Lower Kissimmee Basin Groundwater Model Update Summary Report

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Introduction

The Lower Kissimmee Basin Ground Water Model (LKBGWM) has been developed primarily to provide support for the South Florida Water Management District's (SFWMD) regional water supply plan for the Lower Kissimmee Basin. The model can be used to evaluate potential impacts of projected increases in groundwater withdrawals. This model summary report is designed to provide the reader with an overview of the modeling process; it is not designed to provide all of the technical details typically contained within detailed model documentation to facilitate replication of the model results.

Background

The LKBGWM was developed as a quasi-three-dimensional, steady-state groundwater flow model simulating the Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the uppermost producing zones of the Floridan Aquifer System (FAS), i.e. the upper Floridan aquifer (UFA) and the Avon Park Permeable Zone (APPZ). The model was developed using the U.S. Geological Survey (USGS) SEAWAT modeling code. The model was calibrated to 1995 and 2004 climatic conditions, and was validated using 2010 climatic conditions. The LKBGWM has built upon previous modeling studies conducted by SFWMD in the Lower Kissimmee Basin area (Barton et al., 2005).

Objectives

The LKBGWM is a tool used to update the Kissimmee Basin regional water supply plan, which is required every five years. The model is being used to evaluate potential impacts of projected 2035 water demands under average climatic conditions. The model is also being used to evaluate potential impacts on numerous surface water bodies that have established Minimum Flows and Levels (MFL) by rule. These water bodies are located in the Southwest Florida Water Management District (SWFWMD), but are within the area of influence of groundwater withdrawals in the SFWMD. These evaluations are done within the limits of the tool.

Description of Model

Location and Horizontal Discretization

The LKBGWM covers the southern (lower) portion of the Kissimmee Basin, and includes all of Highlands, Okeechobee, and Glades counties, as well as portions of Polk, Osceola, Indian River, St. Lucie, Martin, Palm Beach, Charlotte, De Soto, and Hardee counties (**Figure 1**). The model code used is a specific version of the USGS SEAWAT code (SEAWAT2000; FAU, 2007), which is the version of the code the SFWMD has used for all groundwater modeling studies of this type. While SEAWAT is capable of simulating both flow and solute transport, only the flow component was utilized with the LKBGWM. Therefore, this model functions similar to the more commonly used MODFLOW code (McDonald and Harbaugh, 1988). A uniform cell size of 2,640 feet was used, resulting in a grid consisting of 130 rows and 130 columns.

Vertical Discretization

The hydrostratigraphy and corresponding representation in the LKBGWM domain is generally based on Reese and Richardson (2008). The groundwater resources in the modeled area are divided into three aquifer systems: The Surficial Aquifer System (SAS), the Intermediate Aquifer System (IAS), and the Floridan Aquifer System (FAS). The SAS is unconfined and produces relatively small quantities of fair to good quality water. While the IAS generally provides regional confinement for the FAS, it contains some localized producing zones, mainly in the western portions of the modeled area. The FAS is the main source of groundwater in the area. It is a confined system consisting of three generally regionally extensive producing zones: the upper Floridan aquifer (UFA), the Avon Park Producing Zone (APPZ), and the lower Floridan aquifer (LFA). While some wells penetrate the LFA, it is currently not used as a major source of water within the modeled area.

Figure 2 shows how the various aquifer systems and producing zones are simulated in the model. The model consists of five layers represented in descending order, the SAS (layer 1), the IAS (layer 2), the UFA (layer 3), the APPZ (layer 4), and the LFA (layer 5). Confining zones between the upper Floridan aquifer and the APPZ, and the APPZ and the LFA, are not simulated as separate layers, but are represented by vertical conductance terms (vcont) between the active layers in the model. The model only simulates the top zone (LF1) of the LFA.

<u>Boundary and Initial Conditions</u>

The model is bounded by constant head cells on all four sides. Layer 5 (LF1), is specified as a constant head boundary due to the lack of data in the modeled area, and for what is believed to be a relatively poor connection to the aquifer above.

The starting heads for layer 1 (SAS) were set at one foot below ground surface elevation for all model runs. For a large portion of the model, the water table is close to land surface. In addition, the various wetlands and water bodies help control the water levels in layer 1. Therefore, an initial starting head of one foot below land surface appears reasonable. In addition, the simulated water levels seem to equilibrate to sites where the water table is deep.

Starting heads for layers 2 through 5 were based on potentiometric data published by the USGS on a semi-annual basis. Since the USGS data shows that the various producing zones in the FAS have similar heads, the starting heads for layers 2 through 5 were all set at the same levels. Starting heads for each model run (1994, 2004, and 2010) were based on the USGS data for each year. **Figure 3** shows the starting heads for layer 3 for the 2010 model run.

<u>Aquifer Parameters</u>

Aquifer parameters for the various aquifers and producing zones were collected from published reports, water use permits, and aquifer performance tests. Hydraulic conductivity for layer 1 and transmissivity values for layers 2 through 4 were regionalized into the model grid using statistical methods and manually checked for anomalous (unreasonable) values, which were individually adjusted. These values were refined during model calibration using parameter estimation (PEST), as discussed later in this report. **Figure 4** shows the final (calibrated) hydraulic conductivity values for layer 1, and **Figures 5 and 6** show the final (calibrated) transmissivity values for layers 3 and 4, respectively. Leakance/vertical conductance values, which govern flow between layers, were calculated using equations in the USGS MODFLOW model documentation (McDonald and Harbaugh 1988). **Figures 7 and 8** show the final (calibrated) vcont values between layers 2 and 3, and layers 3 and 4, respectively. Specific storage/storativity values are not required in the model since it is a steady-state simulation.

<u>Surface Water Features</u>

Lakes, rivers, streams, and canals are represented in the model using the MODFLOW Rivers package. Sources of data include the National Hydrography Dataset (lakes and ponds), the USGS, SFWMD, SWFWMD, and St. Johns River Water Management District databases. Stage information, when available, was used to generate average stages for the period being simulated; otherwise, average surface-water stages were estimated. Other information, such as depth, thickness and conductivity of bottom sediments, and reach length, were all estimated or calculated based on existing information. **Figure 9** shows the surface water bodies included in the model.

Rainfall

Rainfall was not input directly into the model, but was used as a component in the estimation of evapotranspiration and net recharge. Brown (2013b) extracted rainfall data from the SFWMD Regional Systems Model for the 1995 and 2004 simulations.

Regarding the 2010 rainfall, SFWMD has prepared rainfall and evapotranspiration datasets for modeling purposes. At the time of model development, the 2010 rainfall did not undergo QA/QC. However, preliminary studies indicated that 1964 rainfall was similar to 2010 rainfall. Thus, 1964 rainfall was use as a surrogate for 2010 rainfall.

Evapotranspiration

Evapotranspiration (ET) is a natural hydrologic process that removes water from the shallow portions of the SAS in the model. The model simulates ET as a linear function of a maximum ET rate and the depth of the water table below an elevation where the maximum ET rate occurs and an "ET extinction depth" below which it is assumed ET is negligible. The ET surface (the elevation where the maximum ET rate would occur) was set at ground level throughout the model or at stage elevation in cells dominated by surface water bodies. The ET extinction depth was set based on root zone depths, which was varied based on land cover or crop types, except for cells dominated by surface water bodies, where it was set at 20 feet to assure that the maximum ET rate would always be applied.

For 1995 and 2004, the reference ET rate (ET_0) was derived from ARCADIS (2008). For 2010, the reference ET was derived from Brown (2013a). A program that uses the Agricultural Field Scale Irrigation Requirements Simulation (AFSIRS) (Smajstrla 1990) was used to estimate both ET and recharge (Restrepo and Giddings, 1994). **Figure 10** shows the 2010 ET rates applied to the model.

Recharge

Recharge was estimated based on rainfall, crop irrigation requirements, available storage in the soil column, runoff, and evapotranspiration, using a program that uses AFSIRS (Restrepo and Giddings, 1994). The runoff component was separated from rainfall events using the Soil Conservation Service curve-number method. Different land uses were accounted for when estimating the runoff. Recharge was not applied to wetland areas to avoid mounding in the model, as wetland processes are not simulated in the model. Net recharge was estimated on a daily basis, which was then converted to annual values and input into the model. **Figure 11** shows the 2010 net recharge applied to the model.

Wells

The Southwest Florida Water Management District supplied pumpage data for 1995, 2004, and 2010 (SWFWMD written communication, 2013). This pumpage data was incorporated into the model, matching well locations to the appropriate layer, row, and column in the model. For the rest of the modeled area (including the area in SJRWMD), pumpage data was developed as follows:

1. For public water supply (PWS) and industrial uses, pumpage records were used to obtain the withdrawal rates and locations.

2. When available, pumpage data was used to estimate irrigation withdrawal rates.

3. If pumpage reports were unavailable, the demand is based on AFSIRS.

In many cases, wells penetrated more than one aquifer. In these instances, pumpage was assigned to layer 3 (UFA), which historically is the most used source. However, in cases involving layers 1 and 2, the pumpage was assigned to the most productive layer. **Figures 12 through 15** summarize the pumpage data for the 2010 simulation.

Well files were developed for two alternative predictive scenarios representing the year 2035. Alternative 1 represents predicted changes in pumpage in both SFWMD and SWFWMD. Alternative 2 represents predicted changes in pumpage only within the SFWMD. Pumpage within the SWFWMD and SJRWMD was set at 2010 levels in Alternative 2. There were no changes made to pumpage in the SJRWMD area in either alternative; both 2035 predictive runs used 2010 SJRWMD pumpage.

Well files for the two 2035 predictive simulations were made by adjusting authorized (permitted) uses represented in the 2010 well file to those projected for 2035 planning estimates. The planning projections of growth are based on a number of considerations including historic crop trends, economic conditions, Bureau of Economic and Business Research (BEBR) population trends, and input from the local public. The distributions of the 2035 projections were made by reviewing permitted changes between 2011 and December 2013 to determine what new crop types/acres occurred, new wells that were proposed, and the sources of water that were authorized. The result was used as guidance on where to place future crop acres and to tie this to a source of water. New crop acres were not allowed to exceed the 2035 planning growth projections. Projected growth in PWS, industrial, power generation, and recreational uses were also applied to existing permit locations and sources.

The SWFWMD provided the 2010 water use pumping set for uses in those areas within their jurisdiction and within the model domain. Changes in the growth for non-PWS use types (i.e., agricultural, recreational, mining, etc.) located within the SWFWMD were made using projections from their 2010 Regional Water Supply Plan (RWSP) (SWFWMD, 2010). The distribution of the water use changes identified in their RWSP between 2010 and 2035 were made to the existing 2010 water use data set by applying a county-level percentage growth/reduction rate(by use type). For example, if there was a 20% reduction of agriculture estimated from 2010 to 2035 in the RWSP for a given county, then a 20% reduction was applied to all agricultural permits (well by well) for that county. However, PWS uses in SWFWMD were treated in a different manner. In 2013 SWFWMD staff provided updated water use estimates for 2035 PWS use for each utility. The PWS updates were then applied utility-by-utility using the same percentage distribution for each well found in the 2010 well set.

Calibration/Validation/Sensitivity

The model was calibrated using automated methods, which consists of applying parameter estimation (Doherty 2010), where the modeler specifies the parameters of the model that can be automatically changed to achieve better calibration of the model. Parameters that were modified using automated methods include hydraulic conductivity of layer 1, transmissivity of layers 2, 3, and 4; and vcont between layers 1 and 2, layers 2 and 3, and layers 3 and 4.

The quality of the calibration is determined by applying statistical methods to the residuals (difference between simulated and observed water levels at each cell) and comparing that to predetermined criteria. For the LKBGWM, points in layer 1 (SAS) were considered calibrated if simulated and observed water levels were within two feet. Layers 2, 3 and 4 (ICU, UFA, and APPZ) were considered calibrated if simulated and observed water levels were within four feet. These calibration targets are similar to those used in other regional numerical models in the area, including the East Central Floridan Transient model completed in 2013. Various trends in residuals were also analyzed to yield information regarding the calibration.

Calibration/Validation Data and Statistics

A summary of statistics for the calibration/validation model runs are presented in the **Table 1**. Values in the tables are head residuals (feet).

TABLE 1. SUMMARY OF CALIBRATION/VERIFICATION STATISTICS

LAYER	MINIMUM DIFFERENCE	AVERAGE DIFFERENCE	MAXIMUM DIFFERENCE	MINIMUM ABSOLUTE DIFFERENCE	AVERAGE ABSOLUTE DIFFERENCE	MAXIMUM ABSOLUTE DIFFERENCE	% wells calibrated
1995 Model Run							
1	-3.17	0.45	9.17	0.03	1.26	9.17	81%
3	-1.75	0.35	3.32	0.01	0.95	3.32	100%
4	-1.88	0.39	1.98	0.00	0.71	1.98	100%
GLOBAL	**-3.17**	**0.42**	**9.17**	**0.00**	**1.09**	**9.17**	**88%**
2004 Model Run							
1	-3.13	1.70	8.75	0.00	2.14	8.75	61%
2	-0.03	0.24	0.76	0.02	0.26	0.76	100%
3	-2.50	0.27	2.36	0.12	0.93	2.50	100%
4	-2.65	0.52	3.18	0.10	1.32	3.18	100%
GLOBAL	**-3.13**	**1.14**	**8.75**	**0.00**	**1.66**	**8.75**	**78%**
2010 Model Run							
1	-21.87	1.61	43.61	0.01	4.57	43.61	51%
2	-15.39	-3.34	6.49	0.04	5.41	15.39	57%
3	-10.23	-0.97	8.11	0.19	2.75	10.23	81%
4	-9.46	-0.64	5.83	0.05	3.21	9.46	67%
GLOBAL	**-21.87**	**0.62**	**43.61**	**0.01**	**4.16**	**43.61**	**58%**

Figure 16 shows the simulated water levels vs. observed water levels for the calibration points in Layers 1, 3, and 4 (SAS, UFA, and APPZ) for the 2010 simulation. These graphs have fairly high correlation coefficients (R^2) values of 0.9693 and 0.9501, respectively.

Figure 17 presents the water budget for the 2010 simulation. Recharge is the major inflow and ET is the major outflow. This pattern is similar to other models in the area.

Figure 18 presents the simulated UFA contours from the model. When compared with potentiometric maps prepared by the USGS, similar patterns can be observed:

- Highest values are in the northwest, corresponding to the major recharge area of the FAS in Polk County

- The gradient is steepest in the northwest and flattens out throughout the remaining parts of the study area
- Lowest values are in the east and south

Therefore, the model simulates the regional trend reasonably well.

Sensitivity Analysis

During the model calibration process, pilot point regularization was used, where the parameter values are estimated only at user-defined locations during the inverse-calibration process (Doherty, 2003). The parameter values in each cell are obtained through interpolation. PEST was used to perform a sensitivity analyses on the pilot points. There are 185 pilot points. Each point has 7 aquifer parameters:

- Layer 1 hydraulic conductivity
- Layer 2 transmissivity
- Layer 3 transmissivity
- Layer 4 transmissivity
- Vcont between layers 1 and 2
- Vcont between layers 2 and 3
- Vcont between layers 3 and 4

Table 2 lists the 30 pilot point parameters with the highest sensitivities**. Figure 19** shows the locations of the 150 pilot point parameters with the highest sensitivity values. These points were used in the uncertainty analyses.

Many of the most sensitive points are located in the northwest portion of the study area. Overall, this area has high topographic relief and relatively steep hydraulic gradients. In general, the model has inherent difficulty simulating water levels associated with higher topographic relief areas due to the regional size of the model grid (2640-foot cells).

Uncertainty Analysis

Although the aquifer parameters are calibrated to represent reality, the uncertainty associated with those parameters cannot be ignored because of the inherent non-uniqueness of the solution to an inverse problem. It is beneficial to quantify the uncertainty associated with the calibrated aquifer parameters when models are used to assist in the regulatory and planning decision-making process. The uncertainties associated with the calibrated aquifer hydraulic properties are quantified using the *Calibration Constrained Null-Space Monte Carlo* (CCNSMC) simulation technique with *Latin-Hypercube Sampling process* based on PEST. Approximately, 150 aquifer parameters that are sensitive were selected for the uncertainty quantification process.

TABLE 2. LISTING OF PILOT POINT SENSITIVITIES

SENSITIVITY VALUE	PILOT POINT ID	AQUIFER PARAMETER	RANK
9.31134E-04	68	Layer 1 hydraulic conductivity	1
8.68399E-04	27	Vcont between layers 1 and 2	2
6.51349E-04	106	Layer 1 hydraulic conductivity	3
5.51872E-04	163	Vcont between layers 2 and 3	4
5.34860E-04	90	Layer 1 hydraulic conductivity	5
5.30544E-04	89	Layer 1 hydraulic conductivity	6
4.92268E-04	174	Vcont between layers 1 and 2	7
4.90655E-04	18	Vcont between layers 2 and 3	8
4.64273E-04	70	Layer 1 hydraulic conductivity	9
4.54272E-04	90	Vcont between layers 1 and 2	10
4.48569E-04	144	Layer 1 hydraulic conductivity	11
4.37544E-04	99	Vcont between layers 1 and 2	12
4.37149E-04	166	Vcont between layers 2 and 3	13
4.30293E-04	163	Vcont between layers 1 and 2	14
4.15567E-04	144	Vcont between layers 1 and 2	15
4.01825E-04	142	Layer 1 hydraulic conductivity	16
3.85731E-04	13	Layer 3 transmissivity	17
3.73851E-04	170	Vcont between layers 1 and 2	18
3.61616E-04	73	Vcont between layers 2 and 3	19
3.60472E-04	170	Layer 4 transmissivity	20
3.54813E-04	165	Layer 1 hydraulic conductivity	21
3.35390E-04	147	Vcont between layers 1 and 2	22
3.31867E-04	19	Layer 4 transmissivity	23
3.24972E-04	27	Layer 4 transmissivity	24
3.21138E-04	51	Vcont between layers 1 and 2	25
3.17301E-04	24	Vcont between layers 2 and 3	26
3.09847E-04	121	Layer 4 transmissivity	27
3.00264E-04	11	Layer 4 transmissivity	28
2.98293E-04	15	Layer 1 hydraulic conductivity	29
2.97074E-04	171	Layer 4 transmissivity	30

General Limitations

A groundwater model is a tool that is calibrated to observed water levels and flow conditions and is used to predict water levels and flow conditions under various assumptions. This model is a steady-state model and therefore, represents equilibrium under averaged conditions. In reality, the stresses (e.g., water withdrawals) vary with time. MODFLOW averages the hydraulic properties and stresses over the grid cell. This may induce errors in areas where the aquifer parameters or the stresses vary considerably. Moreover, the variability of the extinction depth and evapotranspiration surfaces averaged across a model cell affects the water levels. This is especially true for the surficial aquifer system. MODFLOW assumes horizontal flow in the aquifers and vertical flow through the confining units. However, there may be zones of preferential flow, which are not simulated in the model, because the model assumes flow through porous media, not fractures, for example. The model is also limited by the availability and accuracy of the input data.

Limitations Specific to LKBGWM

While the LKBGWM has a surface water component, the model should not be used to evaluate surface water withdrawals or their effects because:

1. Changes to the Kissimmee River (i.e., restoration activities) were not included. Thus, all scenarios have the same river package cells.
2. Many surface water features do not have detailed information. Therefore, estimates were made.
3. The simulated river flows were not calibrated against measured flows due to the limitations noted here.
4. The model packages used do not fully simulate the interconnections between the various water bodies.

Several cells exhibit ponding, defined as when simulated water levels in layer 1 are above the land surface. Some reasons for this phenomenon are:

1. Several cells are wetlands, where the water levels may exceed land surface.
2. In many instances, the topographic information documented the bottom of a lake as opposed to the surface level. This data ambiguity could lead to erroneous instances of simulated ponding not actually observed.
3. Most small water bodies (drains) were not simulated due to the regional nature of the model. The absence of these drains may induce ponding.
4. Many cells exhibit significant topographic relief. The model represents average conditions. Thus, the model cannot adequately reflect the topographic variability.

One of the principal data limitations is that many permittees use a combination of surface water and groundwater. Since most permittees are not required to report pumpage, estimates were made on the amount for each withdrawal source used by the permittee. Furthermore, many wells are open to more than one aquifer or producing zone.

Caution should be used when performing drawdown analyses. The model parameters are non-unique. Several parameter combinations may produce similar calibration/validation results. However, the model conclusions under various scenarios may differ (ASTM D5611).

There is little hydraulic, water level, or water quality data on the LFA in the study area. Since the model requires each grid cell to have specified values, and field data is lacking, a greater reliance on statistical interpolation and extrapolation of limited field data results in greater uncertainty regarding model calibration and associated predictive simulations. However, there are some areas, particularly in the LFA, where a solute transport model would more effectively simulate the flow by allowing heads to change as a result of changes in water quality, particularly those that effect water density (e.g., chlorides).

2035 Predictive Scenarios

Two predictive scenarios simulating the year 2035 were conducted. One represents estimated increases in pumpage in both the SFWMD and SWFWMD (Alternative 1), and the other represents increases in pumpage in the SFWMD only (Alternative 2). The purpose of preparing both simulations was to help identify the influence of the increased pumpage within SFWMD versus the SFWMD and SWFWMD combined. See the Wells Section above for more information on how the datasets were constructed. **Figure 20** shows the head difference and pumping difference in layer 3 (upper Floridan aquifer) for proposed pumpage increases in both SFWMD and SWFWMD, using the 2010 simulated heads and pumpage as the basis for the difference. Only cells with large pumpage differences (absolute value greater than 10,000 cubic feet per day [cfd]) are shown on the map. Smaller differences were not included to simplify the figure. **Figure 21** shows the head differences in layer 3 (upper Floridan aquifer) based on pumpage increases in SFWMD only.

A comparison of Figures 20 and 21 indicates that the proposed pumpage increases in SFWMD should cause little impact (drawdown) in SWFWMD within the UFA. In addition, proposed pumpage reduction in SWFWMD caused aquifer rebounding in that area (Figure 20). However, both of these conclusions should be considered with the error and limitations associated with the model as noted above.

The purpose of the uncertainty analysis was to help better understand the effects of withdrawals from the simulated 2035 scenarios on the system, in particular the MFL lakes along the Lake Wales Ridge. Typically, an evaluation of groundwater withdrawals on sensitive surface water bodies such as MFL lakes might be conducted using a transient model, allowing the evaluation of changing water levels over time. The uncertainty analysis was an attempt to support this evaluation by specifically recognizing the parameter uncertainty associated with a steady-state model such as LKBGWM.

Stochastic PEST options were used to create 2000 random parameter sets that have a similar level of calibration as the calibrated model. Using the data sets, 2000 Monte Carlo realizations (Calibration Constraint Null Space Monte Carlo, CCNSMC, (Doherty 2010)) were run for the 2010 and 2035 scenarios.

After running the 2000 Monte-Carlo realizations, average, minimum, and maximum head differences (drawdowns) were computed between 2010 and 2035 scenarios, which are shown in **Figure 22**. A positive head difference means the 2010 water level was greater for that cell, and vice versa. In Figure 22, the blue contour shows the average drawdown predicted by Monte-Carlo simulations, which corresponds to the calibrated version model drawdown shown in Figure 20. The maximum head difference is calculated as the average head plus ¼ of a standard deviation and the contours are shown in red. The minimum head difference is calculated as the average head minus ¼ of a standard deviation and the contours are shown in green. Note that when the contours of minimum, average, and maximum difference are closely spaced together, the uncertainty is low, and greater confidence in the results is implied.

In general, the higher uncertainty is observed in the Lake Wales Ridge area and the lower uncertainty is observed in the plain area, which is expected. The highest uncertainty of the drawdowns is observed around the Lake Lotela area, where the uncertainty band (minimum and maximum) varies across six model cells. Further, the area north of Lake Jackson has an uncertainty band of one to two model cells. Model uncertainty is minimal around other MFL lakes such as Lake June in winter, Lake Placid and Clinch Lake, showing a good predictive capability. In addition, an uncertainty band of one to two model cells was observed northwest of Lake Okeechobee, which is a relatively flat area. This shows that the model slightly loses accuracy when the increase in pumping is greater.

<u>MFL Lake Assessment for 2035 Pumping Condition</u>

Both SJRWMD (SJRWMD 2012) and SWFWMD (Sweazy 2013) utilize UFA drawdowns to assess impacts to MFL lakes because of the high connectivity between the MFL lakes and the UFA. This approach, along with the uncertainty analysis, is used in the LKBGWM to assess the impact on MFL lakes due to a 2035 pumping condition. This process gives us a better estimate of the potential impacts caused by the 2035 pumping condition.

As discussed in the previous section, UFA water levels show a rebound or no significant effect underneath MFL lake areas despite the increased pumping within SFWMD (Figure 20). **Figure 23** shows a zoomed-in view of the UFA drawdown map (shown in Figure 22) underneath the MFL lakes (northwest area of the model domain). In Figure 23, average drawdown contours show a rebound between 0.5-1.0 ft in the northern portion of Lake Jackson. However, the Monte Carlo simulations show that the rebound in the UFA beneath Lake Jackson varies between 0-0.5 ft. In the areas underneath Lake Angelo and Lake Verona, the UFA shows about a 1-2 ft rebound as per average contours. The uncertainty analysis predicts a rebound between 0.5-1 ft. In areas beneath Lake Letta, Lake Lotela, Lake Anoka, Lake Denton, and Lake Tulane, the UFA shows about a 1.0 ft rebound on average. However, Monte Carlo simulations suggest that this could be around 0.5 ft in the worst case. Areas underneath Lake June in winter, Lake Placid, Lake Little Jackson, and Lake Clinch do not show a significant drawdown on average. Monte Carlo simulations also did not predict a significant drawdown around these areas.

<u>Conclusions and Recommendations</u>

1. Overall, the model met the calibration criteria for 1995, 2004, and 2010. However, there are some calibration points with significant errors.

2. The model has good mass balance. However, since only basic MODFLOW packages were used, some budget items may be large in order to compensate for missing packages.

Staff recommends utilizing some of the newer surface water packages to simulate the surface water system more thoroughly in the future. Some possible options are:

- Wetland package
- Stream package
- Lake package
- SWM package

Moreover, a comparison of the observed and simulated surface water flows should be included.

3. Floridan Aquifer System withdrawals underneath the MFL lakes are a concern to both SFWMD and SWFWMD. However, this area is sensitive to various aquifer parameters.

Future testing in this area would be beneficial to both water management districts. The testing and monitoring should include:

- Surficial-Floridan Aquifer interaction
- Surface/groundwater interaction
- Relationships between the lakes and the UFA
- Expansion of surface-water and groundwater networks

4. MFL lake levels for the 2035 pumping condition were assessed in terms of the UFA drawdown predicted by Monte Carlo simulations. On average, the results show a rebound in the UFA beneath Lake Jackson, Lake Denton, Lake Letta, Lake Lotela, Lake Anoka, Lake Angelo, Lake Tulane and Lake Verona. In addition, the areas underneath Lake June in Winter, Lake Placid, Lake Little Jackson, and Lake Clinch did not show a significant drawdown for the 2035 pumping condition, Figure 23. According to Monte Carlo simulations, the model shows that in the worst-case scenario, the UFA water level underneath these MFL Lakes were not affected (0 ft or higher rebound) by the pumping condition in 2035. However, Figure 21 indicates that there may be impacts without the recovery strategy.

5. Potential model improvements for an updated model include the following:

a) Convert the model from steady state to transient. This would allow users to examine the model under various climatic conditions.

b) Conduct a study of the surface-water system. Data from this study can be applied to the aforementioned packages.

References

ARCADIS. 2008. Generation of the Expanded Coverage Reference Evapotranspiration Dataset for Hydrologic Modeling.

ASTM Standards: D5611 (reapproved 2002). Standard Guide for Conducting a Sensitivity Analysis for a Ground –Water Flow Model Application.

Barton, H., C. Gefvert., J. Giddings. 2005. Lower Kissimmee Basin Groundwater Model. South Florida Water Management District, West Palm Beach, Fl.

Brown, M. 2013a. Reference Evapotranspiration (1948-2013) using 51-year Hydrological Reanalysis and North American Regional Reanalysis. South Florida Water Management District, West Palm Beach, Fl.

Brown, M., 2013b. Written communication.

Doherty, J. 2003. Ground Water Model Calibration Using Pilot Points and Regularization. Journal of Ground Water, Vol. 41, No. 2, March-April 2003, pp. 170-177).

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

Florida Atlantic University (FAU). 2007. Modflow/SEAWAT – 2000 Documentation. Department of Geosciences, Florida Atlantic University, Boca Raton, FL.

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.

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.

Restrepo, J.I., and J.B. Giddings. 1994. Physical Based Methods to Estimate ET and Recharge Rates Using GIS. Effects of Human-Induced Changes on Hydrologic Systems, American Water Resources Association, Bethesda, MD.

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

St. Johns River Water Management District. 2012. Bureau of Ground Water Sciences Project Review.

Southwest Florida Water Management District. 2010. The 2010 Update of the Regional Water Supply Plan, Brooksville, FL.

Southwest Florida Water Management District, 2013. Written Communication.

Sweazy, C. 2013. A Planning Level Approach to Assessing SWFWMD MFL Lakes within Highlands County using the LKB Model (draft). Unpublished

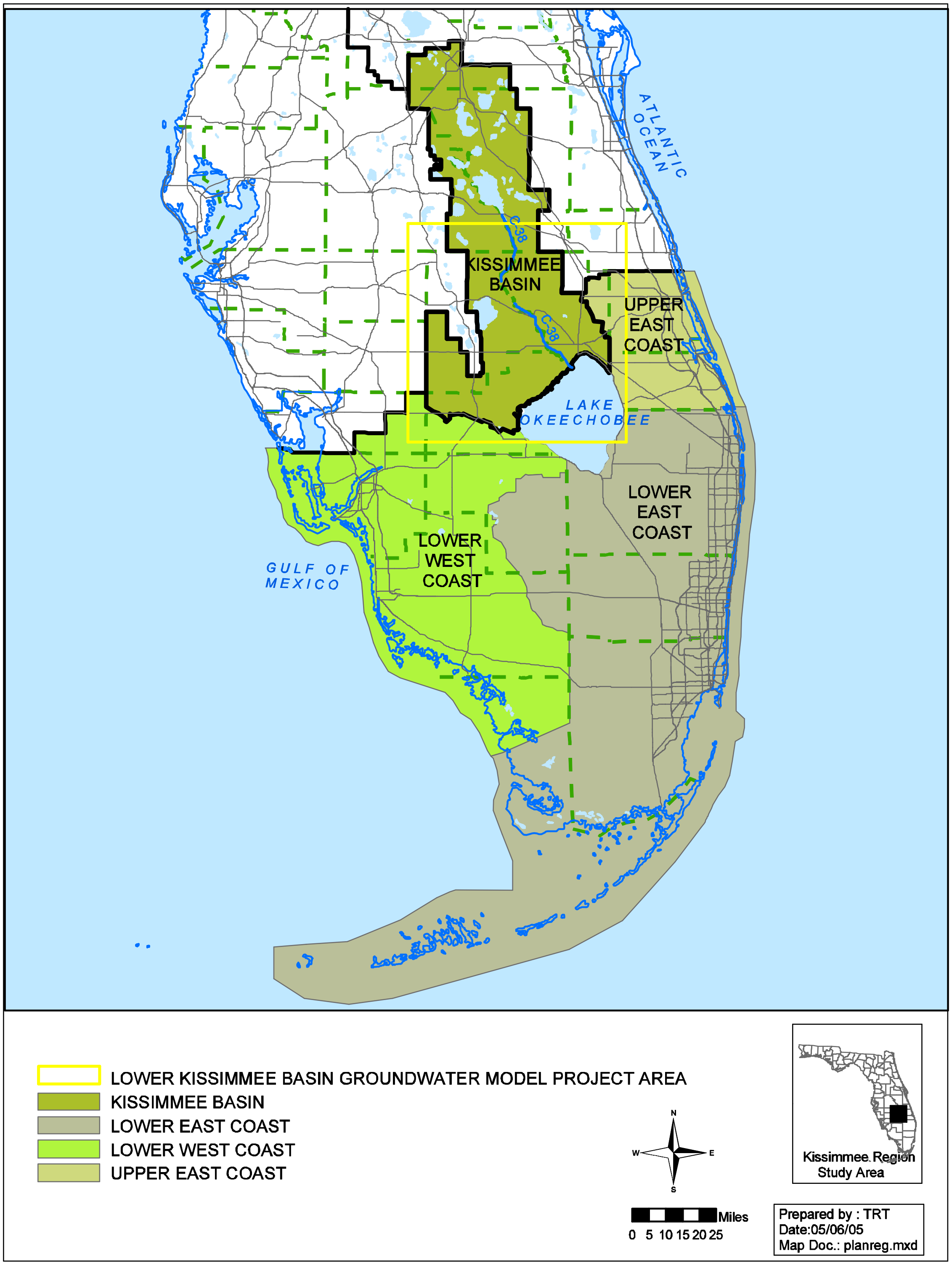


Figure 1. Location of LKBGWM

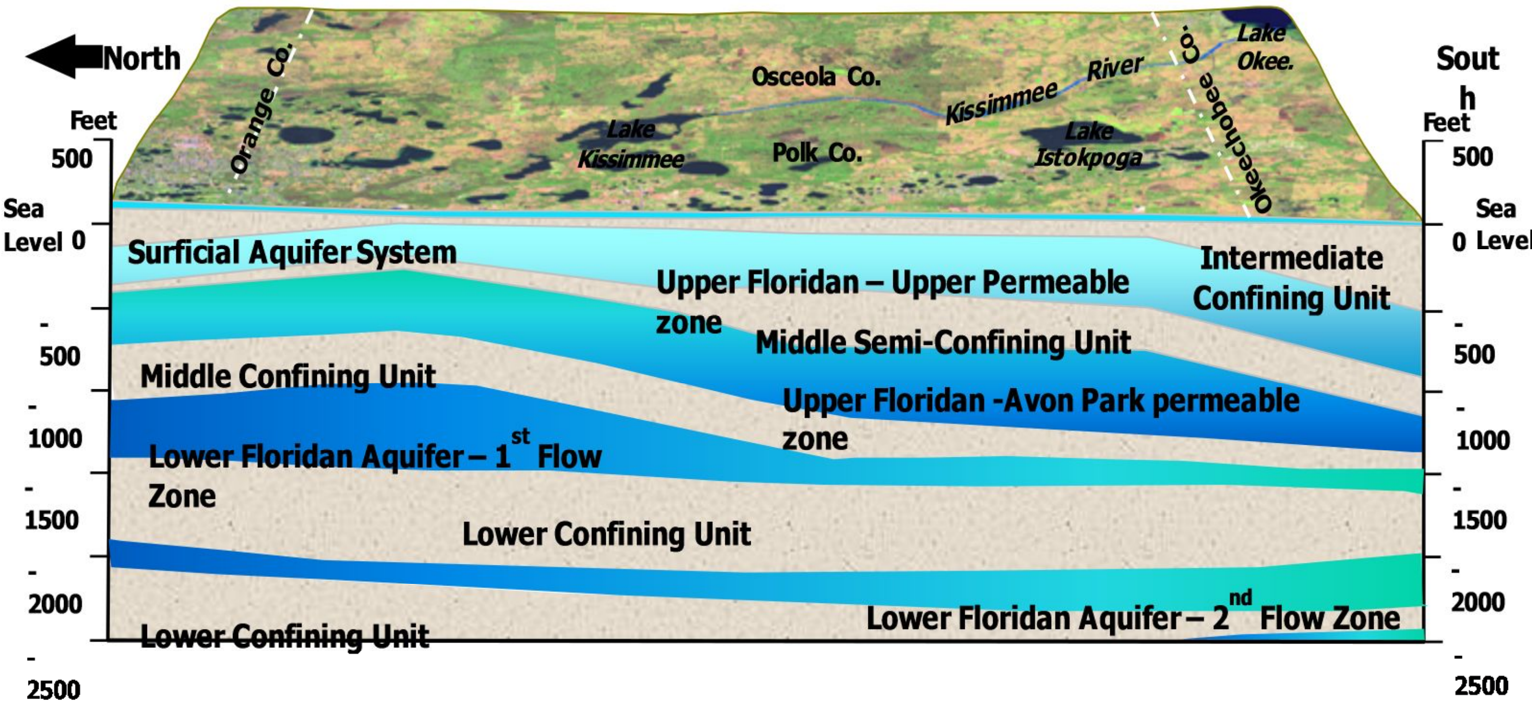


Figure 2. Hydrostratigraphic Cross Section

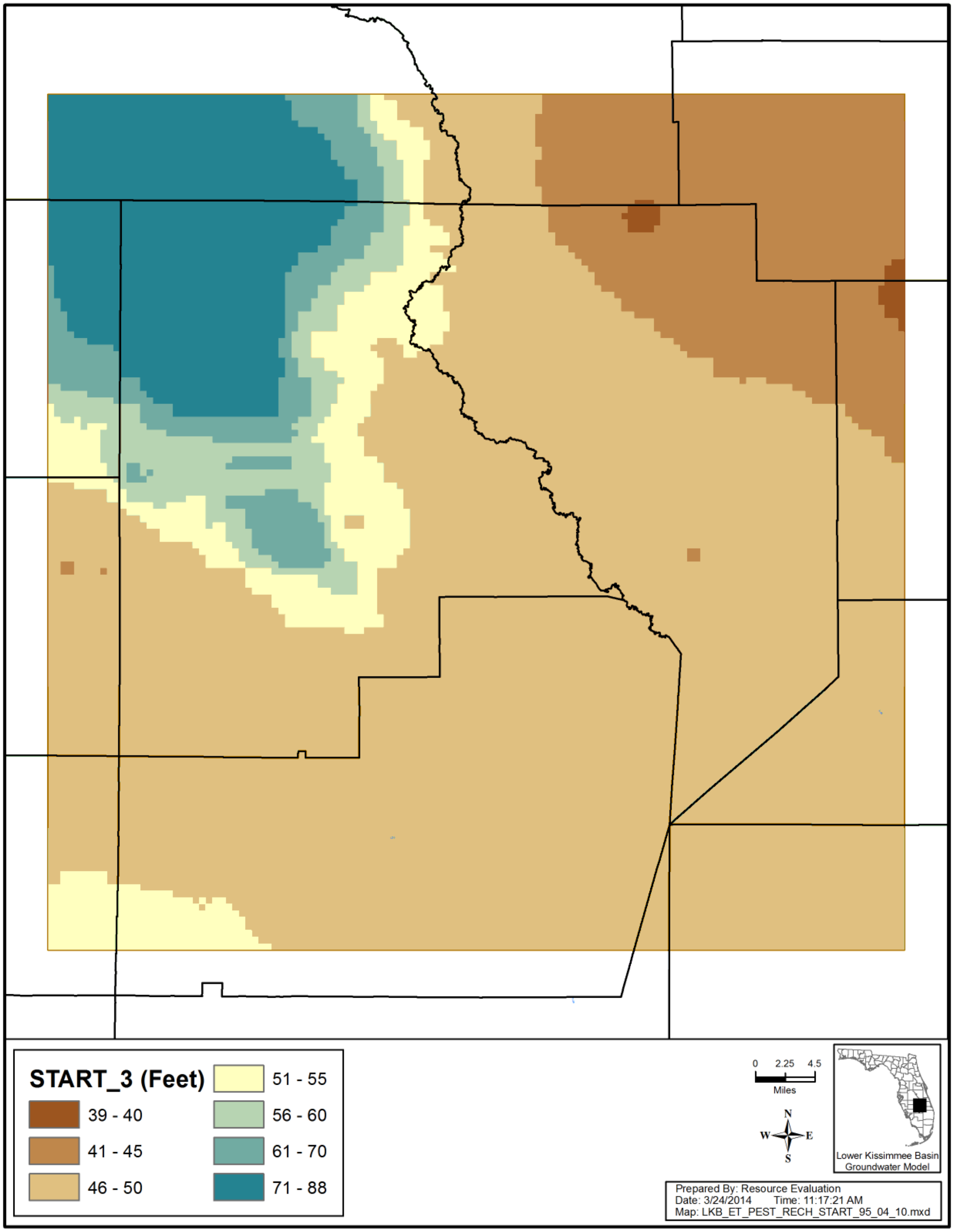


Figure 3. Starting Heads for the 2010 Simulation (Layer 3)

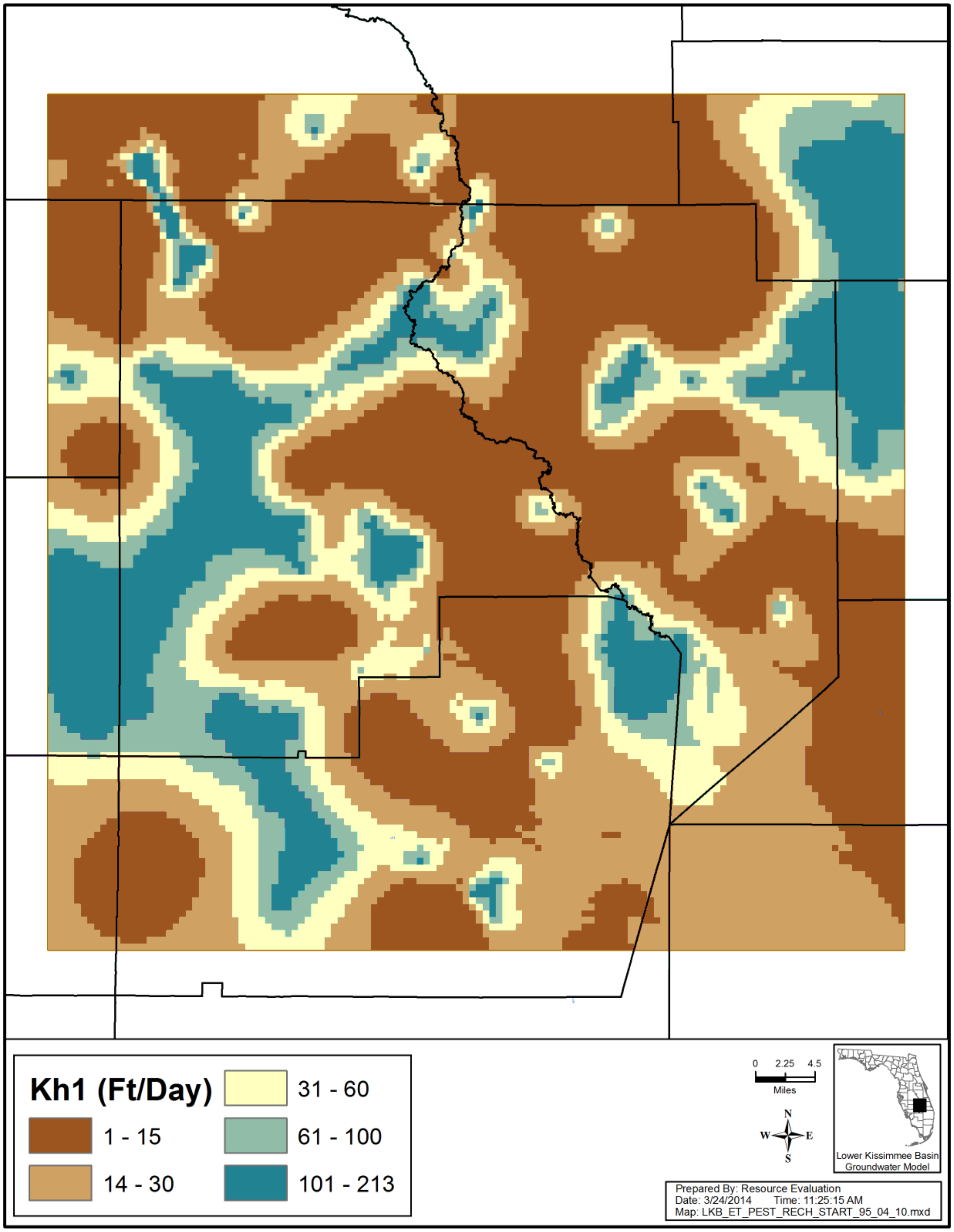


Figure 4. Layer 1 Calibrated Hydraulic Conductivity

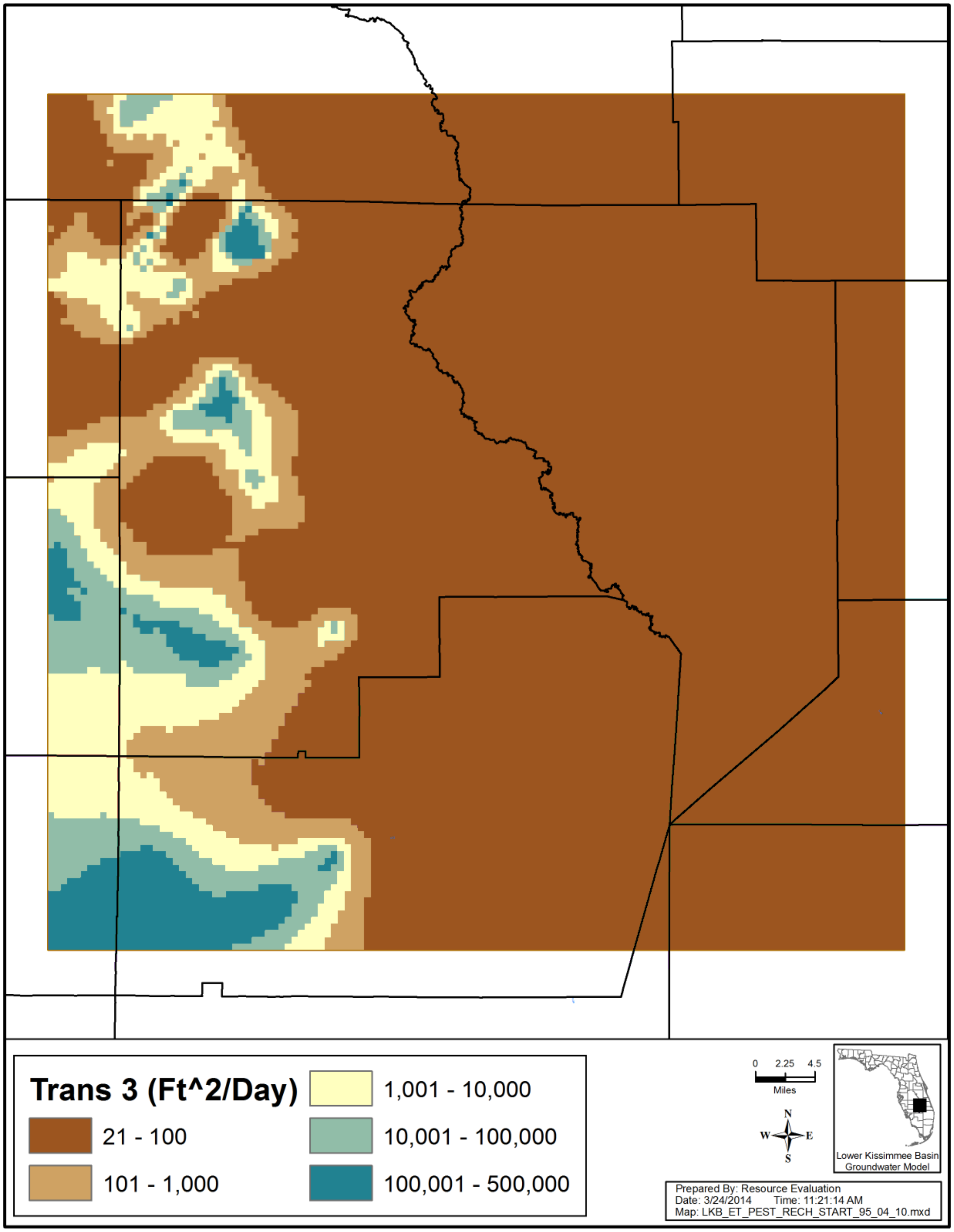


Figure 5. Layer 3 Calibrated Transmissivity (upper Floridan aquifer)

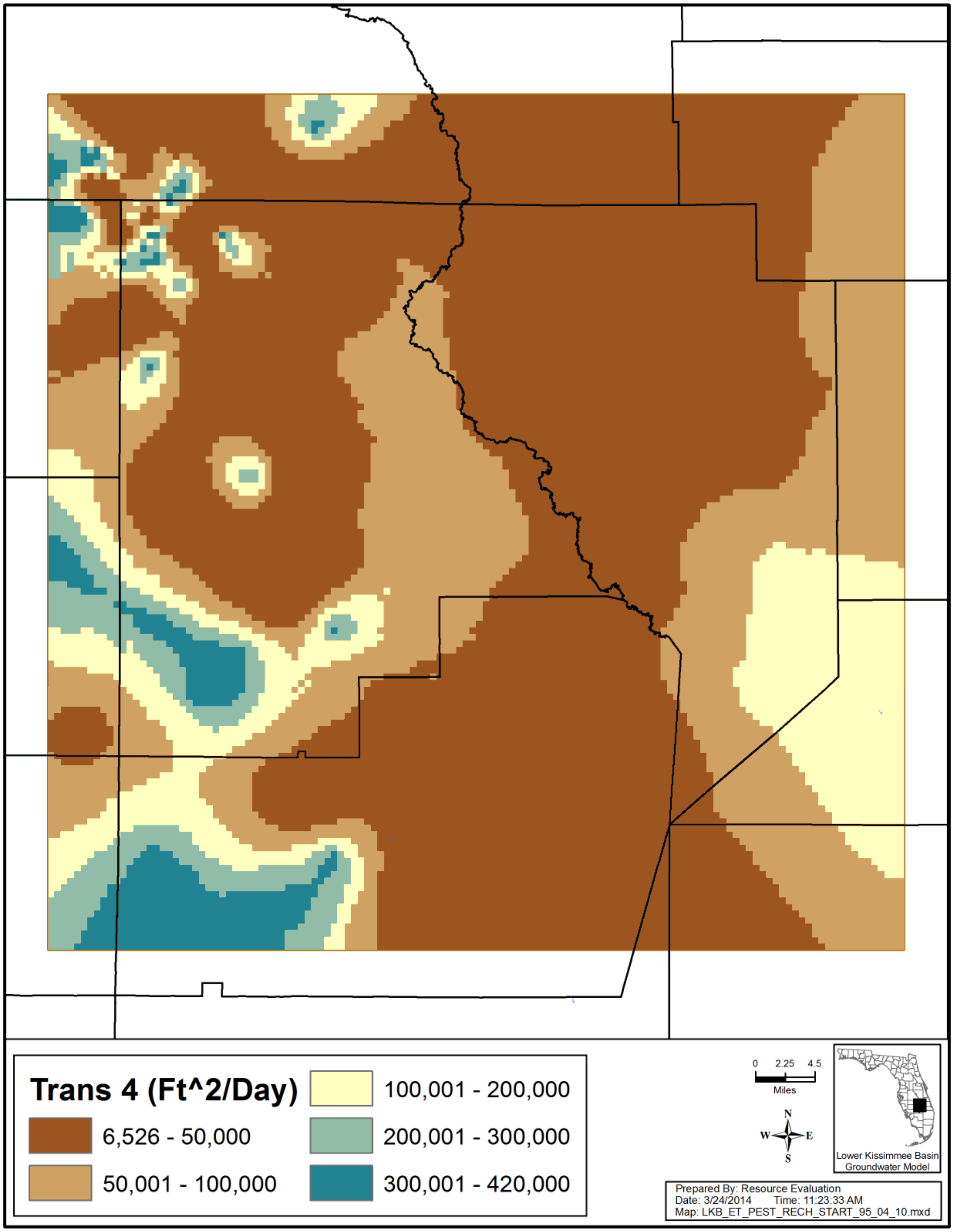


Figure 6. Layer 4 Calibrated Transmissivity (APPZ)

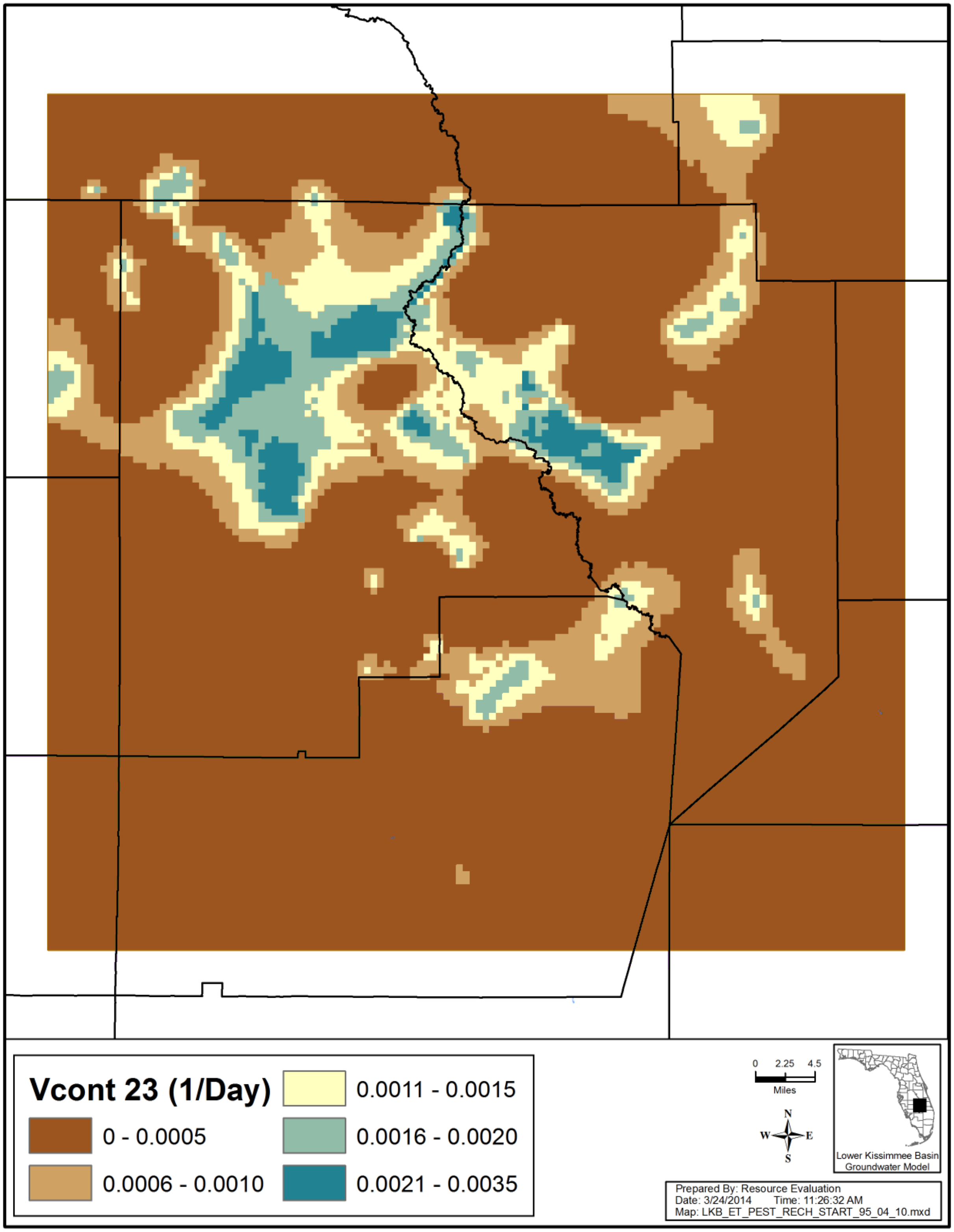


Figure 7. Layer 2/3 Calibrated Vcont

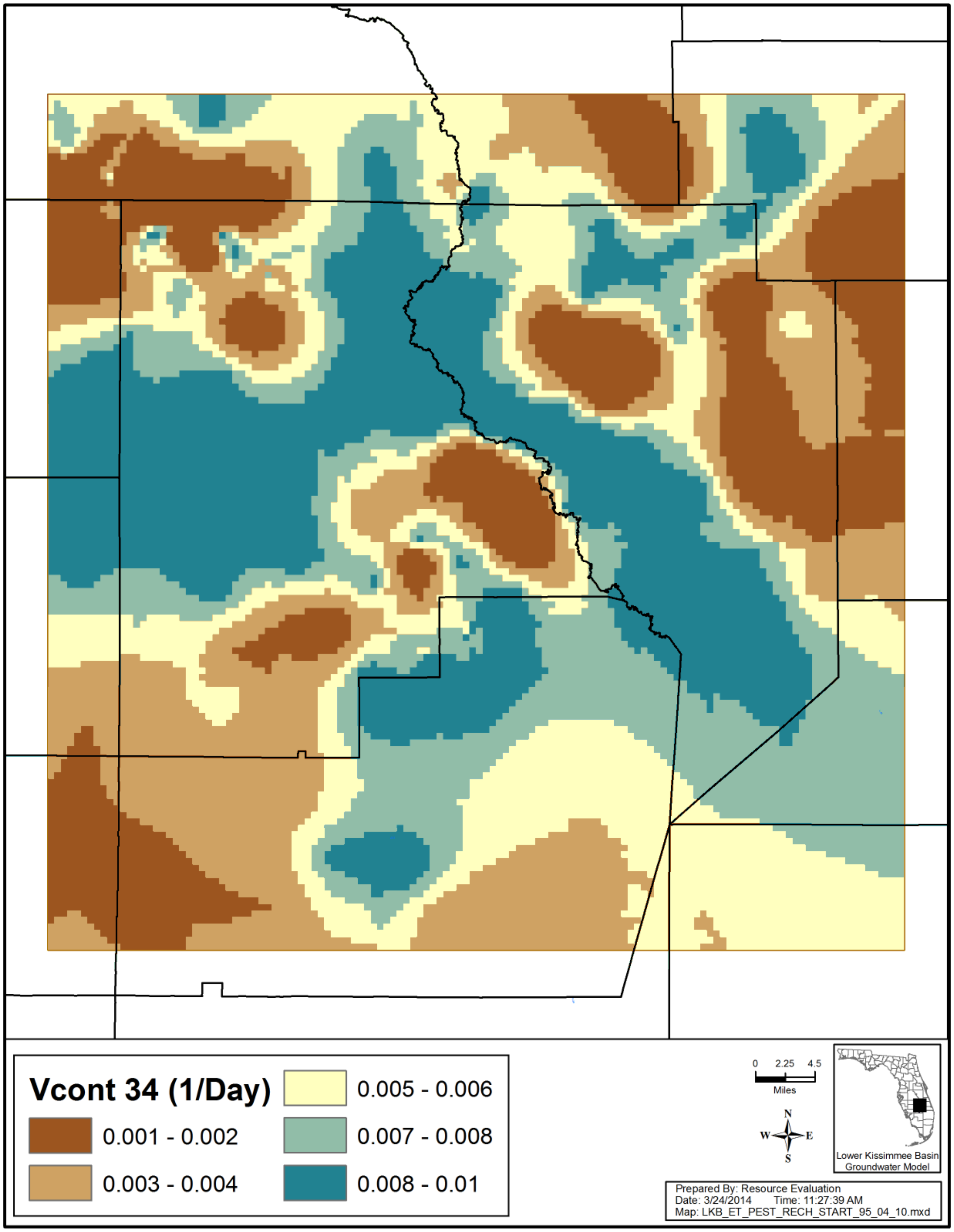


Figure 8. Layer 3/4 Calibrated Vcont

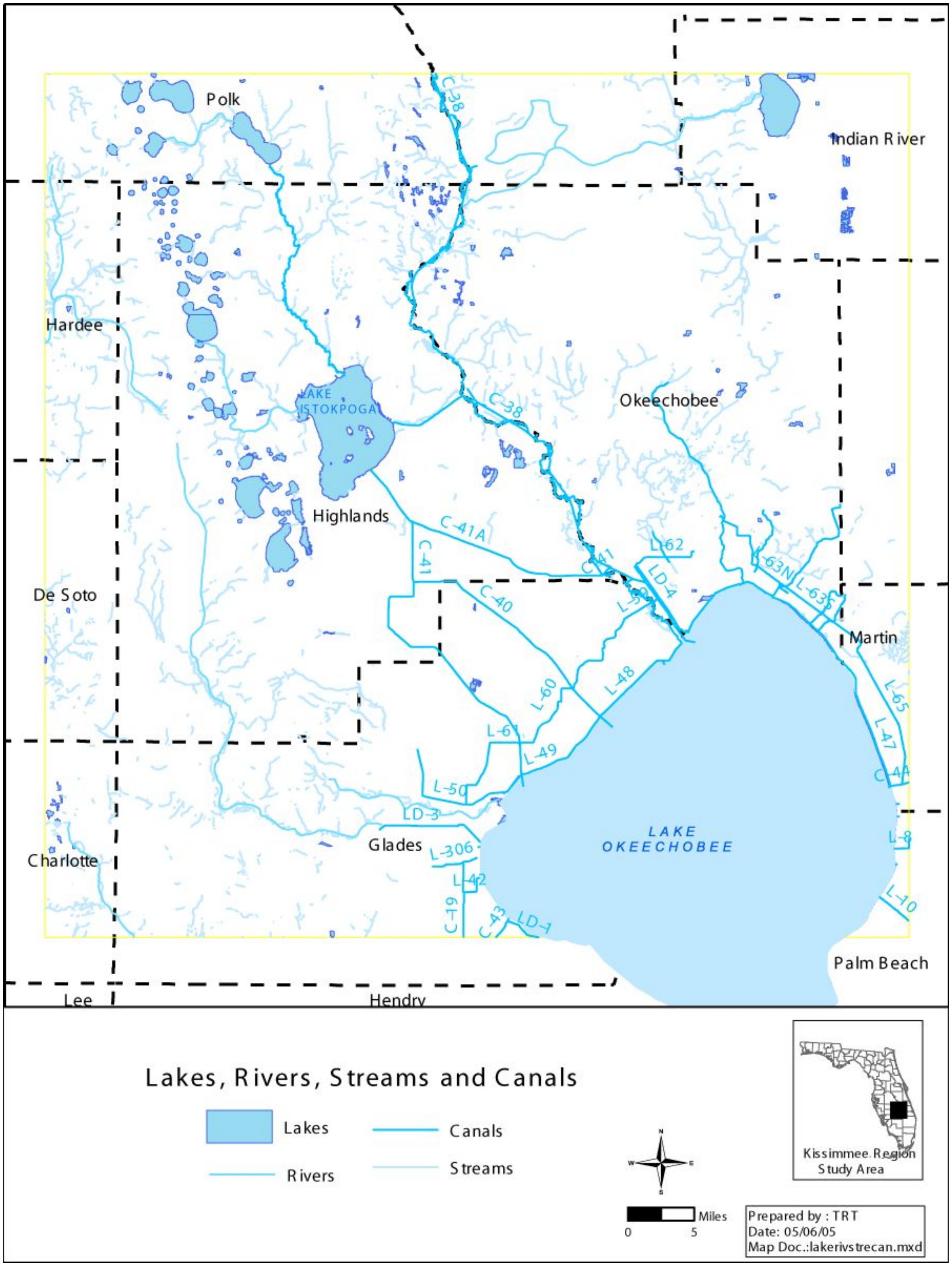


Figure 9. Simulated Surface Water Bodies

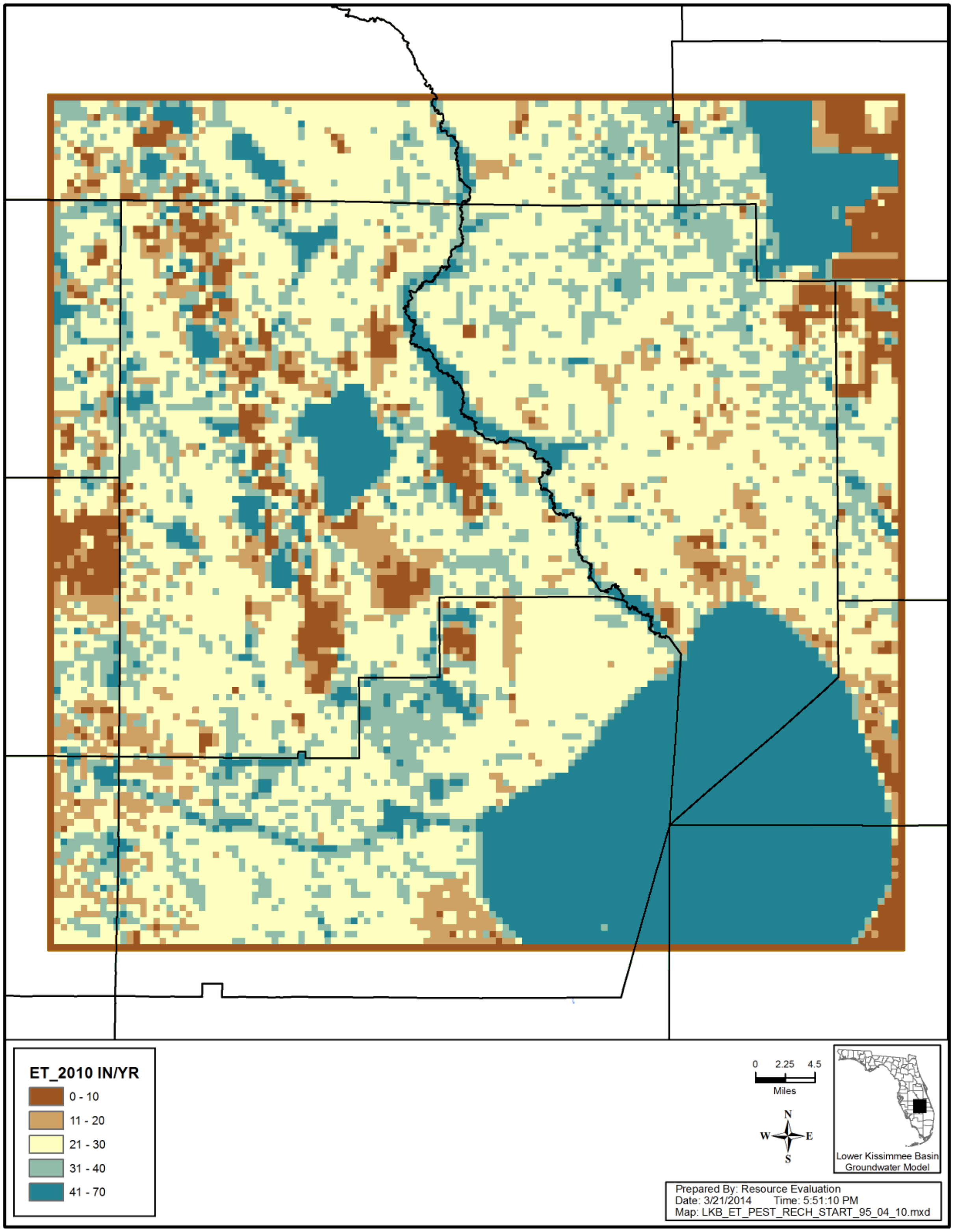


Figure 10. 2010 ET Rate

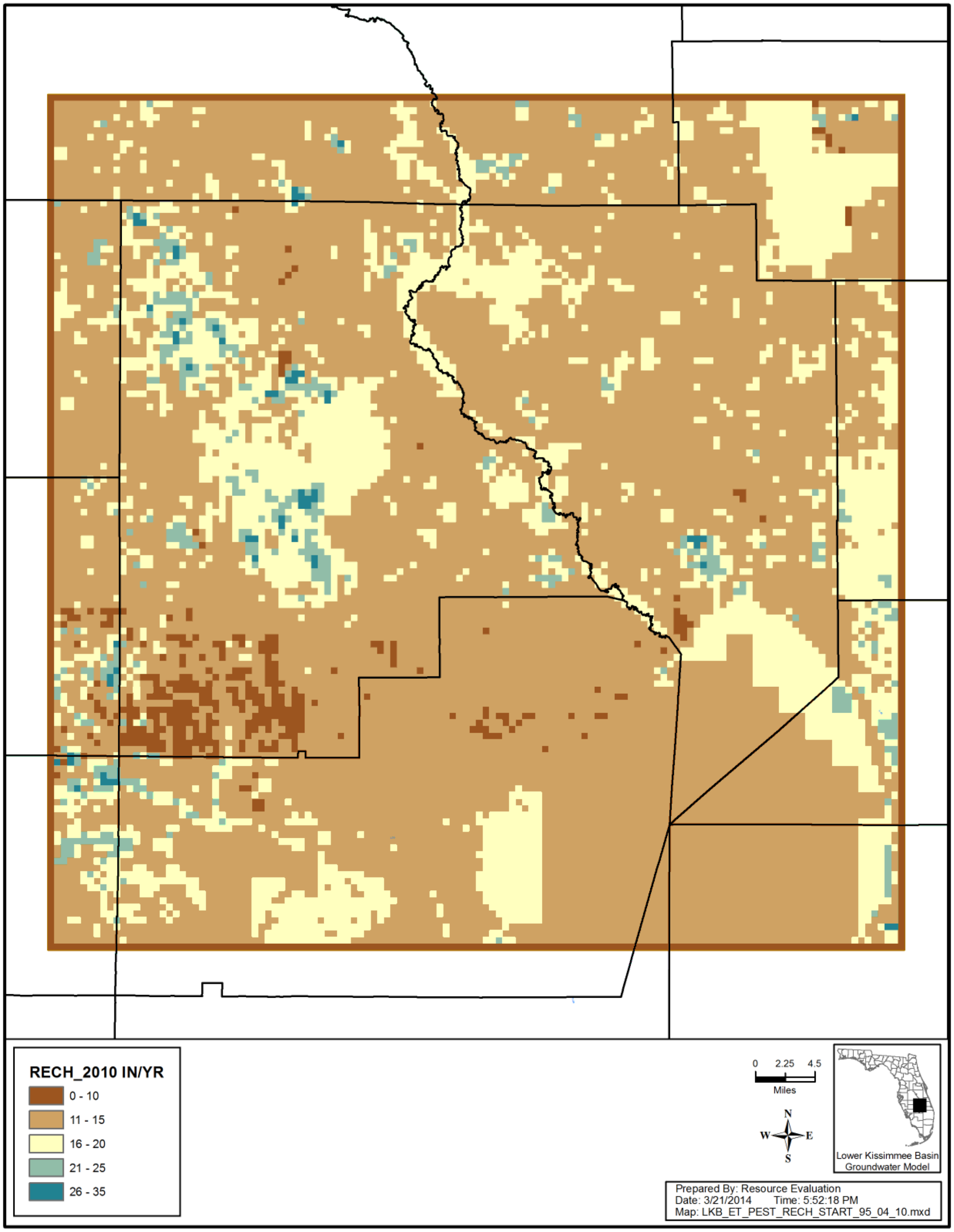


Figure 11. 2010 Net Recharge

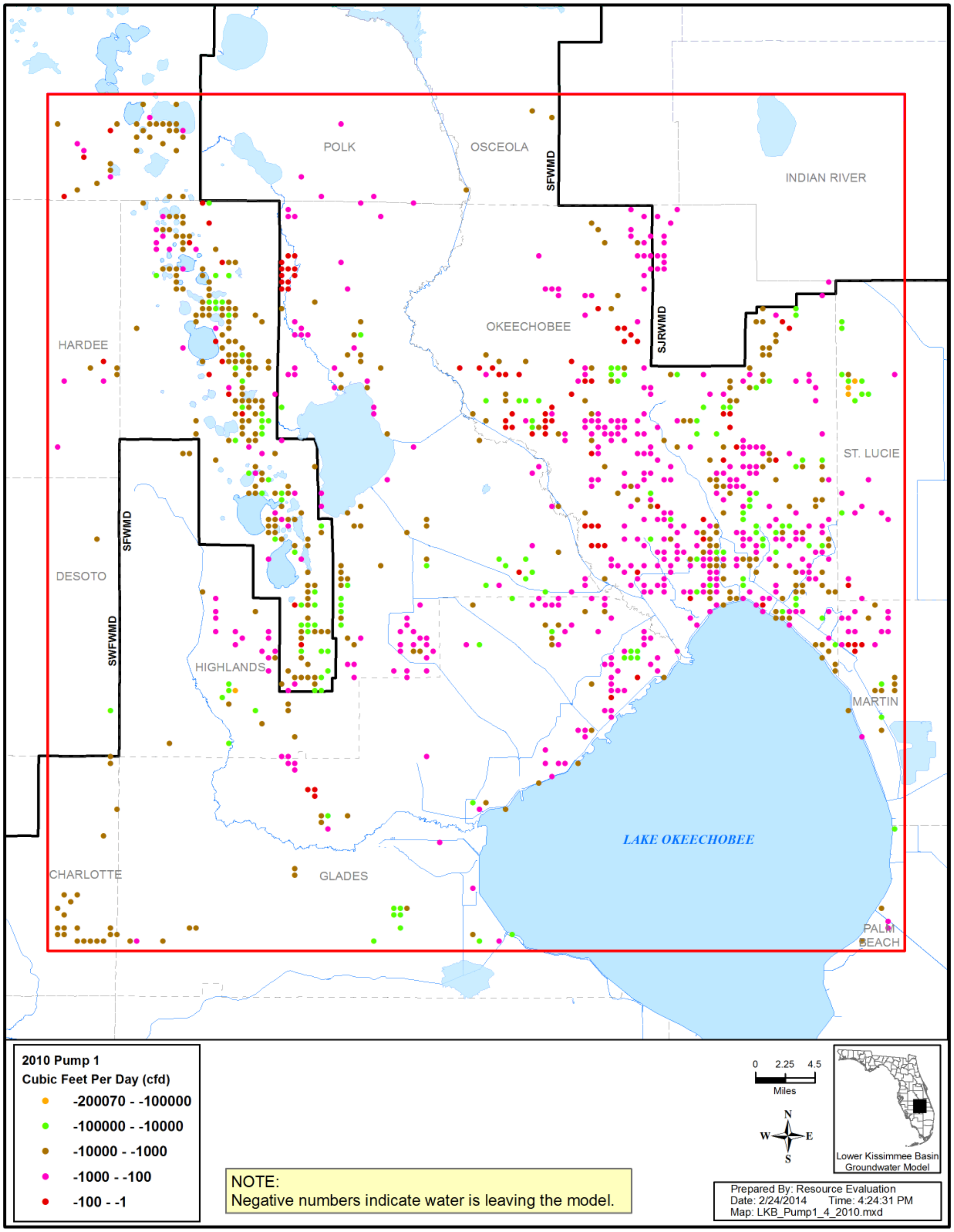


Figure 12. 2010 Layer 1 Well Pumpage

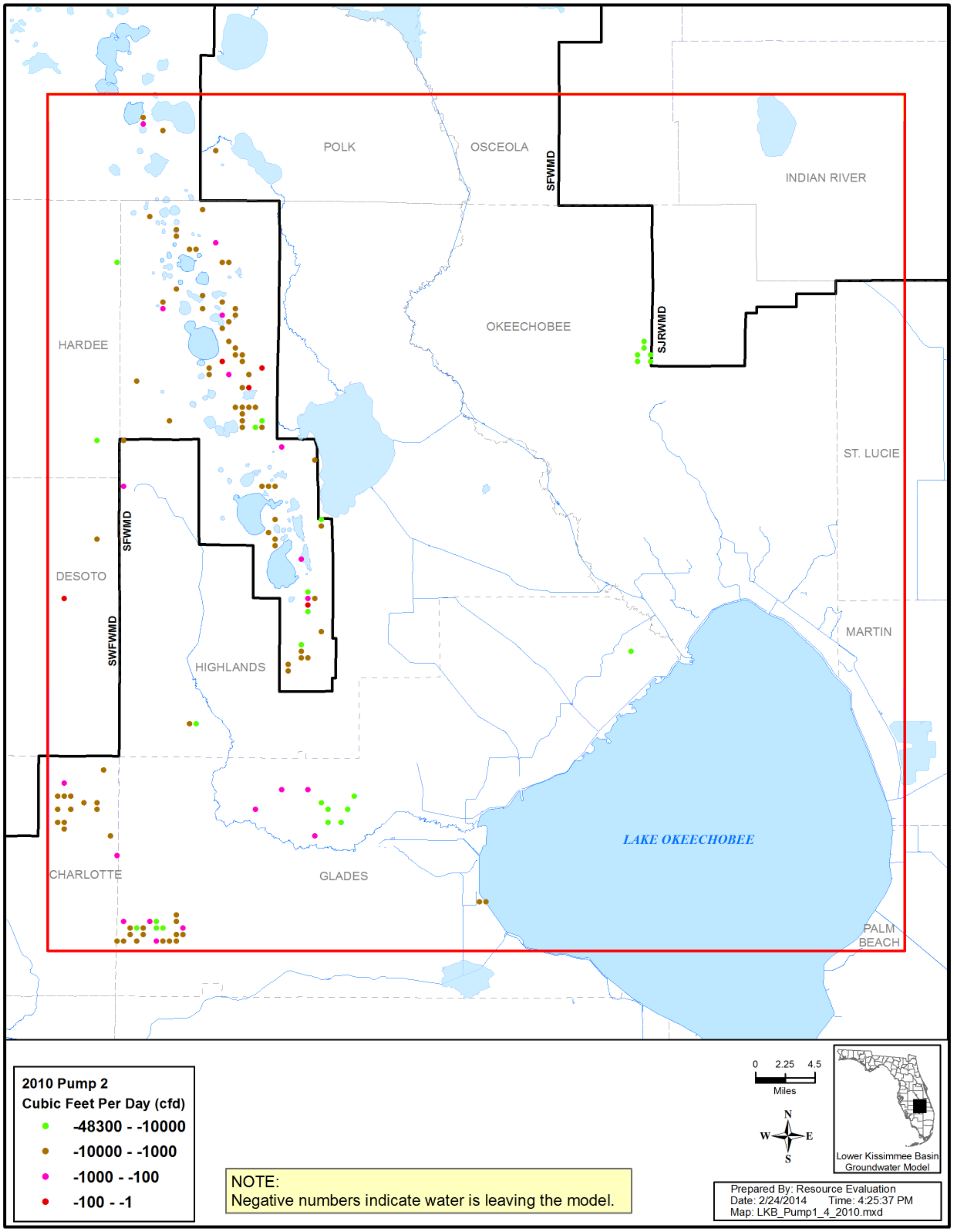


Figure 13. 2010 Layer 2 Well Pumpage

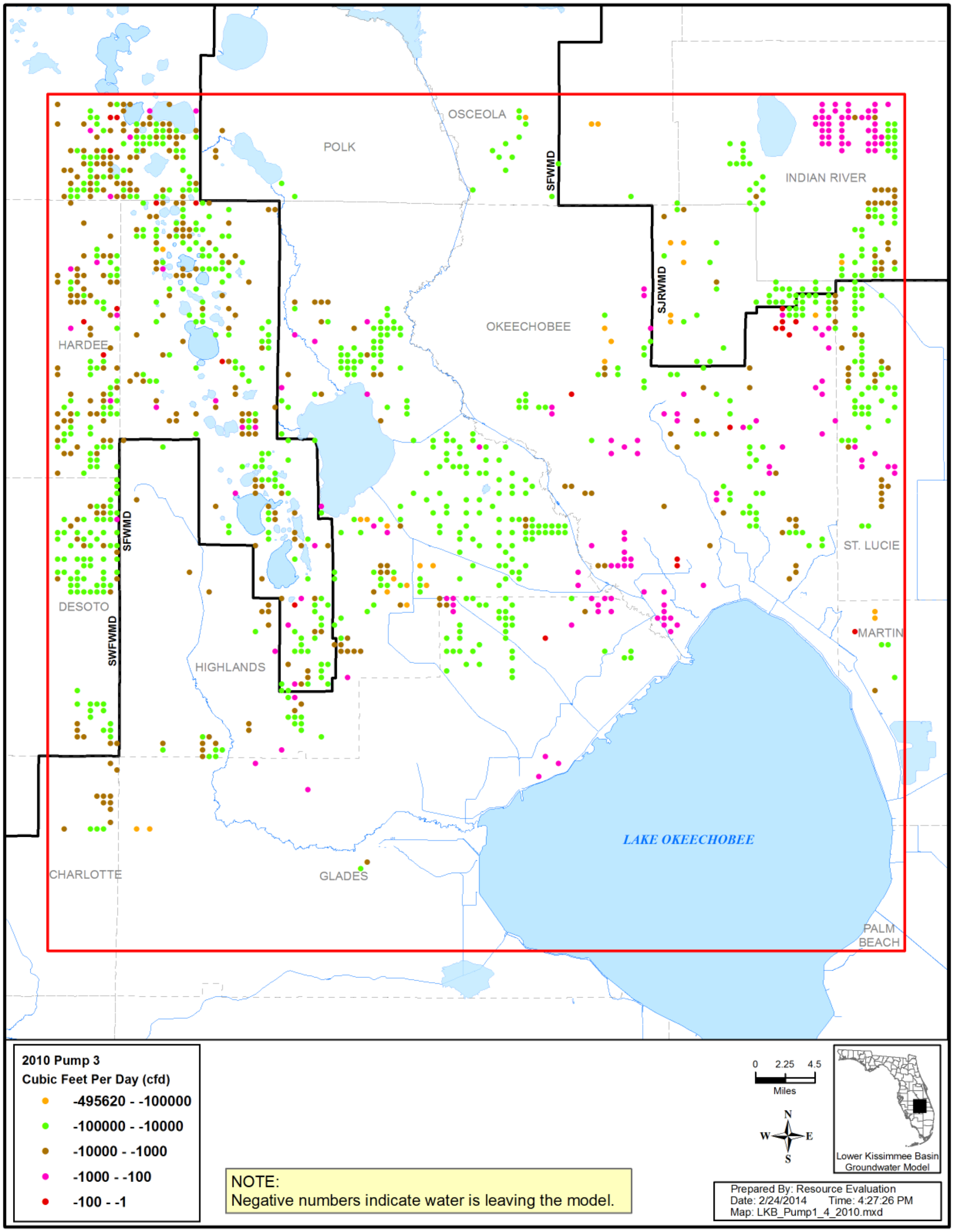


Figure 14. 2010 Layer 3 Well Pumpage

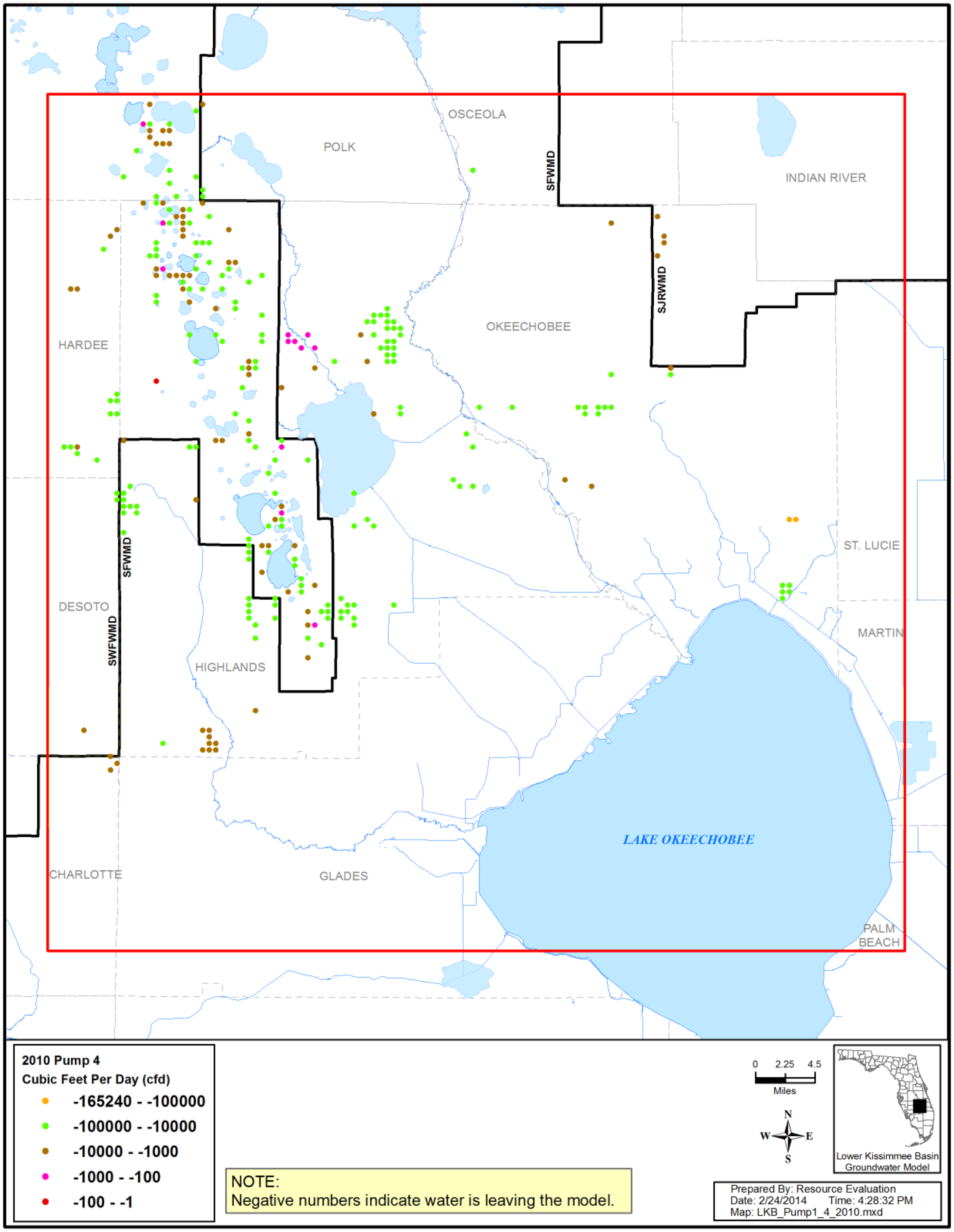
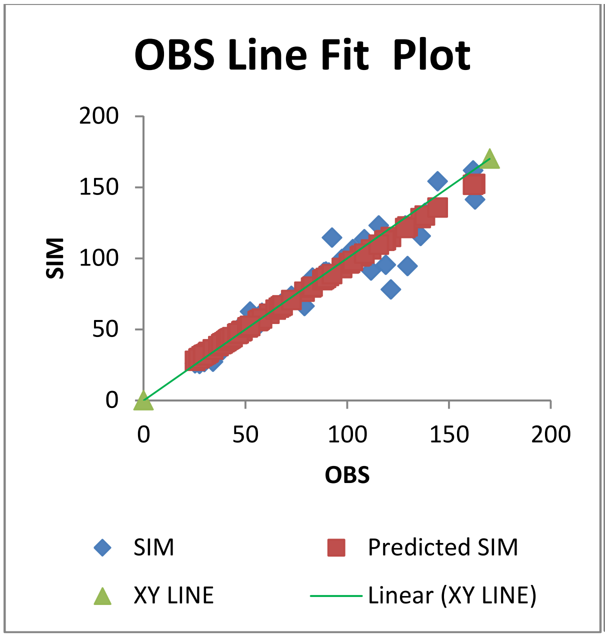


Figure 15. 2010 Layer 4 Well Pumpage

Layer 1



Layer 3

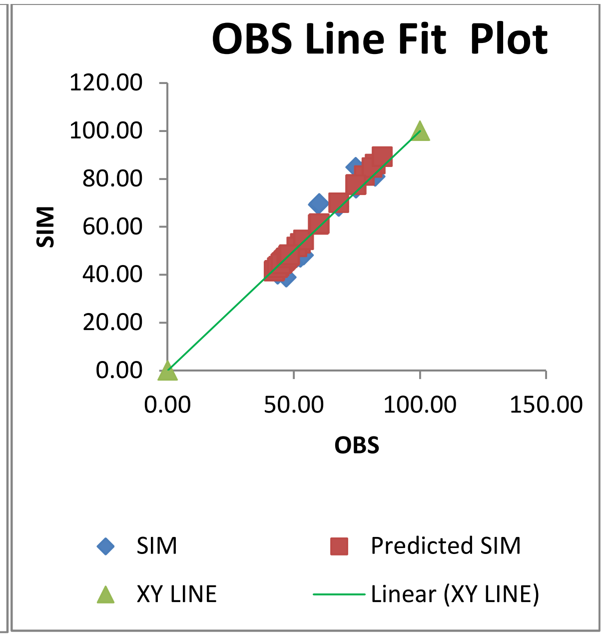
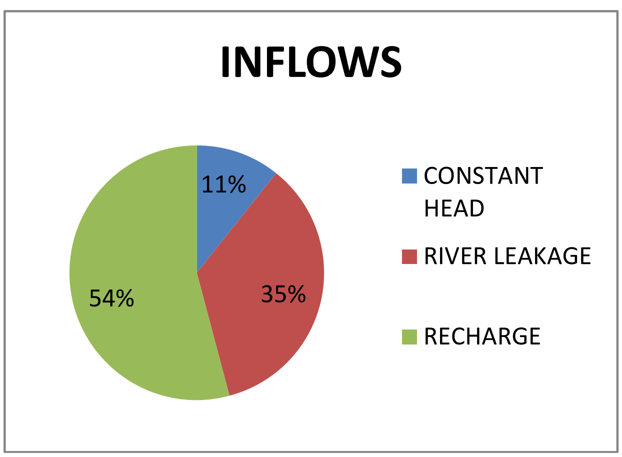


Figure 16. 2010 Calibration Graphs



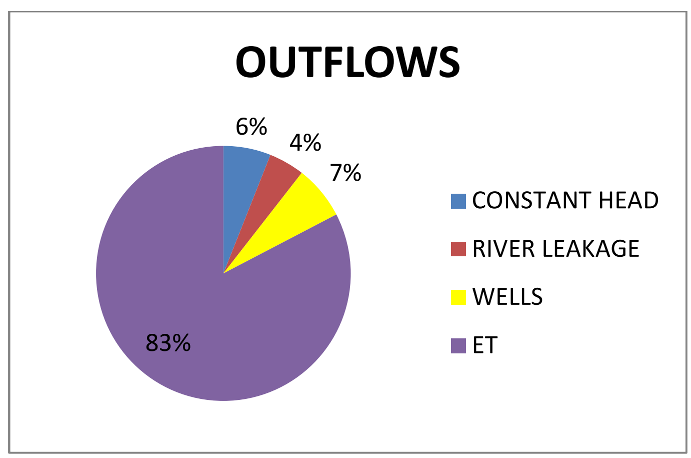


Figure 17. 2010 Overall Water Budget

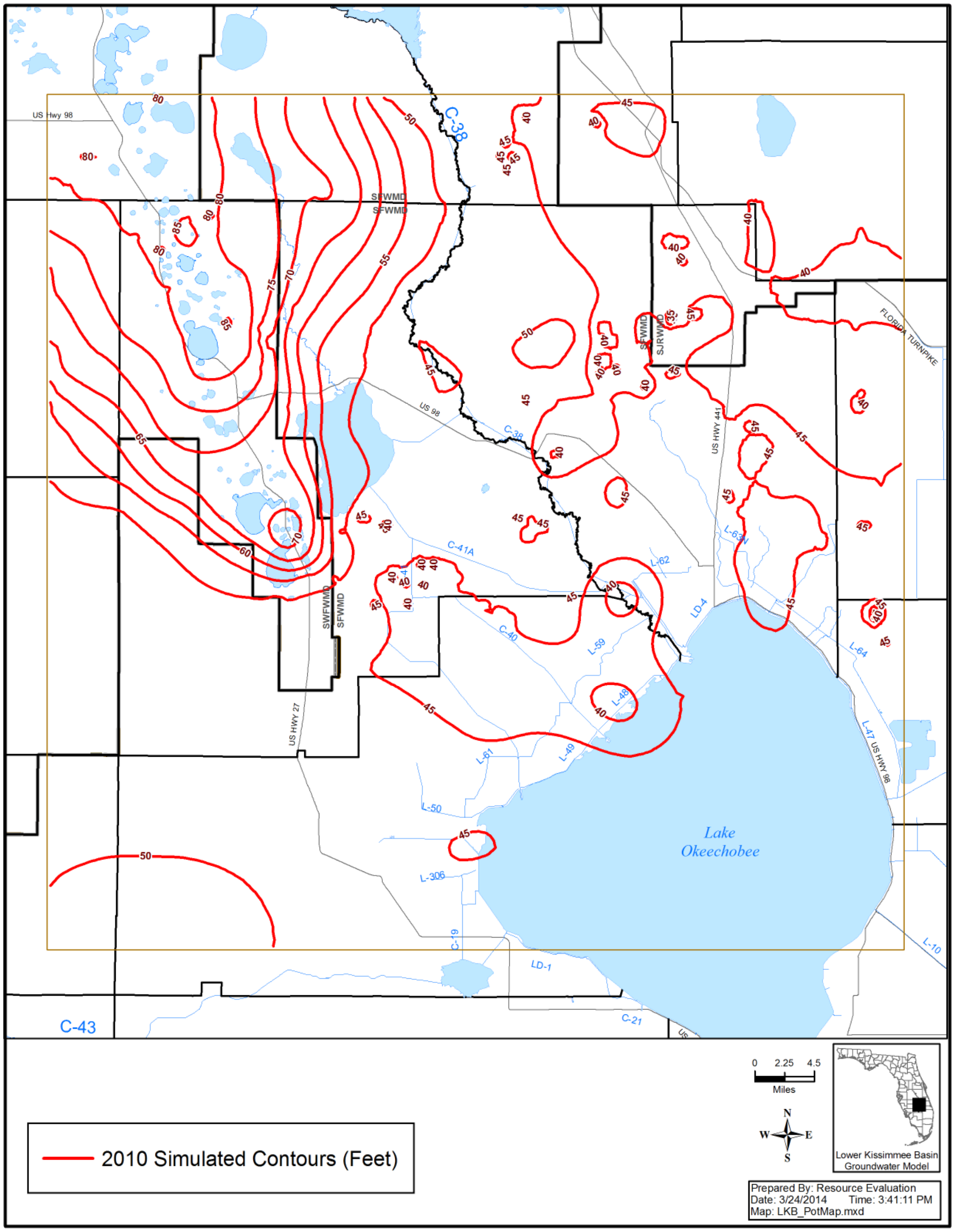


Figure 18. 2010 UFA Simulated Contours

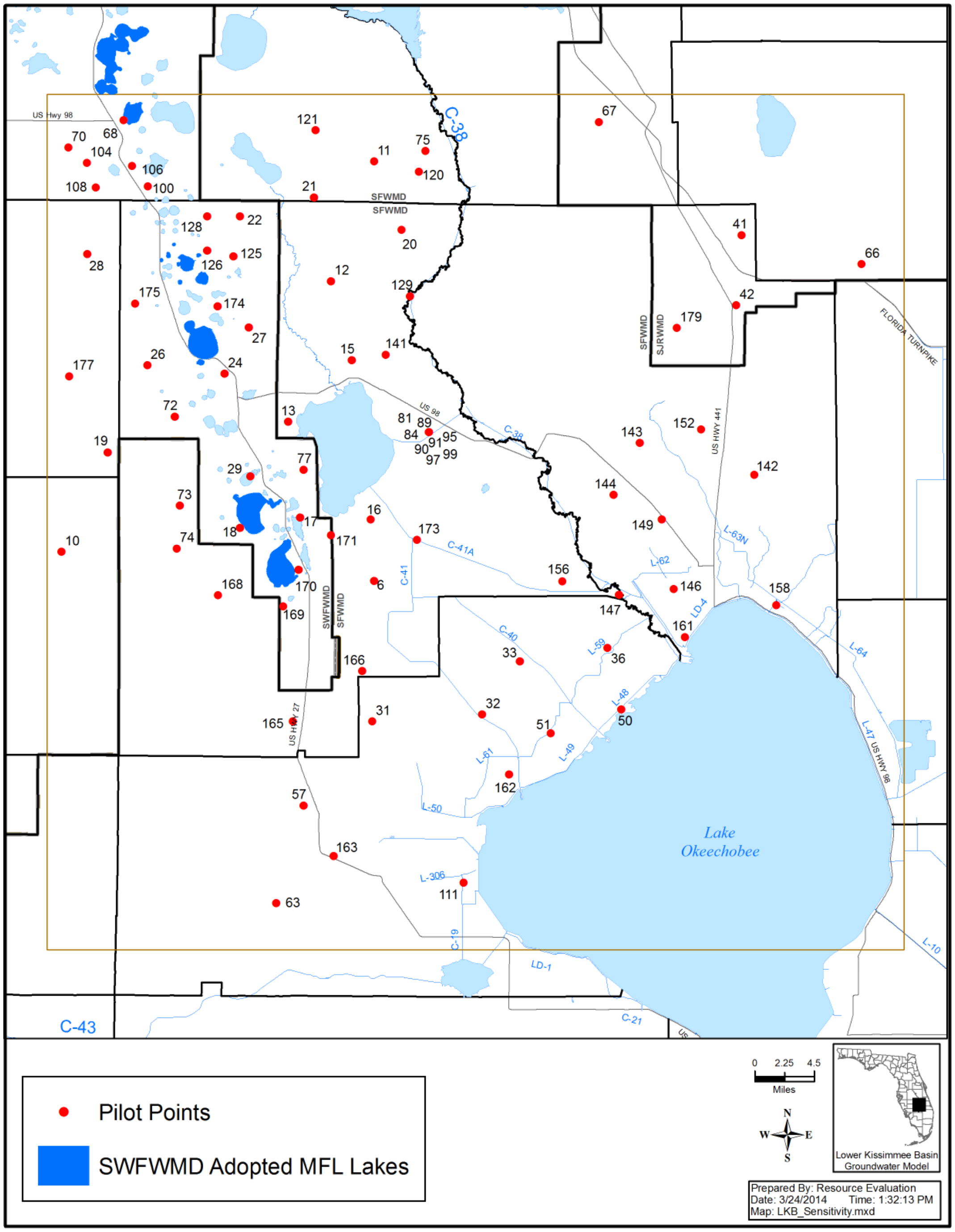


Figure 19. Pilot Point Parameters with the Highest Sensitivity Values and SWFWMD MFL Lakes

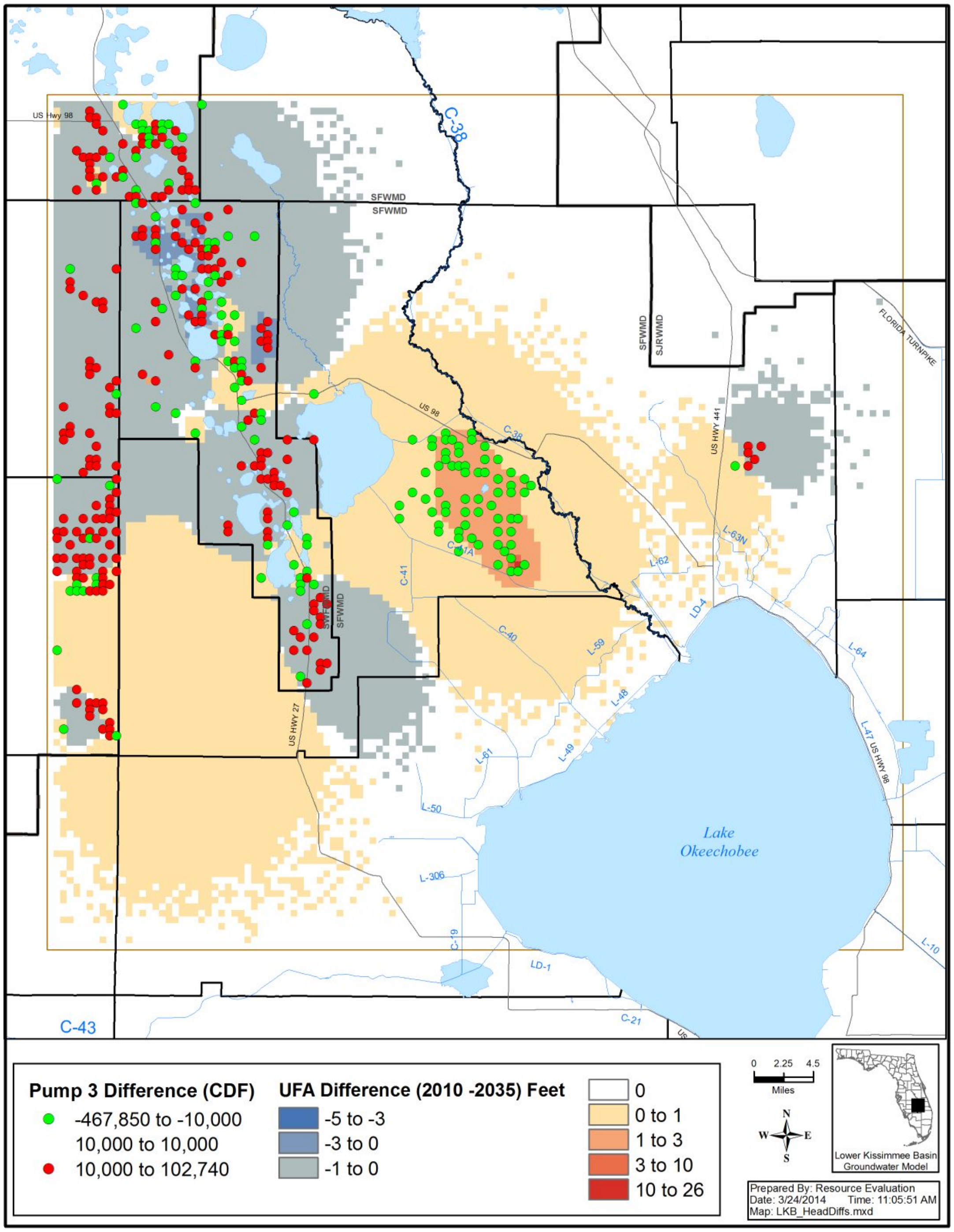


Figure 20. 2035 Layer 3 Head Difference and Pumping Difference (Upper Floridan Aquifer) SFWMD and SWFWMD Proposed Pumpage

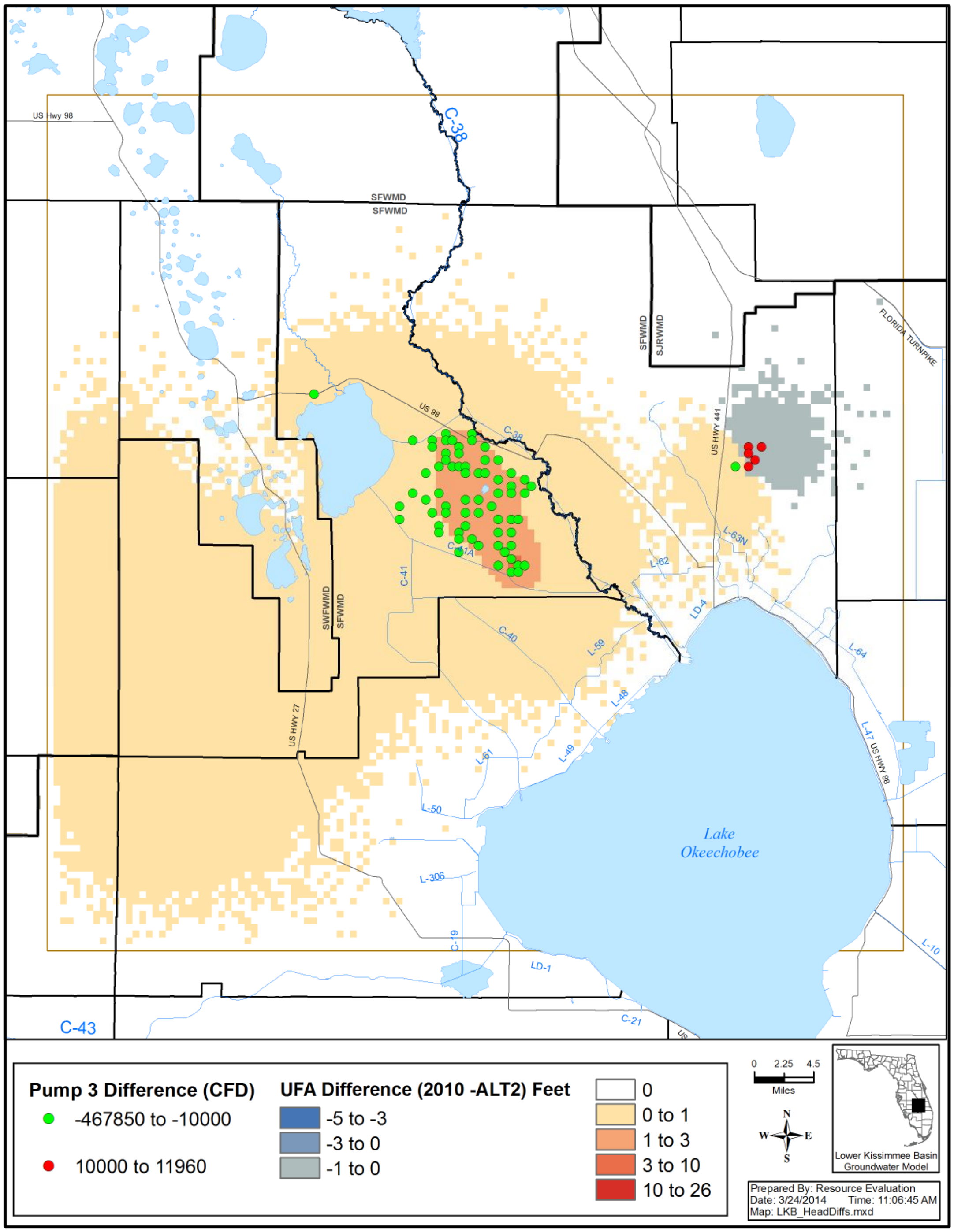


Figure 21. 2035 Layer 3 Head Difference (Upper Floridan Aquifer) SFWMD Proposed Pumpage Only

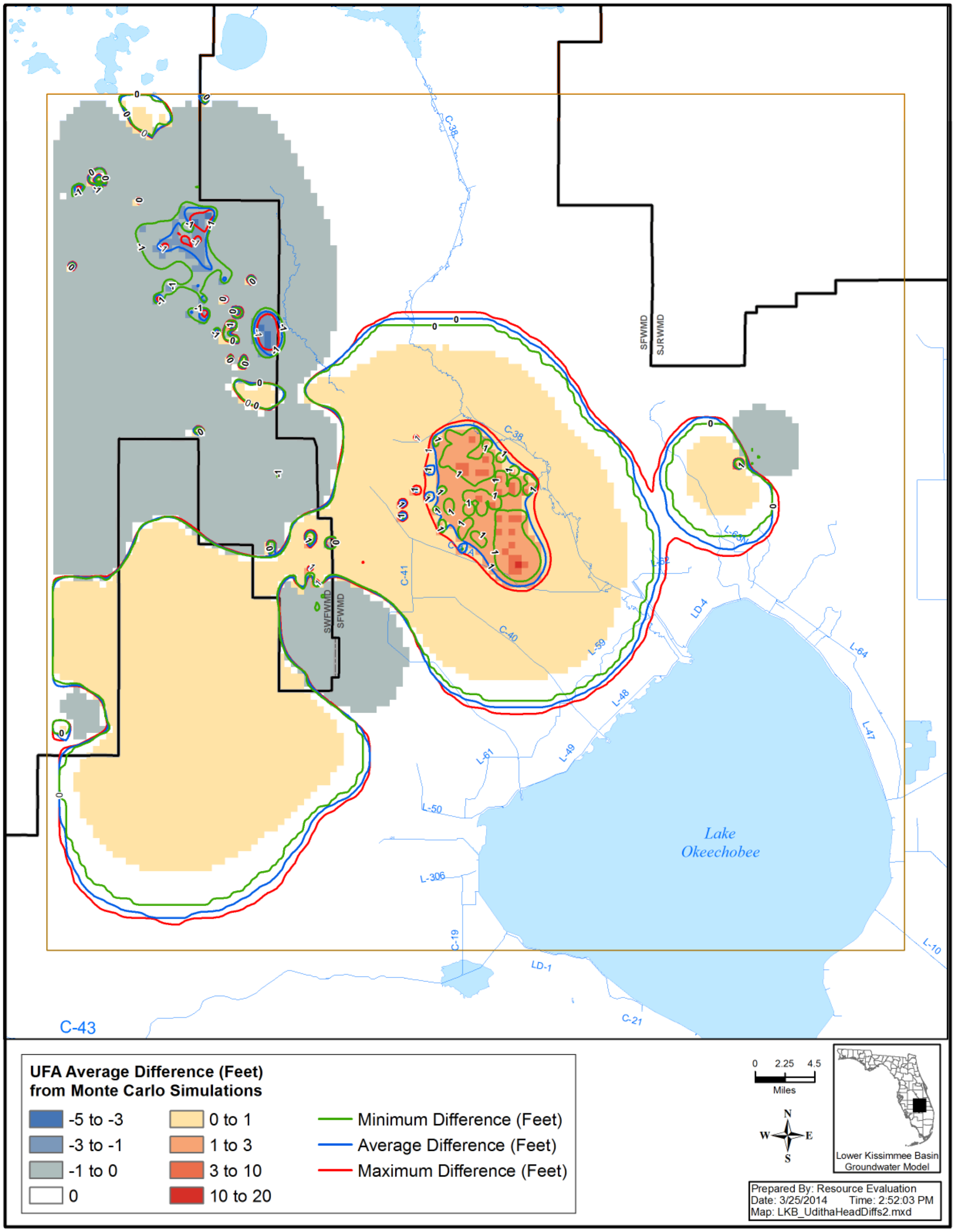


Figure 22. 2035 Minimum and Maximum Head Differences Using Null-Space Monte Carlo Simulations

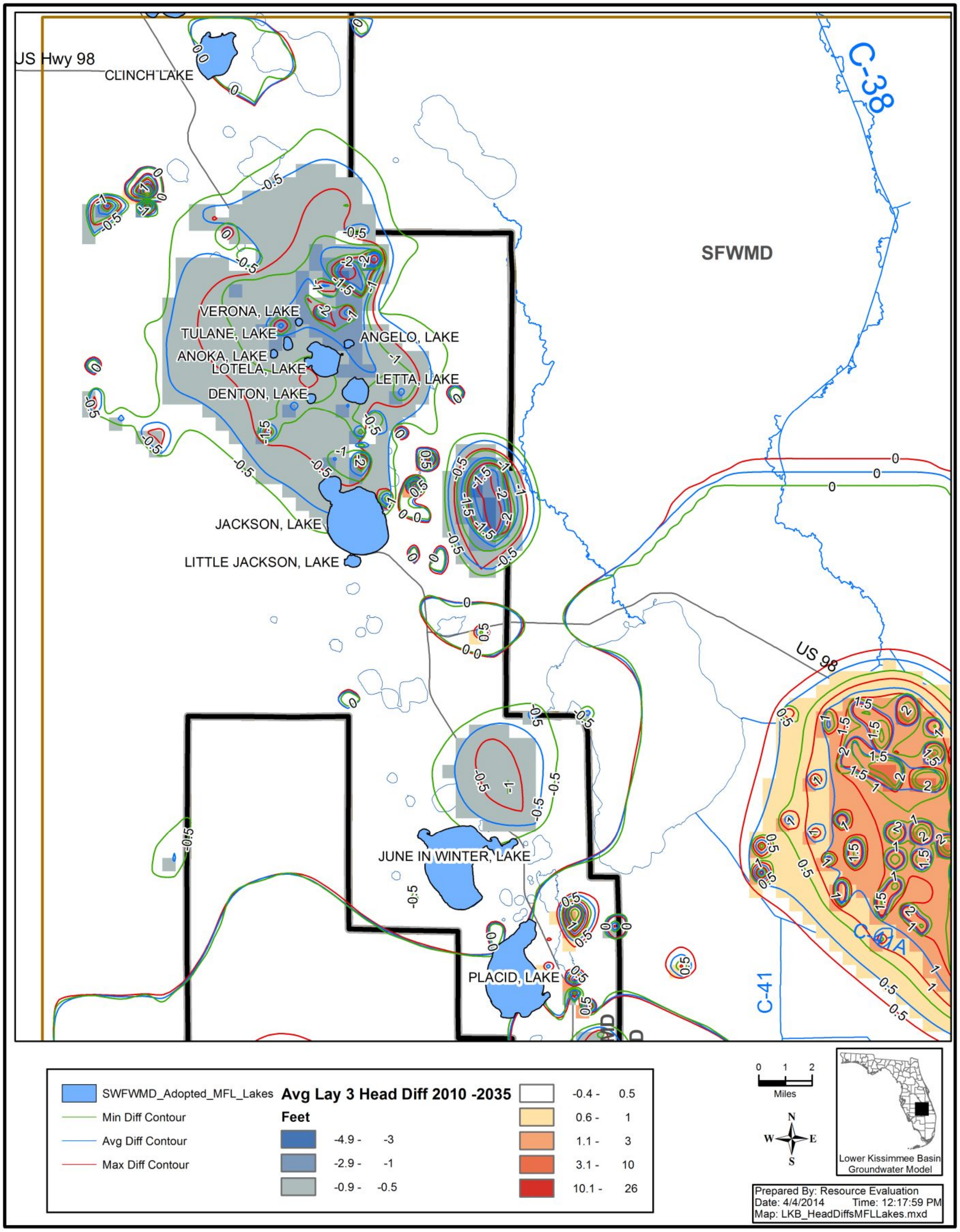


Figure 23. 2035 Minimum and Maximum Head Differences - Lake Wales Ridge MFL Lakes