_2$). Essentially, a chamber of helium with a known volume and pressure is connected to a second chamber containing a geologic core sample and the pressure is allowed to equalize. The porosity then becomes the fraction of the total pore volume and the geologic core bulk volume (API 1998).

Scientists have collected numerous geologic cores throughout south Florida and analyzed them using the helium method. Bennett (2001) collected 48 samples from the UFA, MC1 and APPZ at the L-2 Canal site in Hendry County, 39 from the UFA in the Big Cypress Basin in Collier County (Bennett 2004), and 6 from the UFA at Immokalee in Collier County (Bennett 2002). Anderson (2008) estimated a porosity of 0.43 in the UFA and 0.34 in the APPZ from an FAS exploratory well located at the L-8 canal in Palm Beach County. CH2MHILL (2008) collected several samples at the Paradise Run site on the Kissimmee River near the Glades/Highlands County line from the UFA, APPZ, and the MC2. An additional exploratory well in Hendry County at La Belle yielded 15 core samples from the UFA and 13 from MC1 (Bennett 2003).

Table 3.2-2 lists the calculated values, sample depth, and aquifer for each of the collection sites. A total of 167 samples were analyzed for porosity, 121 in the UFA, 31 in the MC1, 12 in the APPZ, and 3 in the MC2. Excluding the MC2, the other hydrogeologic intervals yield a relatively consistent porosity value of approximately 32 percent. Variations in porosity values occurred within these units generally depending upon the amount of vugs present or secondary infilling of the pore space.

Below the APPZ, only three lab samples were analyzed for porosity in the MC2 and none in either the LF1 or the LC. A review of the deeper compensated neutron and Z-Densilog geophysical logs suggest that the porosity in these lower units is comparable to the UFA and APPZ. Several logs reviewed did show a reduction in porosity units in MC2, which is consistent with the three lab samples which had an average porosity of 19.2 percent.

Table 3.2-2. Helium Derived Porosity Values from the FAS

Site	County	Interval (Depth feet NGVD29)	Hydrogeologic Unit	Mean Porosity (%)	Minimum Porosity (%)	Maximum Porosity (%)	N-Value
L-2	Hendry	830-840	UFA	38.4	34.9	40.2	10
L-2	Hendry	1020-1030	UFA	34.8	20.1	38.1	10
L-2	Hendry	1190-1200	MC1	39.3	32.1	43.5	9
L-2	Hendry	1330-1340	MC1	31.7	27.3	36.6	9
L-2	Hendry	1480-1485	APPZ	30.9	22.3	39.6	5
L-2	Hendry	1630-1635	APPZ	32.0	30.3	33.8	3
L-2	Hendry	1710-1711	APPZ	34.5	34.3	34.6	2
Big Cypress	Collier	850-862	UFA	15.4	5.8	27.9	11
Big Cypress	Collier	880-940	UFA	33.1	21.8	45.3	11
Big Cypress	Collier	970-991	UFA	28.1	18.0	34.8	17
Immokalee	Collier	883-889	UFA	22.3	18.4	32.9	8
Immokalee	Collier	955-1049	UFA	33.0	23.7	39.1	17
Immokalee	Collier	1061-1098	UFA	31.2	22.9	41.2	18
La Belle	Hendry	726-826	UFA	40.4	26.5	51.7	15
La Belle	Hendry	1194-1299	MC1	26.0	11.3	34.7	8
La Belle	Hendry	1450-1454	MC1	24.4	20.0	26.5	5
Kissimmee River	Highlands	800-806	UFA	37.8	36.1	39.4	2
Kissimmee River	Highlands	1104-1262	APPZ	36.7	35.6	37.7	2
Kissimmee River	Highlands	1756-1760	MC2	19.2	16.4	23.7	3
L-8	Palm Beach	944-945	UFA	45.4	45.4	45.4	1
L-8	Palm Beach	1040-1050	UFA	43.0	43.0	43.0	1
L-8	Palm Beach	1289-1290	MC1	33.9	33.9	33.9	1
		Average:					
			UFA	31.5	5.8	51.7	121
			MC1	31.3	11.3	43.5	31
			APPZ	32.7	22.3	39.6	12
			MC2	19.2	16.4	23.7	3

The average porosity values for each layer were used as the starting point for the model. During calibration, these values were adjusted to better represent the effective porosity of the unit.

Dispersivity is a physical parameter that is part of the solute transport process. It includes longitudinal, transverse, and vertical dispersivity (Guo et al. 2011). Measured dispersivity data for the FAS in south Florida was not available and the selection of values for the ECFM was based on literature review. Gelhar et al. (1992) determined that the magnitude of longitudinal dispersivity was scale dependent, that it reflects the spatial variation in hydraulic conductivities, and is significantly larger than the horizontal dispersivity. Field tests conducted at several contamination sites indicate that longitudinal dispersivity is approximately 11 times the transverse dispersivity at Borden Air Force Base (Freyberg 1986), approximately 53 times at Cape Cod (Garabedian et al. 1991), approximately 450 times at Vejen (Jensen et al. 1993), and approximately 60 times at Grindsted (Lønborg et al. 2006). These tests also revealed that the longitudinal dispersivity was approximately 640 times the vertical dispersivity at the Cape Cod site and 900 times at Vejen. As a general approach, Anderson and Ross (2013) suggest that the Peclet Number, or ratio of grid spacing to dispersivity, should be on the order of 2 or less, which is used in the ECFM.

HydroGeoLogic (2006) suggested that the longitudinal dispersivity should range between 1,250 and 5,000 feet and a transverse value of 1/10 the longitudinal. Kwiatkowski (1987) suggested values of 5 feet and 0.5 feet for longitudinal and transverse dispersivity using a model with a much finer resolution. Guo et al. (2011) used a longitudinal value of 100 feet, 20 feet transverse, and 10 feet vertical for a FAS model simulating conditions along the west coast of Florida. Sensitivity analysis conducted by Guo et al. (2011) indicates that the model was not sensitive to variations in these parameters on the order of five times and one tenth the initial values. Similar transport modeling conduct for the FAS used longitudinal dispersivity values generally between 3 and 1,000 feet with the lower values reported by the USACE (2010).

The values for longitudinal and transverse dispersivity used in the model were varying spatially but generally range around 50 and 5 feet respectively. Effective porosities were set at 0.25 for the UFA, MC1, APPZ, and LF1 and 0.25 for the MC2 and LC. A sensitivity analysis of these parameters (discussed later in this report) indicated that the model has some sensitivity to these parameters.

3.3 Pumpage Data

The FAS is a major water source in Florida and numerous wells utilize the UFA or APPZ in the northern portion of the study area for irrigation and public water supply. The BZ is utilized via deep injection wells to dispose of secondary effluent or reverse osmosis concentrate throughout south Florida, but volumetric data of injection was not required because the BZ is treated as a constant head/constant concentration boundary in the model. Historical pumpage records for public water supply utilities are generally available throughout the region and the simulation period through the utilities' monthly operating reports to the FDEP. These reports generally include the raw water that is pumped into a water treatment plant, but do not include withdrawals from individual wells. Usually, more than one well provides water to a treatment plant. For purposes of this study, raw water volumes reported by the utility for an individual treatment plant were distributed equally among all wells providing water to that plant in most cases. When available, individual well pumpage records were also reviewed. The date that wells were constructed during the study period was also reviewed to guard against wells being simulated that may have not been in operation.

Records of actual irrigation withdrawal volumes are rare and confined to the last several years of the study period. When pumpage data was available, sufficient quality assurances had to be conducted before they were included in the data set. As a result, irrigation withdrawals needed to be estimated for the entire study area. Irrigation demands were determined using the Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) program developed by Smajstrla (1990). This program provides a reasonable estimate of daily irrigation requirements based upon observed rainfall and evapotranspiration rates. For the SFWMD and SJRWMD, each district's water use permit database was used to determine the crop type, acreage, irrigation efficiency, and the dates of operation for each user. This information was fed into the AFSIRS program and irrigation requirements were calculated for each day of the simulation period for each individual water use permittee. Because the citrus operations in the northern portion of the study area use a combination of surface water and FAS water, only a percentage of the irrigation demands calculated from AFSIRS were simulated as groundwater. This percentage was estimated from submitted pumpage records and discussions with the land owners and their representatives. The demands were then summed into either monthly demands or an average demand for the 24-year simulation period for input into the transient and steady-state simulations.

Commercial, power production, and industrial users were also included but historical records for these users are not uniformly available. Therefore, the average permitted demand was used throughout the simulation period, adjusted for times when the users may have not been in operation based on available information. One additional use type was included, aquifer storage and recovery (ASR), although it is a relatively minor use in the region. These ASR systems are primarily associated with public water supply utilities or SFWMD facilities and generally have detailed records of injected and recovered volumes as required by the FDEP.

Approximately 2,000 wells are simulated in the model. Wells located generally north of Palm Beach County are used predominantly for both agriculture and public water supply, while public water supply and golf course irrigation are the dominant uses from Palm Beach County southward. Figures 3.3-1 and 3.3-2 show the location of all permitted FAS groundwater wells used in the model. There are no groundwater withdrawal users of the LF1 aquifer within the study area.

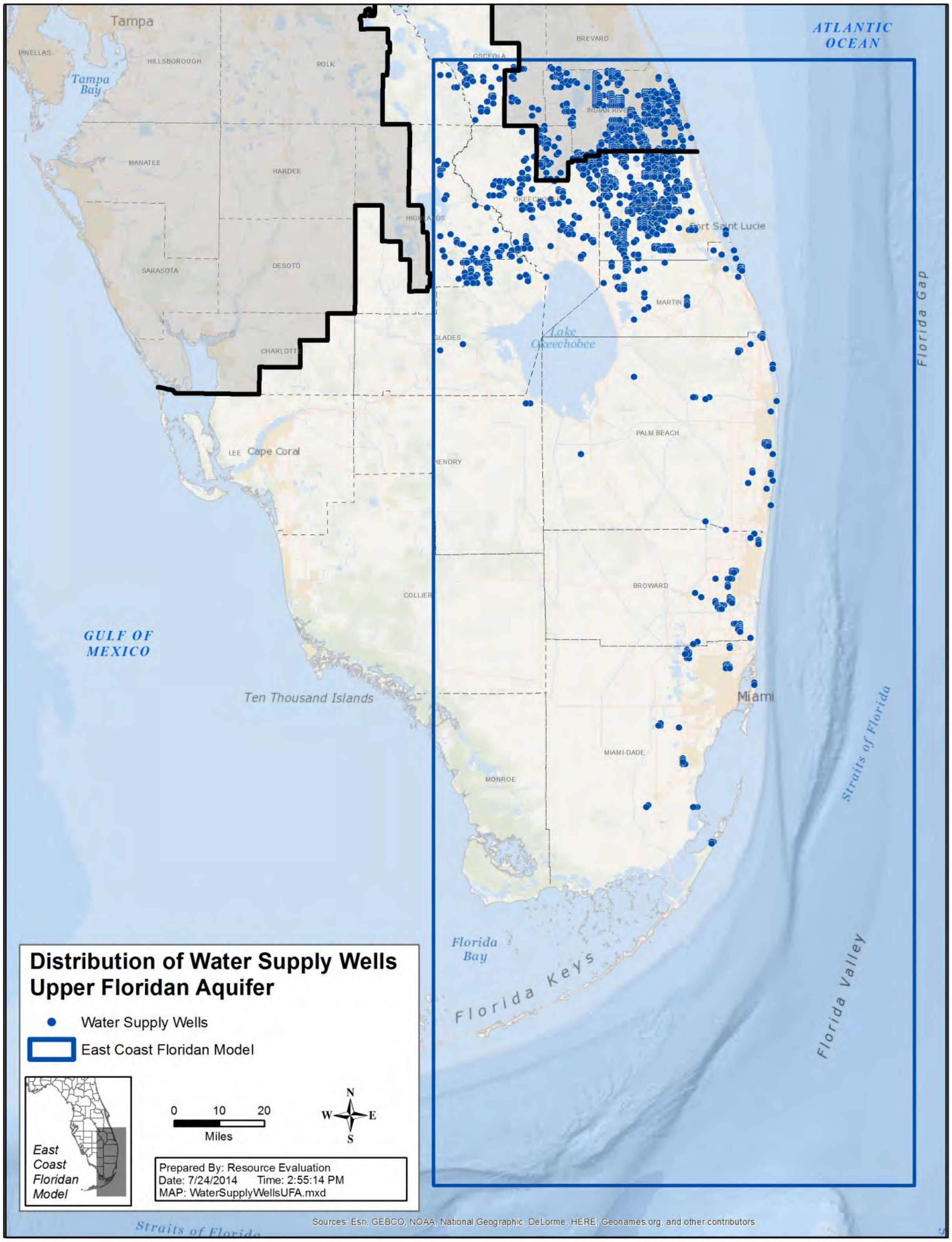

Figure 3.3-1. Distribution of Permitted Water Supply Wells Simulated in the UFA

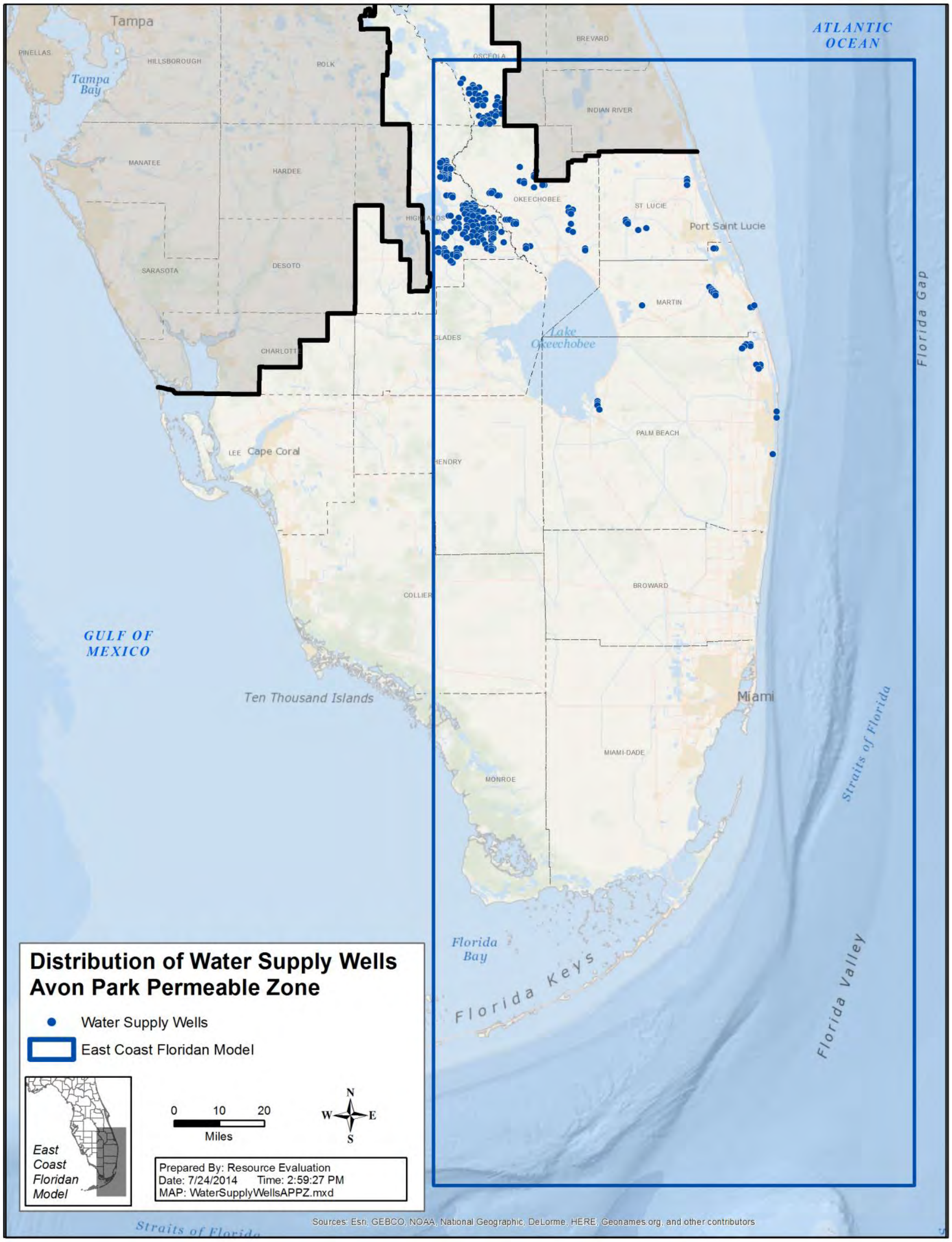

Figure 3.3-2. Distribution of Permitted Water Supply Wells Simulated in the APPZ

3.4 Recharge Data

Within Florida, recharge to the FAS occurs primarily from rainfall, the amounts of which can vary dramatically throughout the year (Figure 3.4-1). Mean rainfall and temperatures are similar in much of south Florida. The mean average temperature in Miami is 68 degrees in January and 84 degrees in August, with a mean annual rainfall of 51.82 inches with the highest month being June. In Fort Pierce (St. Lucie County), the mean average temperature is 62 degrees in January and 82 degrees in July and August, with a mean annual rainfall of 53.96 inches and most falling in September. Mean annual temperature for Lake Placid in Highlands County is 61 degrees in January and 81 degrees in July and August and mean average rainfall is 52.25 with August being the wettest month.

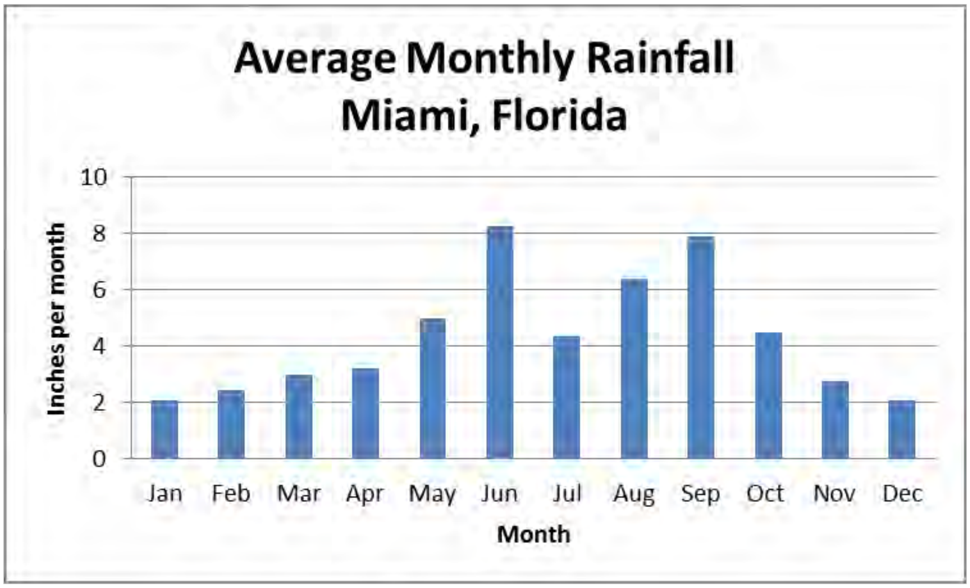

Figure 3.4-1. Average Monthly Rainfall for Miami, Florida

Although the average annual rainfall and temperatures are relatively similar across the study region, large variations in the spatial and temporal distribution occurs on a daily basis. These spatial and temporal differences are obtained daily from rain gauges, Nexrad radar, and climatic stations. This site-specific information is used when calculating the supplemental irrigation demands in the AFSIRS program for a specific property.

The amount of rainfall available for recharge to the SAS is reduced by runoff and evapotranspiration. Evapotranspiration is a physical process and is the sum of the evaporation from water bodies and transpiration losses from plant systems to the atmosphere. Evapotranspiration generally accounts for approximately 70 percent of rainfall and the remaining 30 percent either runs off the land into drainage networks and streams/rivers or percolates into the ground as recharge. Direct rainfall recharge to the FAS within the study area occurs primarily from downward leakance from the SAS through the ICU into the UFA. Stewart (1980) identified areas in Florida where natural recharge occurs to the FAS. In the study area, this occurs primarily in Highlands, Polk, Osceola, and Okeechobee counties in varying degrees. Elsewhere within the study area, recharge into the UFA from rainfall is negligible.

The amount of water available from the SAS as recharge to the UFA depends on several variables. Areas where the soil is well drained are potentially good areas of moderate to high recharge capacity, while in areas with poorly drained soil; the recharge potential could be near zero. A second variable is the thickness and characteristics of the ICU. Areas where the ICU is not well developed and thin, or where local aquifers in the ICU make up a dominant percentage of the overall unit thickness, are prime areas for recharge because flow through this unit is less restrictive. The third primary variable is the downward hydraulic gradient between the SAS and UFA. In other words, recharge requires the water levels in the SAS to be at higher relative elevations than the underlying UFA.

In the study area, the area where all three of these variables exist is along the extreme northwestern edge of the model, coinciding with the well-drained hills of the Lake Wales Ridge and adjacent scarp of the Caloosahatchee Incline. A similar, but smaller ridge exists adjacent to the Kissimmee River at the northwest corner of the model and is referred to as the Bombing Range Ridge and is a significant source of direct recharge to the study area. A third area of low to moderate recharge potential, termed the Osceola Plain, is along the east and west sides of the Kissimmee River. The Kissimmee River itself does not provide recharge, but is a discharge of water from the UFA. The locations of the main physiographic features in the study area are shown in Figure 3.4-2.

Rainfall infiltration into the model domain was estimated from studies conducted along the Lake Wales Ridge area that attempted to estimate recharge from the SAS into the UFA as a result of rainfall and local stresses. Spechler and Kroening (2007) estimated the annual recharge to the FAS in Polk County at 2.1 inches/year over a 10-year period. Stokes (2005) calculated that the average recharge to the FAS east of the Kissimmee River in Osceola and northern Okeechobee counties was generally between 0 and 4 inches/year in 1998 and 2004. This was determined from the hydraulic pressure differences between the FAS and SAS aquifers and aquifer/confining unit properties. Similar values for the same area were determined by Boniol et al. (1993). Sepulveda et al. (2012) calculated an average rainfall recharge rate to the ICU of 3.66 inches/year for central Florida. Stewart (1980), Tibbals (1990), and Yobbi (1996) calculated similar values generally less than 5-10 inches/year.

Figure 3.4-3 shows the areas where direct recharge is applied to the UFA. Simulated rates vary monthly based upon historical rainfall and vary spatially within the recharge zones. The annual average recharge rate applied to the low recharge areas of the Osceola Plain averages 0.5 inches/year. Recharge rates in areas of the Bombing Range Ridge, the southeast edge of the Lake Wales Ridge, and the Caloosahatchee Incline average approximately 2.5 inches/year. In areas where the topography exceeds 80 feet NGVD, recharge rates can exceed 10 inches/year. Total and spatial distribution of recharge was further adjusted during the calibration process and will be discussed in the calibration section.

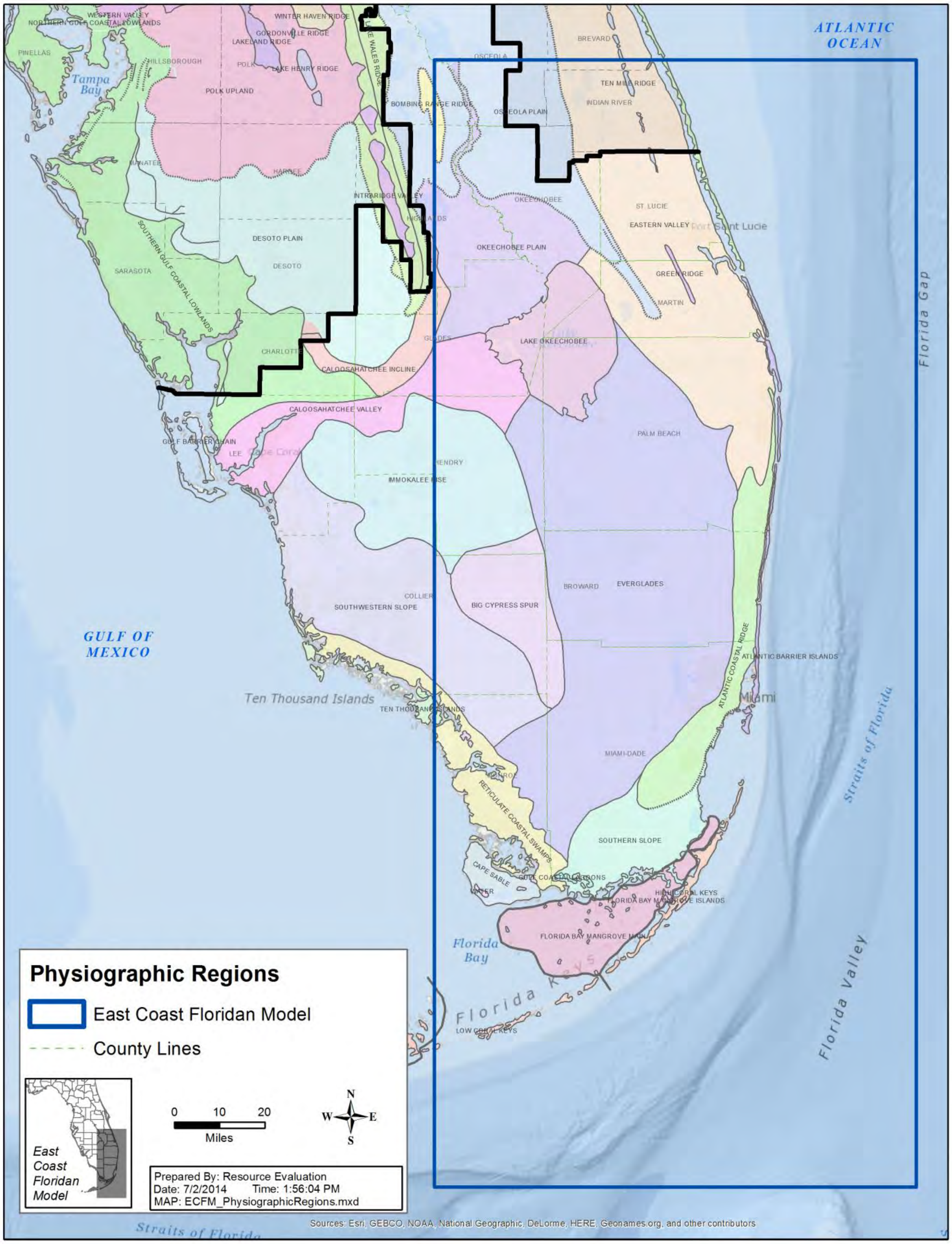

Figure 3.4-2. Physiographic Regions of the ECFM Study Area

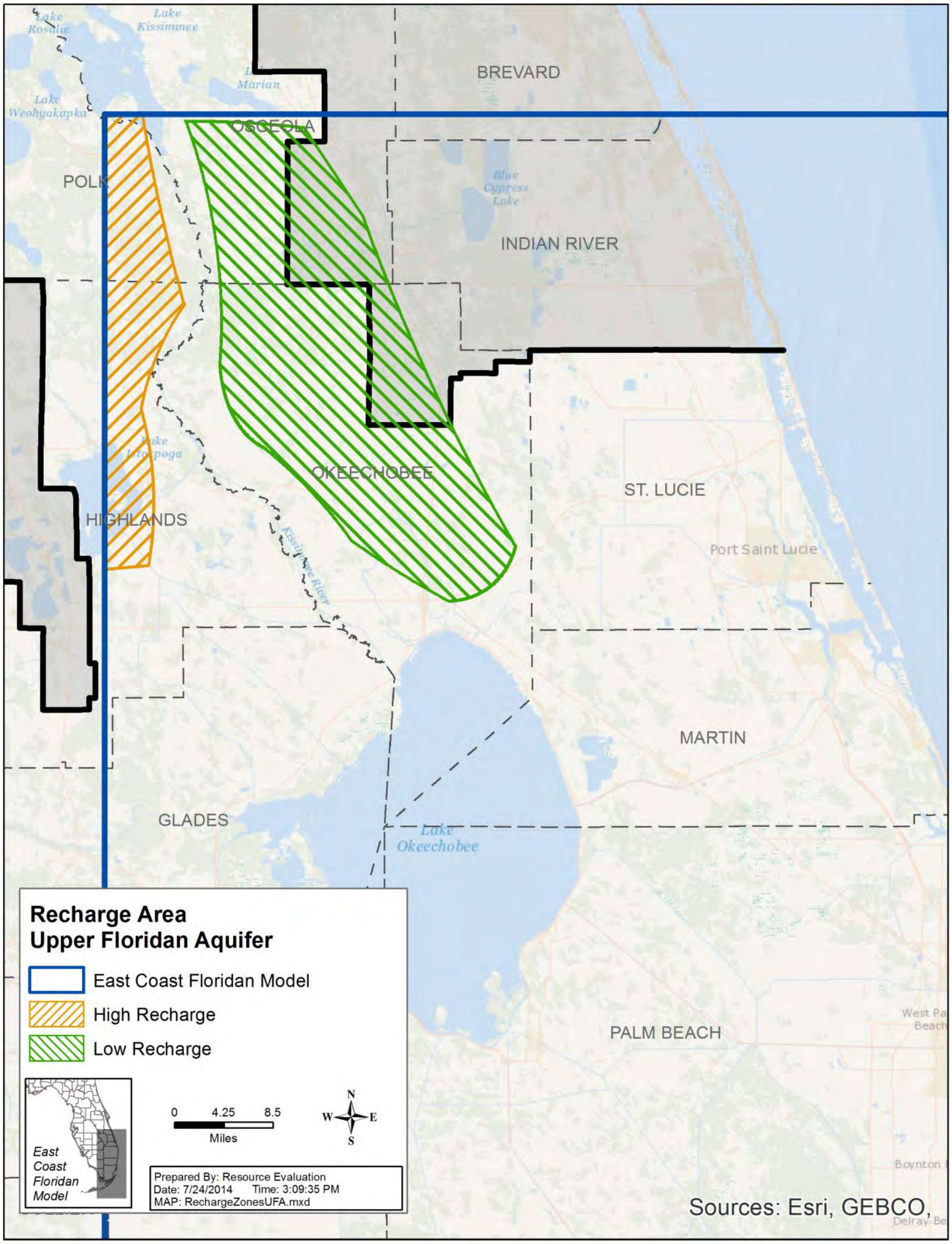

Figure 3.4.-3. Location of Recharge Zones for the East Coast Floridan Model

3.5 Boundary Conditions

Model boundaries are another area where water can enter or leave the model. Water generally enters the system from the boundary in the northwest corner of the model and exits at the offshore outcrops along the east and southern boundaries of the model, as discussed in Section 2.3.

Potentiometric surfaces of the UFA are generated by the USGS in May and September/October of almost every year. These maps were used to initially develop the boundary conditions along the northwestern portion of the model as shown in Figure 3.5-1. Data between May and September of each year were adjusted based upon nearby observation wells where data were collected more frequently to develop a time-series for the monthly stress period transient calibration. If wells with monthly data were not available for areas along the boundary, water levels were linearly interpolated between dates to develop the monthly time-series. Because these potentiometric maps were unavailable for the APPZ and LF1, the UFA values were used but adjusted upwards for the APPZ and downward for the LF1 as determined from cluster well sites with monitor multiple zones where a relationship could be determined. These water levels were then included in the model as general head boundaries, which allowed the water levels to vary between stress periods. Water quality assigned along the northwest boundary was based upon observed water quality data and generally is considered fresh water.

The offshore ocean boundaries were developed from tidal gages at Virginia Key in Miami, Key West and Vaca Key in the Florida Keys, and the Trident Pier at Cape Canaveral. These four stations were the primary tidal stations with long-term data available. Monthly mean average tidal levels referenced to NGVD29 were calculated and applied to the boundary cell that was closest to the tidal station. Tides can vary monthly by a foot or more through a year with October generally having the highest monthly tides. Tides also vary spatially with noticeable differences occurring in the Florida Keys where the Atlantic Ocean transitions to the Gulf of Mexico. Water quality at all of these sites was assumed to be ocean water with a TDS concentration of 35,000 mg/L. Discussion of the specific types of boundary conditions and where they were applied is included in Section 5.2 of this report.

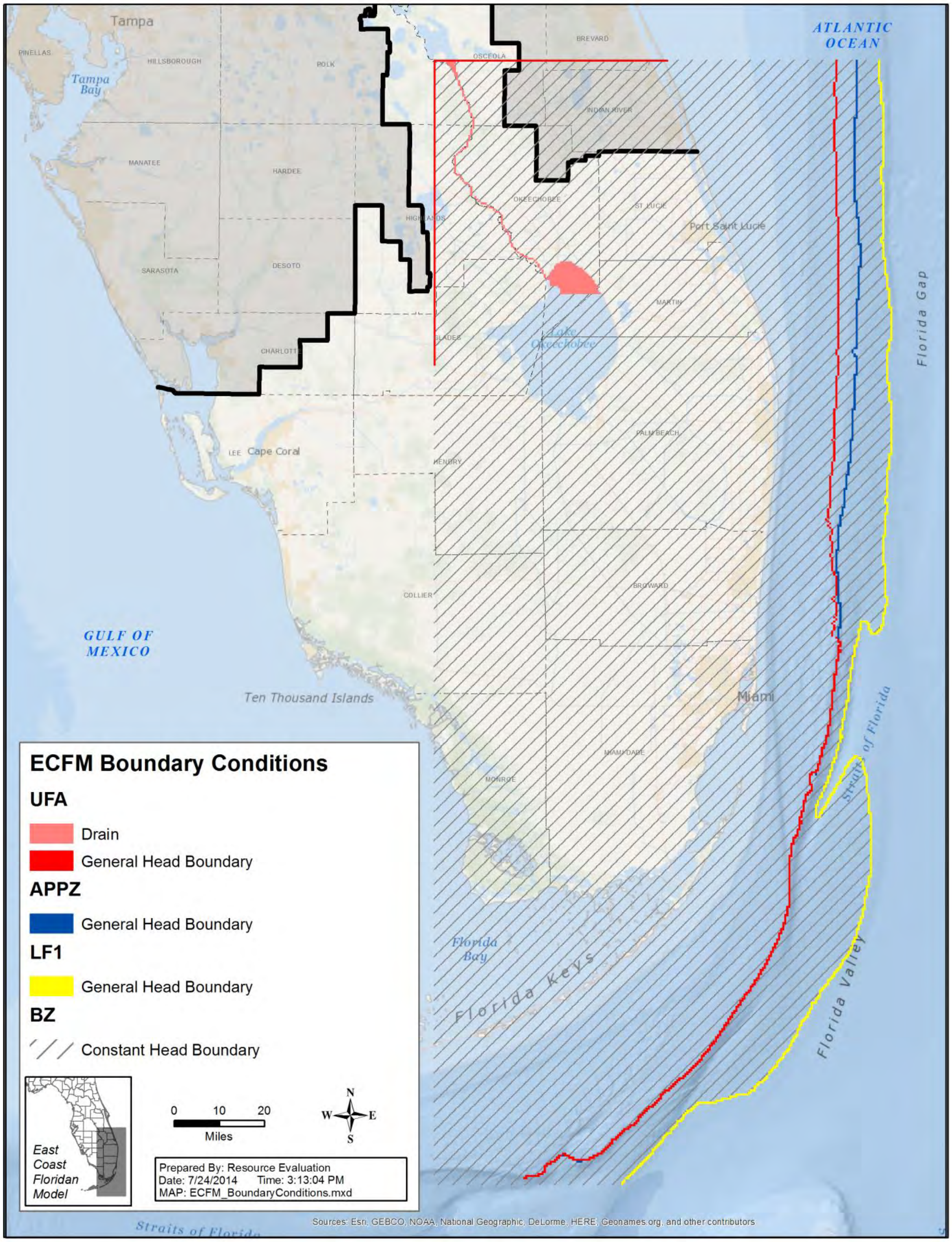

Figure 3.5-1. Boundary Conditions

3.6 Initial Conditions

Potentiometric surfaces (heads) in the UFA, APPZ, and LF1 were collected and compiled from databases maintained by the SFWMD, USGS, and SWFWMD. Within the SFWMD, there are 100 wells in the UFA, 30 wells in the APPZ, and 20 wells in the LF1 from these databases. A constant head condition of 5.0 feet NGVD29 is assumed for the BZ based upon observed data. Figures 3.6-1 through 3.6-3 show the initial heads of the UFA, APPZ, and LF1, respectively.

TDS concentrations in the UFA, APPZ, and LF1 aquifers were collected and compiled from various sources including SFWMD, FDEP, and USGS databases. The FDEP database includes a number of Class I injection monitoring wells that recorded water quality data in the deeper units. Overall, approximately 250 monitoring wells with TDS or chloride data were used in model development. Interpolated average TDS concentrations (measured in grams per liter) are shown for the UFA, APPZ, and LF1 in Figures 3.6-4 through 3.6-6 respectively. A value of 35,000 mg/L (35 g/L) represents the TDS concentration of seawater and less than 500 mg/L (0.5 g/L) represents the TDS of potable water. A constant TDS concentration of 35,000 mg/L (seawater) was assumed for the BZ. Control points were added along ocean boundaries where no data were available during interpolation. TDS concentrations for the confining units were averaged from the values for overlying and underlying aquifers, a multiplication factor of the overlying aquifer, and were further adjusted in areas during calibration.

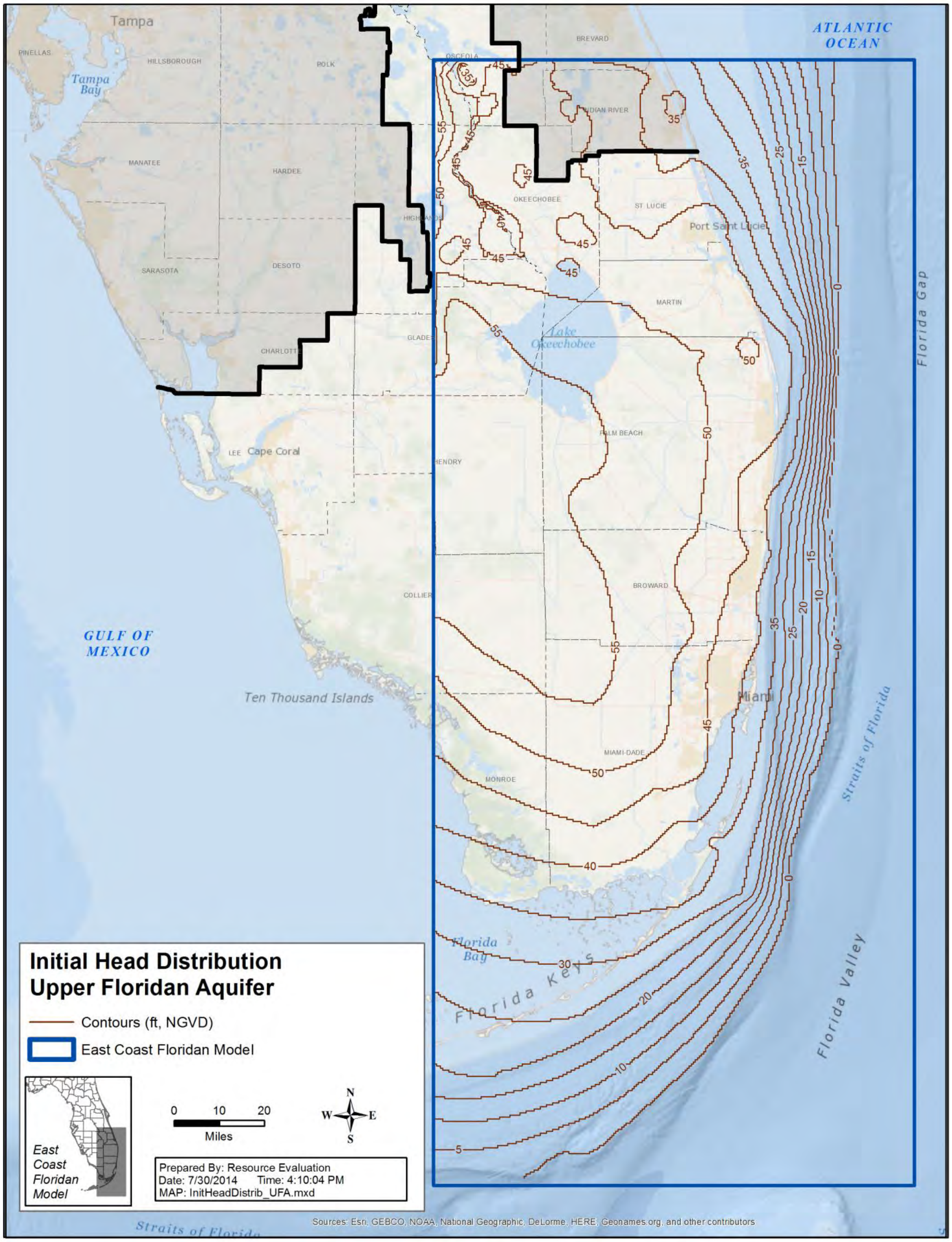

Figure 3.6-1. Initial Head Distribution in the Upper Florida Aquifer

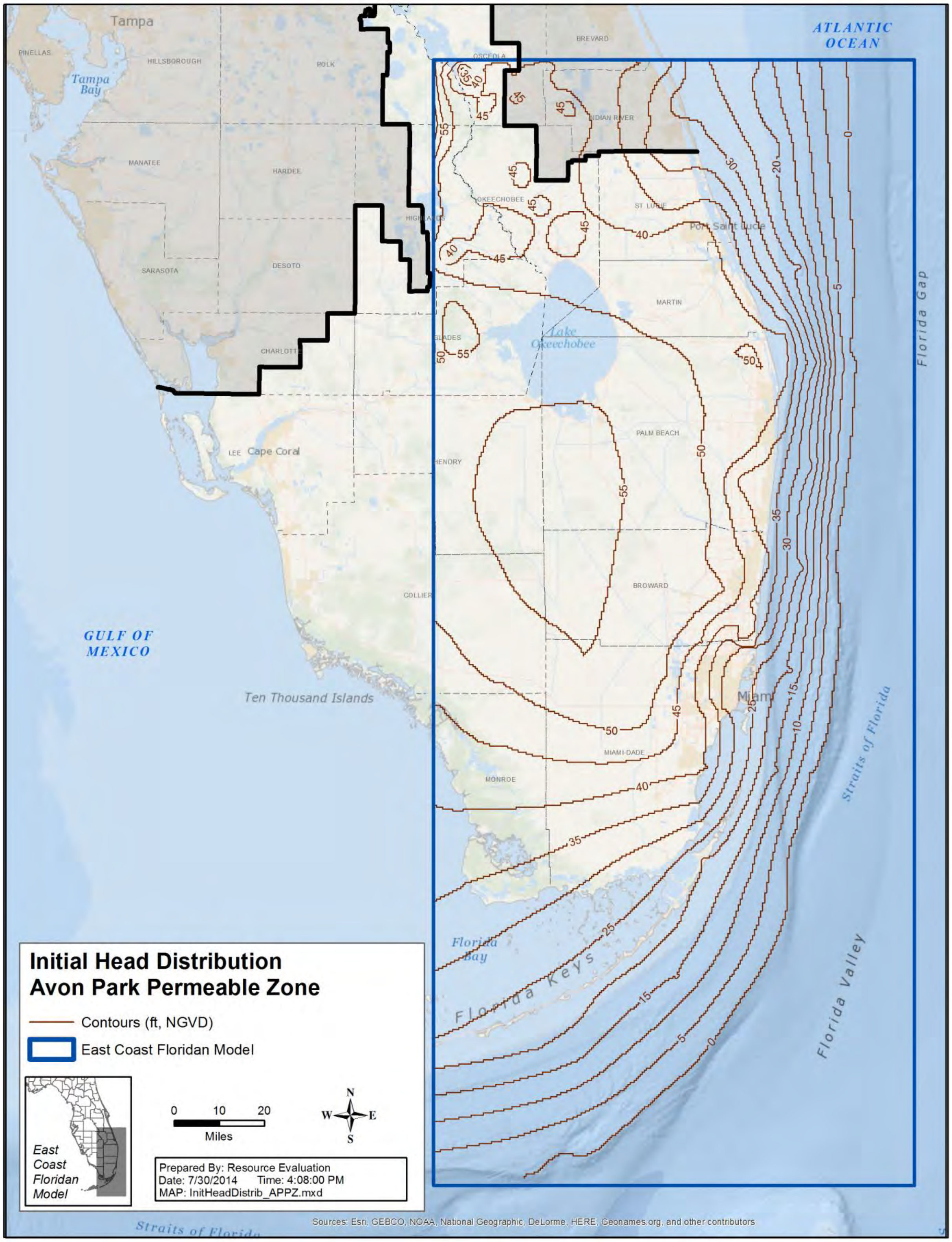

Figure 3.6-2. Initial Head Distribution in the Avon Park Permeable Zone

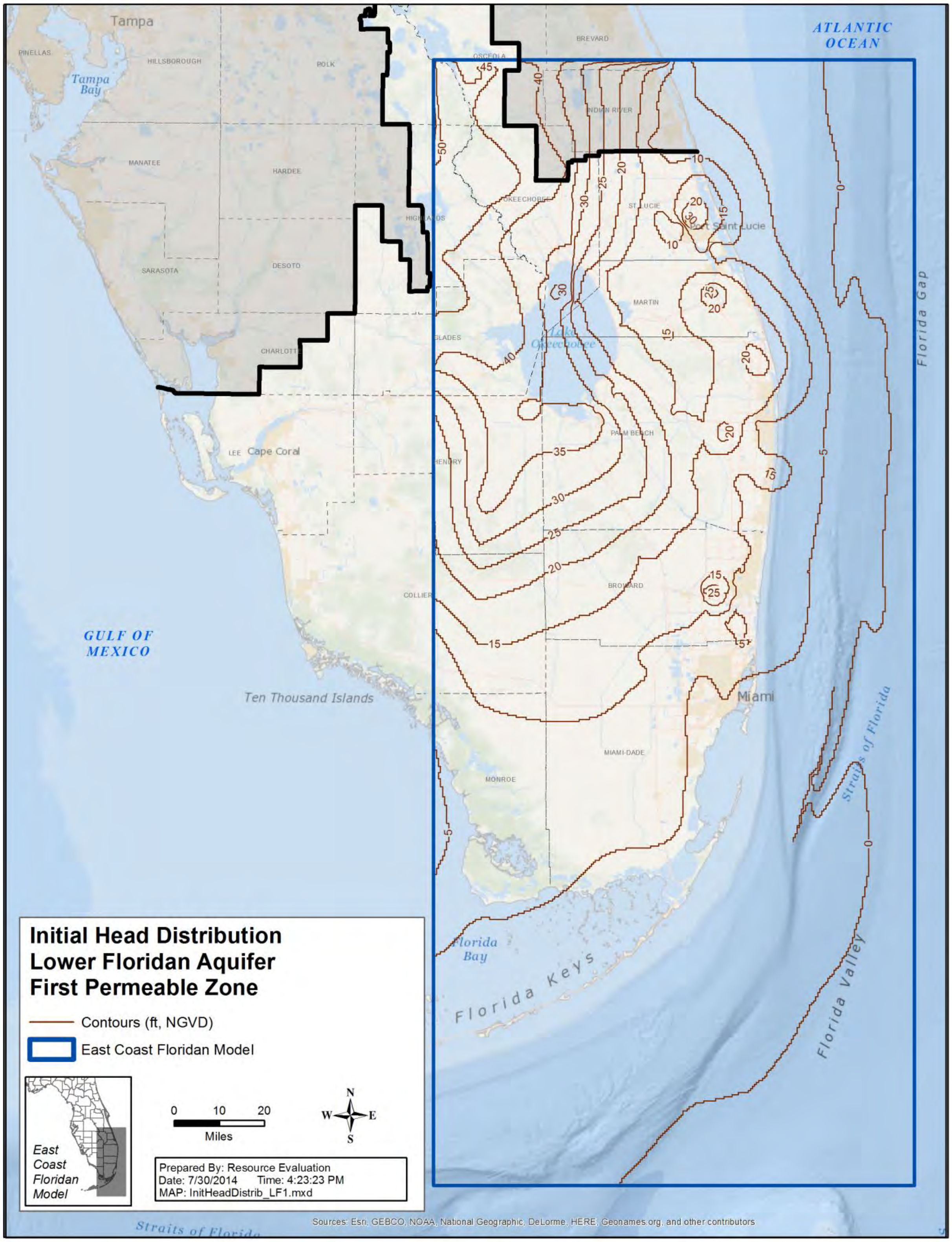

Figure 3.6-3. Initial Head Distribution in the Lower Floridan Aquifer – First Permeable Zone

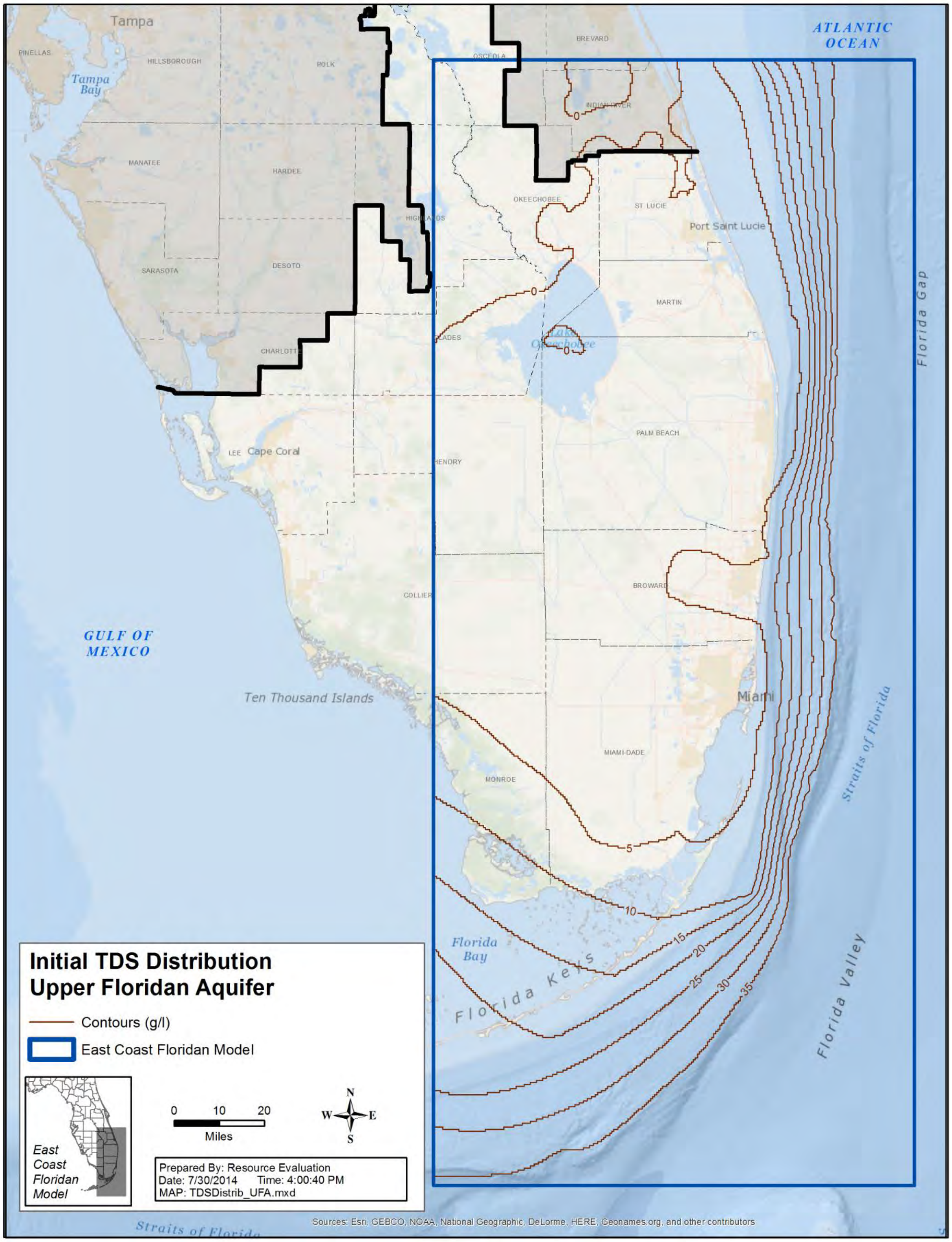

Figure 3.6-4. Initial TDS Distribution in the Upper Florida Aquifer

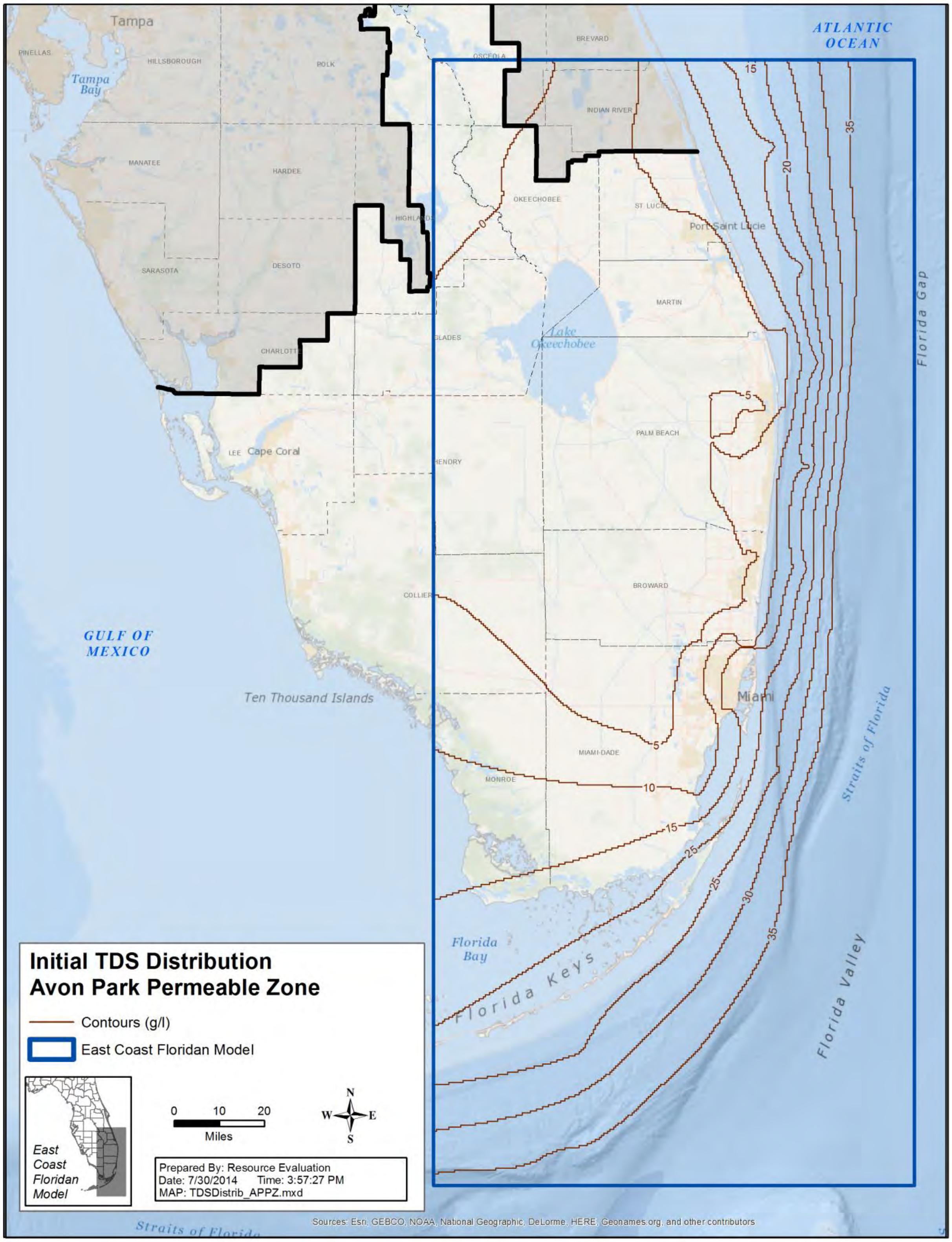

Figure 3.6-5. Initial TDS Distribution in the Avon Park Permeable Zone

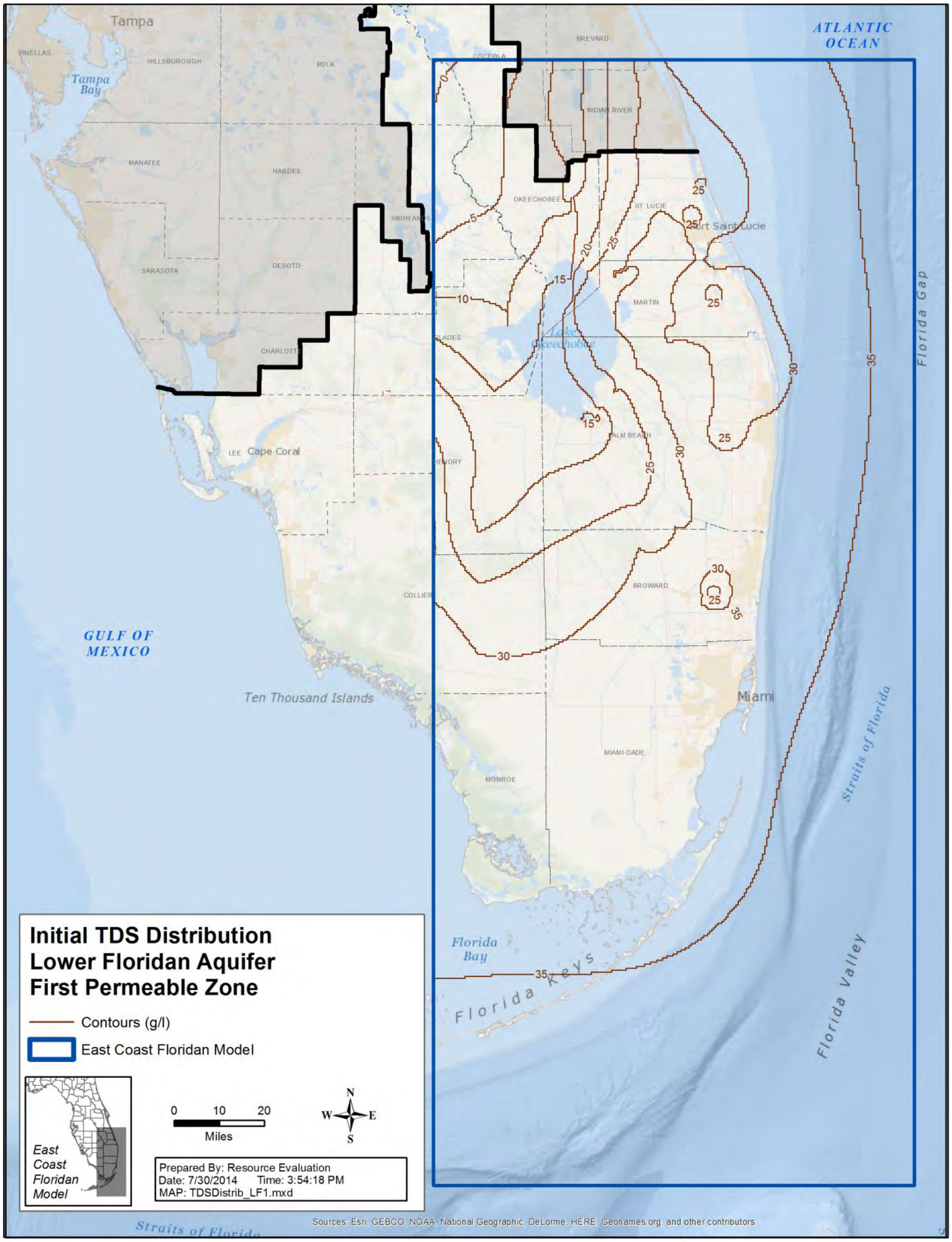

Figure 3.6-6. Initial TDS Distribution in the Lower Floridan Aquifer – First Permeable Zone

4.0 Numerical Model Development

4.1 Spatial Discretization

The model domain (Figure 4.1-1) covers an area from Sebastian Inlet at the north to offshore of Marathon Key in the Straits of Florida at the south, and from the Atlantic Ocean/Florida Straits on the east to the approximate location of the groundwater divide in the FAS along the center of the state. The model grid is aligned in a north to south direction.

The model has 552 rows and 236 columns with uniform grid spacing of 2,400 feet. The selection of the grid size was based on the planned use of the model, data availability, and computational considerations. The model coordinates, based on state plane coordinates of 83 NAD Florida East, located at the southwest corner of the model are:

X-direction: 565465

Y-direction: -44448

Vertically, the model is composed of seven primary layers. In descending order they are the Upper Floridan aquifer (UFA), the Middle confining unit 1 (MC1), the Avon Park permeable zone (APPZ), the Middle confining unit 2 (MC2), the Lower Floridan aquifer – first Permeable Zone (LF1), the Lower confining unit (LC), and the Boulder Zone (BZ), as shown in Table 4.1-1. Each of these aquifers and confining units are treated as a separate layer in the model. Future revisions to the model, or the development of subregional models, may require additional sub-layers to obtain local spatial resolution or computational stability.

Table 4.1-1. Model Layers and Corresponding Hydrogeologic Units

Model Layer	Hydrogeologic Unit	Abbreviation
1	Upper Floridan Aquifer	UFA
2	Middle Confining Unit 1	MC1
3	Avon Park Permeable Zone	APPZ
4	Middle Confining Unit 2	MC2
5	Lower Floridan Aquifer – First Permeable Zone	LF1
6	Lower Confining Unit	LC
7	Boulder Zone	BZ

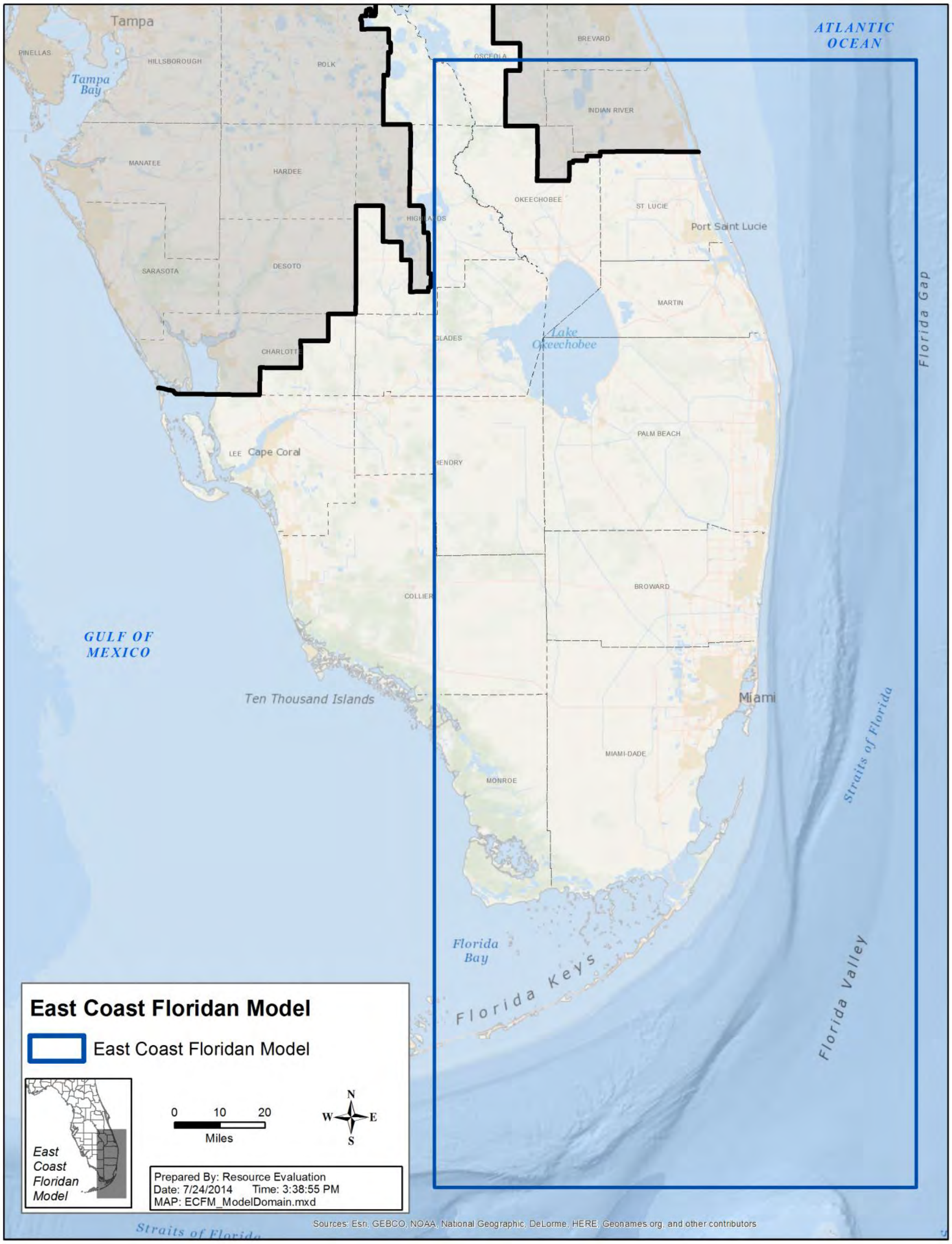

Figure 4.1-1. Model Domain

4.2 Temporal Discretization

The major stresses to the model are boundary conditions related to recharge in the northern portion of the model, local wellfield withdrawals, and seasonal tidal patterns. The primary purpose of the model is to address long-term planning issues on the scale of 20 to 50 years; however, a secondary application is to develop a companion tool for water use permitting purposes with monthly stresses applied over a 2-year period. Taking into account temporal data availability, the transient model calibration period was selected to extend from January 1989 through December 2012. The model simulated monthly time steps and stress periods for a total of 288 stress periods for the 24-year simulation period.

4.3 Software Selection

The SEAWAT code (Guo and Langevin 2002), which is a computer program that couples MODFLOW (McDonald and Harbaugh 1988) for the groundwater flow with MT3DMS (Zheng and Wang 1998) for the variable density component, was used for this project. SEAWAT solves two coupled partial differential equations for flow and transport (Guo and Langevin 2002). The governing equation for the flow in terms of freshwater head is:

$$\nabla \cdot \rho K_f \left(\nabla h_f + \frac{\left(\rho - \rho_f\right)}{\rho_f} \nabla z \right) = \rho S_f \frac{\partial h_f}{\partial t} + n \frac{\partial \rho}{\partial C} \frac{\partial C}{\partial t} - \rho_s q_s$$

where h_f is the equivalent freshwater head [L], K_f is the hydraulic conductivity [LT^{-1}], ρ is the fluid density [ML^{-3}], ρ_f is the freshwater density [ML^{-3}], S_f is the storage coefficient in terms of freshwater head ρ_s [ML^{-3}], q_s represents the volumetric flow rate per unit volume of aquifer representing source and/or sink terms [T^{-1}], C is the salt concentration [ML^{-3}], and t represents time [T].

The governing equation for solute transport in porous media is:

$$\frac{\partial C}{\partial t} = -\nabla \cdot \left(\vec{v} C\right) + \nabla \cdot \left(D \cdot \nabla C\right) - \frac{q_s}{\theta} C_s + \sum_{k=1}^{N} R_k$$

Where D is the hydrodynamic dispersion coefficient tensor [L^2T^{-1}], v is the flow velocity [LT^{-1}], C_s is the source concentration, and ϑ is the effective porosity.

The fluid density is defined as a linear function of salt concentration where C_o is the salt concentration for freshwater [ML^{-3}]:

$$\rho = \rho_f + \frac{\partial \rho}{\partial C} (C - C_o)$$

Practically, C_o is equal to zero. In the SEAWAT model, the flow and solute transport can be coupled in both implicit and explicit coupling procedures. TDS concentration was selected to be the species parameter for fluid density calculation and the species for solute transport simulation. The advection process was solved using an implicit finite-difference scheme and the GCG solver was used to solve the solute transport equation (Guo et al. 2011).

5.0 Model Calibration

5.1 Calibration

Model calibration involved adjusting model input parameters within reasonable ranges until model results (simulated water levels and/or the solute concentration) closely match water level and water quality data observed in the field while staying within the error bands of hydraulic properties observed from aquifer performance tests or other information. For the ECFM, model calibration was achieved by adjusting the parameters both manually and automatically. Manual model calibration is the process of changing one or more parameters in the model for each calibration model run. In the automatic calibration process, the model parameters were adjusted by the computer software PEST (Doherty 2010) for multiple parameters during a single run.

Three separate models were constructed, each of which required some degree of calibration:

1. A steady-state model calibrated to January 1989 conditions.
2. A calibrated steady-state model run in transient mode (long term) or quasi-steady-state model. For this simulation, all internal and external boundary conditions were held constant for each stress period and the model was run out for a period of 400 years. This step was required to determine if the model had reached a steady-state condition relating to the offshore distribution of the TDS values.
3. A monthly transient flow and transport model (long term). This version of the model was a 24-year monthly flow and transport model, which allowed for an examination of temporal changes imposed on the system. This will be the primary tool used in the SFWMD water supply planning process and for evaluating potential water quality changes for major projects. For example, large-scale aquifer storage and recovery projects or a proposed major urban well field would require the use of this version of the model.

5.2 Steady-State Calibration

The constructed steady-state model was calibrated to head targets. The steady-state model was first calibrated by manually adjusting horizontal hydraulic conductivity values within the major aquifers and vertical hydraulic conductivity in the confining units, because flow and transport processes are mostly dominated by horizontal hydraulic conductivity of an aquifer and vertical hydraulic conductivity of confining units between the major aquifers. TDS concentrations were checked at various stages throughout the process to make sure that there were no unrealistic values.

In the non-aquifer-dependent calibration data in the steady-state model, the groundwater pumping rates were assumed to be the reported average pumpage of January 1989 and since the recharge from the overlying SAS is derived primarily from rainfall, the recharge rate to the UFA was the average rainfall changing seasonally.

In the external boundary conditions, the heads specified for the boundaries at the coastal outcrops along the southern and eastern perimeters of the model domain were representative of open sea levels and concentrations. For the steady-state model, the boundaries were specified as constant with a head level of 0.54 feet NGVD29 which is the average tidal value. Also, general head boundaries were specified along the northwest portion of the model. The BZ was treated as a constant head boundary in the model. During the steady-state model calibration, the water levels in the BZ were fixed across the entire model domain.

5.2.1 Calibration Targets

Calibration targets were the monitoring wells from which observed data were obtained for the model calibration process. During model calibration, simulated heads were compared to the average condition field data observed at the target locations for the entire period of record. The goal of model calibration was to match the model-calculated water levels to the measured data at these target locations.

Data for targets available in the model domain were collected and analyzed. The average condition time-series data for the entire period of record from a number of head targets primarily from USGS wells, injection wells, and SFWMD monitoring wells were collected and organized (Figure 5.2-1). There were 151 water level targets available in the model domain.

Data points at OKF-100 from May 2006 through December 2012 and PBF-15L from January 2008 through January 2011 were removed after investigating outliers during the quality assurance and quality control (QA/QC) process. Well OKF-100, located in Okeechobee County, was being modified to a dual zone monitor well and some of the water levels being recorded were influenced by construction activities. In the mentioned period of record, the average level of OKF-100 was 49 to 49.5 feet while in nearby wells OKF-100U and OKF-100L the average level was around 47.5 feet meaning the water level was offset 2 feet. A review of the data from Well PBF-15L in Palm Beach County suggests that it may have been inadequately purged after construction resulting in fresher water entering LF1 from the APPZ producing in the anomalous values.

5.2.2 Steady-State Model Calibration Results

The purpose of the steady-state model calibration was two-fold: a test of the conceptual model and development of initial conditions for the transient model calibration. Solute transport rarely reaches steady state in the region, and the steady-state calibration was used primarily for the initial conditions for the transient model calibration. Under the steady-state model calibration, the calibration was focused on groundwater flow to establish representative initial head distributions in each model layer. The resulting head and TDS distribution output from the steady-state model was then used for the quasi-steady-state model (400 years) and the monthly transient flow and transport model (24 years)

The flow and solute transport components were uncoupled in the steady-state SEAWAT model. Only one stress period with a length of one day was used and the initial transport time step was set as one day. Therefore, the change of the solute concentration and its influence on fluid density were ignored.

After adjusting some model input parameters, the model-calculated water levels at 151 targets reasonably matched observed values at those locations. The two statistical measures of calibration used in steady-state are mean error and mean absolute error. The residuals or errors are often used to quantify the quality of the model calibration (Anderson and Woessner 1992). The mean error and mean absolute error for each one of the aquifers are shown in Table 5.2-1.

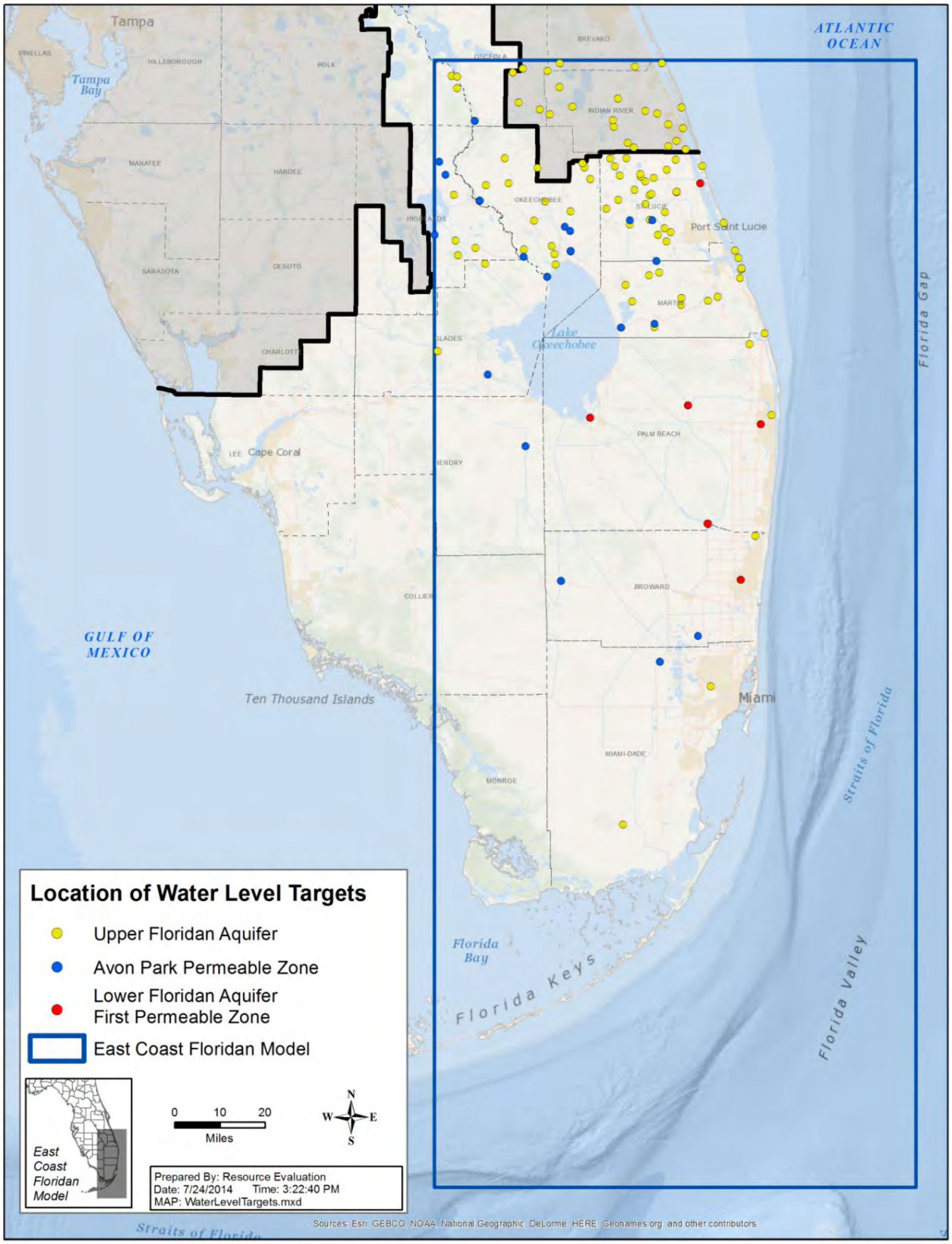

Figure 5.2-1. Wells Used as Water Level Calibration Targets

Table 5.2-1. Global Head Calibration Statistics for the Steady-State Calibration

Aquifer	Observed Average Head (feet NGVD29)	Simulated Average Head (feet NGVD29)	Mean Absolute Error (feet)	Mean Error (feet)
UFA	43.23	44.76	2.311	0.914
APPZ	48.07	48.99	0.969	0.306
LF1	17.19	17.44	1.627	-0.640

Table 5.2-2 shows the model-calculated versus observed average water levels for the UFA, APPZ, and LF1. The differences are shown as errors or residuals at the 151 targets used in the steady-state model calibration, as well as well locations and aquifer assignment. As shown, there are 118 observation wells in the UFA, 27 in the APPZ, and 6 in the LF1. Figure 5.2-2 provides a histogram of the residuals suggesting a normal distribution without any noticeable wide-scale model bias.

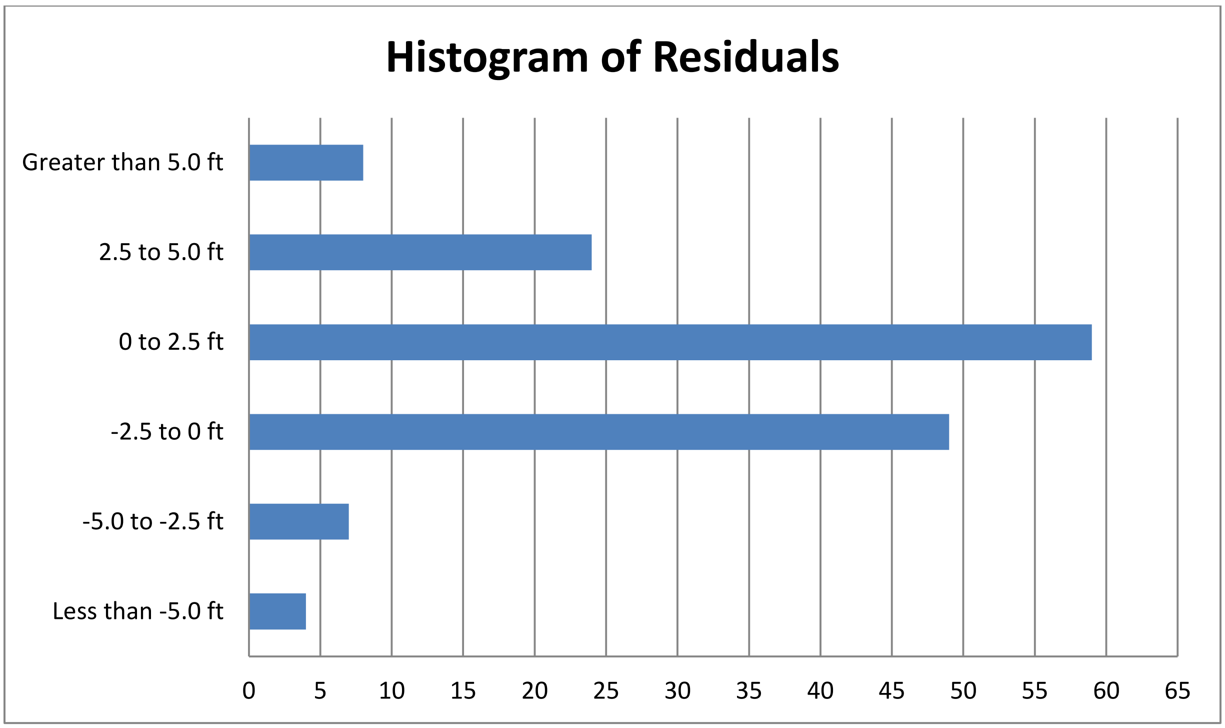

Figure 5.2-2. Histogram of Residuals

Table 5.2-2. Calibration Statistics for the Steady-State Model

Well Name	X Coordinate	Y Coordinate	Observed (Feet. NGVD)	Simulated (Feet. NGVD)	Mean Absolute Error (feet.)	Mean Error (feet.)
Upper Floridan Aquifer						
BEF-1559	801492	1272791	38.41	38.32	0.086	-0.086
BEF-INLET	833065	1276752	33.59	34.6	1.013	1.013
BEF-T6	713065	1276752	40.54	42.46	1.916	1.916
BF-4S	925617	669564	43.16	41.91	1.254	-1.254
BF-6	943147	720952	43.62	43.32	0.299	-0.299
C24GW	819193	1092402	42.41	43.18	0.767	0.767
DF-4	830843	573317	51.98	50.78	1.204	-1.204
ENP-100	787244	381470	41.33	43.61	2.283	2.283
FPU-MZU	878263	1135535	35.37	42.11	6.741	6.741
G-2618	714531	668029	58.97	56.87	2.102	-2.102
G-2619	714531	668029	59.27	56.87	2.403	-2.403
G-3061	890440	543986	44.27	44.51	0.245	0.245
GLY-155	625175	1040994	46.83	44.31	2.517	-2.517
GLY-CLE	569600	938296	49.06	48.96	0.096	-0.096
HIF-13	588742	1122020	46.31	44.33	1.984	-1.984
HIF-37	593589	1051127	45.64	43.07	2.574	-2.574
HIF-40	590473	1067957	46.22	44	2.224	-2.224
HIF-42U	670431	1049061	46.51	44.85	1.655	-1.655
HIF-6	614089	1059784	45.03	42.95	2.080	-2.080
IR-368	861245	1175501	32.93	37.02	4.095	4.095
IR-370	800038	1177861	36.69	40.12	3.428	3.428
IR-373	776388	1201918	40.39	42	1.611	1.611
IRF-1006	840861	1204688	32.15	38.25	6.102	6.102
IRF-1008	857879	1200529	32.33	36.92	4.595	4.595
IRF-189	712827	1248733	41.78	43.56	1.785	1.785
IRF-210	827675	1217555	33.14	37.13	3.994	3.994
IRF-365	701456	1216405	50.66	48.06	2.597	-2.597
IRF-954	792731	1183086	39.73	41.68	1.950	1.950
IRF-955	775465	1209892	40.83	42.12	1.287	1.287
IRF-963	813728	1220628	35.86	38.71	2.851	2.851
IRF-968	727960	1225532	41.37	43.82	2.451	2.451
IRF-BERRY	781590	1235056	38.46	40.67	2.208	2.208
IRF-JOHN	856228	1224858	30.33	34.08	3.751	3.751

Well Name	X Coordinate	Y Coordinate	Observed (Feet. NGVD)	Simulated (Feet. NGVD)	Mean Absolute Error (feet.)	Mean Error (feet.)
IRF-MACE	698704	1267801	50.03	46.1	3.931	-3.931
IRF-RO	850397	1185445	34.54	37.25	2.710	2.710
IRF-USDA	840618	1179238	32.40	37.66	5.256	5.256
L2-PW2	672709	826685	57.88	57.08	0.799	-0.799
MF-10	887369	997409	47.66	49.37	1.710	1.710
MF-2	818006	1027509	48.45	48.34	0.109	-0.109
MF-23	798251	996539	48.46	49.73	1.274	1.274
MF-31	924852	1024479	44.93	46.45	1.518	1.518
MF-33	790675	1016262	46.45	48.45	1.996	1.996
MF-35B	824574	966362	51.68	49.63	2.048	-2.048
MF-37	784921	965985	52.96	51.58	1.381	-1.381
MF-37U	784921	965985	52.31	51.58	0.730	-0.730
MF-40U	826580	1044391	48.97	48.23	0.740	-0.740
MF-51	855845	992395	50.04	49.47	0.571	-0.571
MF-52	856075	1000605	50.66	49.22	1.444	-1.444
MF-53	926802	1035519	44.41	45.31	0.896	0.896
MF-54	926089	1034201	43.66	44.86	1.199	1.199
MF-55	918899	1056573	40.56	45.43	4.871	4.871
MF-9	829646	1030547	48.54	48.01	0.528	-0.528
OKF-1	748651	1140549	43.81	44.71	0.900	0.900
OKF-100U	698055	1025421	48.35	47.28	1.065	-1.065
OKF-101	708302	1040007	46.97	46.96	0.006	-0.006
OKF-105U	619115	1115332	44.94	43.38	1.560	-1.560
OKF-106	725843	1055704	45.00	46.54	1.541	1.541
OKF-17	682570	1091477	45.31	44.13	1.181	-1.181
OKF-23	703526	1061608	43.29	44.39	1.096	1.096
OKF-31	706785	1052121	47.38	46.28	1.104	-1.104
OKF-34	648495	1164880	45.79	46.48	0.695	0.695
OKF-42	618680	1114896	45.62	43.38	2.243	-2.243
OKF-7	725748	1102434	45.34	46.25	0.908	0.908
OKF-71	739963	1159212	41.13	44.19	3.057	3.057
OKF-72	742225	1154167	40.87	44.07	3.204	3.204
OKF-BAS	652722	1135495	45.43	44.22	1.207	-1.207
OKF-MAC	695703	1114107	40.07	42.79	2.716	2.716
OKF-UNK1	626056	1133284	47.02	44.68	2.340	-2.340

Well Name	X Coordinate	Y Coordinate	Observed (Feet. NGVD)	Simulated (Feet. NGVD)	Mean Absolute Error (feet.)	Mean Error (feet.)
OKF-UNK2	670767	1057948	47.47	44.13	3.337	-3.337
OKF-WIL	686759	1153885	45.29	46.45	1.156	1.156
OSF-104U	613202	1208993	44.78	43.25	1.532	-1.532
OSF-231	669433	1270608	43.05	44.02	0.974	0.974
OSF-42	664864	1230516	43.78	43.09	0.688	-0.688
OSF-52	592067	1261155	44.46	39.33	5.135	-5.135
OSF-60A	689767	1222465	43.63	45.51	1.881	1.881
OSF-HAY	657672	1265759	44.16	44.5	0.344	0.344
OSF-S65	592028	1260862	44.63	39.33	5.302	-5.302
PBF-1	953619	959048	47.17	47.64	0.473	0.473
PBF-10R	886678	735581	50.91	49.07	1.842	-1.842
PBF-14	887941	735155	52.83	48.93	3.900	-3.900
PBF-15U	863897	874380	52.37	51.31	1.055	-1.055
PBF-2	961966	862961	46.26	46.83	0.575	0.575
PBF-3	949209	852482	46.21	46.72	0.510	0.510
PBF-747	936328	946544	47.64	49.88	2.244	2.244
POF_IL	585922	1261680	45.60	40.4	5.202	-5.202
POF-20	613137	1208894	44.70	43.25	1.450	-1.450
POF-RR	592275	1247229	41.69	35.92	5.765	-5.765
SLF-11	791262	1165005	38.87	41.24	2.369	2.369
SLF-17	795580	1087367	41.98	44.21	2.233	2.233
SLF-21	850164	1125344	35.21	40.26	5.051	5.051
SLF-36	813513	1137922	38.05	41.39	3.343	3.343
SLF-40	818714	1121382	38.53	41.71	3.185	3.185
SLF-61	838334	1067038	45.57	45.87	0.300	0.300
SLF-62	828553	1075174	43.34	44.77	1.428	1.428
SLF-62B	836003	1082784	44.99	45.08	0.089	0.089
SLF-63	783765	1144482	38.74	41.89	3.149	3.149
SLF-64	777697	1155673	39.82	41.65	1.828	1.828
SLF-65	772449	1164644	38.73	41.77	3.041	3.041
SLF-66	800846	1128080	38.18	41.6	3.416	3.416
SLF-67	767931	1105760	42.72	43.69	0.966	0.966
SLF-69	836584	1101782	40.06	41.83	1.768	1.768
SLF-70	849513	1163325	30.86	35.84	4.979	4.979
SLF-75	821840	1092293	41.47	43.11	1.639	1.639

Well Name	X Coordinate	Y Coordinate	Observed (Feet. NGVD)	Simulated (Feet. NGVD)	Mean Absolute Error (feet.)	Mean Error (feet.)
SLF-76	821840	1092293	41.58	43.11	1.528	1.528
STL-215	838981	1151289	37.02	39.13	2.107	2.107
STL-216	823586	1141800	37.59	40.95	3.363	3.363
STL-219	781692	1116100	38.48	42.7	4.220	4.220
STL-224	850236	1125460	31.80	40.26	8.460	8.460
STL-229	814068	1111165	37.75	42	4.246	4.246
STL-244	807715	1146484	39.64	41.42	1.780	1.780
STL-251	807908	1143253	38.73	41.39	2.663	2.663
STL-346	820780	1123006	37.65	41.52	3.870	3.870
STL-352	880371	1155962	33.67	39.9	6.233	6.233
STL-353	905881	1089007	38.61	47.37	8.760	8.760
STL-354	843337	1077966	40.79	45.81	5.020	5.020
STL-355	819010	1092705	41.25	43.18	1.930	1.930
TCRK_GW1	725866	1056130	46.03	46.54	0.506	0.506
TFRO-5	898492	1001979	50.36	49.2	1.160	-1.160
Avon Park Permeable Zone						
BF-2	925617	669564	47.08	45.79	1.293	-1.293
BF-4M	925617	669564	46.07	45.79	0.281	-0.281
DF-5	830843	573317	51.32	51.91	0.590	0.590
G-2617	714531	668029	59.75	57.36	2.392	-2.392
GLF-6	628323	910488	53.81	53.52	0.292	-0.292
HIF-14	566109	1075009	48.45	50.31	1.859	1.859
HIF-3	571431	1161030	50.17	51.98	1.812	1.812
HIF-4	578783	1145666	45.80	46.19	0.392	0.392
HIF-42L	670431	1049061	43.47	44.26	0.788	0.788
L2-PW1	672709	826685	58.43	57.59	0.839	-0.839
MF-35	824554	970435	48.48	48.67	0.187	0.187
MF-37L	784921	965985	50.98	50.49	0.494	-0.494
MF-40L	826580	1044391	48.70	49.16	0.457	0.457
MIR-MZU	875503	603616	46.83	47.89	1.060	1.060
OKF-100	698055	1025421	47.71	47.66	0.051	-0.051
OKF-100L	698055	1025421	47.34	47.66	0.317	0.317
OKF-105M	619115	1115332	45.11	43.65	1.462	-1.462
OKF-73	719012	1084450	40.83	41.43	0.598	0.598
OKF-74	725336	1079310	42.83	42.12	0.708	-0.708

Well Name	X Coordinate	Y Coordinate	Observed (Feet. NGVD)	Simulated (Feet. NGVD)	Mean Absolute Error (feet.)	Mean Error (feet.)
OSF-104M	613202	1208993	44.74	44.5	0.236	-0.236
PBF-11	886678	735581	52.59	52.23	0.357	-0.357
PBF-15M	863897	874380	53.34	52.79	0.554	-0.554
PBF-4	949209	852482	46.39	47.74	1.352	1.352
PBF-7U	748904	860161	53.54	55.54	1.999	1.999
SLF-14	795303	1092197	39.71	42.87	3.159	3.159
SLF-74	821840	1092293	40.86	42.76	1.901	1.901
TCRK_GW2	725866	1056130	42.59	43.33	0.744	0.744
Lower Floridan Aquifer – First Permeable Zone						
BF-1	925617	669564	9.87	6.02	3.852	-3.852
FPU-MZL	878263	1135535	17.46	20.02	2.560	2.560
PBF-12	886678	735581	14.98	14.6	0.382	-0.382
PBF-15L	863897	874380	12.65	10.84	1.810	-1.810
PBF-5	949209	852482	8.76	8.0	0.758	-0.758
PBF-7L	748904	860161	39.43	39.83	0.400	0.400

Figure 5.2-3 shows the simulated versus observed water levels for the steady-state calibration targets. Based on Golder (2008), head values inside head interval bands of ±2.0 feet and ±4.0 feet were considered to be acceptable targets for calibration of heads.

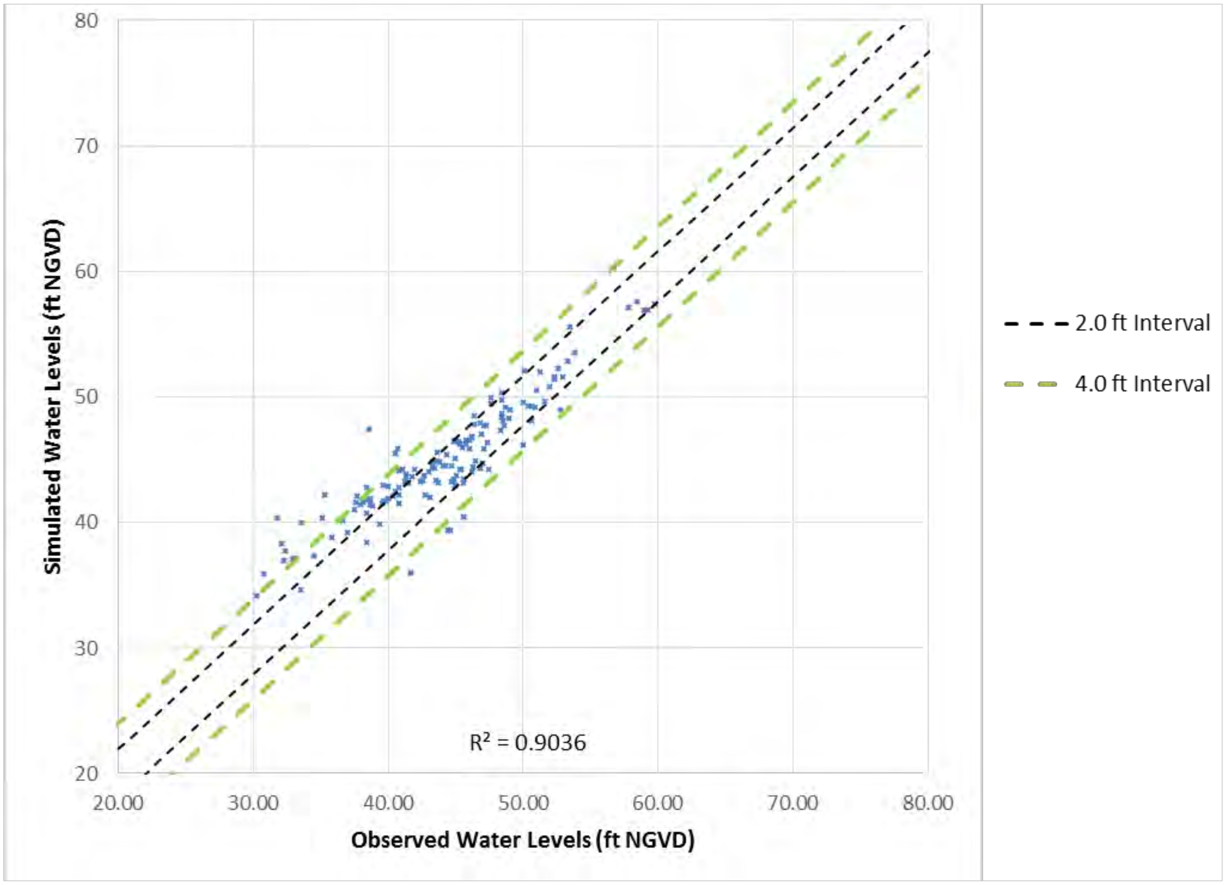

Figure 5.2-3. Scatter Plot of Simulated vs. Observed Water Levels

5.2.3 Steady-State Flow Budget

To understand flow within the aquifers of the model, the flow budget components under steady-state conditions were computed. The flow budget analysis, shown in Table 5.2-3, indicates that the northwestern corner of the model from lateral inflow through the head boundaries along the Lake Wales Ridge area is the major recharge source (50 percent of the total inflow). The remaining inflow comes from the Boulder Zone at the eastern edge of the model, moving upwards to the overlying aquifers and a small amount from recharge due to rainfall. Outflows from the model are dominated by pumpage (wells) and the Boulder Zone head boundary at 34 percent and 32 percent, respectively. Another significant outflow component is through the northwestern head boundary with 22 percent discharge, followed by the Atlantic head boundary and the drains in the Kissimmee basin. Given our understanding of the groundwater flow system and Meyer’s (1989) interpretation of the FAS flow patterns, the outflow through the Atlantic boundary in the model makes sense because groundwater is being discharged from the system along the coast where the Boulder Zone head boundary is contributing to the FAS recharge. A more detailed and explanatory flow budget is discussed in the transient flow budget analysis section.

Table 5.2-3. Steady-State Model Flow Budget Analysis

Budget Term	Flow Budget Amount In (MGD)	Flow Budget Amount Out (MGD)	Flow Budget Percent In (%)	Flow Budget Percent Out (%)
Atlantic Head Boundary	0	54	0	8
Boulder Zone Head Boundary	309	214	46	32
Northwestern Head Boundary	335	146	50	22
Wells	0	232	0	34
Recharge	26	0	4	0
Drains	0	29	0	4

5.2.4 Quasi Steady-State Analysis

The purpose of the quasi-steady-state coupled SEAWAT simulation is to find the point where equilibrium of TDS relating to the offshore distribution of TDS values is reached. The quasi-steady-state simulation consists of using a long-term transient mode to emulate a true steady-state simulation. For this simulation, all internal and external boundary conditions were fixed at the same level for each stress period and the model was run for a period of 400 simulation years. Generally, water levels slowly decreased while concentrations increased with time. Further analysis of the data found that 200 years of simulation was the optimal compromise between the global head error and equilibrium of the TDS. However, further investigation is recommended to determine why the model has a 10,000 TDS line west of Key Largo in the UFA after 100 years when we believe that should not be the case. Figure 5.2-4 shows simulated changes in TDS concentrations in the UFA using the quasi-steady-state model. The solid lines in the figure represent the initial TDS conditions (January 1989) in the UFA, and each of the four dashed lines adjacent to the solid line represent the TDS concentration in subsequent 100-year increments.

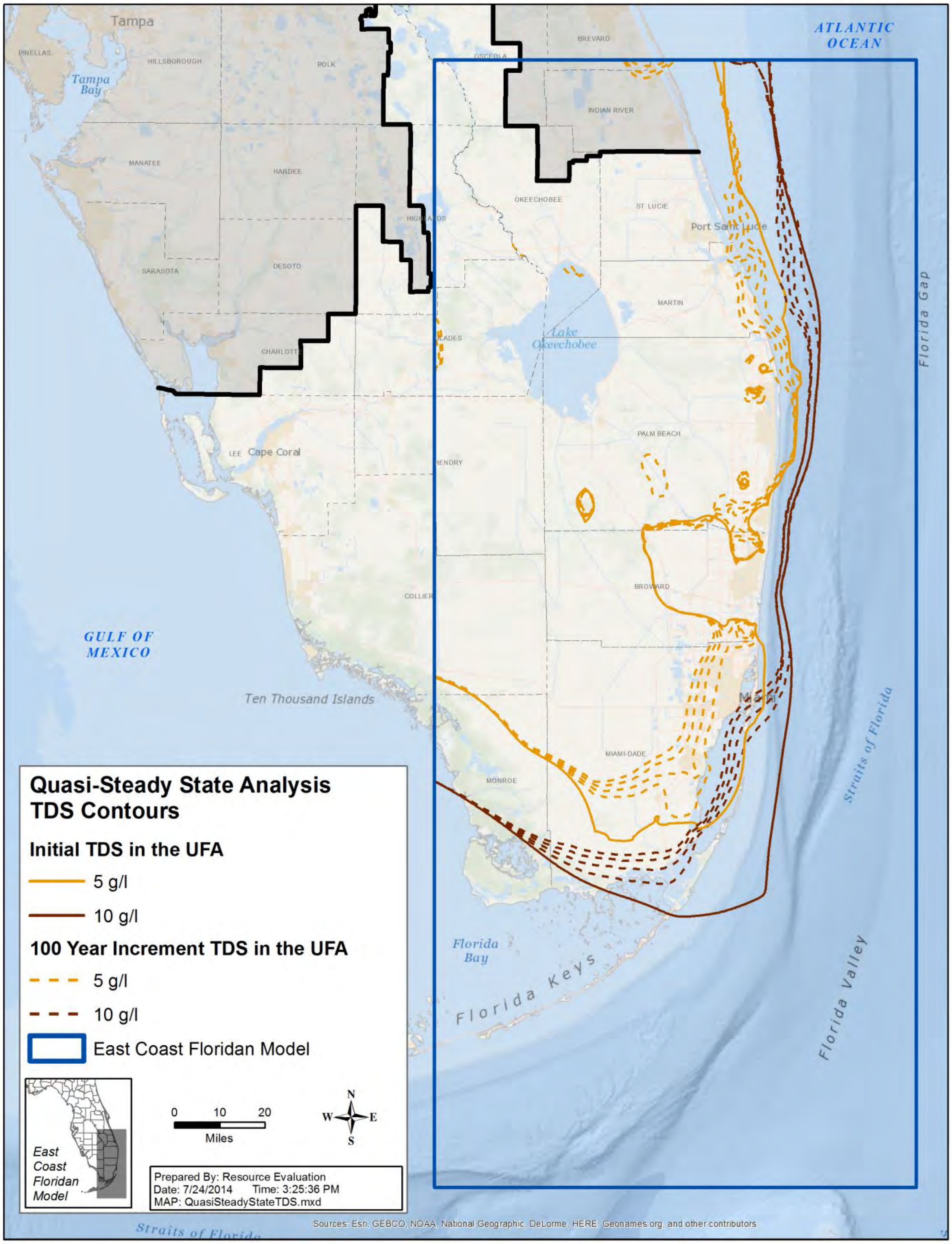

Figure 5.2-4. Quasi-Steady-State Total Dissolved Solids Contours

5.3 Transient Model Calibration

5.3.1 Transient Calibration Methodology

The ECFM used a combination of automated and manual calibration methods. PEST (Doherty and Hunt 2010), a model-independent parameter optimization code, was selected for automatic calibration. To minimize computational time during PEST simulations, BeoPEST (Hunt et al. 2010) was used. BeoPEST manages parallel runs more efficiently than the standard PEST calibration method. In addition, PEST runs were conducted in the Linux environment using a series of over 150 processors on virtual machines optimized to use 4 single core runs (or nodes).

Uniqueness in model calibration is achieved through a certain simplification of parameters called regularization. For this model, regularization was achieved through the application of Tikhonov constraints, which solves ill-posed inverse problems. Tikhonov regularization is the imposition of a “smoothing constraint” on the parameters (Doherty 2010). This approach applies each parameter difference to PEST as extra “observations.” Another advantage of regularization is to apply expert knowledge into parameter estimation processes. In the ECFM, this was done by constraining the aquifer parameter values while taking into account APT field-measured values and prior information gained from previously developed models.

Pilot point technique was used in PEST calibration. Pilot points are parameter points that are distributed throughout the model domain (using kriging) and PEST performs estimations for each of these points. A logarithmic transformation was applied to those parameters that could take values over several orders of magnitude (e.g., hydraulic conductivity). Furthermore, the pilot point technique was introduced to characterize heterogeneities in the hydraulic properties. Pilot points were generated following the guidelines in Doherty (2010): 1) placing pilot points at the center of head calibration targets, 2) placing pilot points at locations of APTs and core samples (for K_v analysis) in the confining units, 3) filling gaps in the model domain with initial educated guess values, and 4) refining the overall pilot point distribution, especially in dense areas prescribed by 1) and 2) resulting in an excessive number of pilot points over a small region. PEST generates surfaces of calibrated parameters; for the surfaces to be reasonable, pilot points were generated beyond the model domain. Otherwise, the parameter surfaces along the boundaries had unreasonable values since there were no constraints.

The calibration targets were monitoring wells from which observed data were obtained. Two types of targets were used: head levels and water quality (TDS). Simulated head and water quality values were compared to field data observed at the target locations. The calibration priority was set first for head and then for TDS. The goal of model calibration was to match the model-calculated head levels and TDS values to the measured data at these target locations. Time-series data were collected and organized from a number of head and water quality targets primarily from USGS, FDEP, injection wells, and SFWMD monitoring wells. Observed data consisted of monthly head and TDS at these wells. Approximately 150 wells had useful head level readings and approximately 230 wells had multiple water quality observations. The locations of the head and water quality target wells are shown in Figures 5.2-1 and 5.3-1, respectively. Since water quality data depend on the level of QA/QC procedures implemented during sampling and laboratory analysis and these data were collected over a number of years with different sampling personnel and different laboratories, some level of spatial and temporal data variability is to be expected. This should be considered when evaluating the quality of the calibration.

For the ECFM calibration effort, the PEST objective function (phi) minimized was defined as the sum of the weighted root-mean-square-error (RMSE) of the heads. Weighting factors for each individual observation value were determined based on data reliability, number of observations, accuracy, and the calibration performance. The ECFM was used to analyze water quality trends in time and space. It is particularly important to include water quality in both spatial distribution and trends so it can be represented as well as possible. TDS concentrations were checked at various stages during the process.

5.3.2 Calibration Parameters

5.3.2.1 Hydrogeologic Parameters

The ECFM was calibrated by adjusting horizontal hydraulic conductivity values within the major aquifers and vertical hydraulic conductivity values in the confining units. Flow and transport processes are mostly dominated by horizontal hydraulic conductivity of an aquifer and vertical hydraulic conductivity of confining units between the major aquifers. Parameters selected for calibration in PEST included horizontal hydraulic conductivity (K_h) in the three upper permeable aquifer units (i.e., UFA, APPZ, and LF1), vertical hydraulic conductivity (k_v) in the confining units, and storativity in the UFA and APPZ.

In the ECFM, most head targets and APTs are located in the UFA, the APPZ and the first confining unit (MC1). Therefore, most pilot points were generated and distributed in these units. Below the APPZ, aquifer parameter and head observations become much sparser spatially across the domain and are primarily concentrated along the coast where deep injection wells are typically located. Pilot points in the LF1 and in the confining units were spatially distributed in a grid fashion (i.e., every 50 cells).

During the PEST calibration process, the model input parameters were adjusted within user-specified ranges. The ranges for pilot points in the permeable units were ultimately set at 0.2 to 5.5 times the initial values, except for points associated with the aquifer performance tests. For those points, the range was constrained between at 0.4 to 2.7 times the initial values. For points associated with APTs in a confining unit, the range was set at 0.2 to 5.5 times these values. These ranges were the constraints for PEST calibration. During iterative calibration, some pilot point intervals were slightly modified. The parameter ranges represented a zone from observed field test values and did not capture local heterogeneities (vertically or horizontally within the same layer) that could have been either unknown or observed in a site-specific test.

The initial set of adjustable parameters in the ECFM during PEST calibration consisted of 1,041 parameter values. Pilot points for horizontal hydraulic conductivity in the UFA, APPZ, and the LF1 are shown in Figures 5.3-2, 5.3-3, and 5.3-4, respectively. Pilot points for vertical hydraulic conductivity in the MC1, MC2, and the LC are shown in Figure 5.3.-5, 5.3-6 and 5.3-7, respectively. Table 5.3-1 summarizes the number of parameters and upper and lower boundaries by aquifer type. Limiting values of storage coefficients were based on extreme values observed in the field. Vertical hydraulic conductivity (K_v) values in the UFA, APPZ, and LF1 were tied to their horizontal hydraulic conductivity

(K_h) using a multiplier of 0.1. Horizontal hydraulic conductivity (k_h) values in the confining units were tied to their vertical hydraulic conductivity (K_v) using a multiplier of 4.0.

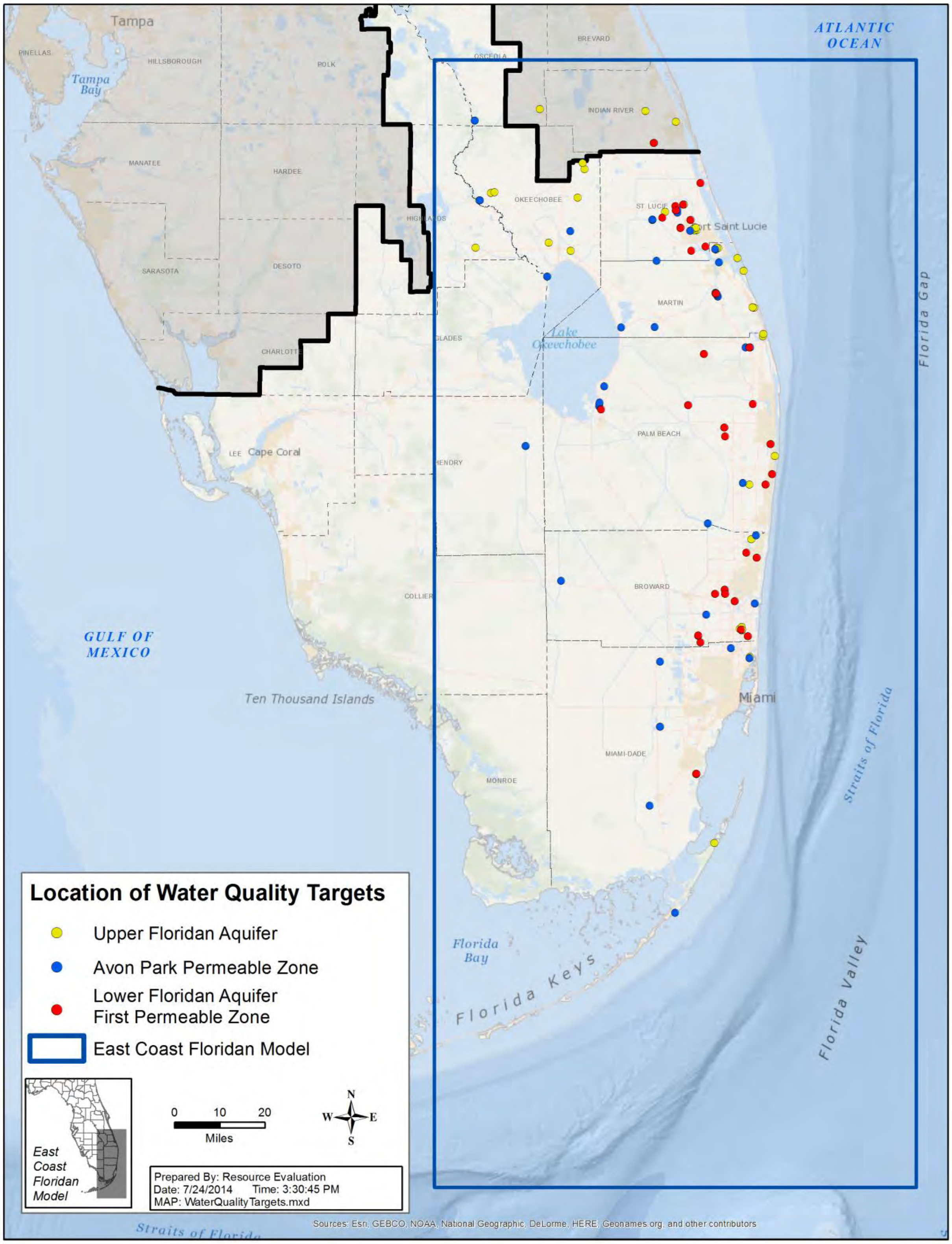

Figure 5.3-1. Location of Wells Used as Water Quality Calibration Targets

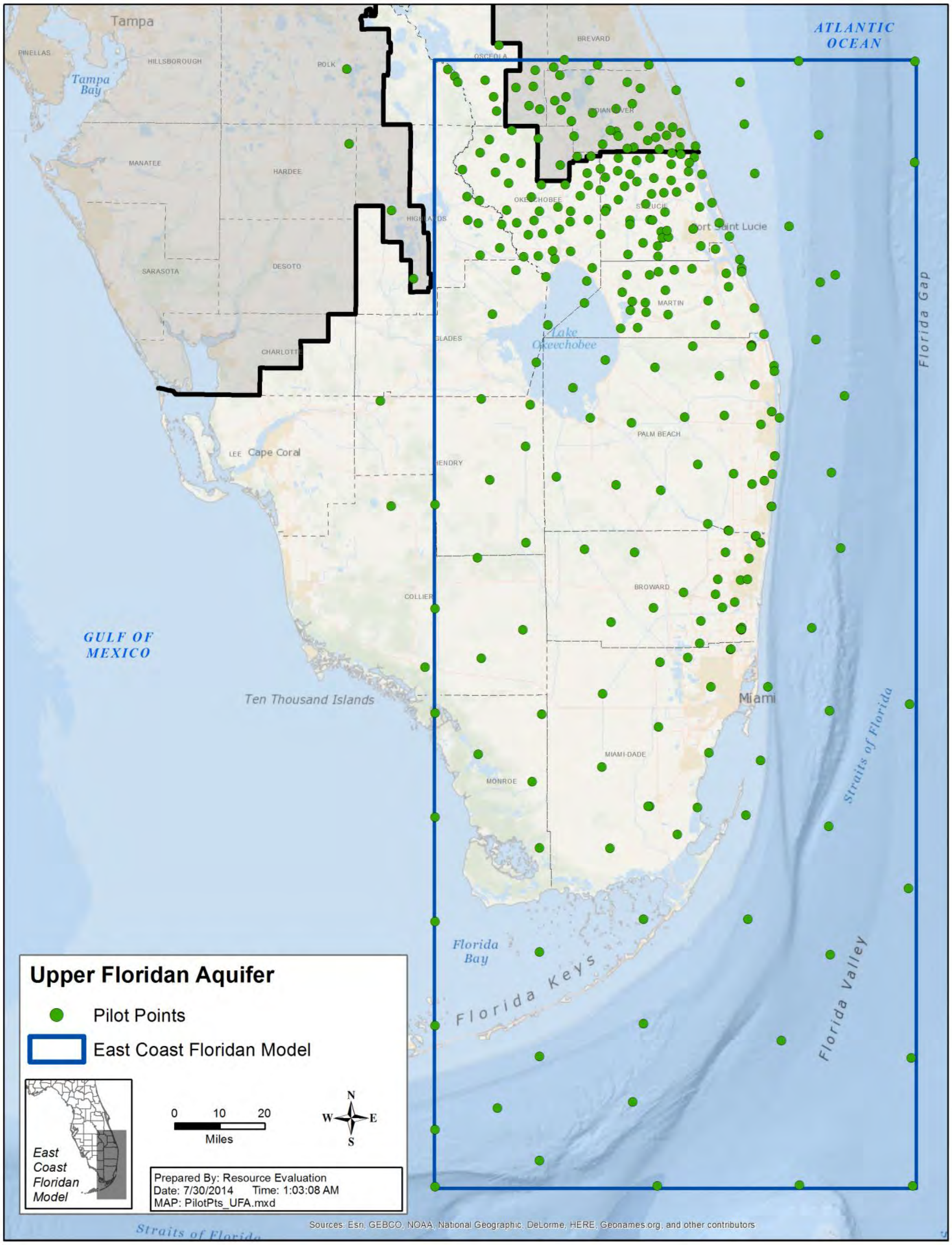

Figure 5.3-2. Distribution of Pilot Points for Horizontal Hydraulic Conductivity in the UFA

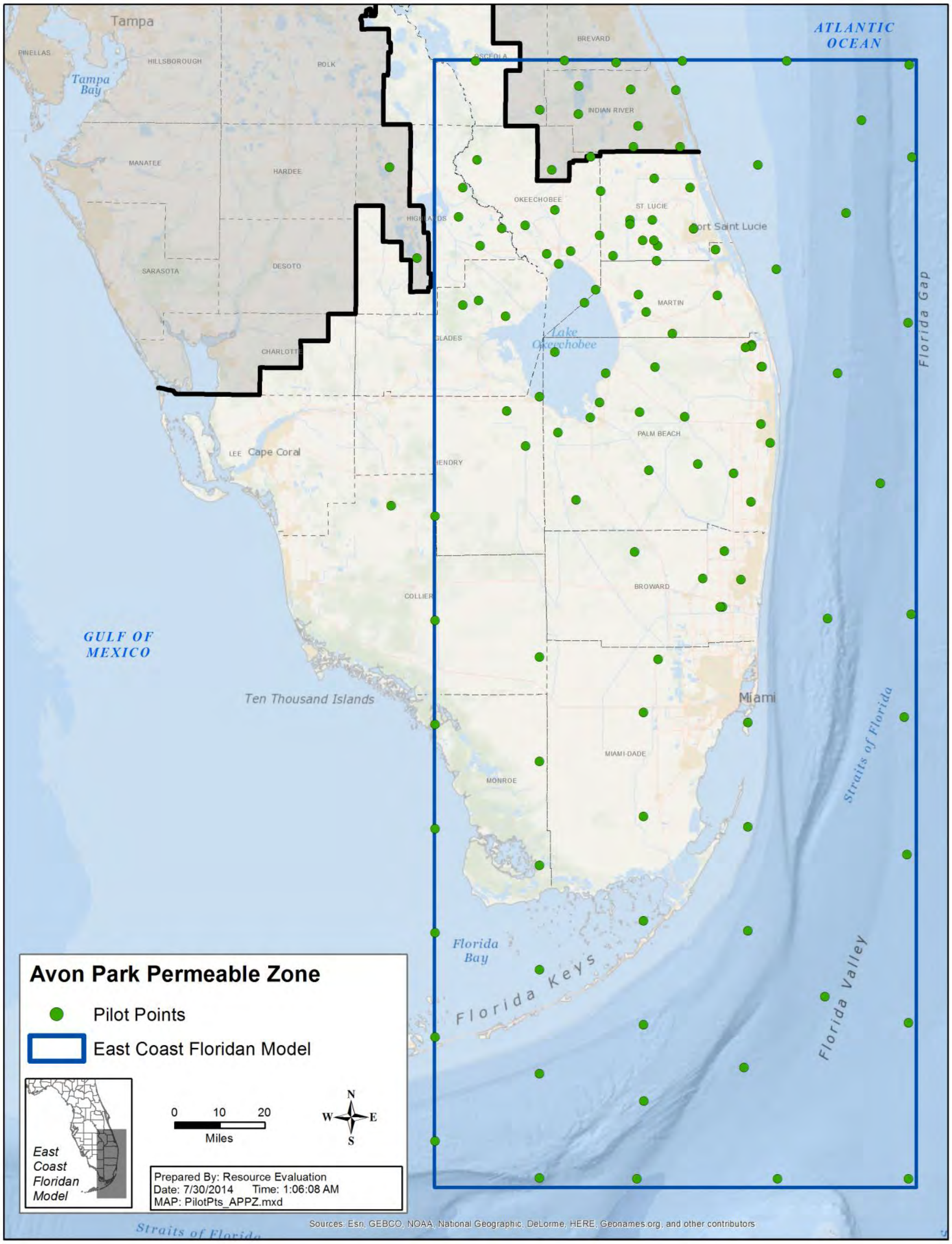

Figure 5.3-3. Distribution of Pilot Points for Horizontal Hydraulic Conductivity in the APPZ

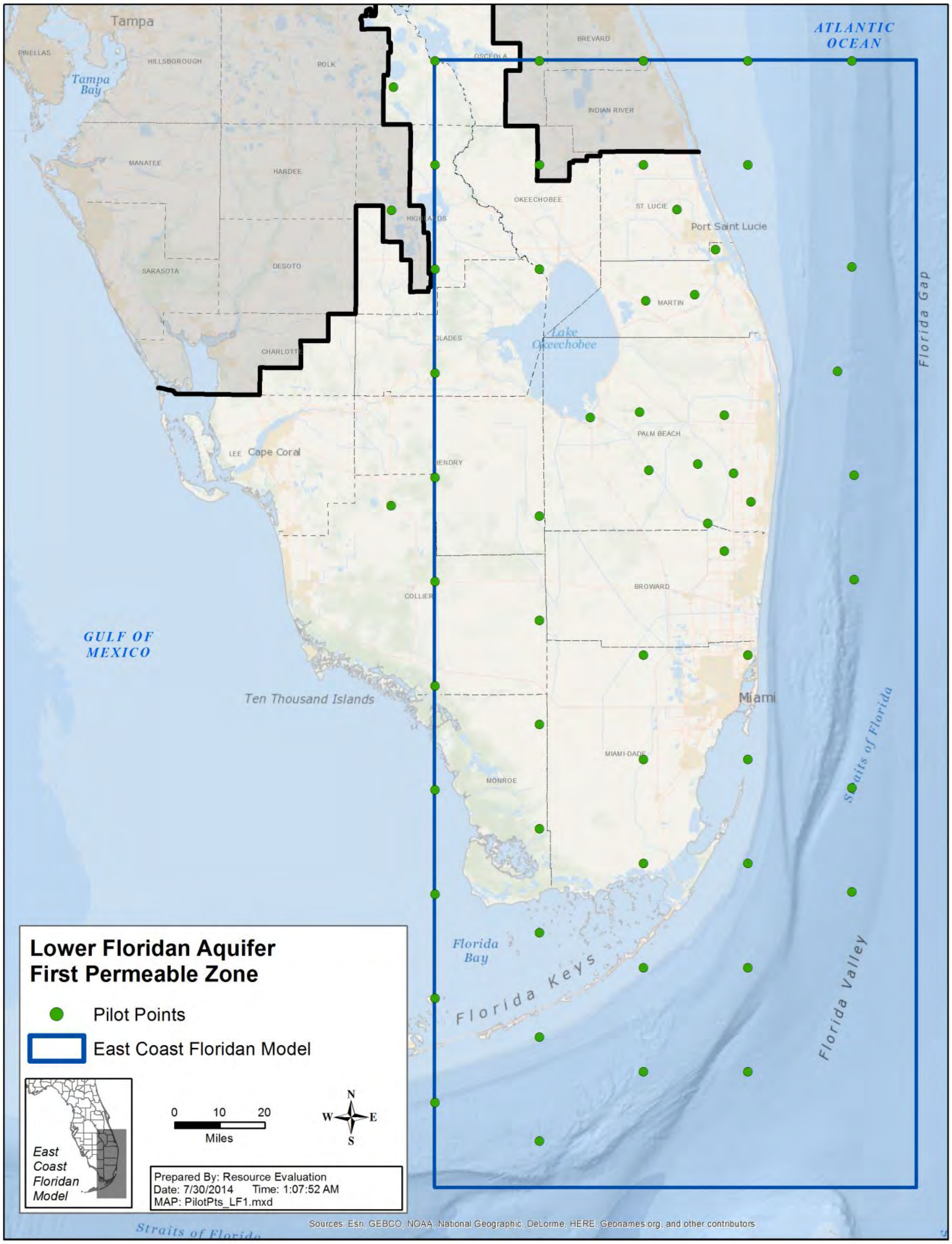

Figure 5.3-4. Distribution of Pilot Points for Horizontal Hydraulic Conductivity in the LF1

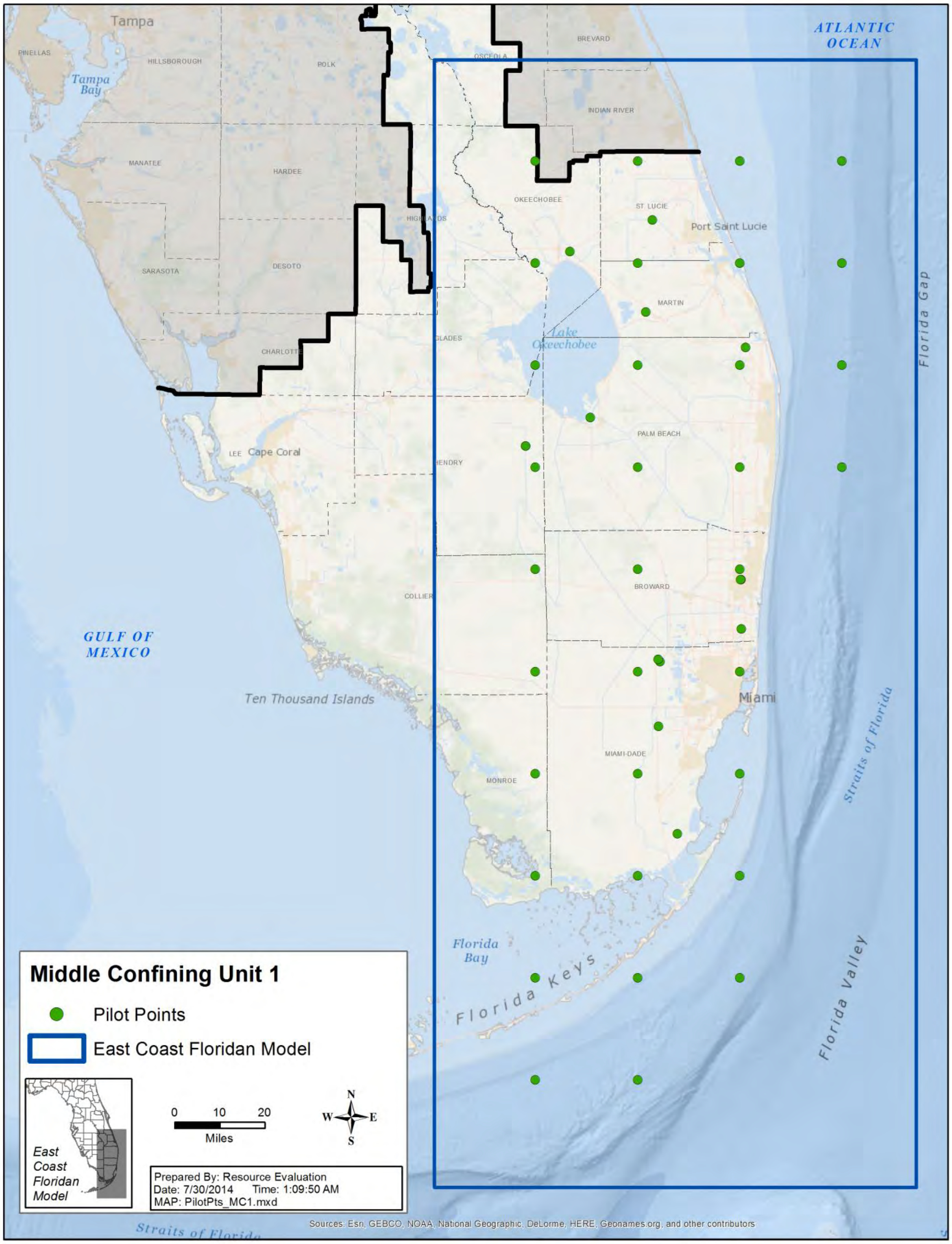

Figure 5.3-5. Distribution of Pilot Points for Vertical Hydraulic Conductivity in MC1

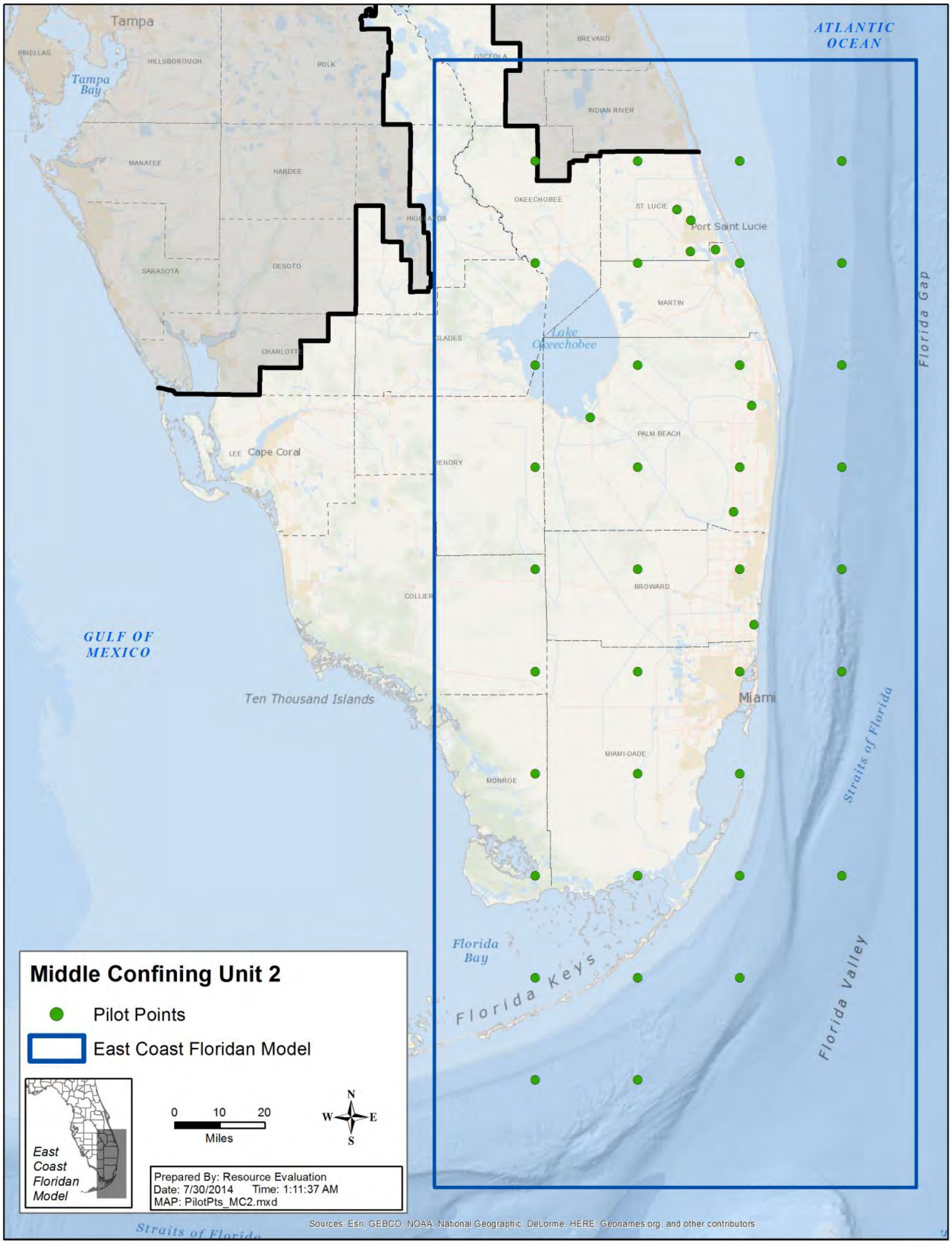

Figure 5.3-6. Distribution of Pilot Points for Vertical Hydraulic Conductivity in MC2

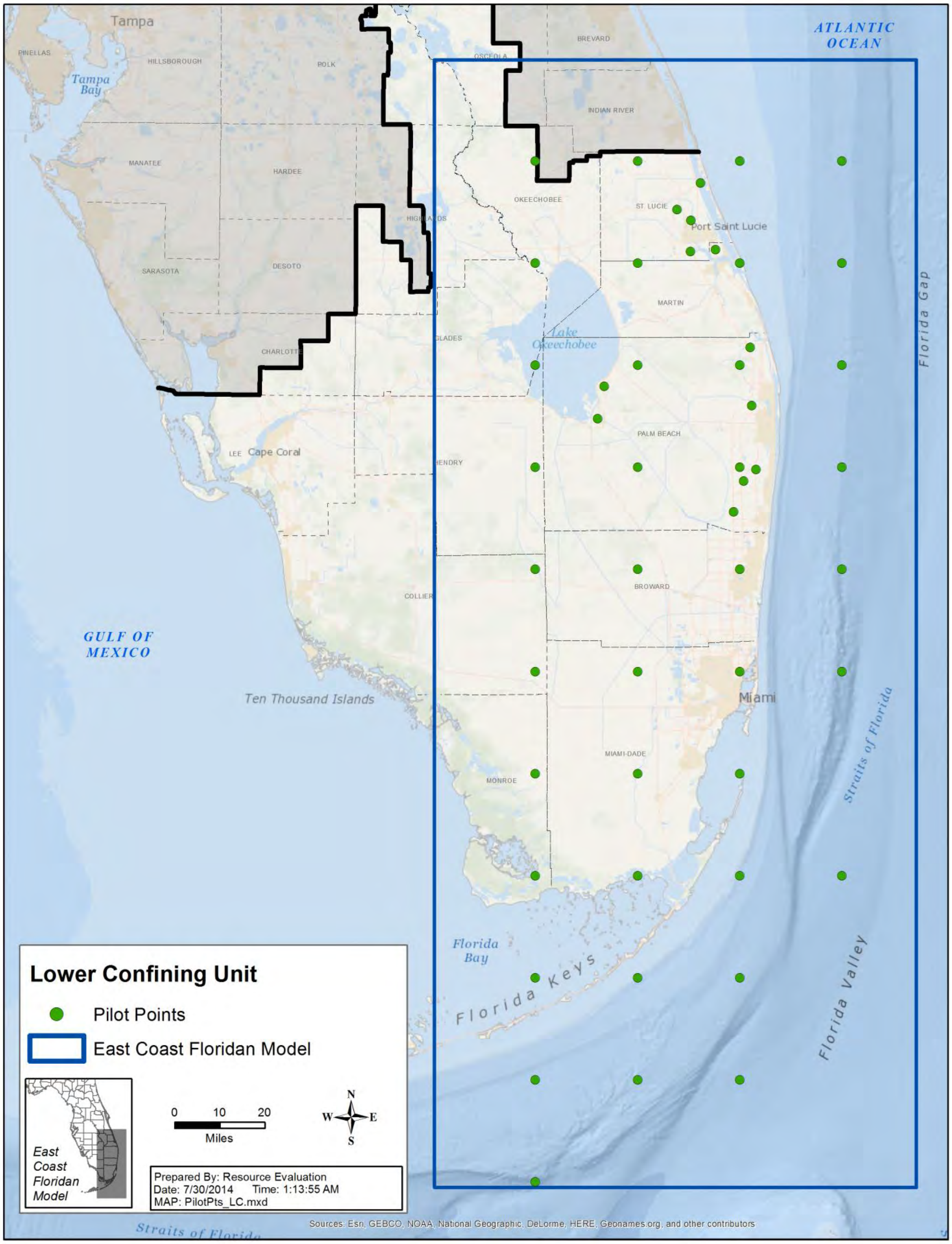

Figure 5.3-7. Distribution of Pilot Points for Vertical Hydraulic Conductivity in the LC

Table 5.3-1. Parameter Groups and Upper and Lower Limit Ranges in PEST

Parameter Group	Description	No. of Parameters (Pilot Points)	Lower Limit Range	Upper Limit Range
K_h Layer 1	Aquifer horizontal hydraulic conductivity in the Upper Floridan	120 APTs and 180 non-APTs Total=300	0.1 - 120.0 (feet/d)	1.2 - 1227.3 (feet/d)
K_v Layer 2	Aquifer vertical hydraulic conductivity in Middle confining unit 1	14 APTs and 33 non-APTs Total=47	$0.1E^{-2}$ - 0.2 (feet/d)	$0.2E^{-1}$ - 5.0 (feet/d)
K_h Layer 3	Aquifer horizontal hydraulic conductivity in the Avon Park permeable zone	26 APTs and 95 non-APTs Total=121	1.2 - 2,103.3 (feet/d)	9.2 - 26789.4 (feet/d)
K_v Layer 4	Aquifer vertical hydraulic conductivity in Middle confining unit 2	8 APTs and 36 non-APTs Total=44	0.1^{-4} - 0.2 (feet/d)	$0.1E^{-1}$ - 5.0 (feet/d)
K_h Layer 5	Aquifer horizontal hydraulic conductivity in the Lower Floridan	7 APTs and 51 non-APTs Total=58	4.0 - 310.5 (feet/d)	30.0 - 2,704.5 (feet/d)
K_v Layer 6	Aquifer vertical hydraulic conductivity in Lower confining unit	12 APTs and 38 non-APTs Total=50	0.00257 - 0.1 (feet/d)	0.5 - 5.0 (feet/d)
Ss Layer 1	Aquifer storativity in the Upper Floridan	120 APTs and 180 non-APTs Total=300	$7.5E^{-8}$ ($feet^{-1}$)	$6.2E^{-4}$ ($feet^{-1}$)
Ss Layer 3	Aquifer storativity in the Avon Park permeable zone	26 APTs and 95 non-APTs Total=121	$7.5E^{-8}$ ($feet^{-1}$)	$1.5E^{-4}$ ($feet^{-1}$)

Figures 5.3-8 through 5.3-12 show the PEST results surfaces of K_h in the UFA, APPZ, and LF1 and S_s in the UFA and APPZ.

Appendix B shows all the APT data used to construct the initial model datasets. Appendix C provides a table comparing the observed hydraulic conductivities from APTs against the final PEST-calibrated values. Certain freedom was allowed in PEST to have a better representation of the aquifer properties.

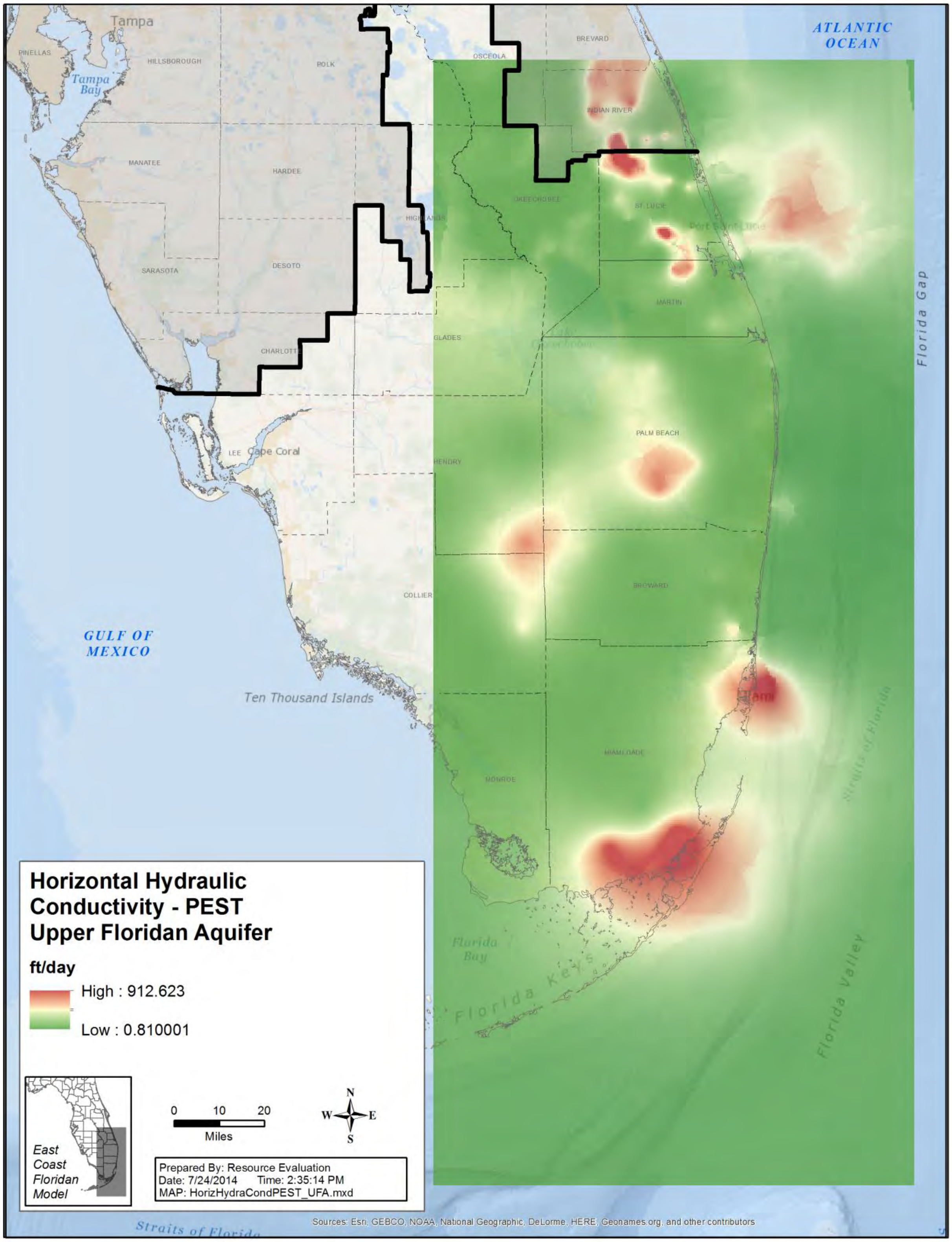

Figure 5.3-8. PEST Horizontal Hydraulic Conductivity in the Upper Floridan Aquifer

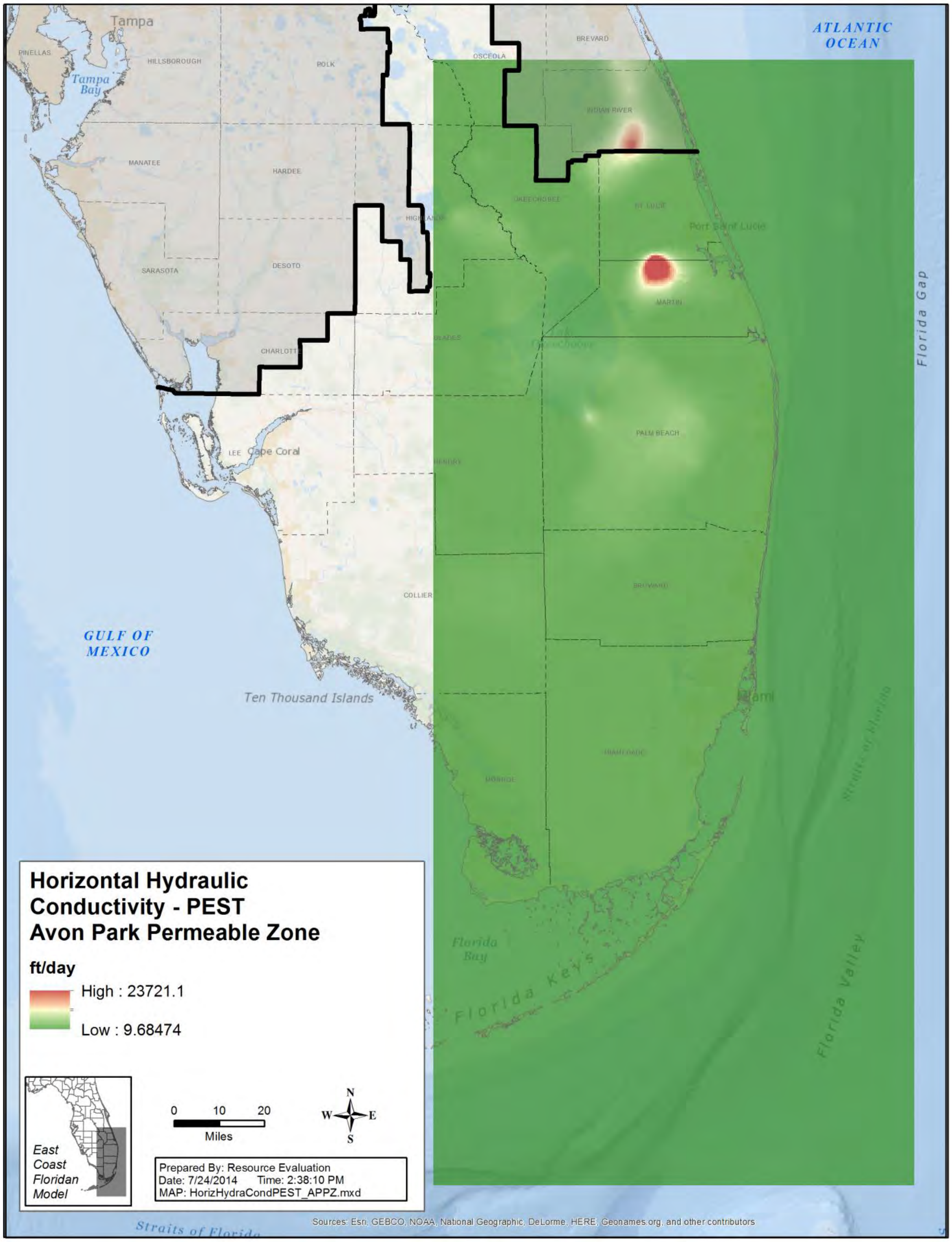

Figure 5.3-9. PEST Horizontal Hydraulic Conductivity in the Avon Park Permeable Zone

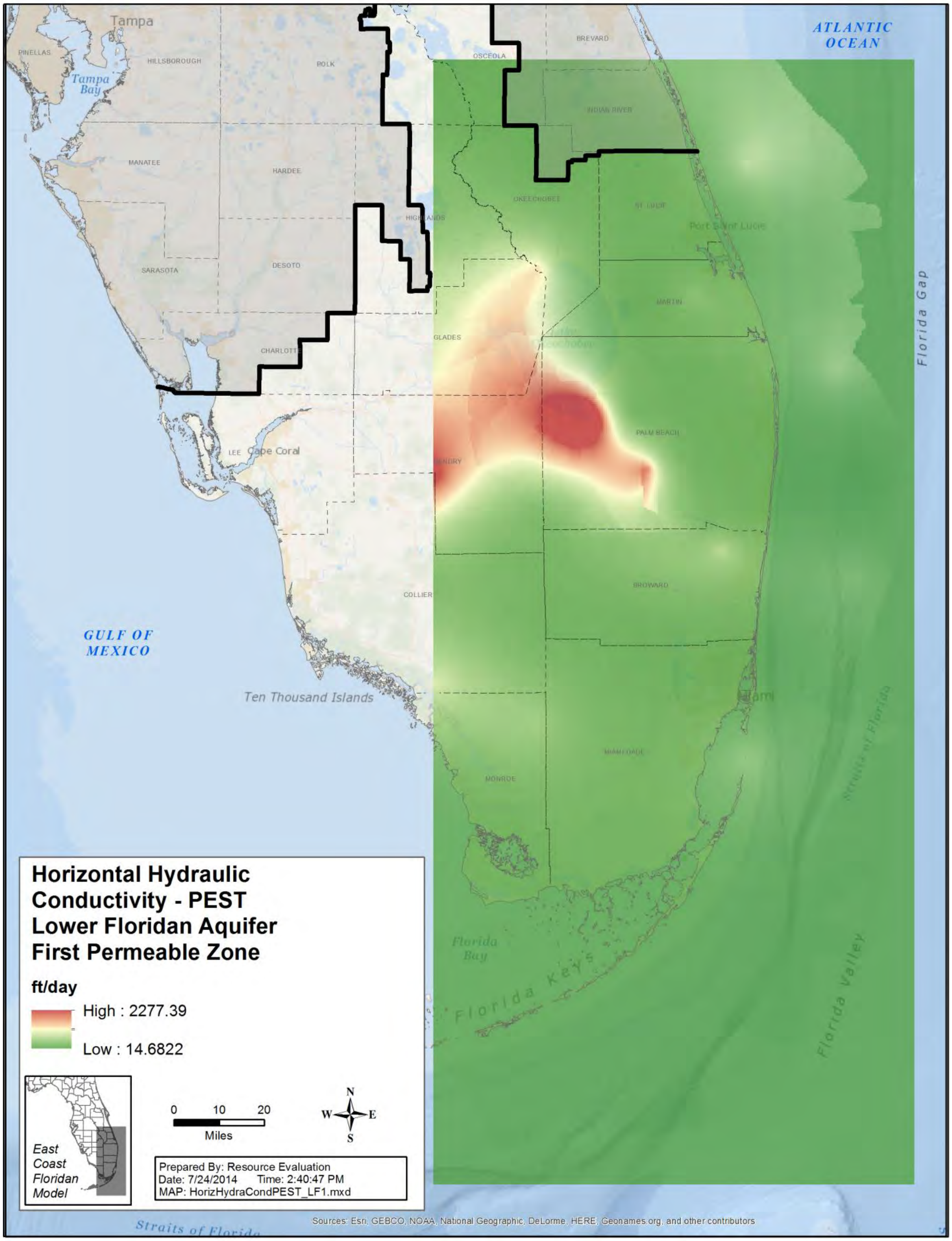

Figure 5.3-10. PEST Horizontal Hydraulic Conductivity in the Lower Floridan Aquifer - First Permeable Zone

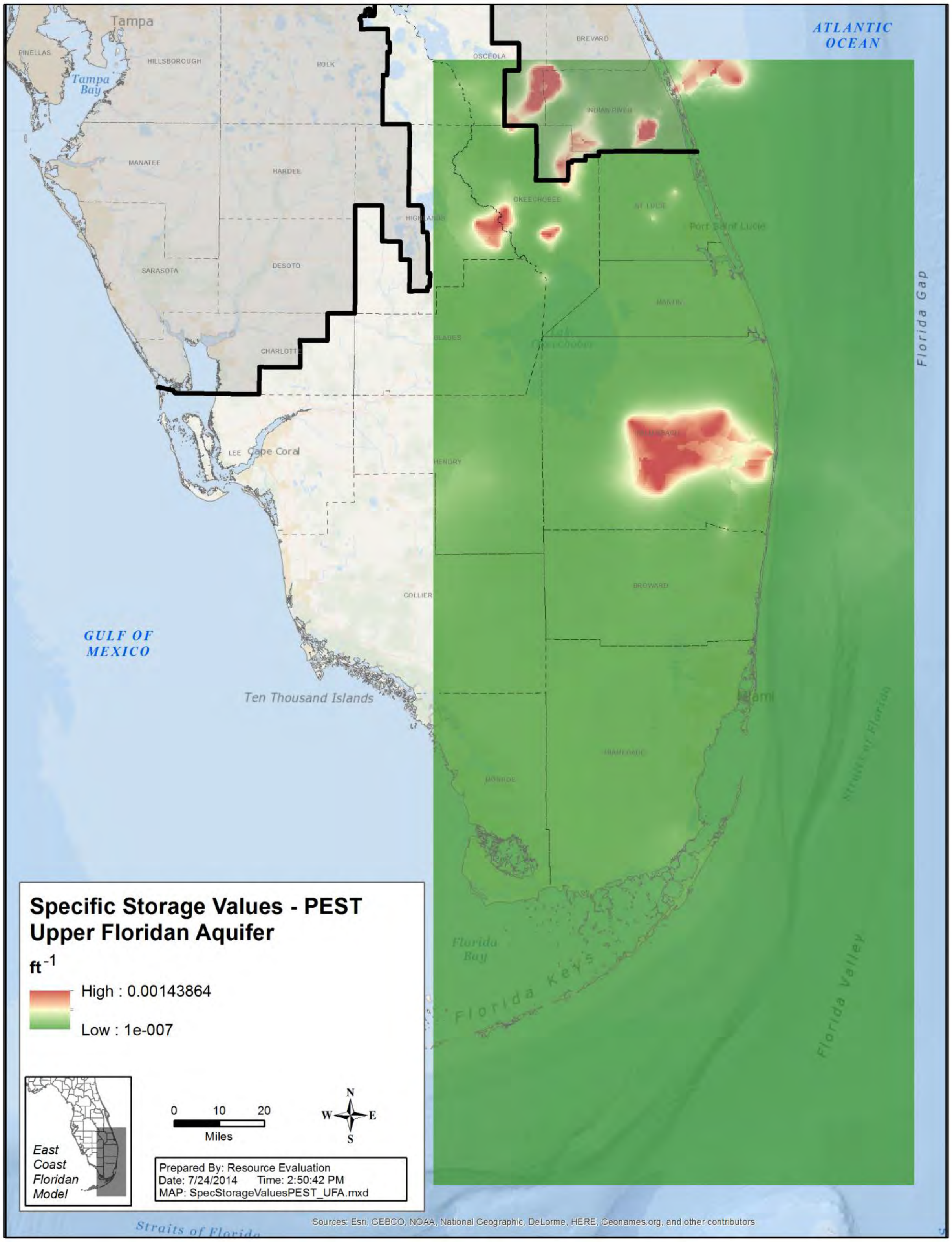

Figure 5.3-11. PEST Specific Storage Values in the Upper Floridan Aquifer

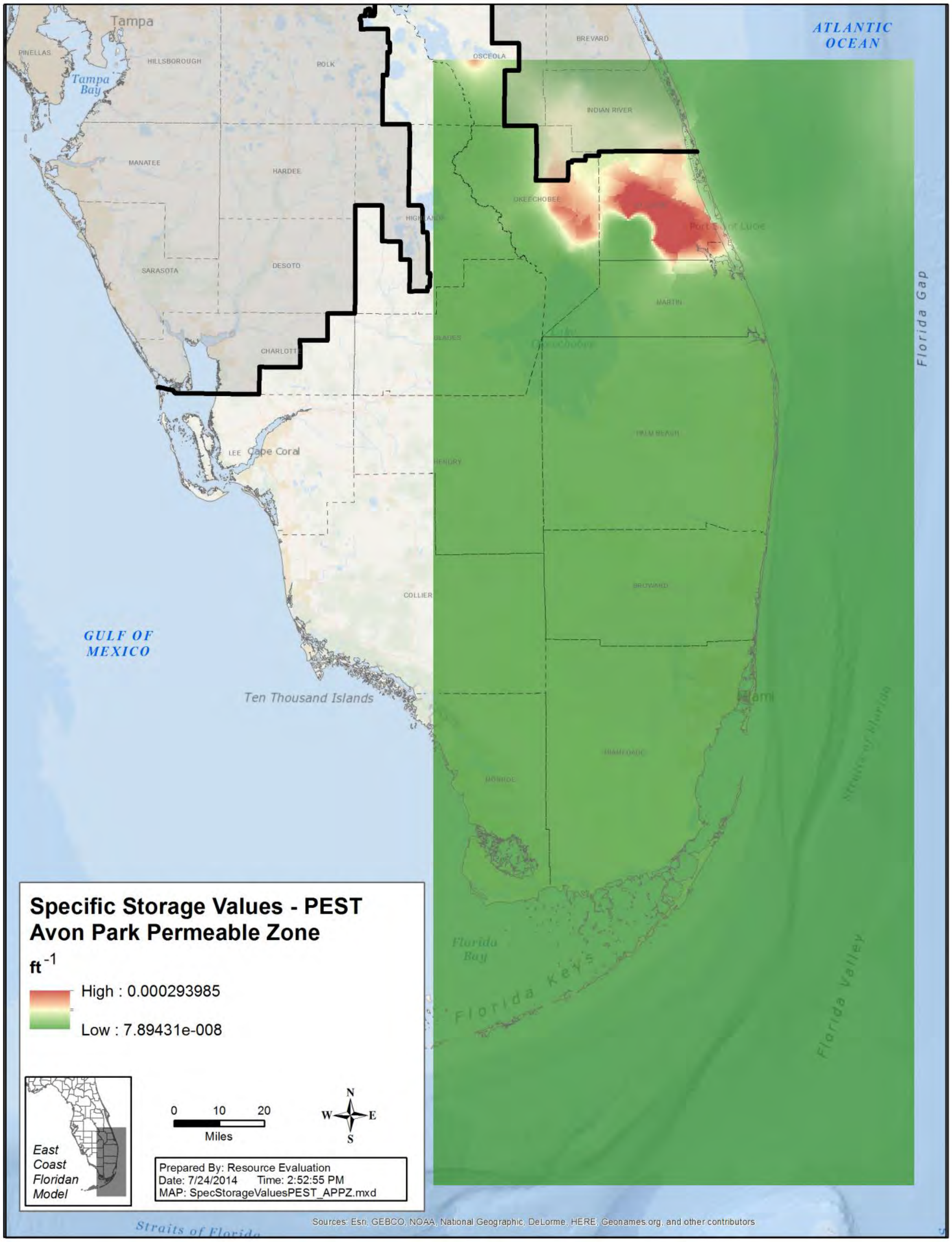

Figure 5.3-12. PEST Specific Storage Values in the Avon Park Permeable Zone

5.3.2.2 Initial Water Quality Distribution and Trends

As mentioned earlier, calibration was not solely based upon PEST. It was an iterative process using both manual and automated calibration. Localized issues, water quality changes, recharge values, better pumpage information, and boundary conditions are the main examples of areas in the model where manual calibration was important.

Water quality of the FAS in the model domain area varies widely depending upon location and depth. Water of potable quality exists in the northern portion of the model where TDS is less than 1,000 mg/L in many areas, and then reaches or exceeds 35,000 mg/L in the eastern and southern portions of the region. Water quality also deteriorates with depth.

The initial TDS spatial distribution was generated using observed values. During calibration, the initial TDS values were adjusted to get closer to the trend of observed values. An iterative process between interpolation adjustments in the initial TDS array, SEAWAT, and PEST was used to calibrate the TDS spatial distribution as well as the time series trends. After every automatic model calibration using PEST, the TDS calibration plots were checked using SEAWAT. Some unrealistic initial TDS values and spatial trends were adjusted and the model was finally recalibrated with PEST. This iterative process using manual calibration and PEST was repeated until the model calibration was acceptable.

At some sites, heads slowly decreased with time, while concentration levels increased. In this case, the initial TDS distribution in the permeable layers and in the confining units (when needed) was adjusted to slow the rate of increase in salinity over time. The salinity may have originated in areas around the corresponding site, from the Boulder Zone, or both. Figures 3.6-4, 3.6-5, and 3.6-6 show the initial TDS spatial distribution in the UFA, APPZ, and LF1, respectively.

5.3.3 Calibration Criteria

The ECFM was evaluated by comparing simulated and observed heads and water quality values. Statistics of the errors and tolerance (or interval) criteria were used to provide an objective assessment of goodness of fit of the simulated behavior to the observed data. This section of the report describes the metrics and criteria used to calibrate the ECFM.

Three of the statistics used in the calibration were the mean error, the mean absolute error, and the root mean squared error (Anderson and Woessner 1992). Residuals are often used to quantify the quality of the model calibration. The mean error globally indicates whether simulated values tend to be disproportionately overestimated or underestimated when compared to historical measurements. However, if mean error is closer to zero that does not necessarily imply a better calibration. Thus, mean error is highly misleading as a criterion. This model calibration metric may indicate the presence of systematic errors in model predictions, showing values that deviate from the measured values by a consistent amount and in a consistent direction. The root-mean-square-error (RMSE) or standard error of the estimate gives an overall indication of the magnitude of a typical error. The closer the RMSE is to zero, the better the model simulates temporal changes. Standard deviation is a measure of the overall spread of residuals. Mean absolute error is calculated using the absolute value of the error. Unlike mean error, by which positive and negative errors could be cancelled out, this value measures the average error in the model.

Other metrics for ECFM performance were scatter plots (with accuracy interval criteria) and statistics at each monitoring site. Scatter plots were generated using observed versus simulated heads (or TDS), including every measured value. Scatter plots are used to identify zones and points in the model that display anomalies, as well as outliers that do not seem to fit with the rest of the points. Another use of the scatter plots is to identify the tendency of the values. If the points align along a straight line that goes from the lower left to the upper right of the plot area, the two variables have a positive correlation. This means that an increase in the value of observed heads (or TDS) is more likely related to an increase in the value of simulated heads (or TDS).

Statistics calculations at each observation site included:

- Mean error: Mean of the difference between calculated and observed values.
- Mean absolute error: Mean of the absolute value of the residuals.
- Standard deviation: Measure of the overall spread of the absolute of the residuals.
- ± Interval band or nominal error: Percentage of time where simulated head lies within a plus or minus “desirable” band of the observed head for each observation site.

The calibration criteria were defined differently for heads and TDS and were based on experience with previous District models and variations in the current model. The criteria intervals were set as a value “difficult to achieve but desirable.” The calibration interval criteria was defined in the scatter plots as outer error bands that represent the minimum and maximum value for a “desirable” simulated value. An indicator for the TDS interval criteria was based on a maximum error close to 20 percent of observation values outside the criteria. This 20 percent calibration criterion was also used to analyze the statistics at each site when defining the percentage of time when simulated head was within a specified band of the observed head for each observation site.

Head interval bands of ±2.0 feet and ±4.0 feet were considered an acceptable alternative target for calibration of heads for the ECFM. The mean absolute error and the nominal error for each site were evaluated at ±2.0 feet calibration criteria.

For water quality, the use of broader or generalized categories as identified by Jacobs et al. (2011) was followed to provide a general understanding of the robustness of the model water quality calibration. The outer error bands represent the minimum and maximum value for each category. For this report, potable water is classified as having a TDS between 0 and 1,000 mg/L, brackish is between 1,000 and 10,000 mg/L, moderately saline is between 10,000 and 18,000 mg/L, and saline is between 18,000 and 35,000 mg/L. However, the calibration criteria for TDS as documented below were used as an alternative target for the performance of the ECFM.

For water quality, the interval calibration criteria bands were defined as ±500, 750, 1,000, 2,000, 4,000 and 4,500 mg/L of the observed values, depending on both the TDS value and the aquifer unit location. This interval was more restrictive in the UFA and less restrictive when the aquifer was deeper or the TDS values higher. In the case of TDS calibration criteria, the low values were more important for water supply purposes. It is acceptable to have higher uncertainty when the TDS is increasingly more saline. This analysis resulted in the following criteria:

- In the UFA, if observed TDS value is from 0 to 4,000 mg/L, use an interval criteria of ±500 mg/L; if observed TDS value is higher than 4,000 mg/L, use an interval criteria of ±750 mg/L.
- In the APPZ (classified in three intervals due to the variability of the values), if observed TDS value is from 0 to 2,000 mg/L, use an interval criteria of ±750 mg/L; if observed TDS value is from 2,000 to 8,000 mg/L, use an interval criteria of ±2,000 mg/L; if observed TDS value is higher than 8,000 mg/L, use an interval criteria of ±4,000 mg/L.
- In the LF1, an interval criterion of ±4,000 mg/L was used. The maximum value in the model simulation was limited to 36,000 mg/L. However, bottom layers of the Lower Floridan aquifer system presented observed values greater than 36,000 mg/L.

5.3.4 Calibration Results

A series of calibration runs were performed with PEST. Each was evaluated by visual comparison of simulated, ECFM, and historical or observed heads and/or water quality trends. Incremental improvements were sequentially identified and incorporated in subsequent runs. The final PEST calibration run took about 15 iterations and was considered the best PEST run with an acceptable TDS distribution.

Furthermore, after each PEST or manual calibration run, the model performance metrics were used to assess whether the calibrated model met the predefined head and water quality criteria. In addition, close inspection of PEST diagnostic statistics gave indication as to which parameters reached the bounds of the limits and to which parameters were insensitive to observations. In many cases, PEST would freeze the value of some parameters when they reached their upper or lower imposed limit, indicating possible high correlation with other parameters or low sensitivity of the heads to the parameters.

During the calibration process, a few observation sites were not used for one of the following reasons: no data during the calibration period, the data were not consistent with the unit or aquifer, or a specific site better fit the spatial and temporal variations of the model-cell results (in cases where there was more than one site in a cell).

5.3.4.1 Water Level Statistics

Figures 5.3-13, 5.3-14, and 5.3-15 show the scatter plots for computed versus observed head for each measured value in the UFA, the APPZ, and the LF1, respectively. The coefficient of determination was 0.9125 for the UFA, 0.926 for the APPZ, and 0.953 for the LF1. The UFA minimum, maximum, and average head observed values were 25.1 feet, 67.6 feet, and 45.2 feet, respectively; while simulated values were 23.5 feet, 80.0 feet, and 44.5 feet, respectively. The APPZ minimum, maximum, and average head observed value were 37.2 feet, 60.8 feet and 49.5 feet, respectively; while simulated values were 35.2 feet, 58.9 feet, and 48.6 feet. The LF1 minimum, maximum, and average head observed values were 7.1 feet, 42.0 feet, and 18.9 feet, respectively; while simulated values were 7.8 feet, 40.1 feet, and 19.5 feet.

The UFA scatter plot in Figure 5.3-13 indicates 470 of 3,273 (14 percent) head observed matching values from 25 to 45 feet, and 502 of 3,254 (15 percent) from 45 to 70 feet are outside the ±2.0 feet interval criteria. Furthermore, only 2 percent of head observed matching values are outside the ±4.0 feet interval criteria. A summary of these head values and statistics is shown in Table 5.3-2. Clusters of points outside the ±4.0 feet interval occurred at monitoring well IRF-RO and IRF-MACE in Indian River County, and may be due to pumpage reporting issues and at well PBF-14 in Palm Beach County since the response to the injection and recovery cycling associated with ASR testing was not fully realized.

The APPZ scatter plot in Figure 5.3-14, indicates 3 of 398 (1 percent) head observed matching values from 35 feet to 45 feet were outside the ±2.0 feet interval criteria and 2 out of 1435 (0.1 percent) from 45 feet to 65 feet were outside the ±2.0 feet interval criteria. Furthermore, 1 percent of head observed matching values were outside the ±4.0 feet interval criteria. A summary of these head values and statistics is shown in Table 5.3-2. The clusters of points outside the criteria of the ±2.0 feet interval at well G-2617 in Broward County may be due to initial conditions and well PBF-15M in Palm Beach County is a tri-zone monitoring well, suggesting a non-model-related issue.

The LF1 scatter plot in Figure 5.3-15, indicates 89 of 363 (24 percent) head observed matching values from 5 feet to 20 feet were outside the ±2.0 feet interval criteria and 5 of 132 (4 percent) from 20 feet to 45 feet were outside the ±2.0 feet. Interval criteria. Further, less than 2 percent of observed matching values were outside the ±4.0 feet interval criteria; most of which were from PBF-15L in Palm Beach County. A summary of these head values and statistics is shown in Table 5.3-2.

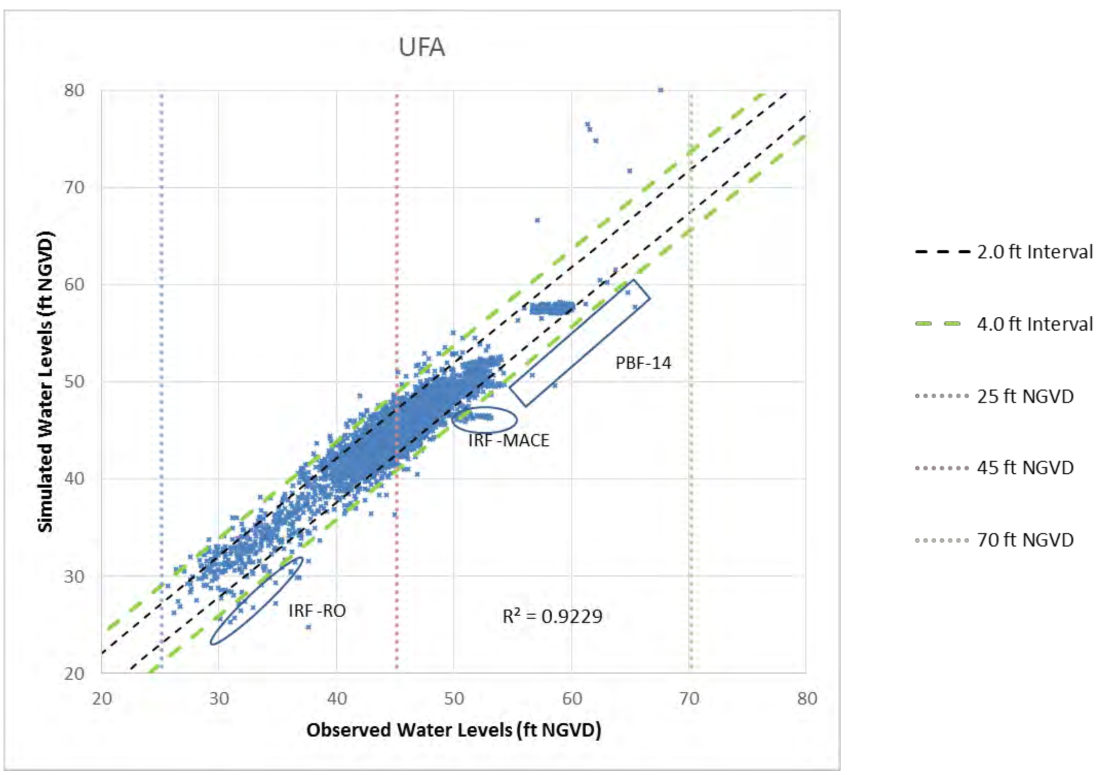

Figure 5.3-13. Scatter Plot of Observed vs. Simulated Heads in the UFA

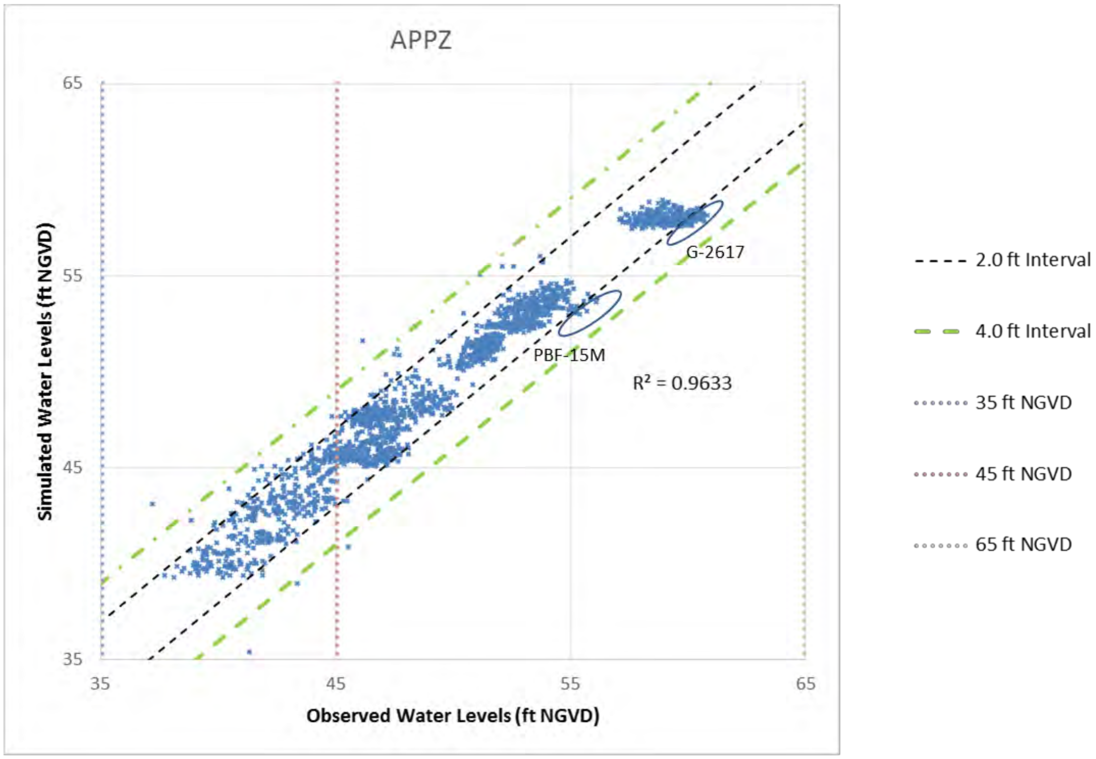

Figure 5.3-14. Scatter Plot of Observed vs. Simulated Heads in the APPZ

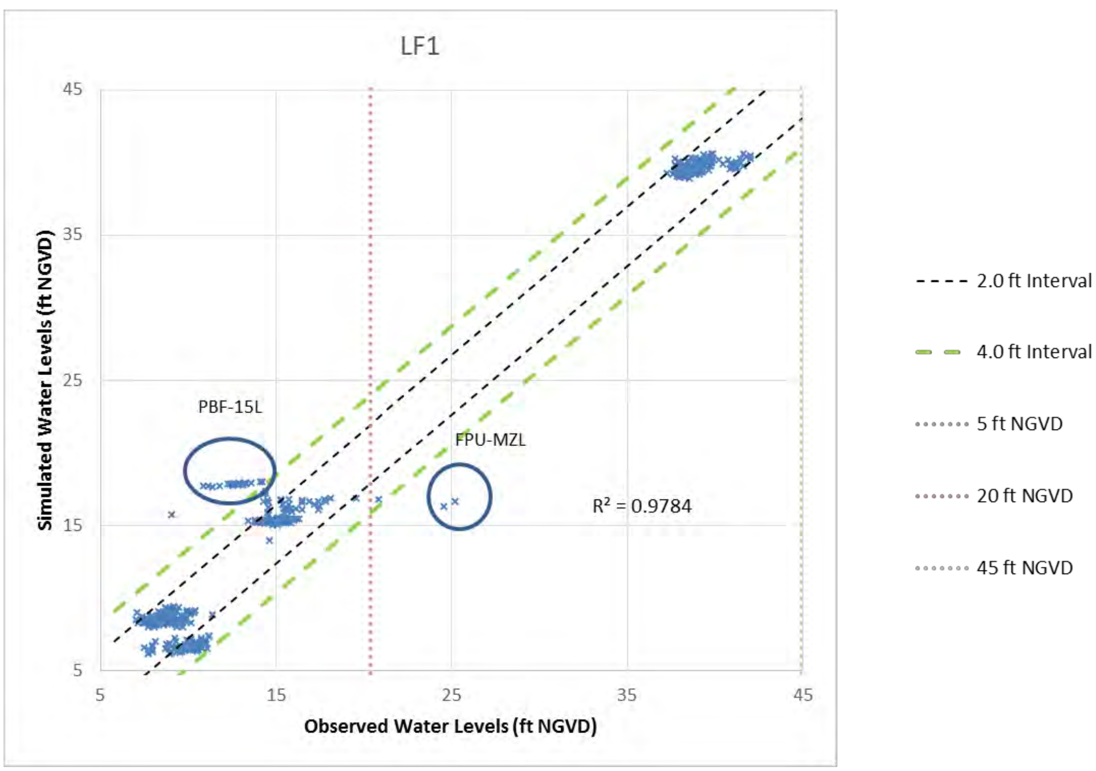

Figure 5.3-15. Scatter Plot of Observed vs. Simulated Heads in the LF1

Table 5.3-2. Percentage of Number of Head Observations outside of Interval Criteria

Aquifer	Observed Head Range (feet, NGVD29)	No. of Records	% of Records Outside ±2.0 feet Interval	% of Records Outside ±4.0 feet Interval
Upper Floridan Aquifer (UFA)	25-45	3,273	14%	2%
	45-70	3,245	15%	2%
Avon Park Permeable Zone (APPZ)	35-45	398	1%	1%
	45-65	1,435	0.1%	1%
Lower Floridan Aquifer – First Permeable Zone (LF1)	5-20	363	24%	7%
	20-45	132	4%	2%

Tables 5.3-3, 5.3-4, and 5.3-5 summarize the head calibration statistics for each observation site in the UFA, APPZ, and LF1, respectively. Table 5.3-3 shows that 102 of 111 groundwater wells with a mean absolute error less than 2.0 feet, or 92 percent. The average values for mean absolute error and standard deviation were 1.33 feet and 0.90 feet, respectively. Overall, 96 of 111 (86 percent) UFA groundwater wells were within ±2.0 for at least 86 percent of the simulation period.

According to Table 5.3-4, 26 of 27 (96 percent) groundwater wells had a mean absolute error less than 2.0 feet; the average values for mean absolute error and standard deviation were 0.94 feet and 0.59 feet, respectively. Overall, 24 of 27 (89 percent) APPZ groundwater wells were within ± 2.0 feet. For at least 96 percent of the simulation period.

In Table 5.3-5, the average values for mean absolute error and standard deviation were 2.0 feet and 0.92 feet, respectively. These numbers were heavily skewed by the performance of PBF-15L and BF-1. Overall, all LF1 groundwater wells except PBF-15L in Palm Beach County and BF-1 in Broward County were within ±2.0 feet for at least 80 percent of the simulation period.

Table 5.3-3. Statistics at each Monitoring Site for Heads in the UFA

Well Site Name (Station ID)	County	No. of Records	Row	Col.	Mean Observed Head (feet)	Mean Error (feet)	Mean Absolute Error (feet)	Standard Deviation (feet)	% of Records within ±2 feet Interval
BEF-1559	Brevard	22	4	99	38.41	0.01	0.41	0.40	100
BEF-INLET	Brevard	44	2	112	33.59	0.93	0.99	0.50	100
BEF-T6	Brevard	24	2	62	40.54	1.01	1.25	0.87	91
BF-4S	Broward	132	255	151	43.16	-0.81	0.93	0.59	96
BF-6	Broward	131	234	158	43.62	-0.04	0.52	0.34	100
G-2618	Broward	124	256	63	58.97	-1.55	1.55	0.46	99
G-2619	Broward	124	256	63	59.27	-1.85	1.85	0.46	95
DF-4	Dade	131	295	111	51.98	-1.03	1.03	0.41	100
ENP-100	Dade	108	375	93	41.33	1.56	1.56	0.48	98
G-3061	Dade	114	307	136	44.27	0.10	0.39	0.31	100
GLY-155	Glades	181	100	25	46.83	-0.25	1.05	0.78	95
GLY-CLE	Glades	45	143	2	49.06	1.31	1.66	1.39	75
L2-PW2	Hendry	127	190	45	57.88	-0.39	0.58	0.36	100
HIF-13	Highlands	41	66	10	46.31	-0.66	1.60	1.05	90
HIF-37	Highlands	36	92	12	45.64	-0.34	1.28	0.71	94
HIF-40	Highlands	57	89	10	46.22	-0.53	0.92	0.78	94
HIF-42U	Highlands	44	97	44	46.51	-1.00	1.10	0.73	100
HIF-6	Highlands	44	92	21	45.03	-0.46	1.43	0.95	84
IR-368	Indian River	17	44	124	32.93	1.68	2.00	1.32	70
IR-370	Indian River	13	43	98	36.69	0.48	1.00	0.62	92
IR-373	Indian River	17	33	88	40.39	-0.38	1.02	0.65	100
IRF-1006	Indian River	22	32	115	32.15	-0.18	1.03	0.72	100
IRF-1008	Indian River	22	34	122	32.33	-0.83	2.46	1.16	45
IRF-189	Indian River	237	14	62	41.78	0.44	1.40	1.03	83
IRF-210	Indian River	43	27	110	33.14	0.48	1.53	1.07	81
IRF-365	Indian River	33	27	57	50.66	-2.16	2.16	0.88	60
IRF-954	Indian River	22	41	95	39.73	-1.77	1.83	1.22	63
IRF-955	Indian River	18	30	88	40.83	-1.40	1.62	1.17	77
IRF-963	Indian River	21	25	104	35.86	-0.15	1.22	0.83	95
IRF-968	Indian River	18	23	68	41.37	-0.28	1.30	0.80	83
IRF-BERRY	Indian River	29	19	91	38.46	-0.43	1.54	1.28	89
IRF-JOHN	Indian River	69	24	122	30.33	1.28	1.76	1.09	76
IRF-MACE	Indian River	53	6	56	50.03	-3.50	3.56	2.11	30
IRF-RO	Indian River	44	40	119	34.54	-2.64	3.25	2.11	43
IRF-USDA	Indian River	44	43	115	32.40	0.24	1.57	1.44	84
MF-2	Martin	18	106	106	48.45	0.07	0.42	0.42	100
MF-23	Martin	36	119	98	48.46	1.29	1.36	0.62	97

Well Site Name (Station ID)	County	No. of Records	Row	Col.	Mean Observed Head (feet)	Mean Error (feet)	Mean Absolute Error (feet)	Standard Deviation (feet)	% of Records within ±2 feet Interval
MF-31	Martin	44	107	150	44.93	0.49	1.08	0.96	93
MF-33	Martin	12	110	94	46.45	-0.38	1.42	1.37	83
MF-35B	Martin	129	131	108	51.68	-1.76	1.76	0.58	89
MF-37	Martin	33	132	92	52.96	-1.05	1.10	0.56	100
MF-37U	Martin	51	132	92	52.31	-0.48	0.55	0.36	100
MF-40U	Martin	44	99	109	48.97	-0.64	0.76	0.53	100
MF-51	Martin	12	121	121	50.04	-0.55	0.75	0.46	100
MF-52	Martin	145	117	122	50.66	-1.31	1.41	0.69	97
MF-53	Martin	5	102	151	44.41	-0.39	0.92	0.41	100
MF-54	Martin	14	103	151	43.66	-0.36	1.10	0.85	92
MF-55	Martin	16	94	148	40.56	0.28	1.78	1.23	62
MF-9	Martin	42	105	111	48.54	-0.26	1.29	0.91	88
TFRO-5	Martin	24	116	139	50.36	-0.99	1.07	0.43	100
OKF-1	Okeechobee	234	59	77	43.81	-1.76	1.92	0.97	69
OKF-100U	Okeechobee	72	107	56	48.35	-0.09	1.18	1.42	87
OKF-101	Okeechobee	88	100	60	46.97	0.00	0.71	0.46	100
OKF-105U	Okeechobee	48	69	23	44.94	-0.59	1.26	0.94	91
OKF-106	Okeechobee	57	94	67	45.00	1.22	1.25	0.72	94
OKF-17	Okeechobee	44	79	49	45.31	-0.55	1.18	0.88	90
OKF-23	Okeechobee	67	92	58	43.29	0.73	2.07	1.32	64
OKF-31	Okeechobee	79	96	59	47.38	-0.55	1.97	1.37	72
OKF-34	Okeechobee	57	49	35	45.79	1.48	2.01	1.57	66
OKF-42	Okeechobee	80	69	23	45.62	-1.49	1.58	0.95	77
OKF-7	Okeechobee	65	75	67	45.34	-0.50	1.19	0.83	92
OKF-71	Okeechobee	18	51	73	41.13	0.27	0.72	0.59	100
OKF-72	Okeechobee	16	53	74	40.87	0.54	0.79	0.73	100
OKF-BAS	Okeechobee	37	61	37	45.43	-0.81	1.32	0.94	86
OKF-MAC	Okeechobee	13	70	55	40.07	1.22	1.23	1.19	84
OKF-UNK1	Okeechobee	24	62	26	47.02	-1.23	1.32	0.84	87
OKF-UNK2	Okeechobee	23	93	44	47.47	-2.26	2.46	1.24	39
OKF-WIL	Okeechobee	10	53	51	45.29	-1.27	1.29	0.76	100
TCRK_GW1	Okeechobee	121	94	67	46.03	-0.12	0.73	0.50	99
OSF-104U	Osceola	55	30	20	44.78	-0.38	0.93	0.67	98
OSF-231	Osceola	22	5	44	43.05	0.14	1.08	0.65	95
OSF-42	Osceola	44	21	42	43.78	-1.16	1.80	1.39	75
OSF-52	Osceola	116	9	12	44.46	0.60	0.98	0.71	94
OSF-60A	Osceola	168	25	52	43.63	-0.34	1.24	1.08	89
OSF-HAY	Osceola	109	7	39	44.16	-0.01	1.16	0.89	94
OSF-S65	Osceola	93	9	12	44.63	0.49	1.36	1.12	83

Well Site Name (Station ID)	County	No. of Records	Row	Col.	Mean Observed Head (feet)	Mean Error (feet)	Mean Absolute Error (feet)	Standard Deviation (feet)	% of Records within ±2 feet Interval
PBF-1	Palm Beach	47	134	162	47.17	0.73	0.92	0.81	93
PBF-10R	Palm Beach	113	227	134	50.91	-0.07	1.60	2.92	90
PBF-14	Palm Beach	71	228	135	52.83	-2.49	2.55	1.38	63
PBF-15U	Palm Beach	58	170	125	52.37	-0.51	0.63	0.46	100
PBF-2	Palm Beach	114	174	166	46.26	0.60	1.21	0.58	99
PBF-3	Palm Beach	131	179	160	46.21	0.81	0.83	0.46	100
PBF-747	Palm Beach	121	140	155	47.64	-0.84	1.04	0.67	98
POF_IL	Polk	189	8	9	45.60	0.20	1.45	1.02	81
POF-RR	Polk	24	14	12	41.69	-0.11	1.24	0.94	83
POF-20	Polk	92	30	20	44.70	-0.44	1.03	0.76	95
SLF-11	St. Lucie	14	49	95	38.87	-0.19	0.96	0.69	100
SLF-17	St. Lucie	18	81	96	41.98	-0.17	1.30	1.16	88
SLF-21	St. Lucie	142	65	119	35.21	0.71	1.31	1.07	90
SLF-36	St. Lucie	20	60	104	38.05	0.75	1.00	0.80	95
SLF-40	St. Lucie	21	67	106	38.53	-0.20	0.98	0.73	95
SLF-61	St. Lucie	17	89	114	45.57	0.15	0.82	0.65	100
SLF-62	St. Lucie	18	86	110	43.34	0.96	1.29	0.81	88
SLF-62B	St. Lucie	70	83	113	44.99	-1.30	1.45	0.63	98
SLF-63	St. Lucie	18	57	91	38.74	0.59	0.87	0.65	100
SLF-64	St. Lucie	18	52	89	39.82	-0.88	1.11	0.74	100
SLF-65	St. Lucie	18	49	87	38.73	0.05	1.11	1.24	94
SLF-66	St. Lucie	18	64	99	38.18	0.24	1.15	0.84	94
SLF-67	St. Lucie	18	73	85	42.72	-0.16	0.85	0.63	100
SLF-69	St. Lucie	31	75	113	40.06	-0.70	1.96	1.47	77
SLF-70	St. Lucie	18	49	119	30.86	-0.27	2.01	2.02	72
SLF-75	St. Lucie	116	79	107	41.47	-0.81	0.95	0.62	99
SLF-76	St. Lucie	116	79	107	41.58	-0.92	1.02	0.75	96
STL-215	St. Lucie	30	54	114	37.02	-1.82	2.15	1.65	66
STL-216	St. Lucie	18	58	108	37.59	0.50	0.83	0.70	100
STL-224	St. Lucie	1	65	119	31.80	1.05	1.05	0.00	100
STL-229	St. Lucie	20	71	104	37.75	-0.59	1.85	1.33	85
STL-251	St. Lucie	11	57	102	38.73	-1.84	1.84	1.20	63
STL-352	St. Lucie	9	52	132	33.67	2.25	2.25	1.76	66
C24GW	St. Lucie	117	79	106	42.41	-0.05	0.83	0.65	98
FPU-MZU	St. Lucie	34	61	131	35.37	2.85	2.85	0.84	35

Table 5.3-4. Statistics at each Monitoring Site for Heads in the APPZ

Well Site Name Station ID)	County	No. of Records	Row	Col.	Mean Observed Head (feet)	Mean Error (feet)	Mean Absolute Error (feet)	Standard Deviation (feet)	% of Records within ±2 feet Interval
BF-2	Broward	48	255	151	47.08	-1.53	1.53	0.37	100
BF-4M	Broward	133	255	151	46.07	-0.42	0.76	0.56	100
G-2617	Broward	124	256	63	59.75	-1.83	1.83	0.46	93
MIR-MZU	Broward	119	282	130	46.83	0.35	0.81	0.46	100
DF-5	Dade	131	295	111	51.32	0.03	0.28	0.22	100
GLF-6	Glades	99	155	27	53.81	0.09	0.48	0.35	100
L2-PW1	Hendry	129	190	45	58.43	-0.39	0.56	0.38	100
HIF-14	Highlands	37	86	2	48.45	0.88	1.03	0.67	97
HIF-3	Highlands	17	50	3	50.17	1.46	1.79	1.56	70
HIF-4	Highlands	26	57	6	45.80	0.01	2.20	1.68	65
HIF-42L	Highlands	44	97	44	43.47	1.32	1.36	0.90	88
MF-35	Martin	21	130	108	48.48	0.35	0.80	0.64	100
MF-37L	Martin	51	132	92	50.98	-0.32	0.47	0.31	100
MF-40L	Martin	44	99	109	48.70	-0.61	0.73	0.50	100
OKF-100	Okeechobee	39	107	56	48.64	-0.53	0.79	0.51	100
OKF-100L	Okeechobee	69	107	56	47.34	0.52	0.93	0.64	98
OKF-105M	Okeechobee	33	69	23	45.11	-0.91	0.94	0.61	96
OKF-73	Okeechobee	18	81	65	40.83	0.25	0.67	0.46	100
OKF-74	Okeechobee	17	84	67	42.83	-0.69	0.79	0.49	100
TCRK_GW2	Okeechobee	121	94	67	42.59	0.38	1.00	0.64	99
OSF-104M	Osceola	55	30	20	44.74	0.85	0.96	0.63	98
PBF-11	Palm Beach	114	227	134	52.59	-0.12	0.49	0.35	100
PBF-15M	Palm Beach	58	170	125	53.34	-0.03	0.49	0.38	100
PBF-4	Palm Beach	43	179	160	46.39	1.47	1.47	0.44	100
PBF-7U	Palm Beach	129	176	77	53.54	-0.58	0.76	0.63	99
SLF-14	St. Lucie	11	79	96	39.71	0.71	0.71	0.46	100
SLF-74	St. Lucie	116	79	107	40.86	-0.43	0.85	0.51	100

Table 5.3-5. Statistics at each Monitoring Site for Heads in the LF1

Well Site Name (Station ID)	County	No. of Records	Row	Col.	Mean Observed Head (feet)	Mean Error (feet)	Mean Absolute Error (feet)	Standard Deviation (feet)	% of Records within ±2 feet Interval
BF-1	Broward	71	255	151	9.87	-3.28	3.28	0.89	19
PBF-12	Palm Beach	113	227	134	14.98	0.33	0.56	0.56	97
PBF-15L	Palm Beach	57	170	125	12.65	5.11	5.11	0.83	0
PBF-5	Palm Beach	130	179	160	8.76	-0.25	0.62	0.50	99
PBF-7L	Palm Beach	129	176	77	39.22	0.46	0.91	0.54	100
FPU-MZL	St. Lucie	33	61	131	16.73	-0.43	1.57	2.20	84

5.3.4.2 Water Quality Statistics

The scatter plots in Figures 5.3-16, 5.3-17, and 5.3-18 show simulated versus observed water quality (TDS) for each measured value in the UFA, APPZ, and LF1, respectively. As recommended in Jacobs et al. (2011), a logarithmic transformation of TDS was applied to show values over several orders of magnitude. As shown by these three figures, greater than 99 percent of the data points fall within the generalized water quality categories for potable, brackish, and saline.

The UFA minimum, maximum, and average water quality observed values were 185 mg/L, 8,780 mg/L, and 3,071 mg/L, respectively indicating a fresh to brackish water environment. The APPZ minimum, maximum, and average water quality observed value were 200 mg/L, 24,826 mg/L, and 6,351 mg/L, indicating a more widely distributed water quality, while the LF1 minimum, maximum, and average water quality observed values were 7,967 mg/L, 36,000 mg/L, and 27,053 mg/L, suggesting primarily seawater conditions.

The UFA scatter plot (Figure 5.3.-16) indicates that for TDS values from 0 to 4,000 mg/L, 458 of 3,453 (13 percent) of matching observed/modeled values were outside the ±500 mg/L criteria, and for TDS values from 4,000 to 10,000 mg/L, 222 of 1,508 (15 percent) were outside the ±750 mg/L criteria. Ten of the 106 UFA observation wells (9 percent) had the mean absolute error greater than the interval criteria with 7 of those wells had water quality less than 4,000 mg/L and 3 wells were greater than 4,000 mg/L. A summary of these values and statistics is shown in Table 5.3-6. The UFA scatter plot shows a cluster of points outside the calibration criteria. Approximately one-third of all values exceeding the criteria occurred at monitor well NMC-MW1A in Martin County and may be related to sampling protocol or incorrect aquifer assumption.

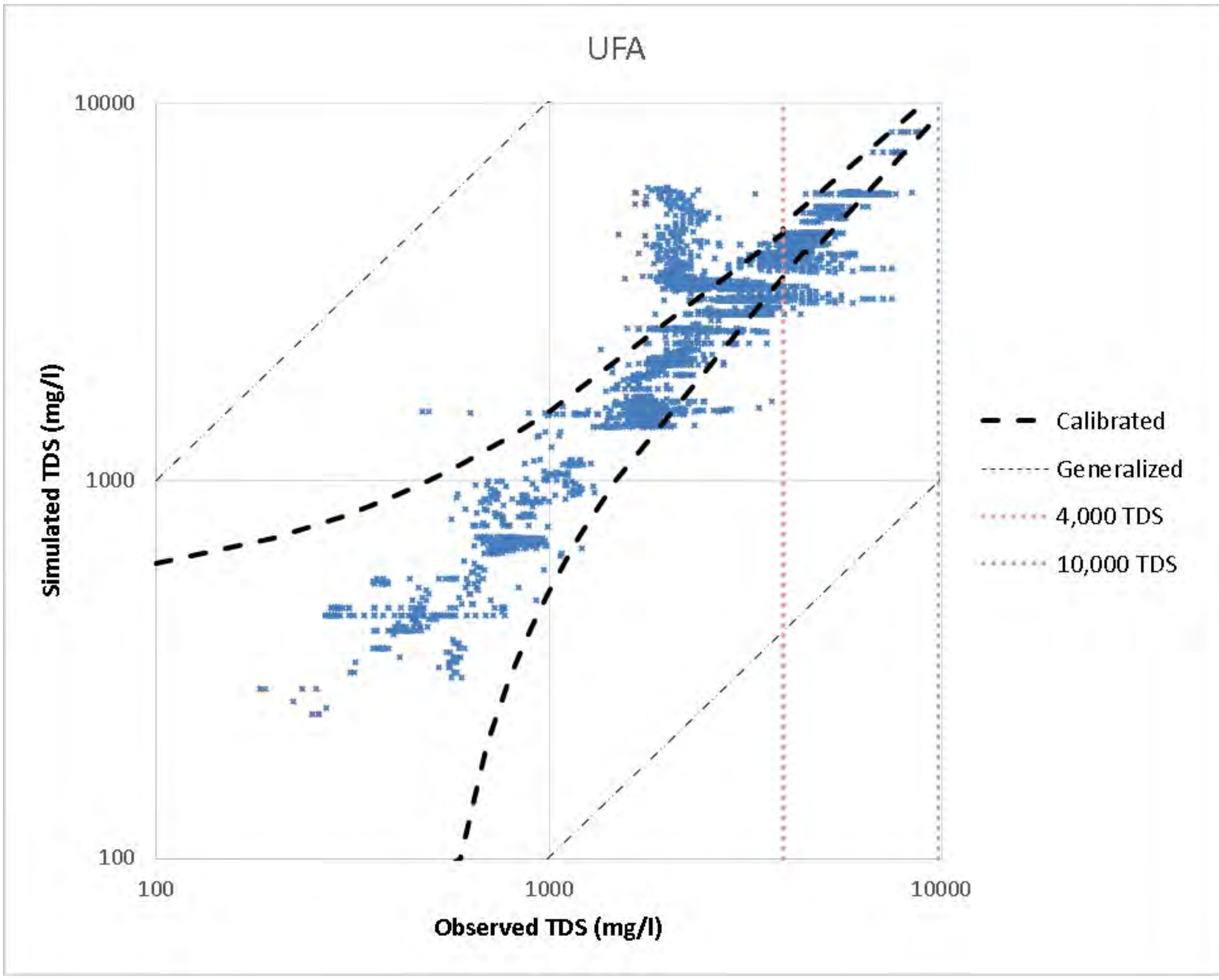

Figure 5.3-16. Scatter Plot of Observed Versus Simulated TDS in the UFA

The APPZ scatter plot (Figure 5.3.-17) indicates that for TDS values from 0 to 2,000 mg/L, 5 of 37 (14 percent) of matching observed/modeled values were outside the ±500 mg/L interval criteria, from 2,000 to 3,000 mg/L, 59 of 128 (46 percent) of matching observed/modeled values were outside the ±1,000 mg/L interval criteria, from 3,000 to 8,000 mg/L, 176 of 3,223 (5 percent) of matching observed/modeled values were outside the ±2,000 mg/L interval criteria, and for TDS values greater than 8,000 mg/L, 299 of 1095 (27 percent) were outside the ±4,000 mg/L interval criteria. A summary of these values and statistics is shown in Table 5.3-6. Nine of the 68 APPZ observation wells (13 percent) had the mean absolute error greater than the interval criteria somewhat evenly distributed between the various calibration intervals. The APPZ shows observed matching values outside calibration criteria. Half of these deviations occurred at only three wells: PSLJA-MW1A in St Lucie County, ST-MW2 in Martin County, and PBC-SR1B in Palm Beach County. These cases show that the observed TDS values had some significant temporal variations that the model is not adequately simulating.

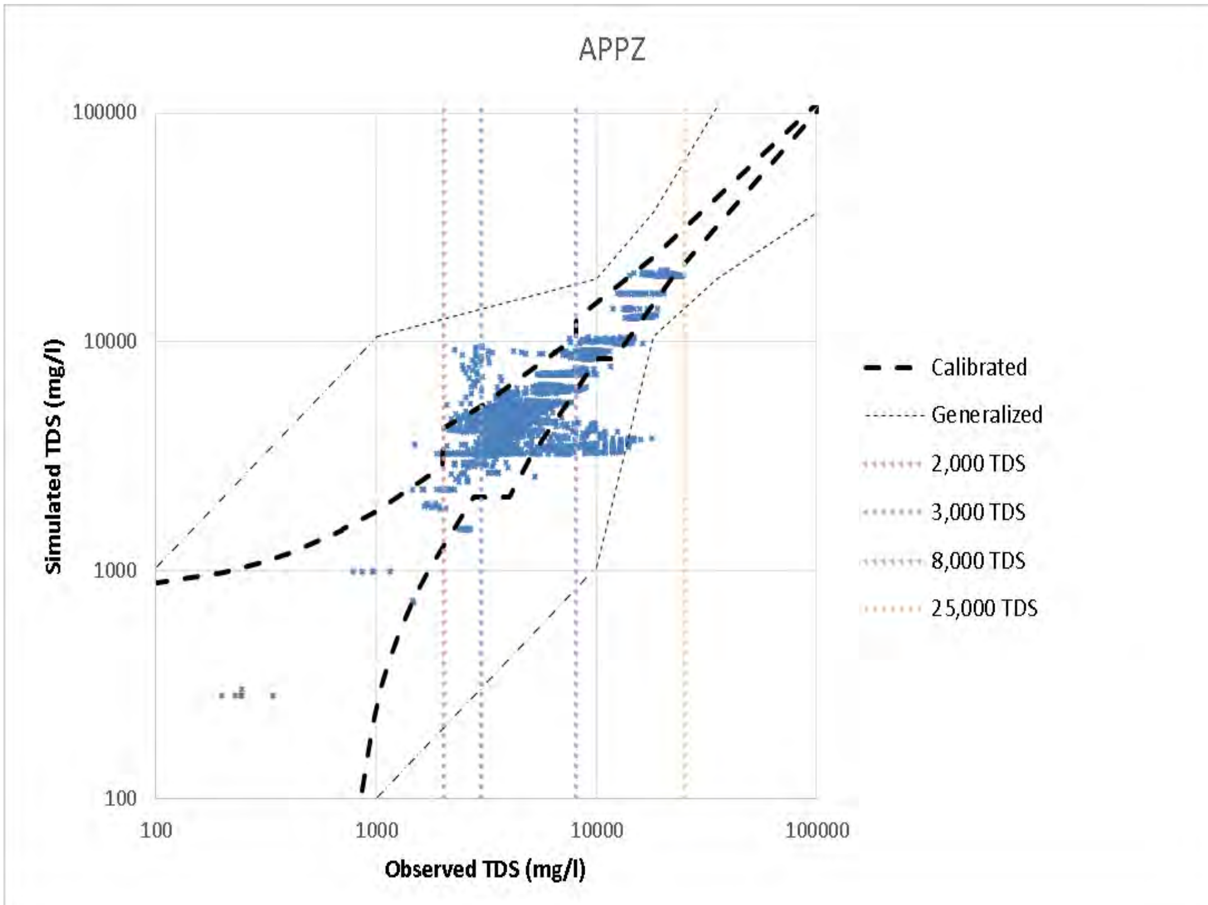

Figure 5.3-17. Scatter Plot of Observed vs. Simulated TDS in the APPZ

The LF1 scatter plot is shown in Figure 5.3-18. A review of the model results indicates that none of the 545 matching observed/modeled values from 0 to 19,000 mg/L and 149 of 3,513 (4 percent) from 19,000 to 36,000 mg/L are outside the ±4,000 mg/L interval criteria. A summary of these values and statistics is shown in Table 5.3-6. Three of the 44 LF1 observation wells (7 percent) had the mean absolute error greater than the interval criteria and all three occurred where the observed water quality exceeded 19,000 mg/L. The three wells not meeting the criteria were NMC-MW1B in Martin County, WP-MW1B in St. Lucie County, and CC-MW1B in Broward County. The LF1 scatter plot shows a horizontal cluster of points with simulated TDS values higher than observed data. These points are from monitor well NMC-MW1B where the simulated TDS values were relatively constant during the simulation while observed data showed TDS decreasing with time. Observed data at this well may have been compromised by multi-zone mixing of the water samples tested. The other two wells show fluctuations in water quality not being simulated by the model, suggesting an additional flux not being properly simulated by the model, possibly associated with the deep well injection of wastewater.

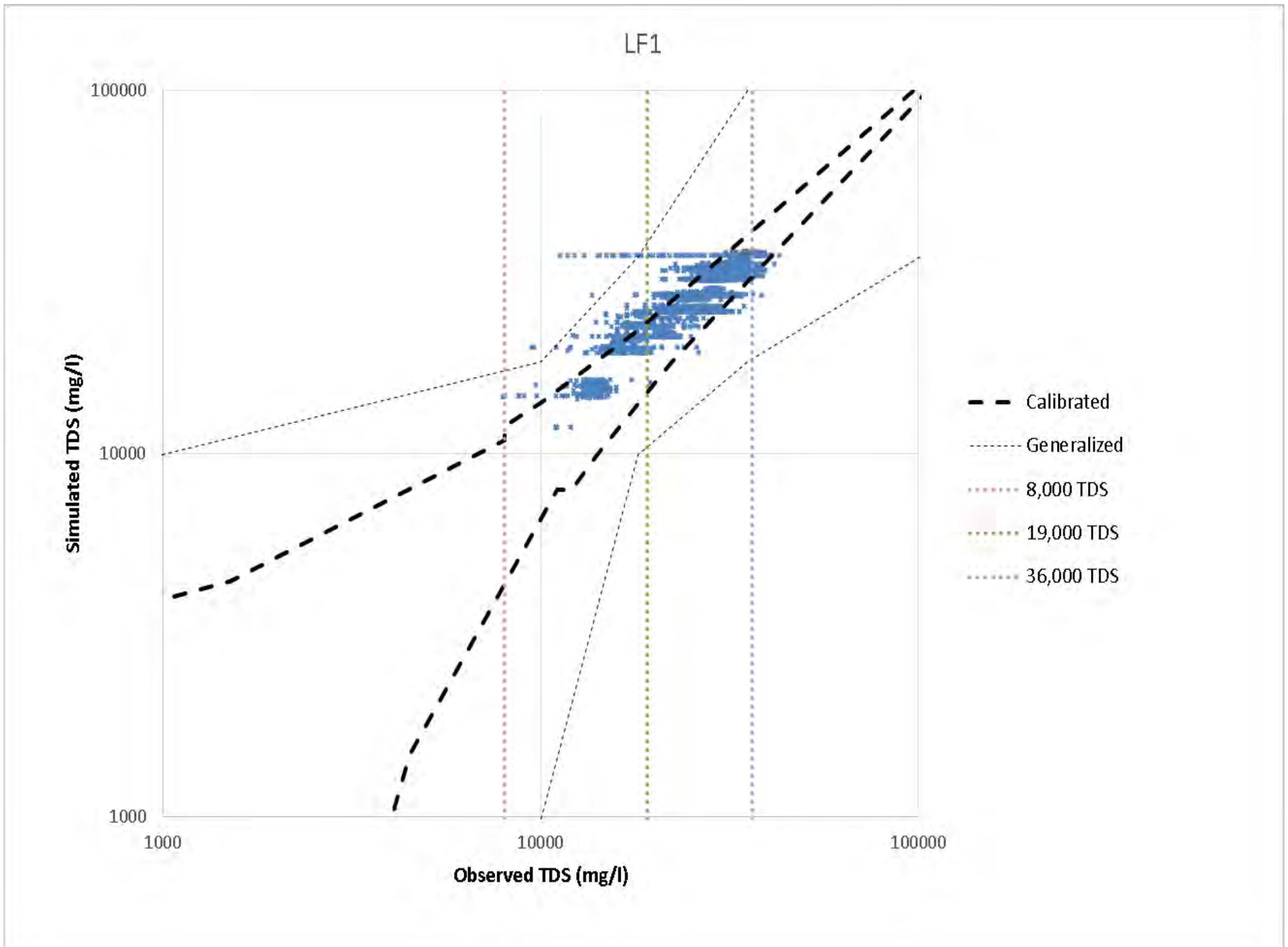

Figure 5.3-18. Scatter Plot of Observed vs. Simulated TDS in the LF1

Table 5.3-6. Percentage of Number of TDS Observations outside Calibration Criteria

Aquifer	TDS range (mg/L)	No. of Records	Desirable Interval Criteria (± mg/L)	% of Aquifer Total Records Outside Desirable Interval
Upper Floridan Aquifer (UFA)	0 - 4,000	3,453	500	9%
	4,000 - 36,000	1,508	750	4%
Avon Park Permeable Zone (APPZ)	0 - 2,000	37	750	0%
	2,000 - 8,000	3,351	1,000-2,000	5%
	8,000 - 36,000	1,095	4,000	7%
Lower Floridan Aquifer First Permeable zone (LF1)	0 - 19,000	545	4,000	0%
	19,000 - 36,000	3,513	4,000	4%

Tables 5.3-7, 5.3-8, and 5.3-9 summarize the TDS calibration statistics for each observation site in the UFA, APPZ, and LF1, respectively. The interval criteria presented in these tables were defined based on the mean observed value while in the scatter plots they were defined based on each observed value.

According to Table 5.3-7, the UFA average values for mean absolute error and standard deviation were 230 mg/L and 152 mg/L, respectively. Overall, 96 out of 106 (91 percent) TDS values for UFA groundwater wells are within the desirable criteria, varying from 500 to 750 mg/L for more than 80 percent of the simulation period.

According to Table 5.3-8, the APPZ average values for mean absolute error and standard deviation were 1,098 mg/L and 536 mg/L, respectively. Overall, 59 out of 68 (87 percent) TDS values for APPZ wells are within the desirable interval criteria, varying from 500 to 4,000 mg/L for more than 80 percent of the simulation period.

According to Table 5.3-9, the LF1 average value for mean absolute error and standard deviation were 2,008 mg/L and 1,429 mg/L, respectively. Overall, 41 out of 44 (93 percent) TDS values for LF1 groundwater wells are within the ±4,000 mg/L interval for more than 80 percent of the simulation period.

Table 5.3-7. Statistics at Each Monitoring Site for Water Quality in the UFA

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (±mg/l)	% of Observations (within ±interval criteria)
BCN-MW1A	Broward	224	242	153	4334	-4	126	94	750	100
BF-4S	Broward	7	255	150	8259	126	409	244	750	85
DEER-FA2	Broward	15	235	156	4669	181	192	125	750	100
G-2619	Broward	16	256	62	2131	-231	231	139	500	100
HOLLY-F13	Broward	27	278	151	4230	-160	253	153	750	100
HOLLY-F5	Broward	42	279	150	4043	-94	254	386	750	92
HOLLY-F6	Broward	14	279	150	3965	31	238	156	500	100
HW-MW1A	Broward	80	280	151	4242	-49	122	97	750	100
PP-MW1A	Broward	244	282	130	3183	78	233	230	500	96
CLEWRO-PW1	Hendry	2	169	47	2650	-10	50	14	500	100
HIF-0006	Hendry	5	92	21	417	-231	378	168	500	84
L2-PW2	Hendry	17	190	45	1714	36	138	100	500	100
IR0312	Indian River	22	43	115	729	125	131	73	500	100
IR0921	Indian River	18	12	91	1753	-96	107	88	500	100
IR0963	Indian River	20	25	104	1174	-224	224	71	500	100
IR-1006	Indian River	22	32	115	641	-104	104	41	500	100
IR-1058	Indian River	16	34	122	1169	-60	62	44	500	100
IR-1183	Indian River	12	12	109	451	106	106	32	500	100
IR-1202	Indian River	9	33	72	735	25	74	39	500	100
IR-916	Indian River	12	14	97	1052	-12	43	32	500	100
IR-954	Indian River	21	41	95	574	-236	236	27	500	100
IR-955	Indian River	20	30	88	819	-117	117	34	500	100
IR-968	Indian River	19	23	68	1457	-77	92	101	500	100
IR-988	Indian River	17	16	119	472	-5	22	18	500	100
IRP-1	Indian River	55	98	149	2243	265	297	191	500	85
OS-MW1B	Indian River	103	41	108	1741	-177	204	137	500	98
VB-MW1	Indian River	2	31	119	2555	-535	535	35	500	0
MCSU-F1	Martin	63	122	157	3476	-615	643	201	500	71
MF-31	Martin	35	108	150	2301	118	171	167	500	94
MF-37U	Martin	6	131	92	1571	-161	161	64	500	100
MF-40U	Martin	7	99	109	2297	103	143	135	500	100
MF-52	Martin	14	117	122	2329	-29	142	117	500	100
MF-9	Martin	27	105	111	2756	44	229	129	500	96
NMC-MW1A	Martin	259	93	138	2103	2190	2190	857	500	0
SAIL-2	Martin	7	104	152	2867	-568	601	249	500	14
ST-UA	Martin	232	100	140	4681	-181	248	213	750	95

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (±mg/l)	% of Observations (within ±interval criteria)
MCSU-F2	Martin	61	122	156	3211	-167	226	219	500	98
DF-4	Miami-Dade	17	295	111	3703	87	118	144	500	100
ENP-100	Miami-Dade	15	375	93	5414	-473	485	248	750	86
MDASR-MW1A	Miami-Dade	81	327	111	1649	-227	529	413	500	60
MDN-FA1A	Miami-Dade	114	293	155	4248	-48	272	181	750	98
MDS-FA1A	Miami-Dade	251	349	129	1805	-306	306	144	500	92
FOURK-E	Okeechobee	36	65	30	452	8	173	91	500	100
FOURK-W	Okeechobee	46	66	28	382	58	107	56	500	100
OK-0001	Okeechobee	11	51	65	375	163	163	14	500	100
OKF-100U	Okeechobee	5	107	56	843	-37	112	96	500	100
OKF-17	Okeechobee	8	79	49	546	4	30	32	500	100
OKF-23	Okeechobee	2	92	58	942	-62	62	30	500	100
OKF-39	Okeechobee	5	90	57	995	7	27	17	500	100
OKF-42	Okeechobee	17	69	23	417	-17	27	19	500	100
OKF-7	Okeechobee	2	75	67	248	7	29	10	500	100
OKF-71	Okeechobee	3	51	73	1622	-166	186	253	500	100
OKF-72	Okeechobee	3	54	74	802	158	158	130	500	100
OKF-81	Okeechobee	2	54	20	421	-11	11	16	500	100
OKF-94	Okeechobee	2	68	71	316	-6	6	6	500	100
TCRK_GW1	Okeechobee	14	94	67	600	-161	166	97	500	100
OS-231	Osceola	11	5	44	375	-15	15	10	500	100
OSF-104U	Osceola	4	30	20	217	23	31	25	500	100
OSF-52	Osceola	7	8	12	801	-10	105	91	500	100
OSF-60	Osceola	3	25	52	381	-27	33	40	500	100
POF-20R	Osceola	4	30	20	255	-15	15	6	500	100
BB-MW1A	Palm Beach	209	203	166	3832	66	168	165	500	99
BOYRO_EPXU	Palm Beach	7	206	162	3975	25	167	81	500	100
EVERCLUB	Palm Beach	74	176	169	3165	35	129	132	500	100
HB-TPW1	Palm Beach	13	219	166	7621	-5	8	4	750	100
JUP-RO1	Palm Beach	111	140	156	4208	-1139	1194	890	750	27
JUP-RO12	Palm Beach	24	144	150	4161	65	422	356	750	79
LW-F1	Palm Beach	18	189	165	4170	-259	264	239	750	100
LW-F2	Palm Beach	18	188	165	4247	-299	304	341	750	94
LW-F3	Palm Beach	18	188	164	4179	-224	224	155	750	100
MAN-15	Palm Beach	66	194	167	4715	-819	972	608	750	48
PB-1196U	Palm Beach	2	146	157	3685	-85	205	120	500	100
PBC-RRF1A	Palm Beach	89	169	157	4435	-35	140	133	750	98
PBC-SR1A	Palm Beach	168	207	152	5200	-100	184	118	750	100

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (±mg/l)	% of Observations (within ±interval criteria)
PBF-10R	Palm Beach	17	227	134	5388	-98	323	346	750	88
PBF-15U	Palm Beach	7	170	125	3338	-1	88	85	500	100
PBF-3	Palm Beach	20	179	160	4565	-153	361	158	750	100
PW-MW1A	Palm Beach	172	144	133	3087	-87	191	192	500	98
SCU-MW1A	Palm Beach	196	151	161	6053	-312	412	456	750	81
TEQ-RO1	Palm Beach	111	135	162	4208	-492	769	776	750	65
TEQ-RO3	Palm Beach	50	136	161	3740	-56	515	334	500	78
FP-FB1	St Lucie	75	63	126	751	-72	78	63	500	100
FP-FB3	St Lucie	79	62	126	860	-178	178	78	500	98
FP-MW1A	St Lucie	181	71	123	1986	70	111	91	500	99
PSL-F1	St Lucie	46	83	127	1773	138	141	107	500	97
PSL-F2	St Lucie	51	84	128	2108	44	67	54	500	100
PSL-F4	St Lucie	47	84	129	2226	-20	61	54	500	100
PSL-F5	St Lucie	51	83	129	2194	-123	130	61	500	100
PSLNP-MW1A	St Lucie	243	79	126	2413	-161	222	191	500	88
PSLSP-MW1A	St Lucie	180	92	133	3009	-251	325	263	500	91
SLF-11	St Lucie	26	49	95	2043	-22	170	171	500	96
SLF-21	St Lucie	34	65	119	872	-2	77	65	500	100
SLF-60	St Lucie	13	87	92	2405	-98	372	362	500	61
SLF-62	St Lucie	26	86	110	2977	-124	273	225	500	73
SLF-62B	St Lucie	10	83	113	2385	93	151	104	500	100
SLF-63	St Lucie	2	57	91	1849	372	490	525	500	50
SLF-64	St Lucie	2	52	89	2670	-170	330	240	500	50
SLF-65	St Lucie	3	49	87	2395	-245	276	208	500	100
SLF-66	St Lucie	2	64	99	1691	-171	699	242	500	0
SLF-67	St Lucie	2	73	85	943	363	363	5	500	100
SLF-69	St Lucie	9	75	113	1644	139	188	85	500	100
SLF-75	St Lucie	26	79	107	2130	376	422	165	500	57
SLF-9	St Lucie	22	62	94	3097	-85	268	203	500	100
STL-215	St Lucie	2	56	114	2280	50	100	71	500	100
STL-352	St Lucie	2	54	132	2505	20	30	28	500	100
STL-376	St Lucie	2	49	119	934	191	191	17	500	100

Table 5.3-8. Statistics at Each Monitoring Site for Water Quality in the APPZ

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (± mg/L)	% of Observations (within ±-interval criteria)
BCN-MW1B	Broward	147	242	153	6629	-561	600	395	2000	98
BF-4M	Broward	8	255	151	4952	361	361	157	2000	100
CC-MW1A	Broward	80	272	134	4599	-132	548	380	2000	100
CS-MW1B (2B)	Broward	182	244	139	5767	-400	532	427	2000	98
DF-MW1A	Broward	21	233	158	7837	-617	682	392	2000	100
FEETL-MW1B	Broward	182	267	157	9499	-453	573	440	4000	100
FEETL-PD1A	Broward	41	266	148	5175	-136	211	128	2000	100
G-2617	Broward	17	256	63	2558	-1058	1058	79	1000	11
HAL-MW1A	Broward	40	283	154	5903	99	420	491	2000	97
MIR-MW1A	Broward	153	283	130	4262	216	363	254	2000	100
MIR-RO1A	Broward	164	286	131	6497	-210	589	582	2000	95
MIRWW-MW2A	Broward	28	282	129	4288	186	634	553	2000	96
PB-MW1A	Broward	85	244	158	5513	-214	477	403	2000	98
PLC-MW1A	Broward	82	262	138	4522	13	116	118	2000	100
PLE-MW1A	Broward	114	262	143	4330	-212	281	326	2000	100
PL-MW2A	Broward	196	260	143	3793	-16	101	101	2000	100
SG-MW1A	Broward	95	262	129	3460	-233	240	124	2000	100
L2-PW1	Hendry	15	190	45	1993	235	246	225	500	80
IR1163	Indian River	9	33	72	1851	50	127	89	500	100
OS-MW1C	Indian River	67	41	108	12342	-2150	2553	1433	4000	86
MCTF-F1	Martin	52	114	138	3623	1318	1318	477	2000	96
MCTF-F2	Martin	53	115	138	3494	936	958	368	2000	100
MCTF-F3	Martin	54	115	139	3730	1122	1122	321	2000	100
MCTF-F4	Martin	54	116	139	3345	1165	1165	296	2000	98
MCTF-F5	Martin	52	116	139	3070	1445	1445	234	2000	96
MF-35B	Martin	18	131	108	3598	-100	227	186	2000	100
MF-37L	Martin	7	131	92	3461	-814	814	158	2000	100
MF-40L	Martin	7	99	109	2489	14	137	57	1000	100
ST-MW2	Martin	178	100	140	9218	-5850	6167	3809	4000	33
DF-5	Miami-Dade	17	295	111	3307	81	121	95	2000	100
FKAA-MW1A	Miami-Dade	31	366	106	14284	-405	644	1093	4000	96
MDASR-MW1B	Miami-Dade	110	327	111	5209	-80	335	288	2000	100
MDN-FA1B	Miami-Dade	111	293	155	20515	-1009	2168	1361	4000	91
MDS-BZB	Miami-Dade	169	350	130	8881	-190	517	500	4000	100
NMB-MW1A	Miami-Dade	30	289	146	15427	723	1979	1196	4000	96
LARGO-MW1B	Monroe	5	420	114	20600	-360	576	250	4000	100
OKF-100L	Okeechobee	5	107	56	956	30	99	86	500	100

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (± mg/L)	% of Observations (within ±-interval criteria)
OKF-105M	Okeechobee	2	69	23	1483	-758	758	24	500	0
OKF-73	Okeechobee	2	82	64	4495	521	521	579	2000	100
OKF-74	Okeechobee	3	84	67	3929	265	265	213	2000	100
TCRK-GW2	Okeechobee	14	94	67	4738	169	765	390	2000	100
OSF-104M	Osceola	6	30	20	252	31	52	18	500	100
ACME-1A	Palm Beach	225	185	144	5058	31	446	289	2000	99
BG-MW1A	Palm Beach	204	176	81	3082	1021	1040	591	2000	94
ENC-MW1B	Palm Beach	22	141	155	3628	760	760	327	2000	100
EN-MW1A	Palm Beach	95	142	155	3917	1547	1552	490	2000	83
JUP-RO6	Palm Beach	22	141	153	7622	788	1963	1096	2000	68
LR-TP1	Palm Beach	37	168	81	7297	-3694	3719	2354	2000	24
LR-TP-4	Palm Beach	22	169	81	5795	-1795	1887	1189	2000	50
LR-TP7	Palm Beach	36	170	81	8211	-4297	4297	1615	4000	33
PB-1196L	Palm Beach	2	141	153	8115	-3750	3750	240	4000	100
PBC-RRF1B	Palm Beach	217	169	157	7056	81	657	568	2000	98
PBC-SC1A	Palm Beach	9	209	163	9673	327	549	468	4000	100
PBC-SR1B	Palm Beach	182	207	152	13303	-3543	3543	1245	4000	54
PBF-11	Palm Beach	16	227	134	2552	344	384	178	1000	100
PBF-15M	Palm Beach	7	170	125	3182	-1350	1350	508	2000	85
PBF-4	Palm Beach	18	179	160	4084	-566	566	220	2000	100
PBF-7	Palm Beach	18	176	77	2818	1347	1347	186	1000	5
PH-MW1A	Palm Beach	239	160	84	3731	-250	322	257	2000	99
WE-MW1A	Palm Beach	30	181	143	9149	-731	881	595	4000	100
PSL-F6	St Lucie	75	84	126	3570	714	720	292	2000	100
PSLJA-MW1A	St Lucie	79	74	119	6319	-2927	2927	1040	2000	16
PSLSP-MW1B	St Lucie	44	92	133	2862	-107	264	258	1000	97
SLF-14	St Lucie	26	79	96	2467	1637	1637	289	1000	3
SLF-74	St Lucie	26	79	107	4554	-666	707	477	2000	96
SLW-F2	St Lucie	61	83	122	3647	-401	494	428	2000	100
STL-380	St Lucie	2	79	107	4265	-440	440	552	2000	100
TP-MW1A	St Lucie	62	72	119	9047	-5564	5564	1622	4000	19

Table 5.3-9. Statistics at Each Monitoring Site for Water Quality in the LF1

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (±mg/L)	% of Observations (within ±interval criteria)
BCN-MW1C	Broward	75	242	153	30628	-311	2402	1352	4000	86
BF-1	Broward	6	255	151	34388	-69	1119	870	4000	100
CC-MW1B	Broward	76	272	134	28724	3591	4963	2498	4000	34
FEETL-MW2B	Broward	32	267	157	33102	-789	1426	653	4000	100
FEETL-PD1B	Broward	39	266	148	33257	505	1050	735	4000	100
HAL-MW1B	Broward	37	283	154	33216	343	1612	1511	4000	89
HW-MW1B	Broward	53	280	151	34976	24	609	452	4000	100
MIR-RO1B	Broward	150	286	131	33033	-1004	1428	1385	4000	96
PB-MW1B	Broward	57	244	158	33313	-376	1819	1383	4000	94
PLC-MW1B	Broward	76	262	138	21100	420	546	348	4000	100
PLE-MW1B	Broward	111	262	143	28807	-358	512	430	4000	100
PL-MW2B	Broward	98	260	143	26944	466	690	706	4000	97
PP-MW1B	Broward	213	282	130	28926	1166	2176	1860	4000	83
OS-MW1D	Indian River	202	41	108	31406	-331	1866	1432	4000	90
NMC-MW1B	Martin	208	93	138	32565	2530	4403	5947	4000	73
STU-MZL	Martin	228	100	140	31434	382	1399	1134	4000	95
TF-MW1A	Martin	40	115	138	21270	1140	2016	1291	4000	97
MDS-FA1B	Miami-Dade	248	349	129	33711	-689	1215	1084	4000	97
OKLF-MW1A	Okeechobee	25	79	80	17964	1658	3877	2937	4000	52
OKU-MW1A	Okeechobee	8	85	64	11125	668	720	206	4000	100
ACME-1B	Palm Beach	177	185	143	25629	-1129	3132	2049	4000	63
BB-MW1B	Palm Beach	143	203	166	27415	-184	865	761	4000	98
BG-MW1B	Palm Beach	176	176	81	13701	1383	1484	1183	4000	96
CL-MW1A	Palm Beach	50	172	46	16964	2013	2367	1795	4000	82
LR-MW1A	Palm Beach	37	172	82	17259	2179	2189	1016	4000	97
LW-MW1B	Palm Beach	2	189	165	34200	-260	900	368	4000	100
PBC-RRF2A	Palm Beach	132	169	157	24063	947	1838	1421	4000	90
PBC-SC1B	Palm Beach	9	209	163	34078	-2747	2820	1885	4000	66
PBF-12	Palm Beach	15	227	134	29550	750	1250	969	4000	100
PBF-15L	Palm Beach	4	170	125	33663	-3226	3226	680	4000	100
PBF-5	Palm Beach	18	179	160	32692	-209	1425	959	4000	100
PBF-7L	Palm Beach	18	176	77	13936	352	580	465	4000	100
PH-MW1B	Palm Beach	213	160	84	19371	1629	2287	1490	4000	88
PW-MW1B	Palm Beach	154	144	133	31973	-1097	1618	1536	4000	91
WE-MW1B	Palm Beach	38	181	143	25976	-586	2273	1801	4000	84
FPML-MW1B	St Lucie	30	71	122	25039	1553	1726	937	4000	100
FP-MW1B	St Lucie	181	61	131	24820	237	1971	1467	4000	91

Well Name (Station ID)	County	Number of Observations	ROW	COL	Mean Observed TDS (mg/L)	Mean Error (mg/L)	Mean Absolute Error (mg/L)	Standard Deviation (mg/L)	Desirable Interval Criteria (±mg/L)	% of Observations (within ±interval criteria)
PSLG-MW1B	St Lucie	23	78	112	33300	30	2781	2653	4000	78
PSLJA-MW1B	St Lucie	82	74	119	26595	767	3152	2200	4000	68
PSLNP-MW1B	St Lucie	231	79	126	18302	3667	3903	1932	4000	50
PSLSP-MW1C	St Lucie	159	92	133	25130	1838	3429	2242	4000	62
SLW-MW1B	St Lucie	51	83	121	35737	28	1176	1007	4000	98
TP-MW1B	St Lucie	60	72	119	26583	1187	1699	1220	4000	96
WP-MW1B	St Lucie	73	94	126	29771	2139	4408	2619	4000	42

5.3.4.3 Summary

Tables 5.3-10 and 5.3-11 summarize the calibration statistics achieved in the calibrated ECFM. These data confirm that the desired 20 percent maximum error was achieved.

Table 5.3-10. Summary of Statistics for Heads

Aquifer	No. of Well Sites	No. of Records	% of Records Outside ± 2.0 feet Interval	% of Records Outside ± 4.0 feet. Interval	% of Sites with less than 2 feet. Mean Absolute Error	% of Sites within ± 2 feet. Interval for more or equal than 80%
UFA	111	6,518	15%	2%	90%	80%
APPZ	27	1,833	22%	3%	81%	78%
LF1	6	495	9%	5%	83%	83%
All Aquifers	144	8,846	16%	2%	88%	80%

Table 5.3-11. Summary of Statistics for Water Quality

Aquifer	No. of Well Sites	No. of Records	Desirable Interval Criteria (± mg/L)	% of Records Outside Desirable Interval	% of Sites within desirable interval for more or equal than 80%
UFA	106	4,961	500-750	14%	91%
APPZ	68	4,483	500-4,000	12%	87%
LF1	44	4,058	4,000	4%	93%
All Aquifers	218	13,502	500-4,000	10%	90%

The mean absolute error obtained in the transient calibration improves upon the previous calibration results achieved by HydroGeoLogic (2006) and by Golder (2008). Tables 5.3-12 and 5.3-13 summarize the mean absolute error for the water levels and for TDS concentrations, respectively, compared with previous models. It also suggests that the head error is not overly biased toward any aquifer.

Table 5.3-12. Global Mean Absolute Error for Heads Compare with Previous Models

Model	ECFAS Phase I (HydroGeoLogic 2006)		ECFAS Phase II (Golder 2008)		ECFM	
Aquifer	No. of Records	1999-2004	No. of Records	2005	No. of Records	1989-2012
UFA	1,368	2.00			6,518	1.31
APPZ					1,833	1.34
LF1	118	1.20			495	1.35
All Aquifers		1.84	827	2.52	8,846	1.32

Table 5.3-13. Global Mean Absolute Error for TDS Concentrations Compare with Previous Models

Model	ECFAS Phase I (HydroGeoLogic 2006)		ECFAS Phase II (Golder 2008)		ECFM	
Aquifer	No. of records	1999-2004	No. of records	2005	No. of records	1989-2012
UFA	86	841	205	665	4,961	242
APPZ	22	800		2,065	4,483	1,098
LF1	15	4,970		10,360	4,058	2,008

5.4 Transient Flow Budget Analysis

There is minimal water exchange between the Floridan aquifer system and the overlying surficial aquifer system over the entire southern and central portion of the model domain due to confinement in the Hawthorn Group sediments that separate these two aquifer systems. Some interaction between the FAS and the SAS occurs in the extreme northern portion of the model domain in Polk, Osceola, Okeechobee, and Highlands counties. Besides lateral freshwater recharge entering the model from the boundary conditions specified along the northwestern portion of the model, recharge from rainfall is also spatially accounted for using the recharge package.

The average rainfall for the simulation period at the Bassinger rain gauge located in the vicinity of the primary recharge area of the model is approximately 49.2 inches/year. Simulated recharge rates vary monthly based upon historical rainfall and vary spatially within topographic zones. The annual average recharge rate applied to the lowest recharge areas generally are between 0.1 and 1.0 inches per year, with the lower rates occurring in western Okeechobee County. Rates in the intermediate recharge zones of Highlands and Polk counties average between 1 and 5 inches/year except along the high ridge areas where it can exceed 10 inches/year.

Volumetric influxes into the model along the northwestern boundary are more difficult to quantify. Fluxes into the model were determined by the conductance term of the General Head Boundary (GHB), the head of the GHB, and the simulated stages in the active model domain adjacent to the GHBs. Heads along the boundaries were determined from the potentiometric maps generated by the USGS for May and September conditions. These maps were not available for every year of the simulation period. Observation well data adjacent to the model boundary was used for the years when the maps were not produced and for the development of monthly water levels for all years of the simulation period.

Elsewhere, model recharge and discharge can occur along the Atlantic Ocean outcrops and from the deeper Boulder Zone. Monthly tidal variations were included in the model along these boundaries using the time variant Constant Head Package of SEAWAT. Historic average monthly tides were obtained from Cape Canaveral, Virginia Key, Vaca Key, and Key West. Average tides were generally higher in the fall months and lowest in the spring months.

Figures 5.4-1, 5.4-2, and 5.4-3 show flow velocity vectors for the UFA, APPZ, and LF1, respectively, and provide a general direction of the simulated flow for February 2007, which was a below-average rainfall month and the beginning of a significant drought. Flow generally moves southeastward from the high area in Polk County towards the coast in the northern portion of the model but also radiates outward from a local high in southwestern Palm Beach County and eastern Hendry County. Flow into the model from the northwest corner in the UFA is somewhat restricted by the presences of a large topographic ridge along the west side of the Kissimmee River within the active model domain which receives recharge from rainfall. The dominant flow into the model is occurring through the APPZ in Polk and Highlands counties and to a lesser degree the LF1 in southern Highlands and northern Glades counties. This observation is consistent with the East Central Florida Transient model budget discussed in Section 2.3, which also shows the main inflow occurring in the APPZ and LF1.

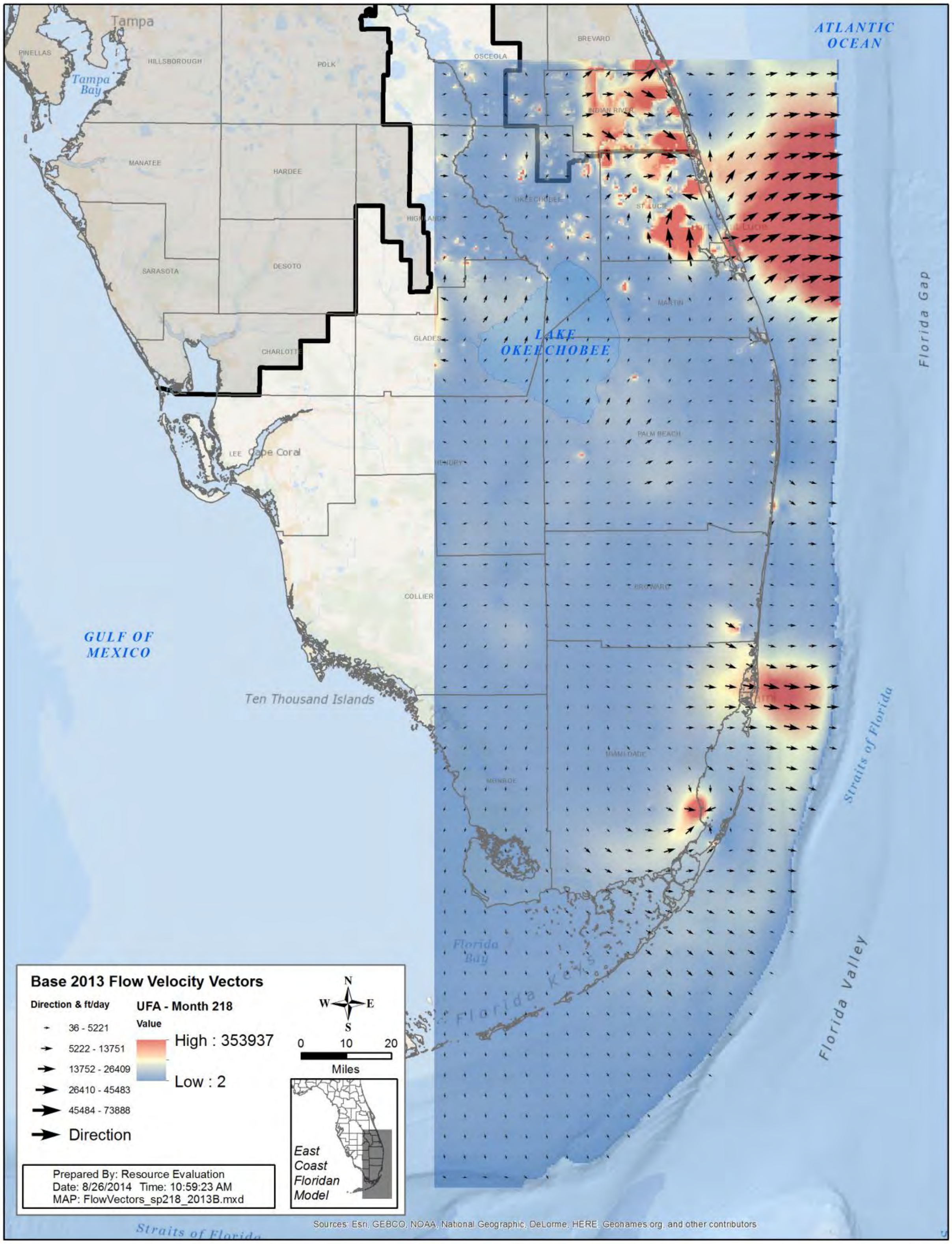

Figure 5.4-1. Simulated Flow Direction for the UFA for February 2007

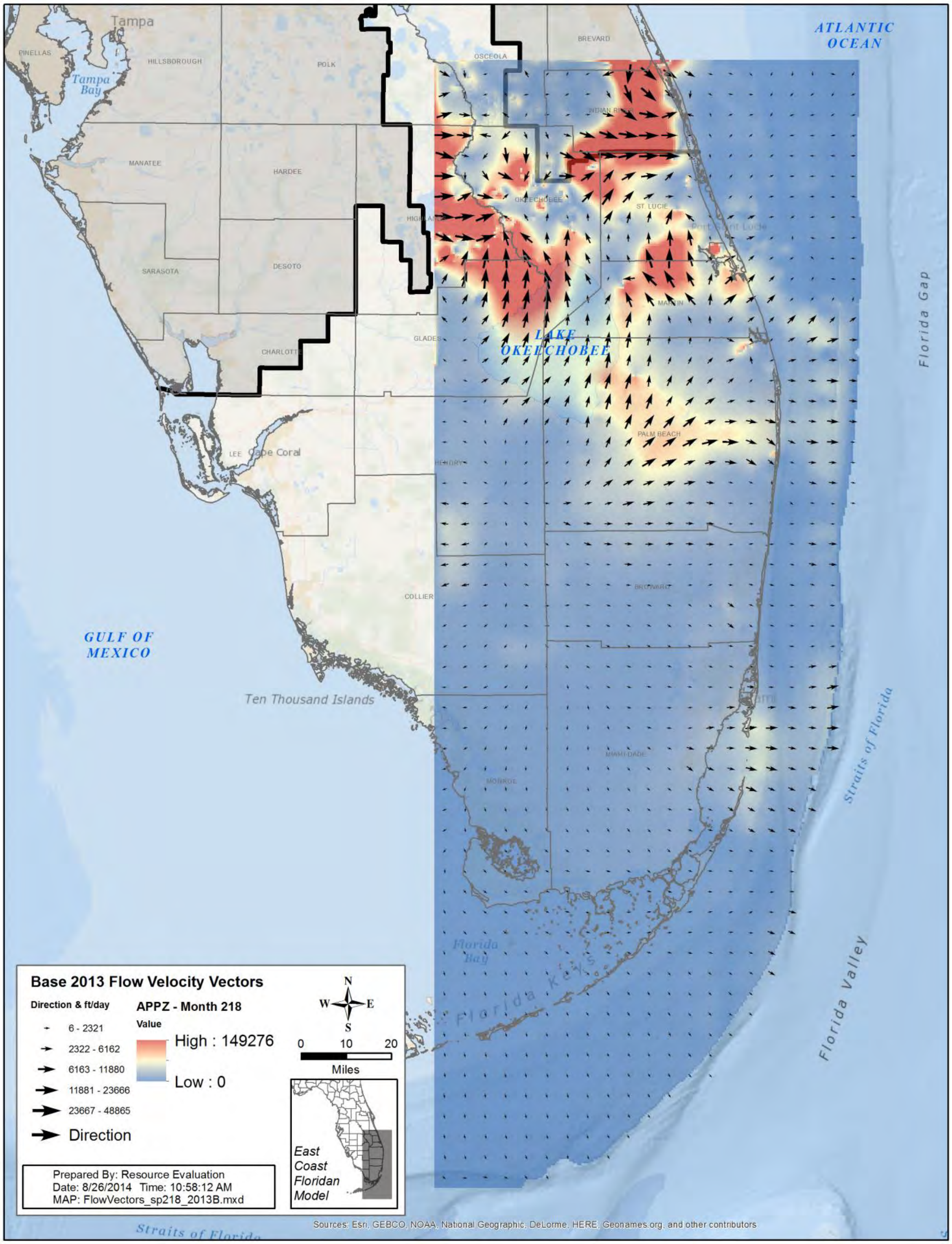

Figure 5.4-2. Simulated Flow Direction for the APPZ for February 2007

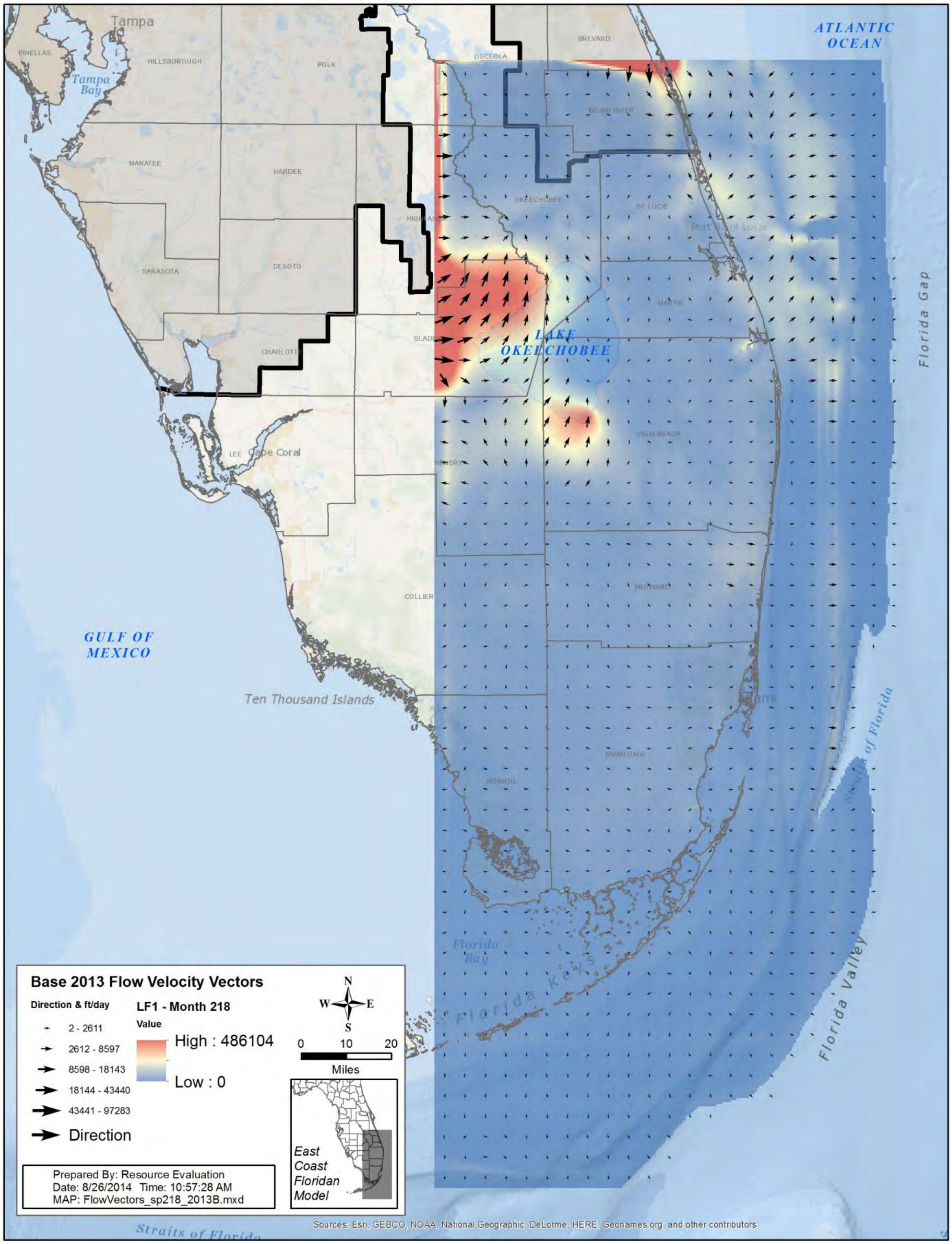

Figure 5.4-3. Simulated Flow Direction for the LF1 for February 2007

Flow within the active model domain is governed by the large pumpage centers that are predominately agricultural demands. Vectors tend to rotate toward these large irrigation withdrawals. An example of the wellfield influence can be seen in extreme south Miami-Dade County where the Florida Power & Light Turkey Point wellfield shows a distinct cone of influence with flow radiating inward from all directions along the edge of Biscayne Bay (Figure 5.4-1). Offshore, large flow vectors are suggested in all aquifers as water is discharged into the Atlantic Ocean along the outcrops.

A water budget analysis for the model provided an understanding of how water is flowing vertically and horizontally through the model. The model was divided into 10 budget zones of approximate equal size for each model layer. Generalized budget flow direction and magnitude for all layers is provided in Figured 5.4-4 and 5.4-5 by budget region. Figure 5.4-4 shows the budget with the calibration wells off and Figure 5.4-5 provides the budgets by region with the production wells on.

Under the no pumpage simulation the model suggests that recharge to the Boulder Zone from the upper units is occurring in the northwestern portion of the model. This tends to reverse in some portions of that area when agricultural withdrawals are implemented, suggesting that the groundwater withdrawals from the UFA and APPZ are being replaced in part by an upward flux from the BZ. Flow from the Polk County high also increases to offset the groundwater withdrawals. Offshore, no noticeable changes occur with and without pumpage with an upward discharge of water occurring from the BZ into the APPZ and UFA outcrops. This upward circulation of water along the coast from the Boulder Zone into the upper units of the FAS is consistent with Meyer's (1974, 1989) and Kohout's (1965) interpretation of the general flow patterns of the FAS in south Florida. Most of the movement from the BZ upwards appears related to the offshore Miami and Pourtales terraces, which have known sinkholes and other collapse features. The model also suggests that offshore discharge along the aquifer outcrops decreases southward.

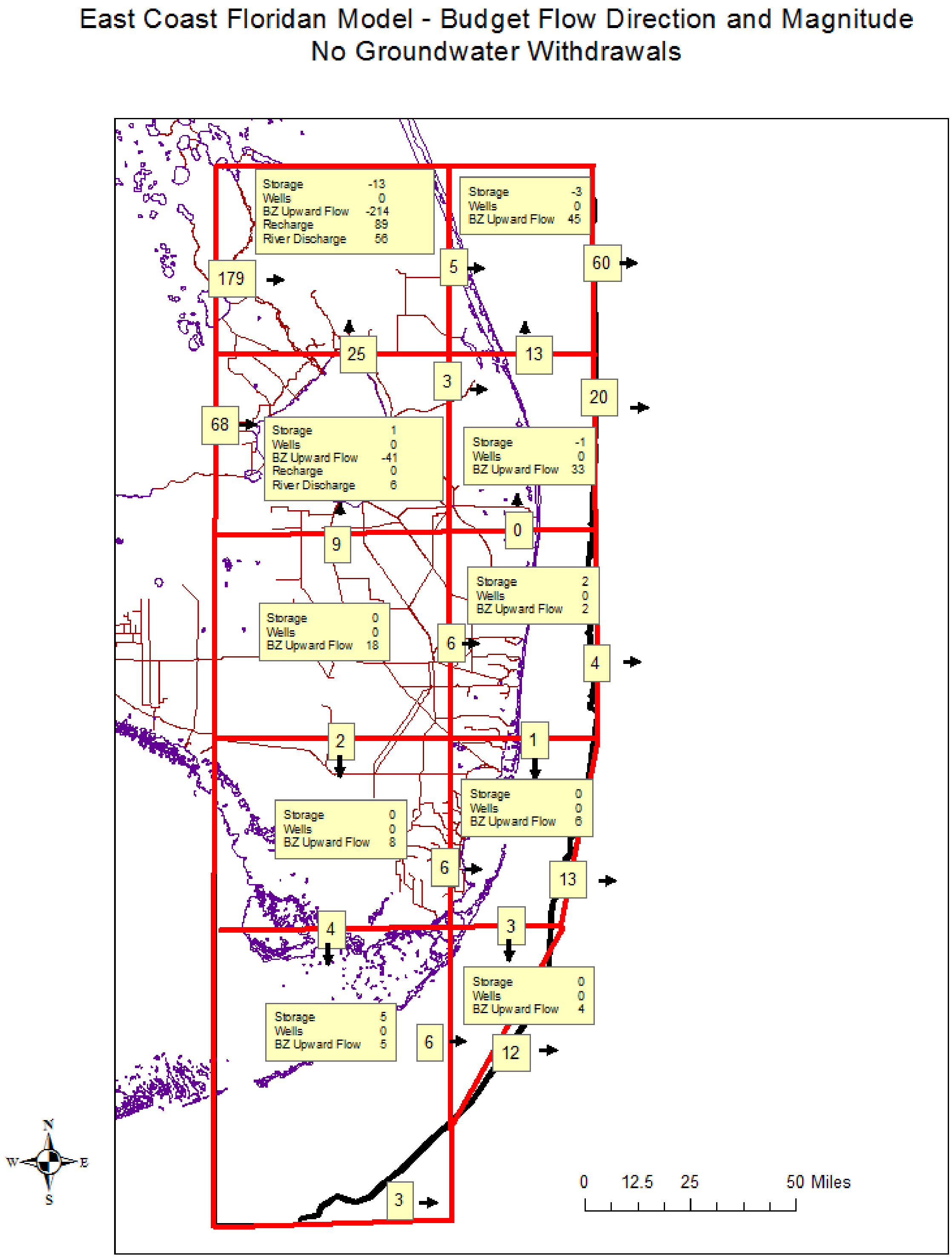

Figure 5.4-4. Flow Budget for the East Coast Floridan Model – No Pumpage

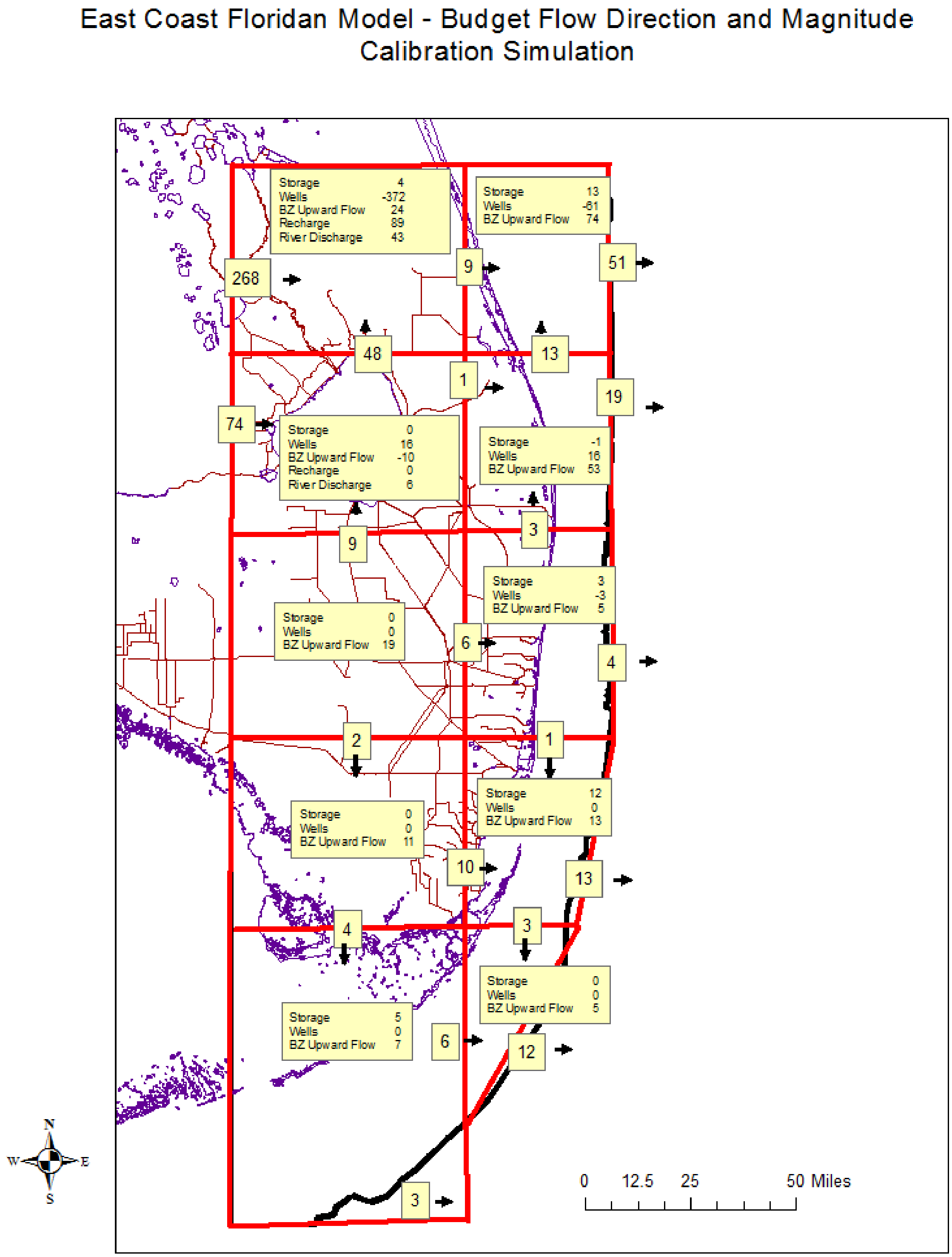

Figure 5.4-5. Flow Budget for the East Coast Floridan Model - Calibration

6.0 Sensitivity Analyses

Understanding the effects of uncertainties in parameter estimation values on model behavior is crucial to the successful use of groundwater models. Global sensitivity analysis (GSA) can be used to quantify the variability in model predictions resulting from uncertainty in parameters driving this groundwater system. The GSA was performed using the GSA++ program (Welter 2014, in press), which is a recent addition to the PEST++ inverse modeling tool kit to determine which parameters dominate ECFM response with respect to heads. The sensitivity analysis was completed using the 1989–2012 transient uncoupled model.

This analysis is performed using the Method of Morris (Morris 1991): a randomized approach that evaluates the impact to the model by changing one factor at a time (OAT). An extension of the Method of Morris (Sin and Gernaey 2009) was also used to ensure a reliable screening of important factors in the ECFM. This method ranks the parameters' importance on each of the model output point head targets. An output file sensitivity measure for each parameter of the model whose magnitude indicates the importance of the primary model parameters that were evaluated in the GSA includes horizontal hydraulic conductivity in the aquifers and the vertical hydraulic conductivity in the confining units. The constant heads in the Boulder Zone, the bottom model layer, were also included as model parameters in the sensitivity analysis.

The Pilot Point technique was used to obtain the spatial distribution for all the parameters. GSA evaluates model output response in relation to change of input parameters through the entire range of the input parameter. The ranges for the hydraulic conductivities were selected based on the intervals used in the PEST calibration. The ranges for the constant head in the BZ were based on aquifer storage and recovery modeling (USACE 2010) conducted in the area and the values used in the ECFM. The BZ heads from the ASR modeling were not measured heads, but were estimated as a function of the density differential due to the large change in temperature across the BZ.

The model simulations for GSA can be visualized as a treatment matrix. The first row of a treatment matrix uses the initial random selection of parameters with a column representing each parameter; each row differs by only one parameter from the previous row for a total of n+1 parameters. Each set of n+1 model simulations is known as a trajectory, providing one estimate of responses for each parameter (Morris 1991). Ten trajectories were used for the GSA, resulting in 6,210 model simulations [(620 parameters + 1) x 10 trajectories].

The GSA provides a qualitative estimate of the relative importance of each model parameter. The Method of Morris is used to screen out the most important parameters before more specific methods are used. The results of the GSA can be interpreted by graphing the elementary effects (mean absolute error) and higher order effects (standard deviation). The absolute mean (μ^*) magnitude represents the overall larger effect of a parameter and the standard deviation (σ) represents the degree of non-linearity and parameter interaction effects (Morris 1991). The mean absolute error and standard deviation were computed for each parameter (Figure 6.1-1). Therefore, the parameter grouping in the lower left corner of the graph indicates parameters that have little effect irrespective of other parameters.

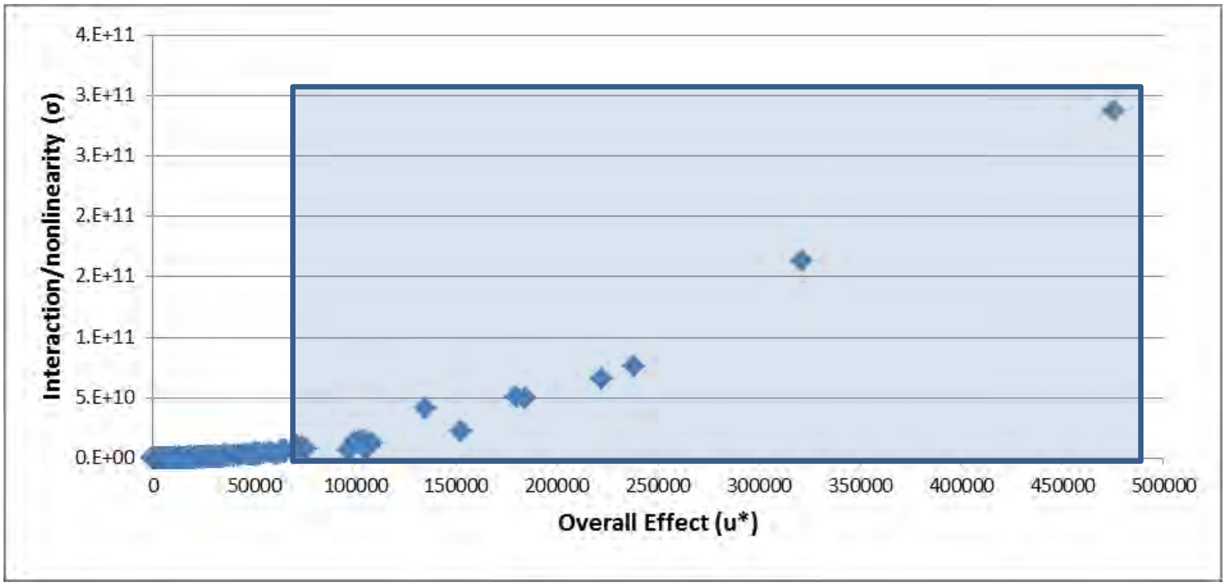

Figure 6.1-1. One at a Time (OAT) Sensitivity Measures (μ* and σ) for All Parameters (Shadowing most significant parameters)

The most sensitive parameters are shadowed in Figure 6.1-1, and are listed in order of importance in Table 6.1-1. This table also includes the initial value and ranges used in GSA for these model parameters. The GSA results indicate that the vertical hydraulic conductivities in the Lower Confining Unit (LC) are the most significant model parameters, as shown in Figure 6.1-2. The GSA also revealed sensitivity to the constant head values in the BZ, to the horizontal hydraulic conductivity in the APPZ, and to vertical hydraulic conductivities in the MC1 and MC2. It should be noted that vertical hydraulic conductivities of these units are some of the least qualified parameters in the model.

The parameters listed above were expected to be the most sensitive since each has the ability to affect water availability in the UFA, principally in Broward, Palm Beach, St. Lucie, Indian River, Okeechobee, and Highlands counties. Figure 6.1-3 shows the location of the wells with most significant changes in heads determined by the GSA. The period most sensitive to heads in the simulation was from 2007 to 2011, which corresponds to several periods of drought and water shortage in the area.

The model was tested using the most sensitive parameters indicated by the GSA. Hydraulic conductivity values and boundary head conditions were tested for model sensitivity to impact heads including:

- Constant head in the Boulder Zone by varying in space (USACE 2010)
- Lower confining unit vertical hydraulic conductivity (k_v6) by one-half and two times
- Northwestern head boundary by adding and subtracting 5 feet
- MC2 vertical hydraulic conductivity (k_v4) by one-half and two times
- APPZ horizontal hydraulic conductivity (k_h3) by one-half and two times
- MC1 vertical hydraulic conductivity (k_v2) by one-half and two times
- Ocean head boundary by adding and subtracting 1 feet

Model calibration statistics such as the mean absolute error of the heads are provided in Appendix D. The error by varying the calibrated parameter is provided relative to the error computed with the calibrated parameter. A negative value means that the change in the parameter is worsening the error in heads. A positive value means that the change in the parameter is lessening the error.

The simulated heads appear sensitive to the LC vertical hydraulic conductivity and to heads in the BZ as shown in the GSA analysis. No sensitivity to boundary conditions at the ocean head was discovered. Sensitivity to head conditions at the northwestern boundary is localized and spatially does not affect a large extent of the model. Sensitivity to vertical hydraulic conductivities of the MC1 and MC2 are localized in northern Palm Beach County (east of the C-18 canal), in St. Lucie County, and Okeechobee County. As shown with the GSA analysis, the vertical hydraulic conductivities of these units are some of the least qualified parameters in the model.

Table 6.1-1. Ranges for the Most Sensitive Parameters Determined by Global Sensitivity Analysis (ranked in order of importance)

Parameter	Name	Initial Value	Lower Bound	Upper Bound
Vertical Hydraulic Conductivity in the LC	ppkz6_r71	0.041	0.0027	0.2
Vertical Hydraulic Conductivity in the LC	ppkz6_r70	0.659	0.0029	1.3
Vertical Hydraulic Conductivity in the LC	ppkz6_a31	1.103	0.0099	2.3
Vertical Hydraulic Conductivity in the LC	ppkz6_r88	0.219	0.0017	0.8
Vertical Hydraulic Conductivity in the LC	ppkz6_r75	0.691	0.0038	1.8
Vertical Hydraulic Conductivity in the MC2	ppkz4_r35	4.000	0.0170	4.0
Constant head in the Boulder Zone	ppch7_r88	5.09	-4.2600	6.0
Vertical Hydraulic Conductivity in the LC	ppkz6_a27	0.268	0.0236	1.1
Vertical Hydraulic Conductivity in the MC2	ppkz4_r44	1.966	0.0136	4.0
Vertical Hydraulic Conductivity in the LC	ppkz6_r81	0.309	0.0034	1.2
Vertical Hydraulic Conductivity in the LC	ppkz6_r78	0.735	0.0056	2.6
Vertical Hydraulic Conductivity in the LC	ppkz6_r85	0.075	0.0021	0.3
Vertical Hydraulic Conductivity in the LC	ppkz6_r72	0.001	0.0003	0.0
Vertical Hydraulic Conductivity in the LC	ppkz6_r89	0.112	0.0024	0.4
Vertical Hydraulic Conductivity in the MC1	ppkz2_r2	0.167	0.0371	0.7
Vertical Hydraulic Conductivity in the LC	ppkz6_r74	0.006	0.0027	0.0
Vertical Hydraulic Conductivity in the MC1	ppkz2_r1	0.741	0.0318	3.0
Vertical Hydraulic Conductivity in the LC	ppkz6_r76	0.045	0.0003	0.2
Vertical Hydraulic Conductivity in the MC2	ppkz4_r36	1.072	0.0202	4.0
Vertical Hydraulic Conductivity in the LC	ppkz6_a29	0.435	0.0041	1.0
Constant head in the Boulder Zone	ppch7_a28	5.09	-3.3600	6.0
Constant head in the Boulder Zone	ppch7_r71	5.09	4.5000	9.5
Horizontal Hydraulic Conductivity in the APPZ	ppkx3_a119	437.707	64.4691	487.5

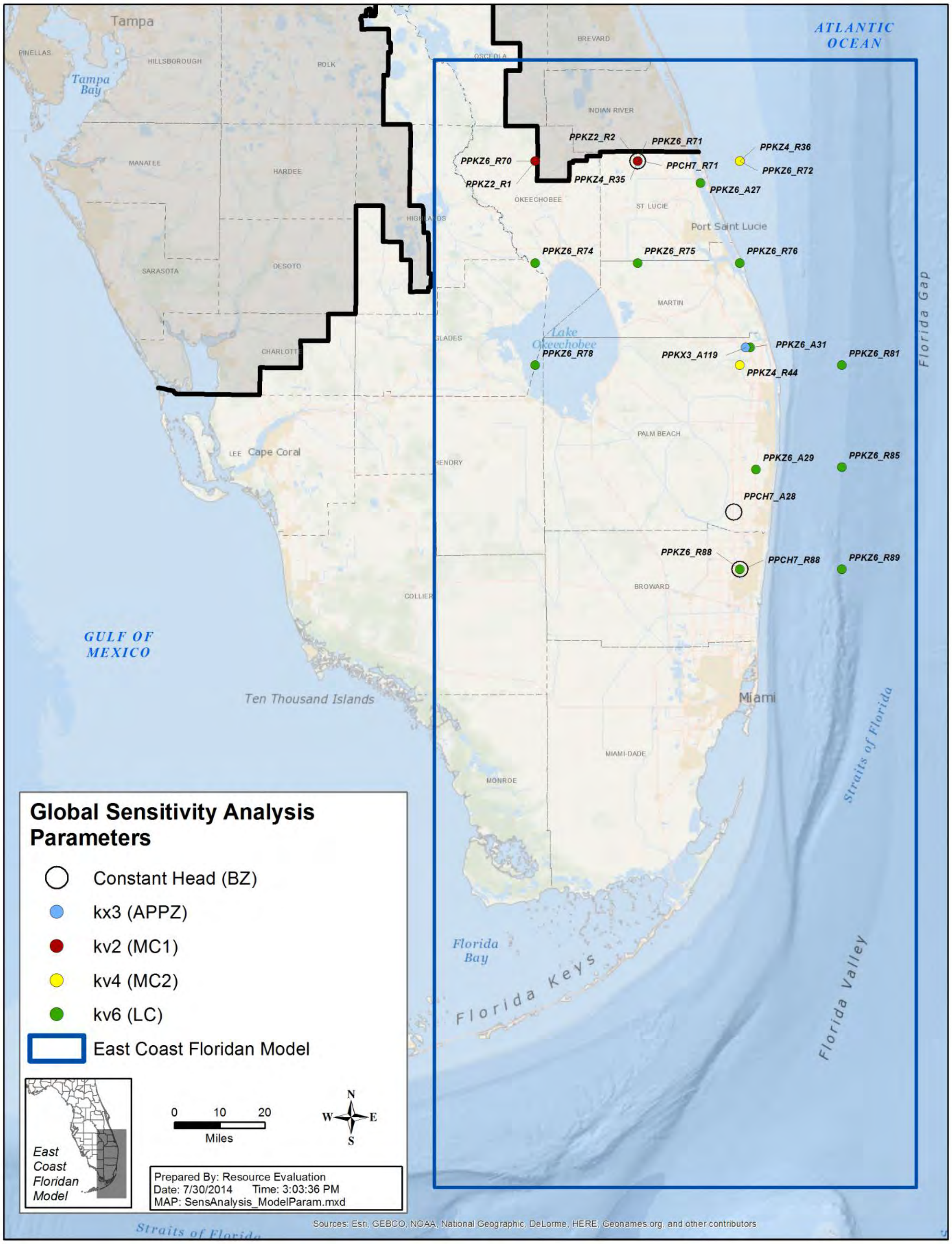

Figure 6.1-2. Location of the Most Significant Model Parameters Determined by Global Sensitivity Analysis

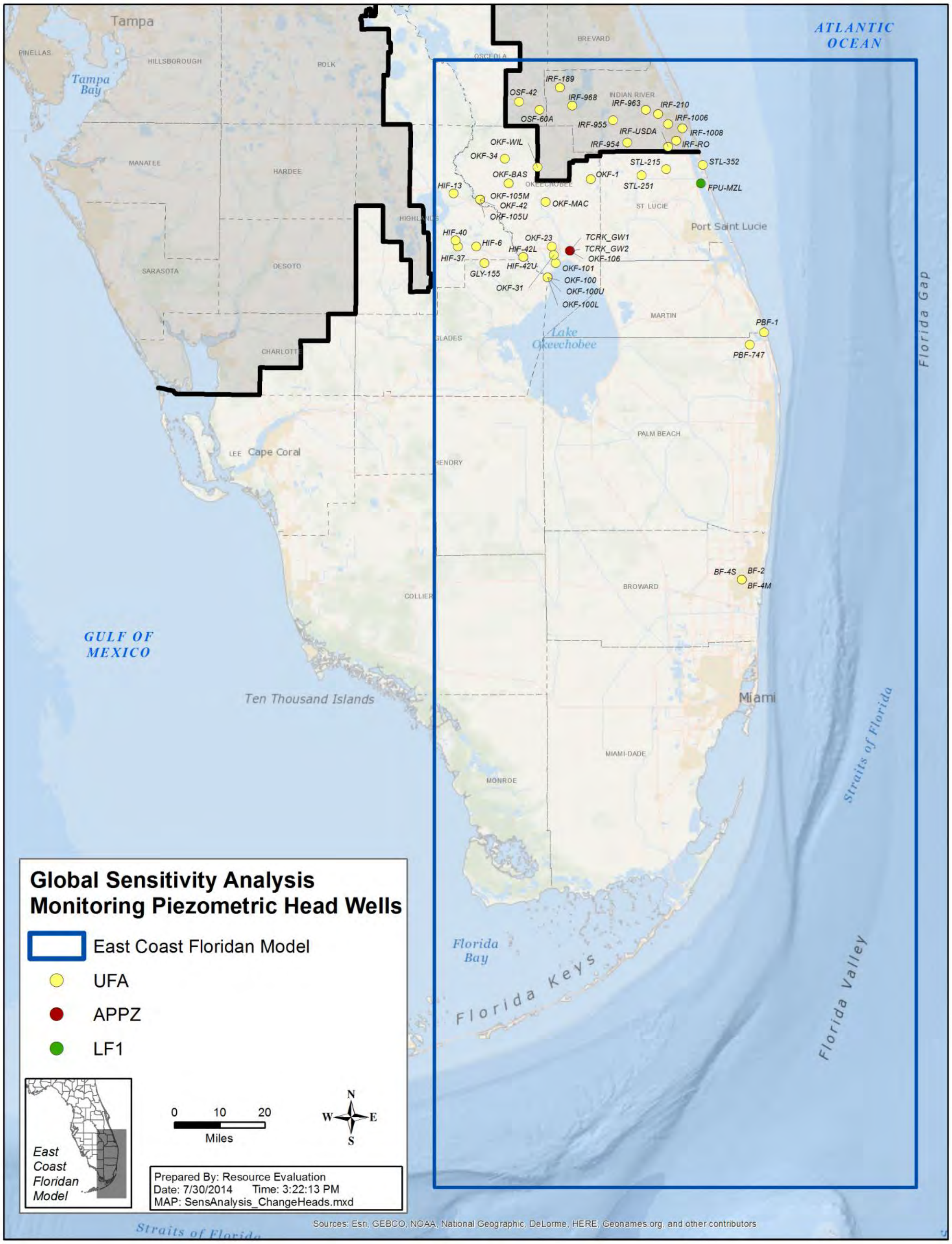

Figure 6.1-3. Location of Wells with the Most Significant Changes in Heads due to the Lower Confining Unit Parameters Determined by Global Sensitivity Analysis

Sensitivity analysis was performed for two transport parameters: dispersivity and effective porosity. The analysis was conducted manually by increasing and decreasing the values. The calibrated porosity values used in the model was 0.25 for all layers. Porosity values were increased to 0.35 and decreased to 0.15. The average Mean Absolute Error (MAE) per well change from the calibration run was minimal when the porosity was increased to 0.35, although decreasing it to 0.15 resulted in a reduction in water level calibration statistics. The water quality changes to the calibration wells observed when the porosity was varied was sporadic, although the global changes in water quality did not vary significantly, suggesting a change to the value used in the model was unwarranted at a regional level. Variations in dispersivity produced changes that were more noticeable. The dispersivity value of the model was adjusted during calibration with the final value being 50 feet across most of the model domain for all layers During the sensitivity analysis, the calibration was run with values of 2400 feet, 1200 feet, 600 feet, 300 feet, 100 feet 50 feet and 10 feet. The results suggest that dispersivity values ranging between 50 and 100 feet produced the best results for this model. In general, more rapid changes in water quality occurred at the higher dispersivity values and more flattening of water quality changes occurs at the lower values. This observation was especially true for new wellfields that had high demands imposed on the model within a short time frame. For the calibrated version of the model, the dispersivity chosen was at the lower end and may not show rapid degradation of water quality for high stress areas. Should the model be used to simulate a new wellfield with individual production wells withdrawing large quantities of water, sensitivity runs should be conducted that vary the dispersivity values around the proposed wellfield to provide a more encompassing analysis of potential water quality degradation.

7.0 Model Applications

The model was designed to provide a regional evaluation of FAS conditions in southeastern Florida. The model reasonably simulates groundwater and water quality conditions in the FAS. Caution is advised when attempting to utilize this tool for evaluations of small-scale withdrawals or where the water quality in the aquifers beneath a wellfield is unknown. Predictions of water quality changes at an existing or future wellfield may require a more detailed delineation of the local hydrogeology and initial water quality distributions. Care should also be taken when evaluating large groundwater withdrawals when the production wells are closely spaced. The model will tend to over predict water quality under these circumstances. The model can be used to evaluate water supply planning options and larger scale groundwater withdrawals. This regional model may be used to develop boundary conditions for a local-scale model to conduct evaluations of existing or proposed FAS withdrawal associated with water use permit applications.

8.0 Summary, Recommendations, and Conclusions

The SFWMD has developed the East Coast Floridan Model to simulate groundwater flow and transport in the Floridan aquifer system of southeastern Florida. The ECFM is based upon the USGS SEAWAT (Guo and Langevin 2002) computer code and builds upon earlier versions of the tool by HydroGeoLogic (2006) and Golder (2008). The ECFM now incorporates 10 key revisions as recommended by an independent peer review panel (Jacobs et al. 2011). Potential uses of the tool include water supply planning, evaluation of regional recharge projects utilizing reuse as a source of water to the FAS, aquifer storage and recovery projects of significant capacity, and construction or expansion of FAS wellfields and their effects on the aquifer system.

The model covers an area extending from Polk County in the north to the Florida Keys in the south and between the Atlantic Ocean on the east to the groundwater divide (along the spine of the Florida peninsula) on the west. Tidal water levels and ocean water TDS concentrations were assigned along the outcrops of the FAS in the Florida Straits. The Boulder Zone was also treated as a constant concentration of seawater. Freshwater recharge to the UFA occurs in the model in Polk, Highlands, Osceola, and Okeechobee counties and varies from 0 to over 10 inches per year along the high ridge areas.

One of the major accomplishments of this project was the expansion of the model into a portion of the FAS recharge area in Polk County, and the extension of the model to the outcrops in the Straits of Florida. Offshore water quality and the exact location of the offshore saltwater interface is unknown.

The current model consists of seven layers, each representing a major aquifer or confining unit in the FAS. The result is that some layers may be too thick to provide a detailed analysis of water quality within a single aquifer. Further subdivision of these units may be required for a detailed evaluation of a site-specific application, but appears to be sufficient for a regional evaluation of water levels and water quality in south Florida.

The steady-state model with estimated historical 1989 pumping stresses was calibrated to 151 observed water level targets using a combination of manual and automated methods. The results of calibration indicate that the model is in reasonable agreement with observed data. The mean residual for the model is 1.91 feet and the absolute mean residual is -0.94 feet.

The transient model has 288 monthly stress periods beginning in January 1989 and extending through December 2012, or a period of 24 years. Historical rainfall rates were used to estimate recharge, coastal boundary conditions were obtained from recorded tidal gauges or monitor wells, and pumpage was estimated using AFSIRS for irrigation withdrawals and actual reported use for public water supply. Transient model calibration used a combination of automated and manual trial and error methods. Automated calibration primarily focused on the aquifer parameters, while the manual calibration dealt with the water quality and transient input parameters like pumpage and recharge. The results of the transient model calibration indicate that the model is in good agreement with observed data and superior to the steady-state results in both water level and water quality. The mean residual water level difference for the model is approximately 1.35 feet with a coefficient of determination greater than 0.92.

An automated sensitivity analysis was conducted to quantify how variations in selected model parameters affect the model results. Primary parameters for the sensitivity analysis were the horizontal hydraulic conductivity in the aquifers, the vertical hydraulic conductivity in the confining units, recharge and boundary conditions rates, and the dispersivity values for the transport component of the model. The simulated heads appeared sensitive to change in both vertical and horizontal hydraulic conductivities. Sensitivity to recharge and boundary conditions inflows were localized and spatially did not affect much of the model. The model was relatively insensitive to dispersivity values at this scale.

Pumpage is a primary input variable into the model and tends to have a varying degree of accuracy associated with it, depending upon the use type. In general:

- There is a high degree of confidence in modeled Public Water Supply withdrawals.
- There is a moderate degree of confidence in modeled commercial and industrial uses.
- All irrigation monthly demands were calculated from AFSIRS using observed climatic conditions. Irrigation demands were further modified during the calibration process to reflect site-specific operations.
- There is a moderate degree of confidence for modeled irrigation demands that utilize the Floridan aquifer system solely and were fully operational.
- A much lower degree of confidence for modeled irrigation demands exists for users of a combination of surface water and Floridan aquifer system
- Additional uncertainty is introduced for citrus operations due to damage and disease (when, where, and how much).

The model tends to suggest that the primary degradation of water quality occurs from the upward migration of poorer quality water from the deeper aquifers. It was observed in the model that this mainly occur at large wellfields that withdraw water on a consistent and steady basis. It is recommended that future wellfields determine the water quality in the underlying aquifer before permit issuance to provide an upper boundary of the degree of degradation that may occur with sustained long-term withdrawals. The model suggests that well spacing can also be a key issue regarding upward migration of poorer quality water.

Although not a requirement or the intended purpose of the model, additional investigation should be conducted with the tool for evaluating changes in water quality of the FAS over the last 25,000 years. This period encompasses times in the recent geologic past when sea level was approximately 400 feet lower than present and flushing of the aquifer may have occurred. The period would also include the rapid rise in sea level during the Holocene. This would allow for a better understanding of the water quality in the FAS offshore, considering that many of the proposed future demands will occur along the existing coastline.

Investigation of the FAS by the District should continue and be expanded based upon the results of this work. Water quality may be an issue as large public water supply wellfields become operational throughout south Florida. A comprehensive database that provides additional information on the characteristics of the APPZ should continue to be expanded to understand the degree and risk associated with water quality degradation over time.

Consideration should also be given to the possibility of combining the Lower West Coast Floridan Aquifer System Model (Guo et al. 2011) and the ECFM into a single tool that encompasses the entire south Florida peninsula.

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References

Anderson, M.P., and W. Woessner, 1992. Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic Press, San Diego, CA.

Anderson, S., 2008. Hydrogeologic Investigation of the Floridan Aquifer System L-8 (PBF-15) Palm Beach County, Florida. Technical Publication WS-25, South Florida Water Management District, West Palm Beach, FL.

Anderson, P., and J. Ross, 2013. Cross-Sectional Model of Turkey Point Cooling Canal System. Technical Memorandum to Florida Power & Light.

American Petroleum Institute, 1998. Recommended Practices for Core Analysis, Chapter 5. American Petroleum Institute.

American Society for Testing and Materials, 2006. Standard Guide for Documenting a Groundwater Flow Model Application, ASTM D5718-95 (2006).

Bennett, M., 2001. Hydrogeologic Investigation of the Floridan Aquifer System at L-2 Canal Site Hendry County, Florida. Technical Publication WS-3, South Florida Water Management District, West Palm Beach, FL.

Bennett, M., 2002. Hydrogeologic Investigation of the Floridan Aquifer System Immokalee Water & Sewer District Wastewater Treatment Plant Collier County, Florida. Technical Publication WS-14, South Florida Water Management District, West Palm Beach, FL.

Bennett, M., 2003. Hydrogeologic Investigation of the Floridan Aquifer System LaBelle, Hendry County, Florida. Technical Publication WS-15, South Florida Water Management District, West Palm Beach, FL.

Bennett, M., 2004. Hydrogeologic Investigation of the Floridan Aquifer System Big Cypress Preserve, Collier County, Florida. Technical Publication WS-18, South Florida Water Management District, West Palm Beach, FL.

Boniol, D., M. Williams, and D. Munch, 1993. Mapping Recharge to the Floridan Aquifer Using a Geographic Information System. Technical Publication SJ93-5, St. Johns River Water Management District, Palatka, FL.

Bush, P., and R. Johnson, 1988. Groundwater Hydraulics, Regional Flow and Groundwater Development of the Floridan Aquifer System in Florida and Parts of Georgia, South Carolina, and Alabama, U.S. Geological Survey Professional Paper 1403-C, 80p., 17 pls.

CH2MHILL, 2008. Paradise Run Aquifer Storage and Recovery Test-Monitor Well HIF-42. South Florida Water Management District, West Palm Beach, FL.

CFWI, 2014. Central Florida Water Initiative Regional Water Supply Plan – Final Draft. Central Florida Water Initiative.

Crain, L., C. Katz, and L. Snell, 1975. Water Resource of Indian River County, Florida. Florida Bureau of Geology Report No.80.

Doherty, J., 2010. PEST: Model – Independent Parameter Estimation User's Manual: 5th Edition, Watermark Numerical Computing.

Doherty, J., and R. Hunt, 2010. Approaches to Highly Parameterized Inversion: A Guide to Using PEST for Groundwater-Model Calibration. U.S. Geological Survey Scientific Investigations Report 2010-5169.

Doherty, J., M. Fienen, and R. Hunt, 2010. Approaches to Highly Parameterized Inversion: Pilot-Point Theory, Guidelines, and Research Directions: U.S. Geological Survey Scientific Investigations Report 2010–5168, 36 p.

Freyberg, D., 1986. A Natural Gradient Experiment on Solute Transport in a Sand Aquifer: 2. Spatial Moments and the Advection and Dispersion of Nonreactive Tracers. Water Resources Research, 22(13):2031-2046.

Garabedian, S., D. LeBlanc, L. Gelhar, and M. Celia, 1991. Large-Scale Natural gradient Tracer Test in Sand and Gravel, Cape Code, Massachusetts, 2, Analysis of Spatial Moments for a Nonreactive Tracer. Water Resources Research, 27(5):911-924.

Gelhar, L., C. Welty, and K. Rehfeldt, 1992. A Critical Review of Data on Field-Scale Dispersion in Aquifers. Water Resources Research, 28(7):1955-1974.

Golder, 2008 East Coast Floridan Aquifer System Model, Phase II Project, Southeastern Florida, Final Model Documentation Report, Boca Raton, FL.

Guo, W., and C.D. Langevin, 2002. User's Guide to SEAWAT: A Computer Program for Simulation of Three-Dimensional Variable-Density Ground-Water Flow. U.S. Geological Survey Techniques of Water-Resources Investigations.

Guo, W., Z. Li, and Giddings, J., 2011. Lower West Coast Floridan Aquifer Model Development, Prepared for the South Florida Water Management District, West Palm Beach, FL.

Guo, W, 2014. Review of "Discussion of the Incorporation of the Peer Review Recommendations into the East Florida Model: Supporting Documentation for SFWMD Order" by SFWMD, Prepared for the South Florida Water Management District. Schlumberger Water Services, Fort Myers, FL.

Hickey, J.J., 1982. Hydrogeology and Results of Injection Tests at Waste-injection Sites in Pinellas County, Florida, U. S. Geological Survey Water-Supply Paper 2183, 42p.

Hunt, R.J., J. Luchette, W.A. Shreuder, J. Rumbaugh, J. Doherty, M.J. Tonkin, and D. Rumbaugh, 2010. Using the Cloud to Replenish Parched Groundwater Modeling Efforts. Rapid Communication for Ground Water, doi: 10.1111/j.1745-6584.2010.00699.

HydroGeoLogic, 2006. Development of a Density-Dependent Saltwater Intrusion Model for the Lower East Coast Project Area, HydroGeoLogic, Inc., Herndon, Va.

Jacobs, B., M. Stewart, R. Therrien, and C. Zheng, 2011. Peer Review Report – East Coast Floridan Aquifer System Model Phase II Project, South Florida Water Management District, West Palm Beach, FL.

Jensen, K,H, K. Bitsch, and P.L. Bjerg, 1993. Large-scale dispersion experiments in a sandy aquifer in Denmark: Observed tracer movements and numerical analyses. Water Resources Research 29, 3:673-696.

Kohout, F.A., 1965. A Hypothesis Concerning Cyclic Flow of Salt Water Related to Geothermal Heating in the Floridan Aquifer: New York Academy of Sciences, Series II, 28(2):249-271.

Kwiatkowski, P.J., 1987. Numerical simulation of seawater intrusion, Cutler Ridge, Florida: University of South Florida, Tampa, FL.

Lønborg, M., P. Engesgaard, P. Bjerg, and D. Rosbjerg, 2006. A Steady State Redox Zone Approach for Modeling the Transport and Degradation of Xenobiotic Organic Compounds from a Landfill Site. Journal of Contaminant Hydrology, 87:191-210.

Lukasiewicz, J., 1992. A Three-Dimensional Finite Difference Ground Water Flow Model of the Floridan Aquifer System in Martin, St. Lucie and Eastern Okeechobee Counties, Florida, Technical Publication 92-03, DRE-311, South Florida Water Management District, West Palm Beach, FL.

Malloy, R.J. and R.J. Hurley. 1970. Geomorphology and geologic structure – Straits of Florida, Geological Society of America Bulletin, V. 81.

McDonald, M.G., and A.W. Harbaugh. 1988. A Modular, Three-Dimensional Finite-Difference Groundwater Flow Model. Techniques of Water Resources Investigations of the United States Geological Survey, U.S. Government Printing Office, Washington, D.C.

Meyer, F., 1974. Evaluation of Hydraulic Characteristics of a Deep Artesian Aquifer from Natural Water-Level Fluctuations, Miami, FL. Florida Bureau of Geology Report of Investigations 75, 32p.

Meyer, F., 1989. Hydrogeology, Ground-Water movement, and Subsurface Storage in the Floridan Aquifer System in Southern Florida, U. S. Geological Survey Professional Paper 1403-B.

Miller, J., 1986. Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina, U.S. Geological Survey Professional Paper 1403-B.

Miller, J., 1990. Ground Water Atlas of the United States, Alabama, Florida, Georgia, and South Carolina, HA 730-G, U. S. Geological Survey.

Morris, M.D., 1991, Factorial Sampling Plans for Preliminary Computational Experiments, Technometrics 33:161-174.

Mullins, H.T., and A.C. Neumann, 1979. Deep Carbonate Bank Margin Structure and Sedimentation in the Northern Bahamas. Society of Economic Paleontologists and Mineralogists. Special Publication 27:165-192.

Reese, R., and K. Cunningham, 2013. Preliminary Stratigraphic and Hydrogeologic Cross Sections and Seismic Profile of the Floridan Aquifer System of Broward County, Florida, U. S. Geological Survey Open File Report: 2013-1141.

Reese, R., and E. Richardson, 2008. Synthesis of the Hydrogeologic Framework of the Floridan Aquifer System and Delineation of a Major Avon Park Permeable Zone in Central and Southern Florida, U. S. Geological Survey Scientific Investigation Report 2007-5207.

Ryder, P., 1985. Hydrology of the Floridan Aquifer System in West-central Florida, U.S. Geological Survey Professional paper 1403-F, 63p.

Sepulveda, N., C.R. Tiedeman, A.M. O'Reilly, J.B. Davis, and P. Burger, 2012. Groundwater Flow and Water Budget in the Surficial and Floridan Aquifer Systems in East-central Florida: U.S. Geological Survey Scientific Investigations Report 2012–5161, 214 p.

Sin, G., and K. Gernaey, 2009. Improving the Morris Method for Sensitivity Analysis by Scaling the Elementary Effects. Computer-Aided Chemical Engineering Series, 26:925-930.

Smajstrla, A.G., 1990. Technical Manual, Agricultural Field Scale Irrigation Requirements Simulations (AFSIRS) Model, Version 5.5. University of Florida, Gainesville, FL.

South Florida Water Management District, 2006. Kissimmee Basin Water Supply Plan 2005 2006 Update. SFWMD, West Palm Beach, FL.

South Florida Water Management District, 2011. Upper East Coast Water Supply Plan Update. SFWMD, West Palm Beach, FL.

South Florida Water Management District, 2013. Lower East Coast Water Supply Plan Update. SFWMD, West Palm Beach, FL.

South Florida Water Management District, 2013. Basis of Review for Water Use Permit Applications within the South Florida Water Management District. SFWMD, West Palm Beach, FL.

Spechler, R., 2010. Hydrogeology and Groundwater Quality of Highlands County, Florida. U.S. Geological Survey Scientific Investigations Report 2010—5097.

Spechler, R., and S. Kroening, 2007. Hydrology of Polk County, Florida. U. S. Geological Survey Scientific Investigations Report 2006-5320.

Stewart, J., 1980. Areas of Natural Recharge to the Floridan Aquifer in Florida. U. S. Geological Survey Map Series 98.

Stokes, J., 2005. Recharge Areas of the Floridan Aquifer in the St. Johns River Water Management District, SJRWMD, Palatka, FL.

Tibbals, C.H., 1990. Hydrology of the Floridan Aquifer System in East-central Florida, U.S. Geological Survey Professional Paper 1403-E, 98p.

USACE, 2010. Final Groundwater Model Calibration Report Aquifer Storage and Recovery Regional Modeling Study, Prepared for U.S. Army Corps of Engineers Jacksonville District, Philadelphia District.

Welter, D., 2014, in press. Discussion on GSA++. SFWMD, West Palm Beach, FL.

Yobbi, D., 1996. Analysis and Simulation of Ground-Water Flow in Lake Wales Ridge and Adjacent Areas of Central Florida: U.S. Geological Survey Water-Resources Investigations Report 94-4254, 82 p.

Zheng, C., and P. Wang, 1999. MT3DMS—A Modular Three Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Ground-water Systems; Documentation and User's Guide. Jacksonville, FL, U.S. Army Corps of Engineers Contract Report SERDP-99-1.

Appendix A. Hydrostratigraphic Control Points

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
BR0920	741790.72	1279135.25	-266.99
BR1202	777335.24	1278500.90	-284.20
OS0231	669164.07	1270810.51	-247.92
IR0630	777059.77	1265267.07	-293.19
IR0631	775121.39	1264897.66	-298.59
IR-202F	725016.64	1264505.89	-270.20
IR0624	825881.10	1262900.85	-347.16
IR0628	779978.06	1262367.61	-297.08
IR0627	736337.51	1261891.96	-284.83
OSF-52	592067.96	1261155.76	-216.74
IR0805	839468.57	1260779.86	-370.88
IR0615	773843.47	1259804.07	-296.97
FLA-OS4	663060.70	1256671.17	-260.59
IR0632	846287.24	1254631.28	-390.47
IR-190F	726111.58	1254611.51	-295.57
IR0921	782273.26	1252195.26	-312.98
IR0740	733770.51	1252070.99	-295.51
IR-154F	848667.16	1245624.41	-395.92
IR-141F	853539.53	1241406.83	-407.47
W-3017	776539.91	1241200.61	-325.99
IR0578	841067.33	1237812.48	-389.36
IR0498	852490.12	1235645.41	-422.47
IR-132F	852228.09	1234028.32	-421.76
OSF-0042	665183.90	1231453.18	-277.73
IR0744	810163.28	1231207.15	-355.39
IR0998	796898.71	1231158.10	-344.66
IR0698	856023.10	1230007.70	-483.44
IR0735	755815.70	1229216.44	-321.52
W-9132	623880.81	1228004.95	-255.29
IR0734	780412.54	1226740.66	-341.75
IR0761	840276.55	1225881.48	-435.75
IR-119F	763825.03	1224905.86	-358.70
IR0024	856228.67	1224858.40	-597.67
IR0167	836188.09	1223854.09	-422.94
IR0745	721854.51	1222965.73	-324.91
IR0747	728021.63	1212433.56	-341.98

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
IR0711	846680.63	1210168.73	-487.75
IR0956	775286.57	1209638.19	-351.37
OSF-104	613202.43	1208993.17	-256.45
POF-20	612721.77	1208412.98	-256.45
IR0336	843092.82	1208233.06	-459.14
IR0634	837700.16	1207602.30	-441.41
IR0806	831945.28	1207302.41	-425.87
IR0970	827413.16	1207282.73	-412.44
IR0623	799223.84	1204315.66	-372.36
IR0730	811246.81	1202126.98	-387.30
IR0333	830800.19	1202017.41	-419.01
IR0639	773424.24	1200697.40	-369.75
IR0696	790782.95	1200550.03	-392.16
IR0991	857520.00	1200434.00	-462.66
IR0854	735490.62	1200087.21	-359.03
IR0330	816779.34	1199636.04	-398.65
IR1163	732237.00	1199254.00	-359.62
IR0638	814534.00	1198819.23	-393.43
IR0329	796818.78	1197743.27	-411.67
IR0490	855305.89	1193548.13	-446.79
IR0716	853715.58	1191043.90	-443.42
IR0325	790275.43	1190955.03	-405.87
IR0636	828872.08	1190294.88	-420.13
IR0779	811294.72	1189766.41	-420.59
IR0323	812505.89	1188409.99	-410.86
OK0003	713813.81	1187944.73	-391.99
IR0706	791995.28	1187830.38	-412.24
W-6173	713545.63	1187741.81	-391.99
IR-42F	816475.57	1185598.21	-429.15
IR0640	826922.13	1183419.63	-420.32
IR0954	792534.25	1182790.72	-410.37
IR-1001	823795.73	1182081.09	-429.50
OK0002	700507.14	1180455.30	-347.37
IR0458	743974.45	1177901.57	-362.22
IR0319	762422.37	1177845.10	-388.32
IR0701	789344.52	1173280.16	-397.41
OK0005	752000.83	1170447.06	-355.29
NRCS29-8	831644.41	1167168.77	-426.49
OKF-2	749670.30	1167109.05	-359.12

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
OKF-34	648495.80	1164880.11	-283.74
SLF-11	791281.52	1164690.00	-394.00
SLF-70	849514.02	1163325.60	-345.93
OK0006	697645.60	1162578.74	-314.56
SLF-45	877700.18	1162258.59	-598.49
W-14703	880144.69	1159546.08	-598.49
OKF-36	647234.31	1159326.57	-296.40
CNT1			-307.81
SLF-42	878899.08	1157114.96	-620.01
SLF-46	880298.42	1155847.66	-620.01
WA-1139	846219.88	1155534.17	-376.08
SL00033	829849.74	1151420.84	-460.75
WA-1032	884333.07	1151289.06	-691.27
WA-1009	852031.51	1148984.38	-404.99
W-13850	832204.35	1148401.36	-475.16
WA-1144	844574.00	1145313.26	-429.42
OKF-37	656417.36	1144178.95	-386.64
WA-823	820433.00	1141990.00	-434.07
SLF-4	823514.09	1141685.71	-437.42
WA-1186	873768.51	1139819.30	-594.60
FPUA-FA9	864455.50	1137362.43	-458.85
STL-422	864382.25	1136039.24	-459.34
W-16897	878265.00	1135537.00	-620.11
OKF-18	652723.99	1135495.01	-390.17
FPUA-FA7	864451.79	1135116.46	-459.34
NRCS121-1	820484.58	1133614.66	-477.17
OKF-19	667496.90	1132972.57	-381.77
SLF-9	789049.08	1131963.83	-444.69
FPUA-FB4	866943.38	1131894.80	-486.68
WA-877	857233.46	1131856.70	-428.32
FPUA-FB3	865979.11	1131422.20	-487.48
SLF-53	803990.95	1131120.66	-517.74
FPU_RO-IW1	866322.66	1130448.90	-487.48
FPUA-FB2	865749.32	1130390.94	-487.48
W-12542	710022.95	1129876.84	-434.14
OKF-29	707591.72	1129873.15	-392.19
WA-1085	772369.64	1129806.14	-444.08
WA-1107	772352.00	1129766.00	-444.08
WA-887	861122.44	1128947.78	-458.92

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
WA-708	871851.62	1127690.95	-576.80
SLF-20	760755.12	1127350.46	-459.08
SLF-21	850164.05	1125344.56	-442.95
NRCS7-1	820540.50	1124314.23	-446.53
SLF-40	820708.50	1122891.04	-446.53
WA-699	855752.29	1121650.12	-480.57
SLF-6	849544.85	1119700.39	-461.48
WA-1119	768343.34	1119696.90	-480.62
W-1022	840892.20	1119559.47	-497.94
WA-875	819450.00	1117751.00	-491.81
WA-1111	774012.00	1116684.00	-455.49
WA-878	804765.93	1115977.32	-482.88
NRCS2-1	812609.45	1115365.86	-466.37
OKF-105	619115.79	1115332.23	-392.79
WA-1158	831988.47	1115278.80	-525.11
WA-820	837948.00	1112983.00	-439.90
SLF-26	879871.92	1111576.39	-585.11
WA-1136	817402.93	1111279.74	-437.85
WA-547	792079.00	1109672.00	-565.79
WA-1083	828138.18	1109304.39	-465.67
WA-1016	836533.80	1106614.50	-485.75
WA-1140	820132.11	1105130.95	-459.00
W-15813	669848.70	1104901.72	-418.22
PSLLTC-IW1	850609.01	1104256.19	-523.93
OKF-7	725748.21	1102434.52	-646.79
HI00014	608903.08	1101998.33	-413.10
WA-1006	825917.20	1101519.55	-498.72
WA-1001	827943.00	1100154.00	-503.22
WA-1003	828597.00	1099067.00	-503.22
SLF-28	891152.09	1093968.22	-588.52
WA-1192	820809.19	1093824.00	-500.07
SLF-0049	819011.52	1092705.62	-588.51
SLF-50	819191.80	1092403.42	-588.51
W-16543	821554.52	1092296.50	-523.37
SLF-14	795303.17	1092197.81	-559.37
W-4086	861040.08	1091886.66	-537.36
OKF-17	682570.05	1091477.77	-515.59
SLF-16	795393.21	1089991.71	-567.30
SLF-47	905882.88	1089007.18	-842.60

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
SLF-17	795581.10	1087367.68	-554.20
WA-580	853835.00	1084427.00	-577.33
OKF-5	718924.84	1083944.62	-558.24
WA-582	847013.00	1082931.00	-553.96
WA-1147	794572.00	1081851.00	-541.18
WA-562	846118.50	1081312.28	-513.95
WA-565	853257.00	1078922.00	-577.34
SLF-48	843338.87	1077966.17	-530.58
SLF-43	911117.85	1074094.09	-682.25
SLF-44	911119.75	1073791.15	-654.94
SLF-31	852047.24	1068111.21	-615.95
STL-386	883687.56	1060716.64	-689.65
SLF-54	763185.64	1059903.84	-722.03
M-1357	897286.99	1059563.00	-712.02
M-1358	895774.04	1057453.54	-707.90
MF-55	918899.17	1056573.38	-883.54
LKOKEE_ASR	725790.79	1055542.97	-680.69
PSLWPT-IW1	866386.80	1055240.95	-708.59
SLF-23	828573.74	1049525.83	-567.64
HIF-42	670431.76	1049061.21	-557.67
MF-3	922774.20	1047512.71	-733.71
MF-40	826580.03	1044391.08	-609.59
MF-1	824173.60	1043550.17	-620.90
WA-1151	831944.00	1042270.67	-614.82
M-1366	916558.20	1041511.80	-787.84
M-1352	900538.04	1041233.26	-772.63
M-1353	900538.04	1041233.26	-772.63
MF-4	928689.09	1037248.04	-754.63
MF-34	887424.10	1035882.11	-586.05
MT00045	911372.68	1033198.43	-733.55
MF-9	828909.34	1031657.18	-537.19
MT00053	915268.52	1031304.32	-733.13
MF-6	791721.61	1027979.53	-658.50
MF-20	781792.20	1025928.25	-646.17
OKF-100	698055.00	1025471.00	-550.39
MF-36B	917747.03	1025361.32	-757.45
W-2396	669875.15	1024930.34	-593.34
MF-31	924777.60	1024359.42	-809.66
W-50146	577647.00	1023691.00	-539.08

Upper Floridan Aquifer (UFA) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
GLF-1	681169.20	1022612.48	-599.94
W-5405	755887.80	1017375.35	-633.98
MF-33	789502.05	1016158.11	-668.88
WA-1155	777036.84	1014605.63	-696.67
W-2860	794482.64	1012539.97	-676.99
WA-546	782925.46	1009574.75	-700.52
TFRO-1	896099.78	1006629.67	-673.47
W-5441	768487.01	1002463.88	-683.43
BREX-1	617719.45	997587.50	-629.24
MF-10	887370.80	997408.48	-623.32
MF-23	798251.70	996539.65	-731.65
M-1364	794741.53	989317.24	-748.42
M-1359	941305.21	989165.79	-853.02
W-15880	593672.60	988827.76	-647.64
M-1332	814920.12	984947.53	-690.17
ICW-1	814300.22	983504.44	-690.17
GLF-0002	650450.00	983226.36	-654.31
M-1363	775246.51	977745.07	-690.31
MF-35	824554.81	970435.35	-692.59
MF-37	784921.90	965985.04	-744.78
EXPM-1	784619.60	965030.14	-747.26
PBF-1	953618.17	959048.57	-900.32
PB-652	941938.50	950090.09	-979.55
PB-747	936328.26	946544.16	-948.68
PB-1171	936530.57	942314.59	-938.64
PB-1197	931130.11	942241.03	-971.06
GLF-5	573863.97	938477.98	-708.60
W-15748	882294.17	934067.52	-838.24
PB-1133	845236.13	920452.15	-761.09
W-16234	939265.37	917555.90	-904.27
GLF-6	628323.00	910488.00	-821.58
PAHO-MW	764969.48	896737.98	-758.71
W-5435	665750.64	893264.36	-658.02
W-2912	658773.04	892960.44	-678.39
PB-1180	936548.02	886437.56	-1008.57
PB-1132	829298.99	876560.53	-777.59
CLEWRO-PW1	676273.80	875746.67	-698.10
PB-1689	939106.00	874638.00	-965.71
PB-1690	939106.00	874638.00	-965.71

Upper Floridan Aquifer (UFA) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
W-16182	906017.95	873416.88	-883.91
PB-1139	836494.27	868917.32	-803.04
PB-1164	697039.56	867334.86	-726.19
PB-1693	961828.64	867125.14	-907.86
PB-734	770045.02	863230.01	-801.14
PBF-7	748904.73	860161.10	-953.45
PB-1186	757541.77	858553.16	-826.46
PB-1187	757542.02	858452.20	-826.46
PB-1700	882091.27	854801.79	-834.27
LYTAL-TW	948920.09	852549.45	-893.52
PB-1699	833135.28	848506.85	-846.92
PB-203_G	776163.41	848505.88	-876.01
HE-987	672655.42	848437.41	-751.68
CNT2			-897.49
PB-1698	791430.83	840273.24	-914.56
W-16052	909414.06	836783.47	-899.04
HE-986	638631.23	835110.41	-708.41
W-10079	723670.01	828699.49	-825.51
W-10080	723670.11	828699.21	-825.51
L2-TW	672740.65	826627.02	-759.90
HE-984	617746.55	820686.41	-810.37
PB-1697	912284.90	812567.20	-886.15
HE-281	614560.43	811703.61	-709.36
W-9112	815144.58	808248.30	-984.61
HE-983	607558.35	802422.43	-771.50
W-16882	943433.87	798935.63	-881.29
HE-1103	591563.30	795073.64	-994.36
PB-1194	962729.50	793720.45	-798.29
PB-1138	697389.89	787875.74	-822.15
PB-1701	743450.45	787643.33	-850.81
BOYRO_EPX	953221.77	786238.39	-853.52
PB-1190	928897.16	785409.03	-907.19
PB-1764	935238.52	782249.22	-918.68
HE-982	591176.70	780030.63	-856.56
HE-981	573171.65	773095.83	-742.90
W-15371	585797.59	769236.21	-624.63
W-7500	769331.75	757920.22	-869.66
CNT2			-813.38
W-15886	917035.99	749286.62	-1018.98

Upper Floridan Aquifer (UFA) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
HE-973	577392.46	746029.62	-1040.51
W-2631	590305.28	746007.68	-974.62
HASR-DZMW	886678.71	735581.37	-970.64
PBF-13	886997.95	735463.95	-970.14
PB-1137	718008.85	728333.10	-890.23
EHILL_MW	911585.82	727630.40	-999.46
HE-976	638038.97	724152.38	-786.93
G-2887	943233.65	721588.18	-947.25
G-2889	948841.82	713346.82	-918.40
G-2916	948841.82	713346.82	-918.40
HE-1101	686455.59	706592.21	-906.83
BCN-I1	932262.64	700321.94	-984.51
CS-I2	897697.47	695859.82	-1009.44
CS-I1	897444.59	695121.17	-1009.44
C-1124	565765.82	694466.64	-796.10
MAR-I2	912742.05	694130.55	-1008.46
G-2917	933649.07	670332.13	-963.05
BF-1	925617.30	669564.23	-965.22
ALLY-TW	714531.25	668029.48	-905.18
W-12994	588270.54	667564.23	-776.93
W-15317	602749.81	662192.80	-874.26
PLT-I1	906662.39	657846.86	-1007.26
SUN-MW1	873510.52	653626.48	-1053.28
SUN-I3	873511.00	653101.00	-1053.28
PLT-ROI1	896118.72	652838.90	-1032.35
C-1133	634361.84	650554.72	-785.86
S-567	935731.67	644497.60	-939.84
D-365	941569.23	644131.58	-963.31
C-1125	641103.56	642475.19	-765.25
FEETL-M1	941140.04	641402.61	-939.05
W-10014	603151.59	618780.40	-850.11
HOL-IW1	941045.23	616690.50	-875.65
W-9413	571216.57	613178.17	-871.16
PBP-I1	875496.54	603962.39	-1039.17
MIRAMARIW1	875549.45	603608.28	-1039.17
HAL-RO1	933450.82	602480.11	-917.33
C-962	687901.36	598265.20	-927.55
MIRAMAR_RO	880764.90	594262.97	-1064.61
MDWNA_I3N	936510.94	576946.30	-913.38

Upper Floridan Aquifer (UFA) Control Points			
Well Name	X Coordinate	Y Coordinate	Elevation (feet. NGVD)
DF-1	828433.47	575983.36	-1123.23
W-10190	576620.87	575813.85	-819.45
C-1127	683726.28	562927.96	-927.99
W-10184	616404.05	549106.71	-824.26
W-10187	651485.64	549088.68	-827.80
W-10183	632572.99	546369.11	-827.31
S-156	943593.10	545803.49	-881.56
G-3061	890440.09	543986.40	-1022.19
W-935	698090.59	536489.50	-991.37
MO-141	658796.08	519812.01	-1054.38
G-3239	712460.74	519040.82	-1021.86
SWW_ASR4	820285.27	498418.67	-1151.67
G-3706	829113.30	497138.54	-1154.25
SWW_ASR5	829113.30	497138.54	-1154.25
G-3768	830277.01	496638.40	-1151.23
I-1_G	870013.56	494694.79	-1022.27
PU-I2	848794.80	493788.69	-1039.88
W-215	886255.72	485288.12	-1050.82
W-889	731542.29	481111.47	-1045.64
S-254	793171.97	465815.69	-1132.78
MDWSA_I5	876304.00	442461.00	-979.62
MDS-I12	871369.33	442406.14	-961.89
FKAAFCEW1	818317.68	403673.39	-1104.91
GB-1	863403.82	402995.17	-1008.77
ENP-100	787244.43	381470.63	-1165.61
S-1533_G	851722.97	370030.57	-1109.22
S-3001	874109.39	369933.79	-1074.68
MO-134	894073.20	359537.44	-1122.46
MO-130	884358.76	339295.52	-1062.38
MO-128	865224.13	308612.88	-1088.20
W-7362	851901.81	287756.51	-1042.34
W-1976	809497.27	244083.18	-1077.36
MO-122	624977.42	137238.57	-1076.13

Middle Confining Unit 1 (MC1) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
OKF-54	682141.15	1197504.02	-645.36
OSF-0042	665183.90	1231453.18	-658.01
SLF-11	791281.52	1164690.00	-909.89
SLF-9	789049.08	1131963.83	-859.53
L2-TW	672740.65	826627.02	-1137.47
OKF-29	707591.72	1129873.15	-765.60
SLF-20	760755.12	1127350.46	-823.90
OKF-34	648495.80	1164880.11	-718.54
S-1533_G	851722.97	370030.57	-1340.25
BF-1	925617.30	669564.23	-1197.68
PBF-7	748904.73	860161.10	-1373.16
W-16039	866992.28	1091917.21	-1066.60
W-16543	821554.52	1092296.50	-839.07
W-16897	878265.00	1135537.00	-1344.97
W-15371	585797.59	769236.21	-1208.56
DF-1	828433.47	575983.36	-1355.58
OKF-100	698055.00	1025471.00	-786.56
GLF-6	628323.00	910488.00	-1095.66
MF-37	784921.90	965985.04	-1076.29
W-5435	665750.64	893264.36	-1085.45
W-15880	593672.60	988827.76	-782.56
LKOKEE_ASR	725790.79	1055542.97	-735.34
BCN-I1	932262.64	700321.94	-1353.33
C-1125	641103.56	642475.19	-1304.45
C-1127	683726.28	562927.96	-1289.58
W-15748	882294.17	934067.52	-1058.45
W-16052	909414.06	836783.47	-1174.48
W-16182	906017.95	873416.88	-1135.76
W-16234	939265.37	917555.90	-1082.66
W-16882	943433.87	798935.63	-1111.53
W-17052	764969.48	896737.98	-1091.84
PB-1764	935238.52	782249.22	-1144.20
PB-1137	718008.85	728333.10	-1045.73
PB-1186	757541.77	858553.16	-1375.68
PB-1689	939106.00	874638.00	-1256.34
PBP-I1	875496.54	603962.39	-1301.35
POF-20	612721.77	1208412.98	-489.91

Middle Confining Unit 1 (MC1) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
IR0024	856228.67	1224858.40	-923.96
W-15813	669848.70	1104901.72	-766.30
W-15317	602749.81	662192.80	-1287.09
W-1976	809497.27	244083.18	-1267.24
MIRAMAR_RO	880764.90	594262.97	-1365.45
CS-I2	897697.47	695859.82	-1403.72
PB-1180	936548.02	886437.56	-1253.64
PB-1190	928897.16	785409.03	-1138.22
MDS-I12	871369.33	442406.14	-1070.90
PSLWPT-IW1	866386.80	1055240.95	-1258.69
HOL-IW1	941045.23	616690.50	-1323.20
EHILL_MW	911585.82	727630.40	-1267.64
FLA-OS4	663060.70	1256671.17	-522.61
S-3001	874109.39	369933.79	-1194.22
ICW-1	814300.22	983504.44	-920.83
FPU_RO-IW1	866322.66	1130448.90	-1190.36
HI00014	608903.08	1101998.33	-512.72
MO-122	624977.42	137238.57	-1416.50
SUN-I3	873511.00	653101.00	-1323.73
M-1352	900538.04	1041233.26	-1300.05
M-1357	897286.99	1059563.00	-1234.19
M-1358	895774.04	1057453.54	-1223.44
C-962	687901.36	598265.20	-1293.93
PSLLTC-IW1	850609.01	1104256.19	-1209.29
TFRO-1	896099.78	1006629.67	-920.96
IR-1001	823795.73	1182081.09	-1050.37
GLF-5	573863.97	938477.98	-779.34
OSF-104	613202.43	1208993.17	-489.91
MF-40	826580.03	1044391.08	-989.23
LYTAL-TW	948920.09	852549.45	-1226.95
HASR-DZMW	886678.71	735581.37	-1211.34
ALLY-TW	714531.25	668029.48	-1260.31
MDWNA_I3N	936510.94	576946.30	-1237.77
OKF-105	619115.79	1115332.23	-568.44
IR1163	732237.00	1199254.00	-751.43

Avon Park Permeable Zone (APPZ) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
ALLY-TW	714531.25	668029.48	-1566.49
BCN-I1	932262.64	700321.94	-1523.96
BF-1	925617.30	669564.23	-1489.70
BREX-1	617719.45	997587.50	-1474.26
C-1124	565765.82	694466.64	-1590.52
C-962	687901.36	598265.20	-1657.59
CLEW_IW-1	674629.73	868695.76	-1482.06
CS-I1	897444.59	695121.17	-1544.07
CS-I2	897697.47	695859.82	-1544.07
DF-1	828433.47	575983.36	-1713.17
EHILL_MW	911585.82	727630.40	-1493.57
FLA-OS4	663060.70	1256671.17	-791.48
FPL_FAW1	860819.14	862422.13	-1392.35
FPU_RO-IW1	866322.66	1130448.90	-1365.75
GLF-6	628323.00	910488.00	-1583.41
HASR-DZMW	886678.71	735581.37	-1498.27
HI00014	608903.08	1101998.33	-1018.24
HIF-42	670431.76	1049061.21	-1174.83
HOL-IW1	941045.23	616690.50	-1386.04
ICW-1	814300.22	983504.44	-1468.61
IR0024	856228.67	1224858.40	-1299.30
IR-1001	823795.73	1182081.09	-1292.21
IR1163	732237.00	1199254.00	-960.67
L2-TW	672740.65	826627.02	-1394.44
LKOKEE_ASR	725790.79	1055542.97	-1287.29
LYTAL-TW	948920.09	852549.45	-1337.83
M-1352	900538.04	1041233.26	-1590.32
M-1357	897286.99	1059563.00	-1517.53
M-1358	895774.04	1057453.54	-1513.09
MDS-I12	871369.33	442406.14	-1422.12
MDWNA_I3N	936510.94	576946.30	-1415.02
MF-37	784921.90	965985.04	-1479.73
MF-40	826580.03	1044391.08	-1305.98
MIRAMAR_RO	880764.90	594262.97	-1634.77
MIRAMARIW1	875549.45	603608.28	-1613.03
MO-122	624977.42	137238.57	-1746.90
OKF-100	698055.00	1025471.00	-991.74

Avon Park Permeable Zone (APPZ) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
OKF-105	619115.79	1115332.23	-1022.21
OKF-34	648495.80	1164880.11	-902.08
OSF-104	613202.43	1208993.17	-846.64
OSF-52	592067.96	1261155.76	-790.12
PB-1137	718008.85	728333.10	-1569.94
PB-1180	936548.02	886437.56	-1618.16
PB-1186	757541.77	858553.16	-1614.91
PB-1190	928897.16	785409.03	-1442.75
PB-1197	931130.11	942241.03	-1428.74
PB-1689	939106.00	874638.00	-1331.59
PB-1764	935238.52	782249.22	-1423.90
PBF-7	748904.73	860161.10	-1597.30
PSLLTC-IW1	850609.01	1104256.19	-1371.37
PSLWPT-IW1	866386.80	1055240.95	-1508.99
S-1533_G	851722.97	370030.57	-1522.68
SMRU_RO2	941570.00	988989.00	-1372.85
SUN-I3	873511.00	653101.00	-1542.28
TFRO-1	896099.78	1006629.67	-1149.01
W-12542	710022.95	1129876.84	-931.96
W-15317	602749.81	662192.80	-1837.04
W-15371	585797.59	769236.21	-1676.99
W-15748	882294.17	934067.52	-1367.73
W-15813	669848.70	1104901.72	-1163.98
W-15880	593672.60	988827.76	-1619.49
W-16039	866992.28	1091917.21	-1470.78
W-16052	909414.06	836783.47	-1296.68
W-16182	906017.95	873416.88	-1285.27
W-16234	939265.37	917555.90	-1291.58
W-16543	821554.52	1092296.50	-1059.94
W-16882	943433.87	798935.63	-1332.62
W-17052	764969.48	896737.98	-1297.69

Middle Confining Unit 2 (MC2) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
ALLY-TW	714531.25	668029.48	-1709.60
BCN-I1	932262.64	700321.94	-1605.65
BF-1	925617.30	669564.23	-1762.62
BREX-1	617719.45	997587.50	-1386.00
C-962	687901.36	598265.20	-1808.40
CLEW_IW-1	674629.73	868695.76	-1755.00
CS-I1	897444.59	695121.17	-1657.00
CS-I2	897697.47	695859.82	-1627.00
DF-1	828433.47	575983.36	-1759.41
EHILL_MW	911585.82	727630.40	-1636.30
FLA-OS4	663060.70	1256671.17	-962.00
FPL_FAW1	860819.14	862422.13	-1484.00
FPU_RO-IW1	866322.66	1130448.90	-1513.00
GLF-6	628323.00	910488.00	-1763.79
HASR-DZMW	886678.71	735581.37	-1657.50
HI00014	608903.08	1101998.33	-1282.17
HIF-42	670431.76	1049061.21	-1514.25
HOL-IW1	941045.23	616690.50	-1513.70
IR0024	856228.67	1224858.40	-1447.07
IR-1001	823795.73	1182081.09	-1402.00
L2-TW	672740.65	826627.02	-1792.16
LKOKEE_ASR	725790.79	1055542.97	-1614.00
LYTAL-TW	948920.09	852549.45	-1485.23
M-1352	900538.04	1041233.26	-1641.26
M-1358	895774.04	1057453.54	-1722.50
MDS-I12	871369.33	442406.14	-1550.00
MDWNA_I3N	936510.94	576946.30	-1500.99
MF-37	784921.90	965985.04	-1677.59
MIRAMAR_RO	880764.90	594262.97	-1825.31
MIRAMARIW1	875549.45	603608.28	-1796.06
MO-122	624977.42	137238.57	-1775.66
OKF-100	698055.00	1025471.00	-1430.78
OKF-105	619115.79	1115332.23	-1437.70
OSF-104	613202.43	1208993.17	-1216.14
PB-1137	718008.85	728333.10	-1709.00
PB-1180	936548.02	886437.56	-1810.00
PB-1186	757541.77	858553.16	-1705.90
PB-1190	928897.16	785409.03	-1498.50

Middle Confining Unit 2 (MC2) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
PB-1197	931130.11	942241.03	-1648.00
PB-1689	939106.00	874638.00	-1471.00
PB-1764	935238.52	782249.22	-1480.75
PBF-7	748904.73	860161.10	-1690.83
PSLLTC-IW1	850609.01	1104256.19	-1531.10
PSLWPT-IW1	866386.80	1055240.95	-1780.80
S-1533_G	851723.19	370030.46	-1636.87
SMRU_RO2	941570.00	988989.00	-1357.20
SUN-I3	873511.00	653101.00	-1682.10
TFRO-1	896099.78	1006629.67	-1356.80
W-12542	710022.95	1129876.84	-1082.00
W-15317	602749.81	662192.80	-1917.00
W-15371	585797.59	769236.21	-1730.00
W-15748	882294.17	934067.52	-1733.23
W-15813	669848.70	1104901.72	-1361.18
W-15880	593672.60	988827.76	-1740.00
W-16039	866992.28	1091917.21	-1635.00
W-16052	909414.06	836783.47	-1604.00
W-16182	906017.95	873416.88	-1432.17
W-16234	939265.37	917555.90	-1554.48
W-16543	821554.52	1092296.50	-1425.00
W-16882	943433.87	798935.63	-1580.44
W-17052	764969.48	896737.98	-1716.97

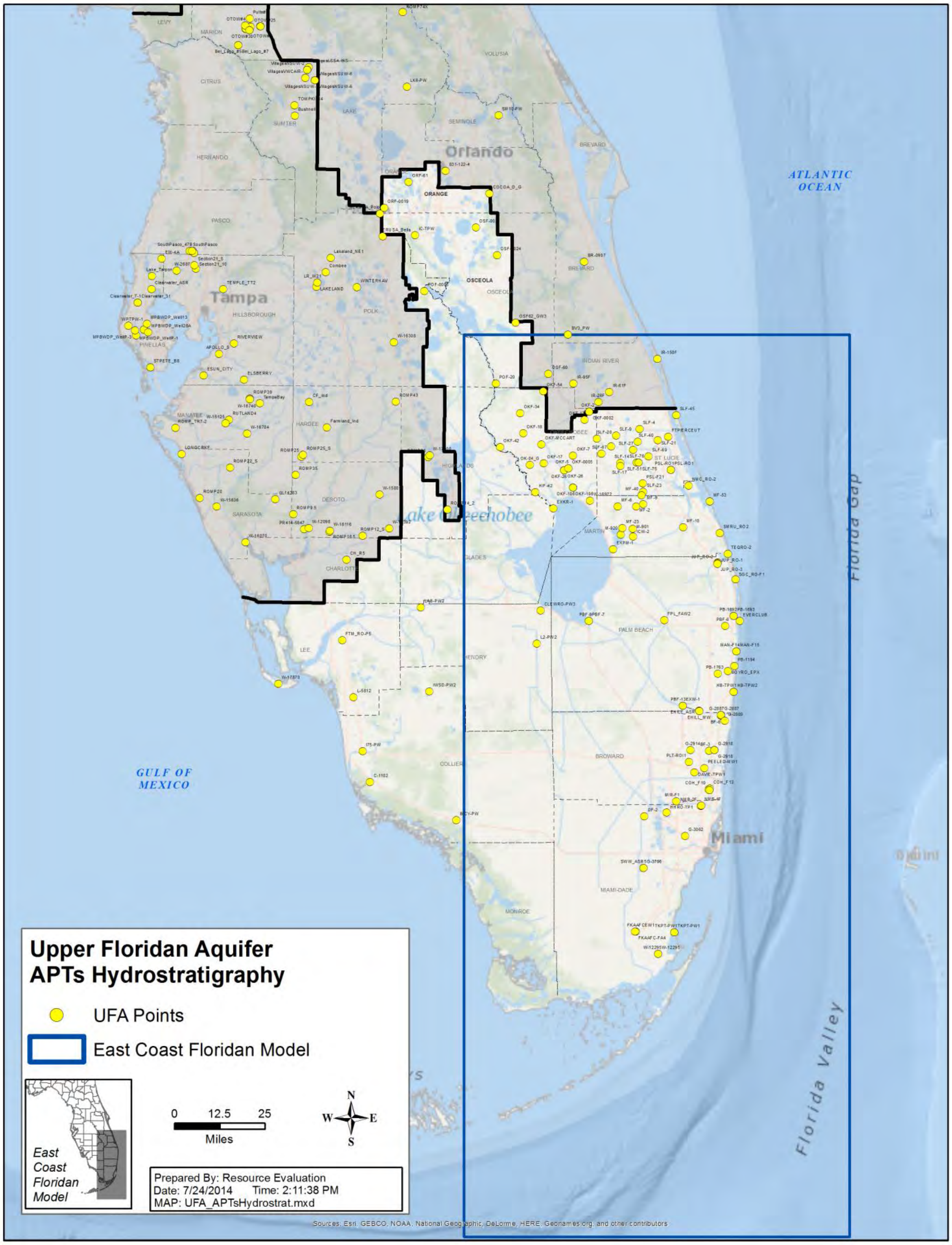
Lower Floridan Aquifer First Permeable Zone (LF1) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
ALLY-TW	714531.25	668029.48	-2234.60
BCN-I1	932262.64	700321.94	-1975.65
BF-1	925617.30	669564.23	-2114.62
C-1125	641103.56	642475.19	-2537.90
C-1127	683726.28	562927.96	-2589.72
C-962	687901.36	598265.20	-2588.40
CS-I1	897444.59	695121.17	-2127.00
CS-I2	897697.47	695859.82	-2127.00
DF-1	828433.47	575983.36	-2499.41
FLA-OS4	663060.70	1256671.17	-1552.00
FPU_RO-IW1	866322.66	1130448.90	-1833.00
FEETL-I3	941404.73	641405.05	-1993.62
G-3239	712460.74	519040.82	-2561.00
GLF-6	628323.00	910488.00	-1893.79
HASR-DZMW	886678.71	735581.37	-2122.50
HE-970	600119.64	808590.55	-2234.90
HOL-IW1	941045.23	616690.50	-1983.70
IR-1001	823795.73	1182081.09	-1927.00
LKOKEE_ASR	725790.79	1055542.97	-1754.00
LYTAL-TW	948920.09	852549.45	-2315.23
M-1352	900538.04	1041233.26	-2021.26
M-1358	895774.04	1057453.54	-2172.50
MDS-I12	871369.33	442406.14	-2440.00
MDWNA_I3N	936510.94	576946.30	-2060.99
MF-37	784921.90	965985.04	-1757.59
MIRAMAR_RO	880764.90	594262.97	-2375.31
MIRAMARIW1	875549.45	603608.28	-2306.06
OKF-100	698055.00	1025471.00	-1570.78
OKF-105	619115.79	1115332.23	-1592.70
OSF-104	613202.43	1208993.17	-1436.14
PB-1137	718008.85	728333.10	-2299.00
PB-1138	697389.89	787875.74	-2138.94
PB-1170	936560.57	942378.59	-1782.00
PB-1180	936548.02	886437.56	-2100.00
PB-1186	757541.77	858553.16	-1905.90
PB-1190	928897.16	785409.03	-1888.50
PB-1197	931130.11	942241.03	-1803.00
PB-1689	939106.00	874638.00	-2331.00
PBF-15	863897.13	874380.65	-1855.81

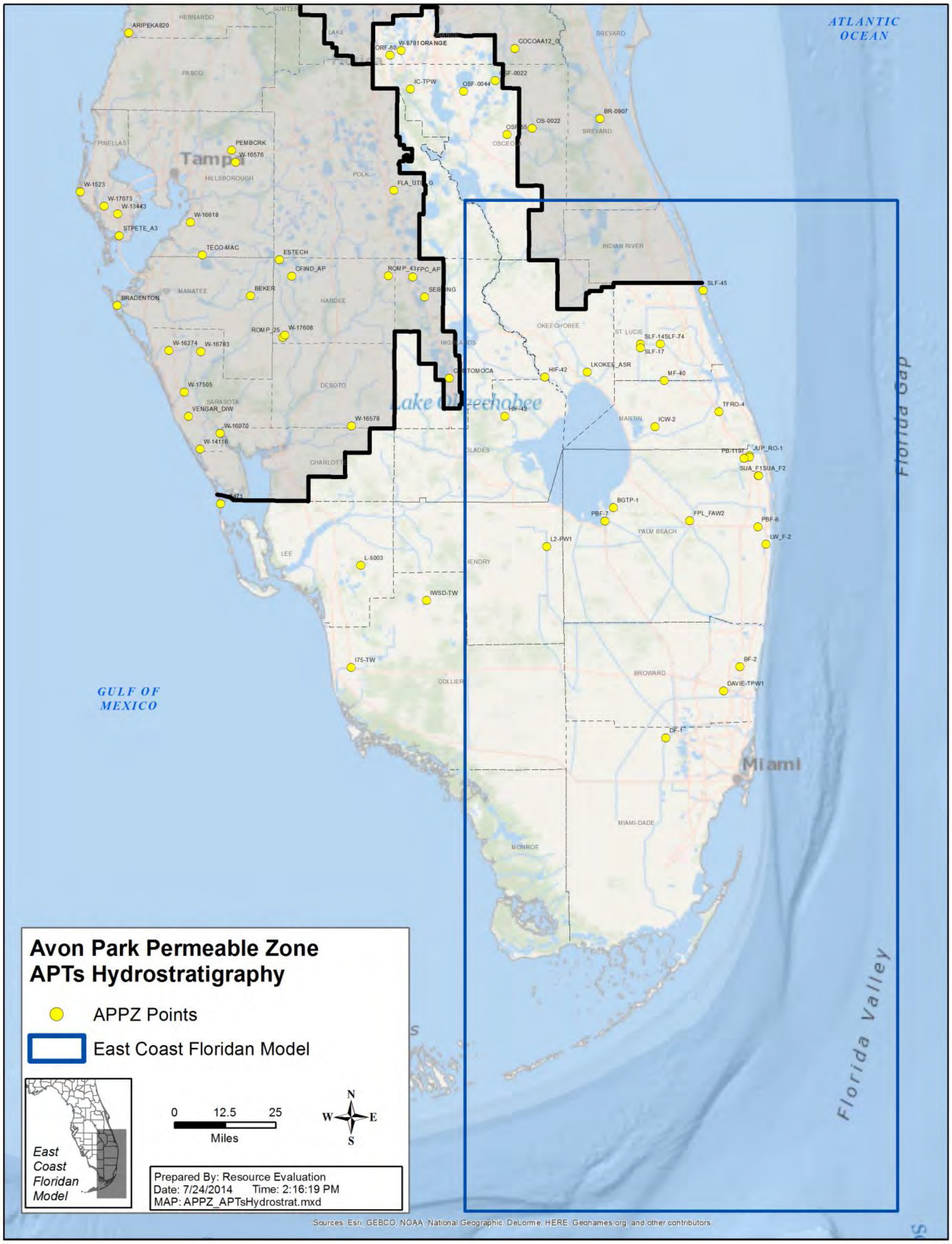
Lower Floridan Aquifer First Permeable Zone (LF1) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
PBF-7	748904.73	860161.10	-1920.83
PBP-I1	875496.54	603962.39	-2300.00
PSLLTC-IW1	850609.01	1104256.19	-2001.10
PSLWPT-IW1	866386.80	1055240.95	-1920.80
PU-I2	848794.80	493788.69	-2530.00
SUN-I3	873511.00	653101.00	-2277.10
W-15317	602749.81	662192.80	-2307.00
W-15371	585797.59	769236.21	-2280.00
W-15748	882294.17	934067.52	-1973.23
W-15813	669848.70	1104901.72	-1511.18
W-15880	593672.60	988827.76	-1960.00
W-15886	917035.99	749286.62	-1914.00
W-16039	866992.28	1091917.21	-2195.00
W-16052	909414.06	836783.47	-1924.00
W-16182	906017.95	873416.88	-2212.17
W-16234	939265.37	917555.90	-1859.48
W-16882	943433.87	798935.63	-1780.44
W-17052	764969.48	896737.98	-1836.97
W-2631	590305.28	746007.68	-2260.40
W-935	698090.59	536489.50	-2603.00
PSLWPT-IW1	866386.80	1055240.95	-2074.20
PU-I2	848794.80	493788.69	-2654.70
SUN-I3	873511.00	653101.00	-2370.70
W-15317	602749.81	662192.80	-2455.10
W-15748	882294.17	934067.52	-2160.00
W-15880	593672.60	988827.76	-2161.00
W-15886	917035.99	749286.62	-2050.40
W-16052	909414.06	836783.47	-2074.70
W-16182	906017.95	873416.88	-2371.80
W-16234	939265.37	917555.90	-2034.50
W-16882	943433.87	798935.63	-1930.60
W-2631	590305.28	746007.68	-2438.50

Boulder Zone (BZ) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
W-16039	866992.28	1091917.21	-2875.00
W-16897	878265.00	1135537.00	-3035.00
W-15880	593672.60	988827.76	-2950.00
BCN-I1	932262.64	700321.94	-3045.65
C-1125	641103.56	642475.19	-2859.90
W-15748	882294.17	934067.52	-2863.23
W-15886	917035.99	749286.62	-2880.00
W-16052	909414.06	836783.47	-2784.00
W-16182	906017.95	873416.88	-2982.17
W-16234	939265.37	917555.90	-3029.48
W-16882	943433.87	798935.63	-2850.44
W-17052	764969.48	896737.98	-2686.97
PB-1137	718008.85	728333.10	-2979.00
PB-1170	936560.57	942378.59	-2882.00
PB-1138	697389.89	787875.74	-3068.94
PB-1186	757541.77	858553.16	-2935.90
PB-1689	939106.00	874638.00	-2931.00
W-2631	590305.28	746007.68	-2960.40
MIRAMARIW1	875549.45	603608.28	-2996.06
PBP-I1	875496.54	603962.39	-3080.00
CS-I1	897444.59	695121.17	-2987.00
W-1976	809497.27	244083.18	-3517.00
MIRAMAR_RO	880764.90	594262.97	-3235.31
CS-I2	897697.47	695859.82	-3087.00
PB-1180	936548.02	886437.56	-3080.00
PB-1190	928897.16	785409.03	-2908.50
HE-970	600119.64	808590.55	-2944.90
MDS-I12	871369.33	442406.14	-2790.00
PSLWPT-IW1	866386.80	1055240.95	-2880.80
HOL-IW1	941045.23	616690.50	-2883.70
PU-I2	848794.80	493788.69	-2960.00
FPU_RO-IW1	866322.66	1130448.90	-2643.00
FEETL-I3	941404.73	641405.05	-2893.62
SUN-I3	873511.00	653101.00	-2912.10
M-1352	900538.04	1041233.26	-2941.26
M-1358	895774.04	1057453.54	-2932.50
C-962	687901.36	598265.20	-2938.40
G-3239	712460.74	519040.82	-2846.00
PSLLTC-IW1	850609.01	1104256.19	-2761.10

Boulder Zone (BZ) Control Points			
Well Name	**X Coordinate**	**Y Coordinate**	**Elevation (feet. NGVD)**
IR-1001	823795.73	1182081.09	-2379.00
OSF-104	613202.43	1208993.17	-2100.00
ALLY-TW	714531.25	668029.48	-2976.60
OLI-IW1	756443.00	1091566.68	-2684.00
OUA-EW1	716865.37	1078247.81	-2735.70

Appendix B. Aquifer Performance Test (APT) Sites – Hydrostratigraphy




Avon Park Permeable Zone
APTs Hydrostratigraphy
APPZ Points
East Coast Floridan Model
East Coast Floridan Model
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Miles
Prepared By: Resource Evaluation
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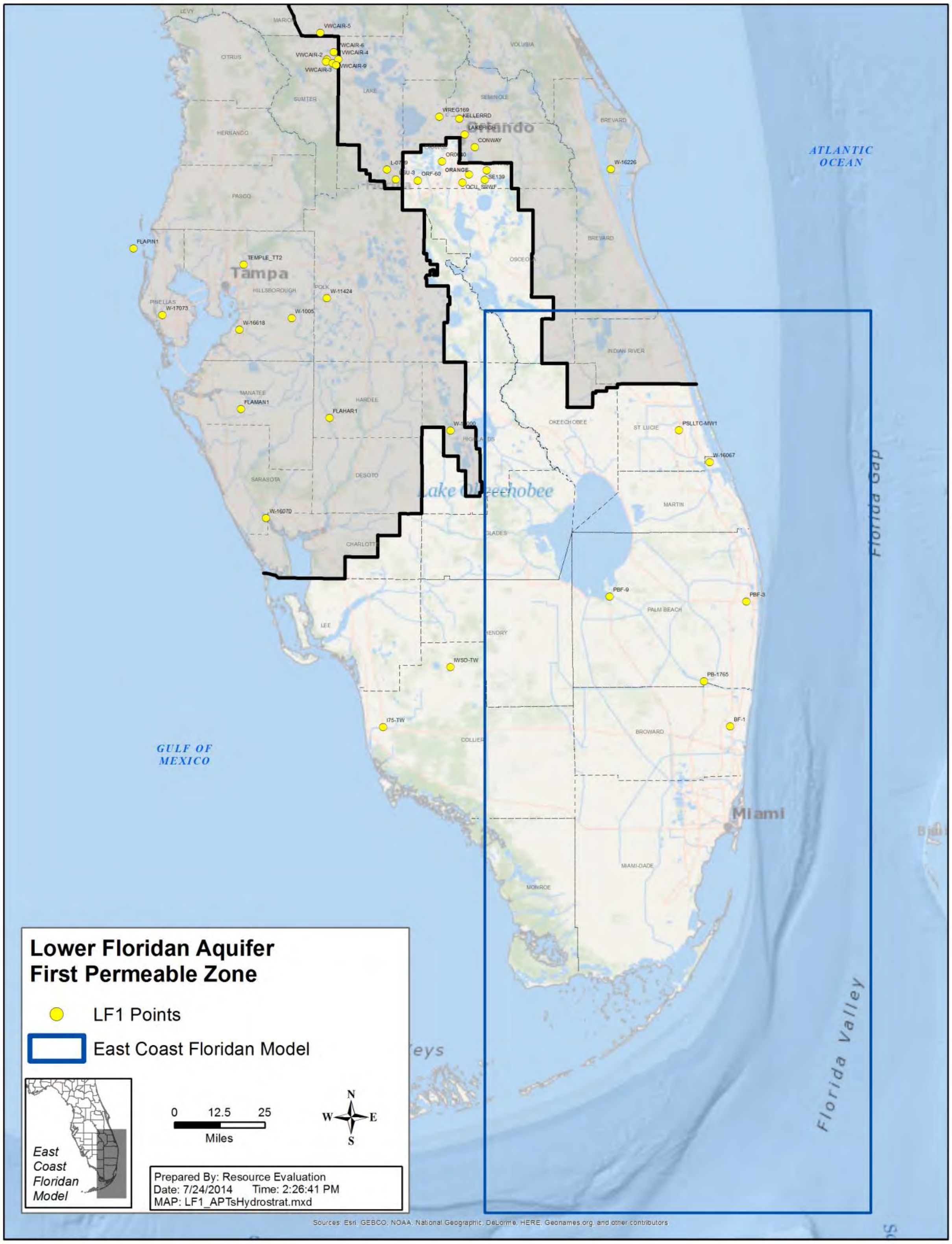
GULF OF MEXICO
Lake Okeechobee
Florida Gap
Florida Valley
Miami
Tampa


Lower Floridan Aquifer
First Permeable Zone
LF1 Points
East Coast Floridan Model
East Coast Floridan Model
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Prepared By: Resource Evaluation
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ATLANTIC OCEAN
GULF OF MEXICO
Tampa
Orlando
Miami
Lake Okeechobee
Florida Gap
Florida Valley

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	X Coordinate	Y Coordinate	Parameter	APT Value (K_h)
831-122-4	538482.00	1520831.00	K_h1	211.95
APOLLO_S	205687.00	1252002.00	K_h1	67.78
Bel_Lago_#5	234172.17	1705375.09	K_h1	10527.86
Bel_Lago_#7	234269.28	1705483.11	K_h1	12308.96
BF-3	925364.13	669470.16	K_h1	81.03
BF-6	943147.00	720952.00	K_h1	143.24
BICY-PW	554522.19	567147.92	K_h1	65.93
BOYRO_EPX	953221.77	786238.39	K_h1	18.20
BR-0907	742209.00	1387439.00	K_h1	111.54
BV3_PW	718706.00	1280248.00	K_h1	20.70
C-1102	427772.40	623495.68	K_h1	46.48
CF_Ind	338346.80	1181164.78	K_h1	6.35
CH_R5	392977.76	949940.23	K_h1	10.44
Bushnell	317100.63	1602093.74	K_h1	212.77
Clearwater_T-1	86074.26	1327228.25	K_h1	68.82
Clearwater_ASR	106501.05	1347051.84	K_h1	416.29
Clearwater_31	86077.42	1327446.45	K_h1	123.13
Pinellas_T-2	95461.03	1287811.62	K_h1	402.72
Pinellas_T-1	95364.07	1287812.99	K_h1	652.40
COCOA_D_G	602935.05	1487461.13	K_h1	803.84
COH_F1	926042.15	611238.97	K_h1	82.23
COH_F10	925258.34	612563.83	K_h1	103.47
COH_F13	926887.52	613758.46	K_h1	78.84
COHWTP_TW	926387.00	611661.00	K_h1	63.52
Combee	362670.83	1372340.06	K_h1	275.09
DAVIE-TPW1	904208.95	637353.16	K_h1	28.71
DF-2	830644.83	573066.45	K_h1	80.21
EHILL_ASR	910871.89	727878.52	K_h1	89.49
EHILL_MW	911585.82	727630.40	K_h1	45.91
ELSBERRY	242492.00	1214147.00	K_h1	12.11
ESUN_CITY	183278.00	1220591.00	K_h1	21.81
EVERCLUB	970850.40	860146.62	K_h1	13.07
EW-4A	121639.00	1391892.00	K_h1	294.90
EXKR-1	696704.82	1025434.64	K_h1	85.89
EXPM-1	784619.60	965030.14	K_h1	53.63
EXW-1	886998.00	735464.00	K_h1	288.67
Farmland_Ind	364027.37	1144029.76	K_h1	19.30
FKAAFCEW1	818317.68	403673.39	K_h1	34.92
FKAAFC-FA4	816711.92	403866.08	K_h1	75.35

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
FPL_FAW2	859757.73	860821.51	K_h1	519.73
FEETM_RO-P5	387000.00	831600.00	K_h1	42.78
FEETPIERCEUT	865825.84	1130401.44	K_h1	121.50
G-2887	943233.65	721588.18	K_h1	139.08
G-2887	943233.65	721588.18	K_h1	145.18
G-2889	948841.82	713346.82	K_h1	24.59
G-2914	898570.86	670420.97	K_h1	36.42
G-2917	933649.07	670332.13	K_h1	134.48
G-2918	933649.07	670332.13	K_h1	24.64
G-2918	933649.07	670332.13	K_h1	26.64
G-3062	890329.38	544270.75	K_h1	102.80
G-3706	829113.30	497138.54	K_h1	34.07
HB-TPW1	961554.37	755841.77	K_h1	76.20
HB-TPW2	962004.40	755976.30	K_h1	93.52
HHRO-TP1	863316.78	578626.71	K_h1	21.33
I75-PW	416551.72	668446.23	K_h1	63.57
IC-TPW	493982.00	1426318.00	K_h1	103.88
ICW-2	814300.22	983904.44	K_h1	52.29
IR-150F	849569.48	1244820.89	K_h1	35.20
IR-26F	763133.00	1181381.22	K_h1	70.10
IR-61F	779014.00	1196271.31	K_h1	119.77
IR-95F	726642.41	1208362.93	K_h1	52.76
IWSD-PW2	514933.43	756198.61	K_h1	330.13
JB_Ranch#20	266425.06	1732887.55	K_h1	34.76
JBRanch#21	266488.94	1732886.89	K_h1	15.24
JBRanch#23	266680.58	1732884.90	K_h1	46.97
JUP_RO-1	938348.14	945723.15	K_h1	15.07
JUP_RO-2	938082.82	944812.51	K_h1	18.09
JUP_RO-3	937999.90	943701.15	K_h1	10.21
L-5812	402976.48	748028.18	K_h1	1372.55
LAB-PW2	502269.39	879736.39	K_h1	51.66
Lake_Tarpon	107030.73	1366467.24	K_h1	129.30
LAKELAND	349081.76	1350573.54	K_h1	218.58
Lakeland_NE1	369721.21	1392940.95	K_h1	136.68
LK6-PW	481778.00	1644074.00	K_h1	320.66
LONGCRKF	150787.00	1105011.00	K_h1	87.91
LR_W21	350104.00	1356800.00	K_h1	217.03
M-901	813705.46	995141.30	K_h1	20.06

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
M-920	796035.19	986474.54	K_h1	18.51
MAN-F14	965578.00	815102.00	K_h1	13.35
MAN-F15	965796.00	814986.00	K_h1	4.74
MF-10	887370.80	997408.48	K_h1	73.22
MF-2	818367.25	1028076.75	K_h1	25.73
MF-23	798332.69	996599.68	K_h1	15.02
MF-53	926802.27	1035519.53	K_h1	1.92
MF-6	791721.61	1027979.53	K_h1	21.80
MF-9	828909.34	1031657.18	K_h1	26.27
MIR-F1	877424.88	595251.28	K_h1	14.04
MPBWDP_Well13	100171.68	1296401.66	K_h1	216.45
MPBWDP_Well28A	101615.02	1284087.80	K_h1	175.65
MPBWDP_WellP-1	83924.27	1279065.39	K_h1	200.53
MPBWDP_WellP-3	82607.26	1286358.95	K_h1	338.68
NERUSA_Bella	446454.98	1424886.78	K_h1	142.14
NERUSA_Polo	442226.97	1458106.36	K_h1	59.10
NMB-2F	913635.00	588117.00	K_h1	94.63
NMB-4F	914112.24	588593.93	K_h1	90.45
NMC_RO-2	895772.00	1058313.00	K_h1	202.11
OK-04_G	662277.86	1089147.84	K_h1	10.47
OKF-0002	749670.30	1167109.05	K_h1	46.40
OKF-0005	718924.84	1083944.62	K_h1	3.86
OKF-0027	712614.47	1081410.93	K_h1	2.73
OKF-0027	712614.47	1081410.93	K_h1	28.24
OKF-106	725843.94	1055704.20	K_h1	71.37
OKF-106	725843.94	1055704.20	K_h1	23.53
OKF-106	725843.94	1055704.20	K_h1	22.78
OKF-106	725843.94	1055704.20	K_h1	21.59
OKF-13	742944.25	1155346.84	K_h1	123.89
OKF-17	682570.05	1091477.77	K_h1	0.45
OKF-18	652723.99	1135495.01	K_h1	4.81
OKF-2	749670.30	1167109.05	K_h1	46.40
OKF-26	712614.47	1081410.93	K_h1	4.34
OKF-26	712614.47	1081410.93	K_h1	37.23
OKF-34	648495.80	1164880.11	K_h1	7.97
OKF-42	618563.38	1115013.95	K_h1	3.68
OKF-5	718924.84	1083944.62	K_h1	62.47
OKF-54	682141.15	1197504.02	K_h1	589.14

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
OKF-7	725748.21	1102434.52	K_h1	7.16
OKF-MCCART	679576.24	1119244.92	K_h1	6.59
ORF-0019	448449.16	1466873.68	K_h1	16.39
OSF-0024	614087.02	1397162.75	K_h1	108.57
OSF-0031	582930.83	1437806.53	K_h1	107.82
OSF-60	689752.00	1222451.00	K_h1	63.88
OSF62_GW3	641699.26	1297795.99	K_h1	46.06
OTOW#23	250266.45	1727457.31	K_h1	42488.68
OTOW#25	252207.07	1732637.43	K_h1	11770.11
OTOW#28	245012.86	1729114.63	K_h1	922.62
OTOW#28	245077.14	1729150.30	K_h1	922.62
OTOW#30	250588.26	1727672.06	K_h1	16850.00
OTOW#4	243986.09	1734545.13	K_h1	4189.62
OTOW#7	250714.47	1727525.22	K_h1	14034.78
PB-1194	962729.50	793720.45	K_h1	103.13
PB-1692	961917.84	867327.75	K_h1	502.33
PB-1693	961828.64	867125.14	K_h1	77.98
PB-1763	938731.19	782343.81	K_h1	7.74
PBF-13	886997.95	735463.95	K_h1	95.29
PBF-6	949133.50	852463.54	K_h1	171.50
PBF-9	748906.29	860073.56	K_h1	39.32
PEELED-MW1	918682.65	643742.17	K_h1	42.54
PLT-ROI1	896118.72	652838.90	K_h1	12.65
POF-0006	507391.51	1344504.24	K_h1	71.13
PR414-5847	331055.00	994816.00	K_h1	11.56
PSL-F21	828188.99	1061837.34	K_h1	392.59
PSL-RO1	869461.00	1081675.63	K_h1	74.56
PSL-RO1	869489.17	1081563.69	K_h1	73.95
Pulte#1	250801.31	1744473.05	K_h1	70.29
RIVERVIEW	227525.00	1267397.00	K_h1	88.28
ROMP16.5	368163.27	990721.35	K_h1	10.78
ROMP25	326969.04	1101085.41	K_h1	20.73
ROMP28	512996.53	1100653.97	K_h1	2.90
ROMP35	318077.92	1074289.91	K_h1	40.47
ROMP39	250823.63	1186463.23	K_h1	77.95
ROMP43	465536.58	1181739.66	K_h1	225.06
ROMP74X	475702.36	1753883.75	K_h1	55.75
ROMP9.5	314867.47	1016762.30	K_h1	18.40

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
ROMP_TR7-2	141536.00	1143313.00	K_h1	53.16
ROMP12_S	416623.07	985037.26	K_h1	38.16
ROMP14_2	541152.26	1023575.29	K_h1	82.05
ROMP20	177627.00	1040684.00	K_h1	60.16
ROMP22_S	222258.00	1085008.00	K_h1	42.59
ROMP25_S	329317.75	1103725.46	K_h1	20.66
RUTLAND4	220482.00	1155109.00	K_h1	52.22
Section21_10	171611.30	1377109.19	K_h1	171.60
Section21_5	169673.31	1382043.04	K_h1	145.28
SGC_RO-F1	964537.00	921100.00	K_h1	228.70
SLF-13	781693.97	1116100.36	K_h1	83.93
SLF-14	795303.17	1092197.81	K_h1	57.78
SLF-17	795581.10	1087367.68	K_h1	23.37
SLF-20	760755.12	1127350.46	K_h1	18.88
SLF-21	850164.05	1125344.56	K_h1	12.05
SLF-23	828573.74	1049525.83	K_h1	26.58
SLF-27	814069.64	1111164.76	K_h1	51.73
SLF-4	823588.46	1141598.19	K_h1	122.43
SLF-40	820708.50	1122891.04	K_h1	36.81
SLF-45	877700.18	1162258.59	K_h1	0.03
SLF-51	819191.26	1092504.73	K_h1	35.26
SLF-67	767932.93	1105760.25	K_h1	29.00
SLF-69	836548.22	1101782.47	K_h1	52.29
SLF-75	821825.10	1092287.51	K_h1	107.95
SLF-76	821840.68	1092293.33	K_h1	427.90
SLF-9	789049.08	1131963.83	K_h1	89.80
SM10-PW	616535.00	1602275.00	K_h1	15.07
SMRU_RO2	941570.00	988989.00	K_h1	295.78
SouthPasco	162591.23	1403371.59	K_h1	138.93
SouthPasco_43A	169033.87	1400599.38	K_h1	110.75
SouthPasco_47A	167131.50	1403096.27	K_h1	126.52
SouthPasco_43B	169033.87	1400599.38	K_h1	110.75
SouthPasco_47B	165842.70	1403112.43	K_h1	126.52
STPETE_B8	105130.00	1232173.00	K_h1	1934.04
SWW_ASR5	829113.30	497138.54	K_h1	31.77
TampaBay	265986.14	1179876.66	K_h1	123.02
TEMPLE_TT2	211934.00	1347210.00	K_h1	273.94
TEQRO-2	953080.00	958167.00	K_h1	33.01

Upper Floridan Aquifer APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
TKPT-PW1	874571.53	402532.21	K_h1	138.33
TOMPKI184	316535.00	1617318.00	K_h1	75.12
VillagesLSSA-WS-9	337310.94	1672942.15	K_h1	134.29
VillagesNSUW-1	335489.97	1669466.34	K_h1	153.59
VillagesNSUW-1	335489.97	1669466.34	K_h1	895.17
VillagesNSUW-2	335201.73	1669432.42	K_h1	508.41
VillagesNSUW-2	335201.73	1669432.42	K_h1	2503.47
VillagesNSUW-5	346880.40	1653807.07	K_h1	7632.65
VillagesNSUW-6	346848.40	1653807.33	K_h1	12738.80
VillagesNSUW-6	346848.40	1653807.33	K_h1	8515.57
VillagesVWCAIR-10	332282.03	1657238.14	K_h1	1184.36
W-12098	337492.93	996078.56	K_h1	12.45
W-12295	851079.11	370734.79	K_h1	247.26
W-12295	851079.11	370734.79	K_h1	294.57
W-14383	288488.00	1038806.00	K_h1	19.26
W-15125	215239.00	1150075.00	K_h1	142.60
W-15636	202618.01	1028237.25	K_h1	70.01
W-15801	441537.08	1045587.42	K_h1	11.87
W-16070	244635.00	975286.00	K_h1	26.71
W-16308	462931.20	1269360.45	K_h1	7.06
W-16740	250814.37	1185194.56	K_h1	63.40
W-16784	247191.00	1135193.00	K_h1	11.40
W-16972	750874.92	1036245.60	K_h1	27.91
W-17000	515233.04	1103529.16	K_h1	2.90
W-17392	455829.19	995732.39	K_h1	21.00
W-17870	292640.61	767416.72	K_h1	86.03
W-18116	368567.94	992516.04	K_h1	2.46
W-2607	143740.00	1374290.00	K_h1	222.81
WINTERHAV	408441.00	1350208.00	K_h1	190.64
WPTPW-1	72923.00	1293285.00	K_h1	186.05
HIF-42	670431	1049061	K_h1	10.42
MF-40	826580.032	1044391.078	K_h1	1416.67
L2-PW2	672709	826685	K_h1	9.93
PBF-7	748905	860161	K_h1	22.36
ORF-61	484377	1504605	K_h1	74.72
POF-20	612722	1208413	K_h1	12.13
CLEWRO-PW3	678404.417	875303.484	K_h1	43.27
TKPT-PW1	874572	402532.00	K_h1	138.33

Middle Confining Unit 1 APT Sites- Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_v)**
BF-2	925545.717	669572.279	K_v2	0.087
DF-2	830644.825	573066.451	K_v2	0.6228
BF-3	925364.134	669470.163	K_v2	0.0601
LAB-PW2	502269.393	879736.393	K_v2	0.3718
SLF-74	821840.676	1092293.325	K_v2	0.3137
PBF-9	748906.286	860073.564	K_v2	0.1409
BICY-PW	554522.187	567147.922	K_v2	0.0436
I75-PW	416551.723	668446.232	K_v2	0.1728
I75-PW	416551.723	668446.232	K_v2	0.2454
W-12295	851079.111	370734.789	K_v2	0.0011
SLF-76_G	821840.676	1092293.325	K_v2	1.5059
DF-1	828433.469	575983.357	K_v2	0.0177
COHWTP_TW	926387	611661	K_v2	0.0087
W-16308	462931.197	1269360.453	K_v2	0.3715
L-5810	382460.504	864984.047	K_v2	0.2899
L-5810	382460.504	864984.047	K_v2	0.2899
W-15999	287769.741	771801.296	K_v2	0.0087
W-17870	292640.612	767416.717	K_v2	0.2289
W-17095	724744.947	1055176.442	K_v2	0.5523
W-12098	337492.929	996078.555	K_v2	0.0206
W-17392	455829.186	995732.389	K_v2	0.0142
G-3706	829113.304	497138.537	K_v2	0.299
W-17608	329318.361	1103797.026	K_v2	0.0781
831-122-4	538482	1520831	K_v2	1.4605
ICW-2	814120.221	983804.438	K_v2	1.7498
SUGARMILLW	162149	1607347	K_v2	0.0961
TOMPKI184	316535	1617318	K_v2	0.0257
GREENSWAM	363276.257	1475099.837	K_v2	0.6915
TEMPLE	206122	1346913	K_v2	0.0501
TEMPLE_TT2	211934	1347210	K_v2	0.1942
EUREKA_SPR	228656	1341934	K_v2	0.0564
RIVERVIEW	227525	1267397	K_v2	0.4053
RUSKIN	205125	1230916	K_v2	0.0194
ESTECH	322684	1202853	K_v2	0.0079
RUTLAND4	220482	1155109	K_v2	0.124
BEKER	284683	1155555	K_v2	0.0071
SEBRING	512894	1154094	K_v2	0.0218
SARASOTA	167801	1142622	K_v2	0.1051

Middle Confining Unit 1 APT Sites- Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_v)**
EVERSRES	173508	1131644	K_v2	0.0289
L2-PW1	672708.954	826685.164	K_v2	0.0186
LONGCRKF	150787	1105011	K_v2	0.0075
CONTOMOCA	545016	1047478	K_v2	0.0073
BELLEAIR_2	73275	1311192	K_v2	0.0725
DUNEDIN	84986	1339028	K_v2	0.0061
OAKSCC	171840	1046207	K_v2	0.0043
SEFFNEBUD2	243381	1330503	K_v2	0.0395
CH-R5	392977.764	949940.229	K_v2	0.1005
ROMP22_S	222258	1085008	K_v2	0.7163
ROMP20	177627	1040684	K_v2	0.0219
W-14383	288488	1038806	K_v2	0.0009
VEN_RO-5	187940	1004201	K_v2	0.0081
PR414-5847	331055	994816	K_v2	0.0237
W-17056	282273	998464	K_v2	0.152
NLWP_FMW2	174832	1374196	K_v2	0.2561
W-16574	179817	1336825	K_v2	0.0072
ROMP14_2	541152.258	1023575.288	K_v2	0.1024
W-2607	143740	1374290	K_v2	0.003
EW-1	116207	1391752	K_v2	0.0125
EW-5	121639	1391892	K_v2	0.0206
NPEMBCRK15	262754	1345534	K_v2	0.1641
NPEMBCRK15	262754	1345534	K_v2	0.1094
PEMBCRK	259677	1345972	K_v2	0.02
W-16576	264687	1330649	K_v2	0.0107
W-1523	61371	1291635	K_v2	0.0306
W-17073	92615	1273195	K_v2	0.0042
W-13443	110408	1263016	K_v2	0.0016
W-16618	205687	1252002	K_v2	0.0038
MC-5060	431502.44	667243.5	K_v2	0.0841
MC-5005	433670.95	695209.75	K_v2	0.1057
SSTPETE_B8	105130	1232173	K_v2	0.1018
SSTPETE_A3	112500	1234000	K_v2	0.0073
CFIND_AP	338380	1181273	K_v2	0.0008
W-15125	215239	1150075	K_v2	0.0181
C-1206	428629.204	630255.734	K_v2	0.3776
PB-1197	931130.107	942241.032	K_v2	0.2796
CHULUOTA_1	618738.58	1568463.21	K_v2	1.8045

Middle Confining Unit 1 APT Sites- Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_v)**
PTMAL-ASR1	785473.94	1339450.53	K_v2	0.0751
FEETM_RO-P5	387000	832900	K_v2	0.575
FEETM_RO-P5	387000	831600	K_v2	0.0958
IC-TPW	493982	1426318	K_v2	0.2983
IC-TPW	493982	1426318	K_v2	0.4522
L2-TW	672740.653	826627.019	K_v2	0.1211
POLKC_3_G	388669.961	1400176.124	K_v2	0.0062
W-16070	244635	975286	K_v2	0.3748
W-15831	130588	1138073	K_v2	0.0727
BR-0910	742259	1387439	K_v2	0.0012
CLW-A1	105102.222	1321909.897	K_v2	0.39
SCRWTP-IW1	432218.001	666047.81	K_v2	0.0029
SCRWTP-IW2	432218.001	666047.81	K_v2	0.0268

Avon Park Permeable Zone APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
ARIPEKA820	124989.87	1499962.47	K_h3	151.61
BEKER	284683.00	1155555.00	K_h3	129.47
BF-2	925588.81	669597.59	K_h3	90.44
BGTP-1	759840.00	877795.00	K_h3	52.85
BR-0907	742209.00	1387439.00	K_h3	971.26
BRADENTON	110061.00	1142636.00	K_h3	474.24
CFIND_AP	338380.00	1181273.00	K_h3	1188.35
COCOAA12_G	630607.76	1479454.51	K_h3	1715.24
CONTOMOCA	545016.00	1047478.00	K_h3	56.15
DF-1	828433.47	575983.36	K_h3	42.97
ESTECH	322684.00	1202853.00	K_h3	278.22
FLA_UTIL_G	472113.66	1293452.00	K_h3	195.70
FPC_AP	497114.00	1180329.00	K_h3	65.15
FPL_FAW2	859757.73	860821.51	K_h3	519.73
I75-TW	416556.67	668295.47	K_h3	70.73
IC-TPW	493982.00	1426318.00	K_h3	222.92
ICW-2	814300.22	983904.44	K_h3	1727.46
IWSD-TW	515033.98	756359.82	K_h3	55.28
JUP_RO-1	938348.14	945723.15	K_h3	15.07
JUP_RO-3	937999.90	943701.15	K_h3	10.21
L2-PW1	672708.95	826685.16	K_h3	3.35
L-5003	428824.38	802202.95	K_h3	10.00
L-6471	245047.50	882879.38	K_h3	285.88
LKOKEE_ASR	725790.79	1055542.97	K_h3	1325.79
LW_F-2	960114.42	830056.00	K_h3	331.11
OS-0022	653638.00	1374722.00	K_h3	1374.75
OSF-0022	605279.77	1437265.82	K_h3	236.47
OSF-0044	563497.09	1423406.41	K_h3	280.41
OSF-55	620768.99	1366860.09	K_h3	113.04
PB-1197	931130.11	942241.03	K_h3	177.29
PBF-6	949133.50	852463.54	K_h3	1323.33
PEMBCRK	259677.00	1345972.00	K_h3	117.90
ROMP_25	326969.04	1101085.41	K_h3	437.76
ROMP_43	465536.58	1181739.66	K_h3	400.00
SEBRING	512894.00	1154094.00	K_h3	30.38
SLF-14	795303.17	1092197.81	K_h3	57.78
SLF-17	795581.10	1087367.68	K_h3	23.37
SLF-45	877700.18	1162258.59	K_h3	0.03

Avon Park Permeable Zone APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
SLF-74	821840.68	1092293.33	K_h3	173.01
STPETE_A3	112500.00	1234000.00	K_h3	6016.04
SUA_F1	949620.15	919515.32	K_h3	75.77
SUA_F2	950499.77	919619.53	K_h3	115.32
TECO-MAC	221390.00	1208917.00	K_h3	562.25
TFRO-4	898107.69	1003309.02	K_h3	565.12
VENGAR_DIW	203162.00	997485.00	K_h3	75.91
W-13443	110408.00	1263016.00	K_h3	6016.04
W-14116	218328.00	954414.00	K_h3	104.83
W-1523	61371.00	1291635.00	K_h3	10178.65
W-16070	244635.00	975286.00	K_h3	230.44
W-16274	177807.00	1083591.00	K_h3	11.72
W-16576	264687.00	1330649.00	K_h3	95.67
W-16578	416623.07	985037.26	K_h3	6023.39
W-16618	205687.00	1252002.00	K_h3	134.67
W-16783	219697.00	1082391.00	K_h3	269.17
W-17073	92615.00	1273195.00	K_h3	10110.99
W-17505	197659.00	1029181.00	K_h3	949.37
W-17608	329318.36	1103797.03	K_h3	346.67
W-8781	482084.00	1477111.68	K_h3	117.19
HIF-42	670431	1049061	K_h3	62.5
HIF-42	617719	997587	K_h3	81.80
MF-40	826580.032	1044391.078	K_h3	11070.00
ORF-60	467175	1470886	K_h3	128.66
PBF-7	748905	860161	K_h3	39.09
DAVIE-TPW1	904208.95	637353.16	K_h3	28.71

Middle Confining Unit 2 APT Sites- Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_v)**
PBF-9	748906.286	860073.564	K_v4	0.9896
IC-TPW	493982	1426318	K_v4	0.0448
POLKC_3_G	388669.961	1400176.124	K_v4	0.1505
W-16067	895855.12	1057464.014	K_v4	0.624
W-16039	866992.277	1091917.211	K_v4	0.1265
W-15944	783677.088	1345938.139	K_v4	0.0023
W-15961	770271.139	1358627.998	K_v4	0.425
W-16133	785016.457	1342111.521	K_v4	0.4117
W-16226	750698.466	1487741.808	K_v4	0.013
W-15886	917035.986	749286.617	K_v4	0.0584
PB-1689	938655.335	874130.76	K_v4	0.0004
BR-0910	742259	1387439	K_v4	0.0164
PSLWPT-IW1	866386.796	1055240.947	K_v4	0.0222
HOL-IW1	941045.229	616690.502	K_v4	1.8257
FEETM-IW1	385735.897	834341.425	K_v4	0.0015
SCRWTP-IW1	432218.001	666047.81	K_v4	0.0326
PSLLTC-IW1	850609.014	1104256.188	K_v4	0.0888

Lower Floridan Aquifer – First Permeable Zone APT Sites - Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_h)**
VWCAIR-1	333647.43	1648425.89	K_h5	182.79
VWCAIR-2	332434.23	1645054.16	K_h5	85.98
VWCAIR-3	342376.53	1643297.93	K_h5	5877.23
VWCAIR-6	344141.06	1659320.74	K_h5	106.08
VWCAIR-4	350841.92	1648902.01	K_h5	28045.80
VWCAIR-9	347539.85	1640419.14	K_h5	3138.54
VWCAIR-5	324453.14	1687890.27	K_h5	804.68
LGU-3	434974.73	1472509.38	K_h5	1185.96
BF-1	925617.30	669564.23	K_h5	6684.27
PBF-3	949209.57	852482.26	K_h5	6.83
W-11424	333686.25	1298278.61	K_h5	9.60
W-17480	568198.61	1485909.54	K_h5	1607.72
W-16067	895855.12	1057464.01	K_h5	10.90
W-17000	515233.04	1103529.16	K_h5	33.85
W-16226	750698.47	1487741.81	K_h5	34.00
OR0640	502712.17	1498940.35	K_h5	432.89
PBF-9	748906.29	860073.56	K_h5	853.83
IWSD-TW	515033.98	756359.82	K_h5	488.53
I75-TW	416556.67	668295.47	K_h5	381.42
TEMPLE_TT2	211934.00	1347210.00	K_h5	9.60
W-17073	92615.00	1273195.00	K_h5	9.62
W-16618	205687.00	1252002.00	K_h5	10.02
OCU_SRWF	532961.00	1467827.00	K_h5	699.15
SE139	565397.00	1471676.00	K_h5	219.75
ORANGE-TW	542554.00	1479513.00	K_h5	1655.63
L-0729	422073.00	1486905.00	K_h5	53.48
CONWAY	550702.00	1519786.00	K_h5	1616.92
LAKEHIGH	536396.00	1538310.00	K_h5	1381.53
KELLERRD	528181.00	1561465.00	K_h5	164.00
WREG169	498697.00	1564705.00	K_h5	1495.22
FLAHAR1	337670.33	1122514.26	K_h5	9.60
FLAMAN1	207567.35	1135366.36	K_h5	9.60
FLAPIN1	49844.06	1371024.94	K_h5	9.60
W-1005	282258.00	1268733.00	K_h5	9.60
W-16070	244635.00	975286.00	K_h5	0.10
PB-1765	886997.95	735463.95	K_h5	197.14
PSLLTC-MW1	850741.00	1104482.00	K_h5	132.89
ORF-60	467175	1470886	K_h5	167.53

Lower Confining Unit APT Sites- Hydrostratigraphy				
APT Site Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**APT Value (K_v)**
POLKC_3_G	388669.961	1400176.124	K_v6	0.905
W-16067	895855.12	1057464.014	K_v6	0.4707
W-16039	866992.277	1091917.211	K_v6	0.5927
W-16897	878265	1135537	K_v6	0.248
W-15961	770271.139	1358627.998	K_v6	0.0307
W-16133	785016.457	1342111.521	K_v6	0.186
W-16226	750698.466	1487741.808	K_v6	0.1142
W-15886	917035.986	749286.617	K_v6	0.0271
W-16882	943433.866	798935.629	K_v6	0.0431
W-17052	764969.483	896737.978	K_v6	0.074
PB-1170	936560.569	942378.588	K_v6	0.1042
PB-1186	757541.77	858553.162	K_v6	0.5628
PB-1689	938655.335	874130.76	K_v6	0.0223
PB-1190	928897.164	785409.026	K_v6	0.0723
BR1216	745357.709	1449248.709	K_v6	1.1824
PSLWPT-IW1	866386.796	1055240.947	K_v6	1.0576
FEETM-IW1	385735.897	834341.425	K_v6	0.3118
PSLLTC-IW1	850609.014	1104256.188	K_v6	0.073

Appendix C. PEST Aquifer Performance Test (APT) Calibrated Values

Upper Floridan Aquifer - PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
BF-3	925364.13	669470.16	K_h1	ppkx1_a1	81.03	49.78773
BF-6	943147	720952	K_h1	ppkx1_a2	143.24	66.41865
BOYRO_EPX	953221.77	786238.39	K_h1	ppkx1_a3	18.2	8.801601
COH_F1	926042.15	611238.97	K_h1	ppkx1_a4	82.23	226.1325
COH_F10	925258.34	612563.83	K_h1	ppkx1_a5	103.47	257.766
COH_F13	926887.52	613758.46	K_h1	ppkx1_a6	78.84	93.70489
COHWTP_TW	926387	611661	K_h1	ppkx1_a7	63.52	56.24379
DAVIE-TPW1	904208.95	637353.16	K_h1	ppkx1_a8	28.71	78.9525
DF-2	830644.83	573066.45	K_h1	ppkx1_a9	80.21	29.16727
EHILL_ASR	910871.89	727878.52	K_h1	ppkx1_a10	89.49	32.54182
EHILL_MW	911585.82	727630.4	K_h1	ppkx1_a11	45.91	16.69455
EVERCLUB	970850.4	860146.62	K_h1	ppkx1_a12	13.07	31.07989
EXKR-1	696704.82	1025434.64	K_h1	ppkx1_a13	85.89	90.07144
EXPM-1	784619.6	965030.14	K_h1	ppkx1_a14	53.63	86.43069
FKAAFCEW1	818317.68	403673.39	K_h1	ppkx1_a16	34.92	89.45521
FKAAFC-FA4	816711.92	403866.08	K_h1	ppkx1_a17	75.35	45.46932
FPL_FAW2	859757.73	860821.51	K_h1	ppkx1_a18	51.973	142.9257
FEETPIERCEUT	865825.84	1130401.44	K_h1	ppkx1_a19	121.5	334.125
G-2887	943233.65	721588.18	K_h1	ppkx1_a20	139.08	55.02831
G-2889	948841.82	713346.82	K_h1	ppkx1_a22	24.59	17.13453
G-2914	898570.86	670420.97	K_h1	ppkx1_a23	36.42	73.42106
G-2917	933649.07	670332.13	K_h1	ppkx1_a24	134.48	56.10024
G-3062	890329.38	544270.75	K_h1	ppkx1_a27	102.8	282.7
HB-TPW1	961554.37	755841.77	K_h1	ppkx1_a29	76.2	30.59983
HB-TPW2	962004.4	755976.3	K_h1	ppkx1_a30	93.52	178.1502
HHRO-TP1	863316.78	578626.71	K_h1	ppkx1_a31	21.33	58.6575
ICW-2	814300.22	983904.44	K_h1	ppkx1_a32	52.29	25.88038
IR-150F	849569.48	1244820.89	K_h1	ppkx1_a33	35.2	21.04444
IR-26F	763133	1181381.22	K_h1	ppkx1_a34	70.1	192.775
IR-61F	779014	1196271.31	K_h1	ppkx1_a35	119.77	250.2534
IR-95F	726642.41	1208362.93	K_h1	ppkx1_a36	52.76	19.18546
JUP_RO-1	938348.14	945723.15	K_h1	ppkx1_a37	15.07	37.46992
JUP_RO-2	938082.82	944812.51	K_h1	ppkx1_a38	18.09	37.08019
JUP_RO-3	937999.9	943701.15	K_h1	ppkx1_a39	10.21	22.82086

Upper Floridan Aquifer - PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
M-901	813705.46	995141.3	K_h1	ppkx1_a40	20.06	54.86398
M-920	796035.19	986474.54	K_h1	ppkx1_a41	18.51	6.730909
MAN-F14	965578	815102	K_h1	ppkx1_a42	13.35	6.004483
MAN-F15	965796	814986	K_h1	ppkx1_a43	4.74	4.650888
MF-10	887370.8	997408.48	K_h1	ppkx1_a44	73.22	35.48522
MF-2	818367.25	1028076.75	K_h1	ppkx1_a45	25.73	55.76976
MF-23	798332.69	996599.68	K_h1	ppkx1_a46	15.02	41.305
MF-53	926802.27	1035519.53	K_h1	ppkx1_a47	1.92	8.58
MF-6	791721.61	1027979.53	K_h1	ppkx1_a48	21.8	34.42354
MF-9	828909.34	1031657.18	K_h1	ppkx1_a49	26.27	71.15782
MIR-F1	877424.88	595251.28	K_h1	ppkx1_a50	14.04	38.61
NMB-2F	913635	588117	K_h1	ppkx1_a51	94.63	260.2325
NMB-4F	914112.24	588593.93	K_h1	ppkx1_a52	90.45	248.7375
NMC_RO-2	895772	1058313	K_h1	ppkx1_a53	202.11	73.49455
OK-04_G	662277.86	1089147.84	K_h1	ppkx1_a54	10.47	4.499772
OKF-0002	749670.3	1167109.05	K_h1	ppkx1_a55	46.4	74.16809
OKF-106	725843.94	1055704.2	K_h1	ppkx1_a59	71.37	109.4822
OKF-17	682570.05	1091477.77	K_h1	ppkx1_a60	0.45	0.7662525
OKF-18	652723.99	1135495.01	K_h1	ppkx1_a61	4.81	11.13837
OKF-26	712614.47	1081410.93	K_h1	ppkx1_a63	37.23	14.57342
OKF-34	648495.8	1164880.11	K_h1	ppkx1_a64	7.97	21.9175
OKF-42	618563.38	1115013.95	K_h1	ppkx1_a65	3.68	1.338182
OKF-7	725748.21	1102434.52	K_h1	ppkx1_a66	7.16	9.652073
OKF-MCCART	679576.24	1119244.92	K_h1	ppkx1_a67	6.59	2.997365
OSF-60	689752	1222451	K_h1	ppkx1_a68	63.88	35.56661
PB-1194	962729.5	793720.45	K_h1	ppkx1_a69	103.13	50.3558
PB-1692	961917.84	867327.75	K_h1	ppkx1_a70	502.33	105.45
PB-1693	961828.64	867125.14	K_h1	ppkx1_a71	77.98	47.8524
PB-1763	938731.19	782343.81	K_h1	ppkx1_a72	7.74	2.814545
PBF-13	886997.95	735463.95	K_h1	ppkx1_a73	95	44.26619
PBF-6	949133.5	852463.54	K_h1	ppkx1_a74	171.5	62.36364
PBF-9	748906.29	860073.56	K_h1	ppkx1_a75	39.32	108.13
PEELED-MW1	918682.65	643742.17	K_h1	ppkx1_a76	42.54	21.12012
PLT-ROI1	896118.72	652838.9	K_h1	ppkx1_a77	12.65	15.37628
PSL-F21	828188.99	1061837.34	K_h1	ppkx1_a78	256	93.09091
PSL-RO1	869461	1081675.63	K_h1	ppkx1_a79	74.56	54.42082
PSL-RO1	869489.17	1081563.69	K_h1	ppkx1_a80	73.95	203.3625

Upper Floridan Aquifer - PEST Aquifer Performance Test (APT)						
APT Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**Pilot Point Name**	**APT Target Value**	**Calibrated PEST Value**
SGC_RO-F1	964537	921100	K_h1	ppkx1_a81	228.7	116.4345
SLF-13	781693.97	1116100.36	K_h1	ppkx1_a82	83.93	233.1615
SLF-14	795303.17	1092197.81	K_h1	ppkx1_a83	57.78	158.895
SLF-17	795581.1	1087367.68	K_h1	ppkx1_a84	23.37	9.436454
SLF-20	760755.12	1127350.46	K_h1	ppkx1_a85	18.88	11.43774
SLF-21	850164.05	1125344.56	K_h1	ppkx1_a86	12.05	26.58134
SLF-23	828573.74	1049525.83	K_h1	ppkx1_a87	26.58	9.665455
SLF-27	814069.64	1111164.76	K_h1	ppkx1_a88	51.73	45.32961
SLF-4	823588.46	1141598.19	K_h1	ppkx1_a89	122.43	336.6825
SLF-40	820708.5	1122891.04	K_h1	ppkx1_a90	36.81	101.2275
SLF-51	819191.26	1092504.73	K_h1	ppkx1_a92	35.26	96.965
SLF-67	767932.93	1105760.25	K_h1	ppkx1_a93	29	62.28598
SLF-69	836548.22	1101782.47	K_h1	ppkx1_a94	52.29	19.01454
SLF-75	821825.1	1092287.51	K_h1	ppkx1_a95	107.95	227.6611
SLF-76	821840.68	1092293.33	K_h1	ppkx1_a96	427.9	85.64638
SLF-9	789049.08	1131963.83	K_h1	ppkx1_a97	89.8	177.6295
SMRU_RO2	941570	988989	K_h1	ppkx1_a98	295.78	122.7494
SWW_ASR5	829113.3	497138.54	K_h1	ppkx1_a99	31.77	77.71867
TEQRO-2	953080	958167	K_h1	ppkx1_a100	33.01	58.68943
TKPT-PW1	874571.53	402532.21	K_h1	ppkx1_a101	138.33	259.2403
W-12295	851079.11	370734.79	K_h1	ppkx1_a103	294.57	810.0675
W-16972	750874.92	1036245.6	K_h1	ppkx1_a104	27.91	53.01327
HIF-42	670431	1049061	K_h1	ppkx1_a105	10.42	5.00816
L2-PW2	672709	826685	K_h1	ppkx1_a106	9.93	27.3075
CLEWRO-PW3	678404.42	875303.48	K_h1	ppkx1_a107	43.27	118.9925
LTC_F-1	964926.26	914793.51	K_h1	ppkx1_a108	51.44	24.29519
IR-21F	872567.79	1178893.97	K_h1	ppkx1_a135	18	49.5
IR-42F	816475.6	1185597.98	K_h1	ppkx1_a137	163	448.25
IR-47F	825817.63	1189272.01	K_h1	ppkx1_a138	66	181.5
IR-53F	781908.73	1190928.15	K_h1	ppkx1_a139	266	731.5
IR-54F	838401.68	1191751.03	K_h1	ppkx1_a140	154	423.5
IR-64F	772533.77	1197766.2	K_h1	ppkx1_a142	106	291.5
IR-72F	845822.73	1201379.1	K_h1	ppkx1_a143	25	55.4465
IR-77F	830800.68	1202017.1	K_h1	ppkx1_a144	39	19.69683
IR-80F	805525.67	1202521.14	K_h1	ppkx1_a145	74	87.69929
IR-12F	830016.62	1175353.91	K_h1	ppkx1_a147	144	52.36364
IR-20F	800038.64	1177861.01	K_h1	ppkx1_a148	125	45.45455

Upper Floridan Aquifer - PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
IR-202	729822.88	1190798.27	K_h1	ppkx1_a149	56	73.71615
IR-245	853941.72	1178292.95	K_h1	ppkx1_a150	45	123.75
IR-57F	855388.75	1194962.06	K_h1	ppkx1_a151	42	115.5
BICY-PW	554522.19	567147.92	K_h1	ppkx1_a153	65.93	36.14315
BV3-PW	718706	1280248	K_h1	ppkx1_a154	20.7	33.96597
IWSD-PW2	514933.43	756198.61	K_h1	ppkx1_a155	330.13	280.1687
LAB-PW2	502269.39	879736.39	K_h1	ppkx1_a156	51.66	116.6333
OSF62_GW3	641699.26	1297795.99	K_h1	ppkx1_a157	46.06	126.665
ROMP43BeeB	465536.58	1181739.66	K_h1	ppkx1_a158	225.06	225.0598
ROMP14_2	541152.26	1023575.29	K_h1	ppkx1_a159	82.05	219.0138
W-16308	462931.2	1269360.45	K_h1	ppkx1_a160	7.06	7.06
W-17000	515233.04	1103529.16	K_h1	ppkx1_a161	2.9	1.367995

Middle Confining Unit 1 - PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
BF-2	925545.72	669572.28	K_v2	ppkz2_a1	0.087	0.010488821
DF-2	830644.82	573066.45	K_v2	ppkz2_a2	0.6228	3.858944
BF-3	925364.13	669470.16	K_v2	ppkz2_a3	0.0601	0.005783607
SLF-74	821840.68	1092293.33	K_v2	ppkz2_a4	0.3137	0.031942423
PBF-9	748906.29	860073.56	K_v2	ppkz2_a5	0.1409	1.405328
W-12295	851079.11	370734.79	K_v2	ppkz2_a6	0.0011	0.000236421
DF-1	828433.47	575983.36	K_v2	ppkz2_a9	0.0177	0.2038943
COHWTP_TW	926387	611661	K_v2	ppkz2_a10	0.0087	0.1231499
W-17095	724744.95	1055176.44	K_v2	ppkz2_a11	0.5523	0.05244
G-3706	829113.3	497138.54	K_v2	ppkz2_a12	0.299	0.4962002
ICW-2	814120.22	983804.44	K_v2	ppkz2_a13	1.7498	0.16625
L2-PW1	672708.95	826685.16	K_v2	ppkz2_a14	0.0186	0.001840124
PB-1197	931130.11	942241.03	K_v2	ppkz2_a15	0.2796	3.829832
L2-TW	672740.65	826627.02	K_v2	ppkz2_a16	0.1211	0.011495

Avon Park Permeable Zone - PEST Aquifer Performance Test (APT)						
APT Name	**X Coordinate**	**Y Coordinate**	**Parameter**	**Pilot Point Name**	**APT Target Value**	**Calibrated PEST Value**
BF-2	925588.81	669597.59	K_h3	ppkx3_a109	90.44	32.88727
BGTP-1	759840	877795	K_h3	ppkx3_a110	52.85	309.5675
DF-1	828433.47	575983.36	K_h3	ppkx3_a111	42.97	23.2566
FPL_FAW2	859757.73	860821.51	K_h3	ppkx3_a112	519.73	1429.257
ICW-2	814300.22	983904.44	K_h3	ppkx3_a113	1727.46	628.1673
JUP_RO-1	938348.14	945723.15	K_h3	ppkx3_a114	15.07	43.6425
JUP_RO-3	937999.9	943701.15	K_h3	ppkx3_a115	10.21	41.2775
L2-PW1	672708.95	826685.16	K_h3	ppkx3_a116	3.35	9.2125
LKOKEE_ASR	725790.79	1055542.97	K_h3	ppkx3_a117	1325.79	482.1055
LW_F-2	960114.42	830056	K_h3	ppkx3_a118	331.11	180.4341
PB-1197	931130.11	942241.03	K_h3	ppkx3_a119	177.29	117.3199
PBF-6	949133.5	852463.54	K_h3	ppkx3_a121	1323.33	481.2109
PBF-9	748906.29	860073.56	K_h3	ppkx3_a122	853.83	2348.032
SLF-14	795303.17	1092197.81	K_h3	ppkx3_a123	57.78	158.895
SLF-17	795581.1	1087367.68	K_h3	ppkx3_a124	46.74	16.99636
SLF-74	821840.68	1092293.33	K_h3	ppkx3_a126	173.01	67.38944
SUA_F1	949620.15	919515.32	K_h3	ppkx3_a127	75.77	27.55273
SUA_F2	950499.77	919619.53	K_h3	ppkx3_a128	115.32	165.8607
TFRO-4	898107.69	1003309.02	K_h3	ppkx3_a129	565.12	652.6636
HIF-42	617719	997587	K_h3	ppkx3_a130	81.8	234.19
DAVIE-TPW1	904208.95	637353.16	K_h3	ppkx3_a152	28.71	81.35044
CONTOMOCA	545016	1047478	K_h3	ppkx3_a162	56.15	31.33922
IWSD-TW	515033.98	756359.82	K_h3	ppkx3_a163	55.28	24.52283
SEBRING	512894	1154094	K_h3	ppkx3_a164	30.38	11.04727
PSL-F21	828188.99	1061837.34	K_h3	ppkx3_a168	512	186.1818
MF-40	826580	1044391	K_h3	ppkx3_a169	11070	26789.4

Middle Confining Unit 2 - PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
PBF-9	748906.29	860073.56	K_v4	ppkz4_a17	0.9896	4.0
W-16067	895855.12	1057464.01	K_v4	ppkz4_a18	0.624	0.3775805
W-16039	866992.28	1091917.21	K_v4	ppkz4_a19	0.1265	0.012065
W-15886	917035.99	749286.62	K_v4	ppkz4_a20	0.0584	1.29756
PB-1689	938655.34	874130.76	K_v4	ppkz4_a21	0.0004	0.007549776
PSLWPT-IW1	866386.8	1055240.95	K_v4	ppkz4_a22	0.0222	0.49324
HOL-IW1	941045.23	616690.5	K_v4	ppkz4_a23	1.8257	0.17347
PSLLTC-IW1	850609.01	1104256.19	K_v4	ppkz4_a24	0.0888	0.008455

Lower Floridan Aquifer – First Permeable Zone PEST Aquifer Performance Test (APT)						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
W-16067	895855.12	1057464.01	K_h5	ppkx5_a131	10.9	22.9925
PBF-9	748906.29	860073.56	K_h5	ppkx5_a132	853.83	2348.03
PB-1765	886997.95	735463.95	K_h5	ppkx5_a133	197.14	77.16359
PSLLTC-MW1	850741	1104482	K_h5	ppkx5_a134	132.89	48.32
W-17000	515233.04	1103529.16	K_h5	ppkx5_a165	33.85	64.86461
IWSD-TW	515033.98	756359.82	K_h5	ppkx5_a166	488.53	972.7065
SE-DEW	517725.44	1248246.59	K_h5	ppkx5_a167	36.22	17.72383

Lower Confining Unit - PEST Aquifer Performance Test (APT)

Lower Confining Unit - PEST Aquifer Performance Test (APT						
APT Name	X Coordinate	Y Coordinate	Parameter	Pilot Point Name	APT Target Value	Calibrated PEST Value
W-16067	895855.12	1057464.01	K_v6	ppkz6_a25	0.4707	4.0
W-16039	866992.28	1091917.21	K_v6	ppkz6_a26	0.5927	1.176464
W-16897	878265	1135537	K_v6	ppkz6_a27	0.248	0.2945609
W-15886	917035.99	749286.62	K_v6	ppkz6_a28	0.0271	0.003046729
W-16882	943433.87	798935.63	K_v6	ppkz6_a29	0.0431	0.4472296
W-17052	764969.48	896737.98	K_v6	ppkz6_a30	0.074	0.00703
PB-1170	936560.57	942378.59	K_v6	ppkz6_a31	0.1042	1.902701
PB-1186	757541.77	858553.16	K_v6	ppkz6_a32	0.5628	1.559534
PB-1689	938655.34	874130.76	K_v6	ppkz6_a33	0.0223	0.00209
PB-1190	928897.16	785409.03	K_v6	ppkz6_a34	0.0723	0.00684
PSLWPT-IW1	866386.8	1055240.95	K_v6	ppkz6_a35	1.0576	4.0
PSLLTC-IW1	850609.01	1104256.19	K_v6	ppkz6_a36	0.073	0.006935

Appendix D. Relative Difference of the Mean Absolute Error in Heads.

The error by varying the calibrated parameter is provided relative to the error computed with the calibrated parameter. A negative value means that the change in the parameter is worsening the error in heads. A positive value means that the change in the parameter is lessening the error.

Sensitivity Run by Varying Calibrated Parameters															
County	Well	# of points	Layer	Head Error at BZ	K_v6 Error times 0.5	K_v6 Error times 2.0	Head Error at NW minus 5	Head Error at NW plus 5	K_v4 Error times 0.5	K_v4 Error times 2.0	K_h3 Error times 0.5	K_h3 Error times 2.0	K_v2 Error times 0.5	K_v2 Error times 2.0
Polk	POF-RR	24	UFA	-0.53	-0.16	0.09	-0.59	0.42	-1.06	0.54	-1.12	0.64	-1.71	0.58
Highlands	HIF-13	39	UFA	-1.53	0.06	-0.21	-0.22	-1.21	-0.12	-0.65	-0.12	-0.36	-0.06	0.02
Highlands	HIF-14	35	APPZ	-0.07	0.00	-0.02	-3.20	-3.14	0.00	-0.05	0.01	-0.03	0.00	0.00
Highlands	HIF-3	15	APPZ	-0.66	-0.02	0.02	-1.52	-2.42	0.03	-0.05	0.05	-0.25	-0.02	0.02
Highlands	HIF-37	34	UFA	-0.96	-0.65	-0.11	-1.16	-0.70	-1.12	-0.26	-0.93	0.07	-0.16	0.06
Highlands	HIF-4	24	APPZ	-2.02	0.24	-0.23	0.64	-2.52	0.61	-0.96	0.46	-0.80	-0.07	0.05
Highlands	HIF-40	57	UFA	0.01	-0.75	-0.29	-1.88	-1.51	-1.32	-0.66	-0.61	-0.32	-0.11	0.03
Highlands	HIF-42L	44	APPZ	-3.75	0.00	-1.72	0.27	-0.33	0.41	-0.73	0.44	-1.29	-0.10	0.06
Highlands	HIF-42U	44	UFA	-1.56	-2.06	0.20	-0.36	0.25	-1.23	0.33	-1.19	0.33	-0.08	0.02
Highlands	HIF-6	42	UFA	-1.93	-0.56	-0.45	-0.34	-0.31	-0.74	-0.47	-0.26	-0.27	-0.10	0.01
Osceola	OSF-104M	55	APPZ	-2.84	0.07	-0.04	0.15	-0.16	0.57	-0.45	0.57	-0.88	-0.24	0.16
Osceola	OSF-231	22	UFA	-1.73	0.01	-0.02	-0.50	-0.64	-0.16	-0.07	-0.04	0.05	0.02	-0.01
Osceola	OSF-42	42	UFA	-1.42	-0.09	0.04	-0.01	0.01	-0.55	0.23	-0.46	0.26	-0.29	0.16
Osceola	OSF-60A	168	UFA	-2.78	-0.18	0.05	-0.01	0.01	-0.83	0.08	-0.11	0.08	-0.13	0.07
Osceola	OSF-HAY	108	UFA	-2.47	-0.04	-0.02	-0.35	-0.49	-0.33	-0.21	-0.09	0.02	-0.07	0.01
Glades	GLF-6	100	APPZ	-4.79	0.06	-0.02	0.02	-0.03	0.04	-0.02	-0.02	0.05	0.00	0.00
Glades	GLY-155	173	UFA	-2.33	-0.96	-0.56	-0.31	-0.19	-0.99	-0.38	-0.42	-0.08	-0.12	0.06
Glades	GLY-CLE	43	UFA	-0.45	0.02	-0.01	-3.67	-4.42	0.09	-0.10	-0.06	0.07	0.17	-0.47
Okeechobee	OKF-1	222	UFA	-2.58	-1.80	-1.16	0.00	-0.01	-0.15	-0.07	-0.01	0.01	0.01	-0.03
Okeechobee	OKF-100	39	APPZ	-2.12	-1.06	-0.16	-0.10	0.08	-0.35	0.11	-0.43	0.09	0.04	-0.03

Sensitivity Run by Varying Calibrated Parameters														
County	Well	# of points	Layer	Head Error at BZ	K_v6 Error times 0.5	K_v6 Error times 2.0	Head Error at NW minus 5	Head Error at NW plus 5	K_v4 Error times 0.5	K_v4 Error times 2.0	K_h3 Error times 0.5	K_h3 Error times 2.0	K_v2 Error times 0.5	K_v2 Error times 2.0
Okeechobee	OKF-100L	70	APPZ	-3.22	-0.86	-1.02	0.01	-0.06	-0.07	-0.13	-0.33	-0.33	0.01	-0.05
Okeechobee	OKF-100U	72	UFA	-2.63	-1.12	-0.71	-0.02	-0.01	-0.22	-0.04	-0.24	-0.25	-0.17	-0.25
Okeechobee	OKF-101	88	UFA	-2.13	-2.02	-0.32	-0.13	0.10	-0.56	0.16	-0.73	0.14	-0.18	0.04
Okeechobee	OKF-105M	33	APPZ	-2.08	-1.31	0.10	-0.80	0.16	-2.17	-0.46	-0.69	-0.03	0.15	-0.15
Okeechobee	OKF-105U	42	UFA	-2.37	-0.41	-0.44	-0.14	-0.37	-0.92	-0.99	-0.18	-0.44	0.02	-0.01
Okeechobee	OKF-106	51	UFA	-3.44	-0.46	-1.73	0.10	-0.11	0.33	-0.28	0.29	-0.61	0.37	-0.25
Okeechobee	OKF-17	42	UFA	-3.69	0.34	-1.47	0.20	-0.24	0.53	-0.62	0.17	-0.49	-0.01	0.01
Okeechobee	OKF-23	61	UFA	-1.69	-0.64	-0.53	-0.01	-0.01	-0.09	-0.02	-0.05	-0.17	-0.10	0.02
Okeechobee	OKF-31	71	UFA	-1.32	-1.15	0.02	-0.09	0.07	-0.32	0.13	-0.33	0.18	-0.02	-0.01
Okeechobee	OKF-34	55	UFA	-4.35	0.56	-0.36	0.20	-0.20	1.33	-1.28	-0.28	0.00	-0.10	0.07
Okeechobee	OKF-42	78	UFA	-1.89	-0.83	-0.13	-0.41	-0.09	-1.57	-0.51	-0.30	-0.06	-0.01	0.00
Okeechobee	OKF-7	58	UFA	-3.48	0.56	-1.73	0.05	-0.05	0.46	-0.35	-0.22	0.16	0.17	-0.06
Okeechobee	OKF-71	13	UFA	-1.63	0.89	-0.92	0.04	-0.04	0.40	-0.30	0.08	0.06	0.46	-0.25
Okeechobee	OKF-72	11	UFA	-1.75	1.10	-1.07	0.05	-0.05	0.40	-0.29	0.12	0.03	0.69	-0.38
Okeechobee	OKF-73	13	APPZ	-2.54	0.73	-1.62	0.05	-0.05	0.44	-0.29	0.47	-0.61	-0.20	0.12
Okeechobee	OKF-74	13	APPZ	-2.55	-0.90	-1.32	0.00	0.00	-0.07	-0.07	-0.24	-0.47	-0.04	-0.01
Okeechobee	OKF-BAS	36	UFA	-3.28	-0.38	-0.21	0.00	-0.06	-1.28	-0.82	-0.24	-0.07	-0.03	0.02
Okeechobee	OKF-MAC	13	UFA	-4.00	-1.40	-1.32	0.01	-0.02	-1.53	-1.42	-0.61	-1.11	-0.09	-0.02
Okeechobee	OKF-UNK1	23	UFA	-3.46	0.00	-0.33	0.10	-0.21	-0.86	-1.13	-0.19	-0.01	-0.08	0.05
Okeechobee	OKF-WIL	10	UFA	-4.39	-0.11	-0.49	0.02	-0.04	-1.45	-1.72	-0.01	-0.24	-0.03	0.01
Okeechobee	TCRK_GW1	121	UFA	-2.63	-2.14	-0.92	-0.06	0.04	-0.35	0.07	-0.34	0.01	-0.63	0.04
Okeechobee	TCRK_GW2	121	APPZ	-3.05	-1.46	-1.30	0.01	-0.03	-0.02	-0.10	-0.03	-0.28	-0.03	0.01
Hendry	L2-PW1	129	APPZ	-3.10	0.02	-0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Hendry	L2-PW2	127	UFA	-2.94	0.03	-0.02	0.00	0.00	0.01	0.00	-0.01	0.01	0.03	-0.11
Brevard	BEF-1559	22	UFA	-0.15	-0.18	-0.19	-4.05	-4.03	0.01	0.00	-0.04	-0.05	-0.18	-0.19

Sensitivity Run by Varying Calibrated Parameters															
County	**Well**	**# of points**	**Layer**	**Head Error at BZ**	**K_v6 Error times 0.5**	**K_v6 Error times 2.0**	**Head Error at NW minus 5**	**Head Error at NW plus 5**	**K_v4 Error times 0.5**	**K_v4 Error times 2.0**	**K_h3 Error times 0.5**	**K_h3 Error times 2.0**	**K_v2 Error times 0.5**	**K_v2 Error times 2.0**
Brevard	BEF-INLET	42	UFA	-0.04	-0.03	-0.08	-4.46	-4.49	0.00	0.00	0.00	-0.04	-0.07	-0.15
Brevard	BEF-T6	24	UFA	-0.59	0.12	-0.16	-2.74	-3.51	0.11	-0.13	-0.04	0.06	0.06	-0.05
Dade	DF-4	131	UFA	-5.48	-0.63	-0.80	0.00	0.00	0.08	-0.06	-0.08	0.09	0.02	-0.01
Dade	DF-5	131	APPZ	-4.53	0.32	-0.86	0.00	0.00	0.17	-0.09	-0.11	0.21	0.03	-0.01
Dade	ENP-100	108	UFA	-2.29	1.31	-0.98	0.00	0.00	0.09	-0.05	-0.09	0.18	0.72	-0.49
Dade	G-3061	114	UFA	-8.17	-1.96	-0.60	0.00	0.00	-0.10	0.04	0.02	-0.11	-0.03	0.01
Broward	BF-1	71	LF1	-7.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Broward	BF-2	48	APPZ	-7.04	-0.14	0.02	0.00	0.00	-0.07	0.04	0.05	-0.07	0.01	-0.01
Broward	BF-4M	133	APPZ	-6.85	0.16	-0.05	0.00	0.00	0.09	-0.07	-0.08	0.09	-0.02	0.02
Broward	BF-4S	132	UFA	-7.87	-0.04	-0.04	0.00	0.00	0.01	-0.01	-0.01	0.01	0.01	-0.05
Broward	BF-6	131	UFA	-7.62	0.05	-0.02	0.00	0.00	0.01	-0.01	0.01	-0.01	0.05	-0.04
Broward	MIR-MZU	119	APPZ	-5.99	-0.14	-0.90	0.00	0.00	0.06	-0.07	-0.06	0.08	-0.01	0.01
Palm Beach	PBF-1	39	UFA	-3.31	-0.09	-0.37	0.00	0.00	0.01	-0.01	-0.05	0.10	0.00	-0.01
Palm Beach	PBF-10R	113	UFA	-4.23	-0.08	0.01	0.00	0.00	-0.01	0.00	-0.02	0.01	-0.10	0.10
Palm Beach	PBF-11	114	APPZ	-5.03	-0.14	-0.01	0.00	0.00	-0.02	0.01	-0.01	-0.02	-0.01	-0.02
Palm Beach	PBF-12	113	LF1	-3.07	0.19	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.01	-0.01
Palm Beach	PBF-14	71	UFA	-5.28	-0.26	-0.01	0.00	0.00	-0.02	0.01	-0.04	0.03	0.04	-0.08
Palm Beach	PBF-15M	58	APPZ	-1.67	-0.18	-0.24	0.00	0.00	-0.03	0.02	-0.14	0.03	0.00	0.00
Palm Beach	PBF-15U	58	UFA	-1.67	-0.18	-0.24	0.00	0.00	-0.03	0.02	-0.13	0.03	0.00	0.00
Palm Beach	PBF-2	114	UFA	-5.10	-0.13	-0.27	0.00	0.00	0.08	-0.06	-0.09	0.12	-0.02	0.02
Palm Beach	PBF-3	131	UFA	-4.54	0.25	-0.35	0.00	0.00	0.14	-0.11	-0.19	0.27	-0.03	0.02
Palm Beach	PBF-4	43	APPZ	-5.29	-0.47	-0.19	0.00	0.00	0.01	-0.04	-0.09	0.00	0.00	0.00
Palm Beach	PBF-5	130	LF1	-5.78	-0.34	-0.21	0.00	0.00	-0.11	0.02	-0.04	0.03	-0.01	0.00
Palm Beach	PBF-747	121	UFA	-4.16	-1.27	0.39	0.00	0.00	-0.16	0.09	-0.37	0.34	0.02	-0.02
Palm Beach	PBF-7L	129	LF1	-1.02	0.16	-0.14	0.00	0.00	0.00	0.00	-0.06	0.10	0.00	0.00

Sensitivity Run by Varying Calibrated Parameters															
County	Well	# of points	Layer	Head Error at BZ	K_v6 Error times 0.5	K_v6 Error times 2.0	Head Error at NW minus 5	Head Error at NW plus 5	K_v4 Error times 0.5	K_v4 Error times 2.0	K_h3 Error times 0.5	K_h3 Error times 2.0	K_v2 Error times 0.5	K_v2 Error times 2.0
Martin	MF-23	28	UFA	-1.62	0.12	0.01	0.01	0.00	0.03	-0.02	0.13	-0.15	0.06	-0.03
Martin	MF-31	38	UFA	-2.51	-0.50	-0.37	0.00	0.00	0.00	0.00	0.01	-0.02	0.00	-0.01
Martin	MF-33	6	UFA	-1.95	0.16	-0.02	0.01	-0.01	0.03	-0.01	0.25	-0.29	0.30	-0.26
Martin	MF-53	1	UFA	-3.44	-1.16	0.61	0.00	0.00	-0.09	0.05	-0.08	0.07	-0.11	0.06
Martin	MF-54	10	UFA	-2.79	-0.91	0.20	0.00	0.00	-0.06	0.03	-0.07	0.06	-0.12	0.08
Martin	TFRO-5	24	UFA	-2.67	-0.57	0.27	0.00	0.00	-0.08	0.04	0.19	-0.26	-0.01	0.01
Indian River	IR-368	13	UFA	-0.82	0.66	-2.27	0.13	-0.14	0.22	-0.17	0.35	-0.54	0.42	-0.35
Indian River	IR-370	10	UFA	-1.84	1.31	-1.92	0.24	-0.24	0.26	-0.16	0.12	-0.17	0.67	-0.41
Indian River	IR-373	13	UFA	-1.91	-0.41	-1.74	0.24	-0.40	0.21	-0.18	-0.08	0.05	0.24	-0.22
Indian River	IRF-1006	22	UFA	-1.30	-3.16	-2.74	-0.07	-0.15	-0.02	0.00	-0.31	-0.60	-0.61	-0.20
Indian River	IRF-1008	22	UFA	0.73	-3.79	0.73	-0.34	0.24	-0.26	0.12	-0.69	0.58	-1.11	0.28
Indian River	IRF-189	225	UFA	-2.55	-0.26	-0.25	0.01	-0.09	-0.30	-0.30	0.01	-0.02	0.01	-0.04
Indian River	IRF-210	41	UFA	-0.65	-2.29	-1.15	-0.54	-0.18	-0.10	0.05	-0.46	-0.16	-0.95	-0.12
Indian River	IRF-954	22	UFA	0.80	-4.08	0.84	-0.48	0.37	-0.67	0.30	-0.37	0.42	-1.26	0.44
Indian River	IRF-955	18	UFA	-0.10	-3.36	0.16	-0.65	0.38	-0.49	0.23	-0.09	0.20	-0.70	0.23
Indian River	IRF-963	21	UFA	0.37	-3.22	0.19	-1.45	0.54	-0.36	0.17	-0.78	0.56	-1.45	0.48
Indian River	IRF-968	18	UFA	-1.81	-1.12	0.08	-0.13	0.10	-0.73	0.10	-0.01	0.02	-0.11	0.03
Indian River	IRF-JOHN	62	UFA	-0.81	-0.64	-2.01	0.17	-0.50	0.09	-0.07	0.19	-0.60	0.10	-0.43
Indian River	IRF-RO	42	UFA	0.89	-3.23	1.37	-0.31	0.27	-0.31	0.17	-0.74	0.72	-1.31	0.64
Indian River	IRF-USDA	42	UFA	-0.92	-2.48	-1.82	-0.12	0.01	-0.14	0.03	-0.39	-0.26	-0.96	-0.12
St. Lucie	SLF-11	9	UFA	-1.79	0.18	-1.69	0.12	-0.12	0.18	-0.11	0.05	-0.08	0.28	-0.20
St. Lucie	SLF-14	11	APPZ	-2.96	2.70	-2.12	0.09	-0.09	0.56	-0.32	-0.06	-0.03	-0.05	0.02
St. Lucie	SLF-17	13	UFA	-2.03	0.77	-1.18	0.02	-0.02	0.21	-0.13	-0.07	0.04	0.48	-0.26
St. Lucie	SLF-21	135	UFA	-0.03	-3.02	-0.89	-0.08	0.06	-0.89	0.12	-0.40	0.16	-0.65	0.15
St. Lucie	SLF-36	13	UFA	-1.68	1.18	-1.83	0.11	-0.11	0.28	-0.18	0.15	-0.24	0.61	-0.33

Sensitivity Run by Varying Calibrated Parameters															
County	Well	# of points	Layer	Head Error at BZ	K_v6 Error times 0.5	K_v6 Error times 2.0	Head Error at NW minus 5	Head Error at NW plus 5	K_v4 Error times 0.5	K_v4 Error times 2.0	K_h3 Error times 0.5	K_h3 Error times 2.0	K_v2 Error times 0.5	K_v2 Error times 2.0
St. Lucie	SLF-40	13	UFA	-1.33	0.96	-1.42	0.06	-0.06	0.24	-0.16	0.13	-0.22	0.59	-0.32
St. Lucie	SLF-63	13	UFA	-2.09	1.35	-1.87	0.14	-0.14	0.31	-0.19	0.06	-0.07	0.71	-0.34
St. Lucie	SLF-64	13	UFA	-2.09	-0.19	-1.81	0.11	-0.13	0.20	-0.16	0.04	-0.05	0.22	-0.26
St. Lucie	SLF-65	13	UFA	-2.11	1.11	-1.86	0.18	-0.18	0.33	-0.21	0.04	-0.05	0.63	-0.36
St. Lucie	SLF-66	13	UFA	-1.86	0.99	-1.76	0.10	-0.10	0.27	-0.17	0.09	-0.15	0.58	-0.43
St. Lucie	SLF-67	13	UFA	-1.93	-0.58	-1.12	0.01	-0.01	0.01	-0.05	-0.03	0.02	-0.17	-0.17
St. Lucie	SLF-69	31	UFA	0.76	-1.66	0.78	-0.05	0.05	-0.57	0.39	-0.44	0.50	-0.62	0.31
St. Lucie	SLF-70	13	UFA	-0.74	0.24	-1.85	0.07	-0.07	0.17	-0.11	0.33	-0.58	0.13	-0.68
St. Lucie	SLF-74	116	APPZ	-0.62	-1.85	-0.47	-0.02	0.02	-0.38	0.04	-0.16	0.03	0.01	0.00
St. Lucie	SLF-75	116	UFA	0.46	-1.77	0.44	-0.04	0.04	-0.61	0.29	-0.37	0.35	-0.89	0.39
St. Lucie	SLF-76	116	UFA	0.53	-1.80	0.50	-0.05	0.05	-0.63	0.32	-0.39	0.38	-0.91	0.42
St. Lucie	STL-215	23	UFA	0.32	-2.38	0.18	-0.10	0.09	-0.33	0.16	-0.31	0.29	-0.74	0.27
St. Lucie	STL-216	13	UFA	-1.62	1.05	-1.93	0.11	-0.12	0.28	-0.20	0.19	-0.31	0.54	-0.34
St. Lucie	STL-251	11	UFA	0.11	-4.47	-0.17	-0.29	0.20	-0.74	0.29	-0.45	0.40	-1.29	0.34
St. Lucie	STL-352	9	UFA	-0.30	-2.30	-3.00	0.03	-0.05	-0.14	-0.23	0.02	-0.11	0.02	-0.06
St. Lucie	FPU-MZL	34	LF1	-0.13	-3.65	-1.62	0.00	0.00	-0.13	-0.12	-0.01	0.00	0.00	0.00
St. Lucie	FPU-MZU	34	UFA	-0.73	-1.33	-3.13	0.16	-0.17	0.73	-1.18	0.22	-0.38	0.46	-0.27
	AVERAGE			**-1.79**	**-0.49**	**-0.48**	**-0.22**	**-0.22**	**-0.16**	**-0.11**	**-0.11**	**-0.04**	**-0.07**	**-0.03**

Appendix E. Review of "Discussion of the Incorporation of the Peer Review Recommendations into the East Florida Model" by Weixing Guo, Schlumberger Water Services

Review of "Discussion of the Incorporation of the Peer Review Recommendations into the East Florida Model: Supporting Documentation for SFWMD Order" by SFWMD

Prepared for

South Florida Water management District

Prepared by

Weixing Guo

Schlumberger Water Services

Fort Myers, Fl

September 30, 2014

1. Introduction

In the early 1990s, the South Florida Water Management District (SFWMD) undertook the development of county–wide groundwater flow models for most counties under its jurisdiction. With the rapid increase of population and water demand in southern Florida, fresh water withdrawals also increased significantly to meet the demand. In the early 2000s, the District started to consider brackish water as alternative water source for future water supply.

The first density-dependent solute transport model for the Floridan Aquifer System (FAS) in the East Coast (EC) area was developed by HydroGeologic as the Phase I East Coast Floridan Aquifer System (ECFAS-I) model in 2006. Phase II of this modeling effort (ECFAS Phase II) was developed by Golder Associates in 2008. In February 2011, the South Florida Water Management District (SFWMD) initiated a peer review of the ECFAS Phase II model. The peer review Panel provided their review recommendations in June 2011 (Jacobs et al., 2011).

The peer review panel's recommendations can be divided into both short term and long term (Jacobs et al., 2011). The development of the East Coast Floridan Model addressed the recommendations of the Peer Review (Jacobs et al, 2011) of the ECFAS Phase I by HydroGeoLogic (2006) and Phase II by Golder Associates (2008); as well as lessons learned from calibration of the Central Florida Transient Model (USGS, 2012), the Lower West Coast Floridan Aquifer System Model Development (Guo, Li and Giddings, 2011) and improved understanding of the FAS including continued data acquisition which follows the Reese and Richardson (2008) design.

The District finished their revision of the ECFAS model following the Peer Panel's suggestions and provided their responses to the Peer Review Panel's recommendations in September 2014 (Giddings et al., 2014). Schlumberger Water Services (SWS) was retained as an external expert to provide technical assistance during the model revision process and to provide the final review of the District's responses to the Peer Panel recommendations.

2. Review of The District Responses to the Peer Panel Comments and Recommendations

After reviewing both the ECFAS Phase I (Hydrogeologic, 2006) and Phase II (Golder Associates, 2008) models, the Peer Review Panel provided 10 comments and recommendations. The original Panel's comments and recommendations are included and shown in italics, while the District, (referred to as the SFWMD here) responses to the Peer Review Panel comments and recommendations can be found in the documentation to be reviewed (Giddings, et al., 2014) and will not be included in this report.

(1) The Panel is not confident in the model calibration for the reasons enumerated above and recommends that the model be recalibrated. The Panel recommends that the model first be calibrated to pre-development, quasi-steady-state conditions and those results used as initial conditions for the calibration of the transient model. As a goal, the Panel recommends that the pre-development model be calibrated to measured 1980 water quality and potentiometric head values. The use of 1980 conditions is contingent on the availability of sufficient data and the achievement of significant reductions in execution time that would allow for the calibration of a 20-year transient simulation.

The District has adopted the recommendations and calibrated the model in two stages: steady-state model for the pre-development conditions and 20 year long transient flow and solute transport. Although the Panel suggests calibrating the model to the conditions of 1980 to represent pre-developed conditions, the District has properly justified their selection of 1989 based upon close examination of the data availability and pumping history in the model area.

(2) Recalibration should employ automated calibration procedures to the extent possible, with use made of the parameter uncertainty estimates resulting from those methods. The Panel anticipates that this will result in less variability in hydraulic conductivity since deviations in hydraulic conductivity from measured values can be included as part of the objective function that is minimized in calibrating the model. Commonly used calibration codes for this purpose are PEST and UCODE. Either may be used for model calibration, however the code selection should consider the capability of the calibration code to make use of parallel processing or cloud-based computation.

Use of automated calibration tools such as PEST and UCODE would reduce the uncertainty in parameter estimation if these tools are used correctly. This approach has been used in both phases during the ECFAS model development (HydroGeologic 2006; Golder Associates, 2008). The application of automated calibration methods may be hindered by the long computational time. However, this approach should be at least applied during flow-calibrations. The District utilized an interactive approach between manual calibration and automated model calibration. BeoPest, which manages parallel runs efficiently, was used in order to minimize computational time during PEST simulations.

Automated calibration was conducted using pilot points for both steady-state and the transient simulations. The parameters were well selected for automated model calibration process. Quite often, unrealistic model calibration results are obtained using automated calibrations, even with reasonably established parameter limits. This situation can be avoided when a combination of manual model calibration and automated processes are used for model calibration, as the District did.

The final model simulation results are in close agreement with observed water level and water quality data over the model domain.

(3) Calibration of water quality at individual wells is neither realistic nor desirable for a regional model such as the one reviewed here. It would be preferable to revise goals utilized in calibration of water quality to broad use categories of water quality such as potable, brackish, and saline as had been used in the Phase I modeling project.

The District closely examined the water quality data available. The District also followed the Panel's recommendation to provide model calibration results for each aquifer and compared them to each category including freshwater (TDS between 0 and 1,000 mg/l), brackish water (from 1,000 to 18,000 mg/l), saline water (from 18,000 to 35,000 mg/l) and hyper-saline water (TDS greater than 35,000 mg/l). As shown, 99% of the data points fall within the generalized water quality boundaries. The approach applied by the District is reasonable and consistent with the recommendation made by the Panel.

(4) Calibration indicators, such as scatter plots of measured versus simulated potentiometric head, should be generated independently for each major aquifer unit to provide more information on the effectiveness of the calibration within each unit. Mapped residual values should also be used that are

generated on a unit-by-unit basis to further assist in understanding the success of the model in representing measured field parameters.

The District followed the recommendations by showing the calibration scatter plots and residual values for each major aquifer unit. As shown in Figure 15, the histogram of the mean error of all the wells, indicates a relatively normal distribution. Most residual values (69.7%) are within the -1 ft to +1 ft range. The distribution of residuals for each major aquifer unit shows no obvious patterns although it seems most residual values in the UFA and the AVPZ are negative and the residuals in the LF1 on the positive side. In general, the results shown indicate that the model simulation results are in close agreement with observed water levels.

(5) Volumetric flow targets should be used in calibration instead of relying only on water level measurements. For example, the upper flow rate into the surficial aquifer could be a target. It would better constrain the hydraulic properties of the various zones, since computed flow rates are more sensitive to hydraulic conductivity than computed hydraulic heads. The freshwater inflow to the model could also be compared to the estimated recharge entering the ECFAS in Polk County.

The District followed the recommendations made by the Panel. The District expanded the model boundary northward and westward to include the major recharge area to the UFA. This expansion allows the use of results of some previous studies on the recharge to the UFA in the vicinity of the Lakeland area. This is a significant improvement from the previous ECFAS models. The District also developed flow direction maps to help improve the understanding of flow within the FAS. A flow budget comparison between the no-pumping case and pumping case is very helpful to understand the dynamics of the groundwater flow system.

(6) In light of limited information on dispersivity and porosity, efforts should be made to justify the choice of these parameter values. The literature on dispersivity should be consulted. We anticipate that this will result in a dispersivity value set based on the regional transport scale. Effective porosity values should be determined based on calibration of the transient water quality simulation.

The District approach regarding the dispersivity and porosity is consistent with the Panel's recommendations. The District has collected some porosity data by core sample analysis and geophysical methods. These values appear to be relatively high but are in the ranges of typical values for the lithologies evaluated. Dispersivity values are rarely measured in the field and often they are determined by literature review and solute transport model calibration, as the Peer Review Penal has recommended and what the District did for this study. The District collected some porosity data as mentioned above. The value of longitudinal dispersivity applied in the model is 1200 ft, which is within the middle of the range (between 3 to 5000 ft) used in other solute transport models reported in large scale modeling studies for south Florida. In addition, the close match of simulated water quality change versus observed values at the Lake Region wellfield and Miami-Dade West Wellfield ASR testing site support the choice of the selected dispersivity values. However, some sensitivity analyses may be necessary to assess the sensitivity of the model to the dispersivity parameter.

(7) The model domain might be rotated so that the western boundary is aligned with the north-south trending groundwater divide. This will reduce the dependence of the model on potentiometric head values along this boundary and is a good standard practice. Some portion of the northern model boundary should remain as a specified constant head boundary. Flow from the recharge area in Polk County will

largely enter through this portion of the northern boundary, with some contribution directly from the surficial aquifer in the northwest corner of the model.

The District extended the northern and western model boundaries following the Panel's recommendations. However, the District did not rotate the model as suggested. One of the reasons for the model rotation is to reduce model boundary effect. With a larger model domain, the boundary effects in the ECFAS Phase II model are significantly reduced so the need for model rotation becomes less critical. Actually, the Panel also indicated that keeping the model grids in a north-south orientation is acceptable as long as the model northern and western borders are expanded. Therefore, the Panel's recommendations on model boundaries and grid orientation should be satisfied.

(8) Efforts should be made in the next model phase to reduce model execution time without compromising model solution accuracy. Explicit coupling is recommended for the SEAWAT transport solution. Under explicit coupling, the density matrix is updated at the completion of each time step of the flow solution and is a reasonable compromise between the more intensive implicit coupling and uncoupled solutions. Other means of reducing model execution time should be evaluated including the lengthening of stress periods and flow model time steps and increasing grid size in cells that lie seaward of the coast line. Analysis of simulation error introduced by these efforts should be evaluated by comparative simulations and sensitivity analysis that evaluate deviations from the base case solution based on the existing temporal discretization.

The District has made significant efforts to reduce the run time of model simulations, from 10 days to several hours. The District has used the latest version of SEAWAT code compiled for 64-bit computers and multiple core processors. And more importantly, by removing the Surficial Aquifer System and the intermediate Confining unit, the number of active model cells is reduced significantly. The District's response satisfies the Panel's recommendations.

(9) Ideally, additional wells would be installed to obtain water quality and potentiometric head data in the Boulder Zone and Lower Floridan Aquifer. Given the installation costs of these wells, the Panel hesitates to make this recommendation. We do however recommend that the SFWMD continue to work with utilities in collecting additional water quality and potentiometric head information from deep regional aquifers at existing and newly installed wells. We also recommend that the SFWMD utilize underground injection control borehole logging criteria within deep wells installed in this area in order to gain the most possible information about the units' hydraulic properties.

The District's response to the Panel's recommendations is satisfactory. The District used all available data including the water quality and head data from deep aquifers that met their data quality standard. As recognized by the Panel, the cost to drill new wells may prevent the District from adding new wells that may significantly improve our understanding of the deep aquifers. The District also promises to continue their efforts to expand their data collection in the future.

(10) Future model users should be proficient in modeling, but might still benefit from a User's Manual given the complexity of using a transient, density-dependent model. Important material to be included in the Manual would be documentation of flow and transport properties, selection of stress periods, time step duration, and solution algorithms, information on the assignment of pumping stresses and transient and fixed boundary conditions, recommendations for construction of subregional models, and a description of model limitations.

The District plans to develop the document recommended by the Panel and to release it in 2014. However, the document is not available yet at the time of this review. Therefore, the complete satisfaction of the District response to the Panel's recommendation is contingent on the release of the user's manual.

3. Additional Comments

In addition to the review of the District's response to the Panel's comments and recommendations, some extra comments are provided below:

(1) Add a potentiometric contour map of the UFA for both predevelopment condition (i.e. the steady-state model) and transient conditions. It would be of great interest to see how the results from this model compared to Myer's conceptual model (1989).

(2) Values of dispersivity: Some sensitivity analyses may be performed to assess the sensitivity of solute transport modeling results to these parameters.

(3) Editorial Comments
(to be provided separately)

4. Conclusion

The District has adequately addressed all of the comments and recommendations from the Review Panel. District staff has made significant efforts to incorporate all of the recommendations. The ECFAS variable-density model has been greatly improved due to these efforts. The model will be a useful tool for understanding the Floridan Aquifer System in south Florida and for future water resources management.

Base on this review, the District has implemented all the Panel's pertinent recommendations with one contingency condition that the District will finish the User's manual as suggested by the Review Panel and promised by the District.

5. References

Giddings, J.B., A. Montoya, and L. Jurado, 2014. Discussion of the Incorporation of the Peer Review Recommendations into the East Coast Floridan Model: Supporting Documentation for SFWMD Purchase Order PO-4500065323.

Golder Associates, 2008. *East Coast Floridan Aquifer System Model, Phase II Project, Southeastern Florida, Final Model Documentation Report*. Boca Raton, Florida: Golder Associates.

Hydrogeologic. 2006. *Development of a DensityDependent Saltwater Intrusion Model for the Lower East Coast Project Area*. Herndon, Virginia: Hydrogeologic, Inc.

Meyer, F. W. 1989. *Hydrogeology, groundwater movement, and subsurface storage in the Floridan aquifer system in southern Florida*. Washington: U.S. Geological Survey.

Appendix F. Updates

This appendix provides a listing of all updates to the model.