Technical Peer Review – District Wide Regulation Model, Version 2 Southwest Florida Water Management District

Peer Review Panel

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Executive Summary

The Southwest Florida Water Management District (SWFWMD or the District) initiated a voluntary peer review of the District Wide Regulation Model Version 2 (DWRM2) in the summer of 2008. The objectives of the peer review were to determine if DWRM2 could be used to evaluate ground-water withdrawal impacts to surficial, intermediate, and Floridan aquifer water levels and surface-water flows. As part of the peer review process, the panel reviewed the documentation, model conceptualization, model calibration, model results, and the focus telescopic mesh refinement (FTMR) approach that will be applied in individual water-use permit applications evaluated with DWRM2. Peer review activities focused on the model's capacity to accurately simulate drawdown and changes in surface-water boundary condition flows at both regional and FTMR (local) scales.

DWRM2 represents a major improvement over previous ground-water regulation flow models developed in the District. The hydrogeologic conceptualization accurately represents key aquifers in the DWRM2 domain (the entire District area). Specific improvements to the hydrogeologic conceptualization include active simulation of the surficial aquifer system (SAS) and explicit representation of two laterally extensive permeable units (PZ2 and PZ3) of the intermediate aquifer system (IAS). DWRM2 also makes use of recent hydrostratigraphic data developed by the Florida Geological Survey, aquifer performance test data from the District's database, and the best available ground-water withdrawal data from the SWFWMD, the St. Johns River Water Management District (SJRWMD), Suwannee River Water Management District (SRWMD), and the South Florida Water Management District (SFWMD). DWRM2 was calibrated to observed water-level data using a rigorous approach and automatic calibration techniques. Defined steady-state water-level calibration criteria were achieved in DWRM2.

The FTMR approach available with DWRM2 is a unique and innovative approach that allows use of the best available hydrogeologic framework and external boundary conditions in local-scale ground-water models developed for water-use permit applications. Use of the FTMR approach with DWRM2 allows the District and external users (for example, ground-water consultants) to work together with a common understanding and greatly simplifies the process required to evaluate ground-water withdrawal impacts relative to pre-development and existing hydrologic conditions. Furthermore, the FTMR process for DWRM2 can be used to evaluate ground-water impacts resulting from actual or permitted ground-water withdrawals.

Although the DWRM2 and FTMR approach represents a major improvement over previous approaches to evaluate water-use permit applications, the Peer Review Panel recommends a number of revisions to the model and improvements to the DWRM2 and FTMR approach. Proposed revisions include 1) modification of the method used to calculate and distribute net ground-water recharge data; and 2) incorporation of base flow, spring flow, depth to water (DTW) data, and SAS-upper Floridan aquifer (UFA) water-level difference data as calibration targets in the automated calibration process. Proposed improvements include 1) adoption of a consistent geographic information system (GIS) based, grid-scale independent approach to assign river boundary condition parameters based on a defined stream ordering scheme in the DWRM2 and FTMR process; 2) adoption of a GIS-based, grid-scale independent

approach for defining UFA springs in DWRM2 and FTMR models; 3) improvement of the method used to assign base elevations for SAS boundary conditions for accurate representation of SAS-boundary condition gradients in DWRM2; 4) removal of conceptual drain boundary conditions used to control water levels above land surface; 5) addition of DWRM2 and FTMR water-budget comparisons to standard reports generated by the FTMR process; 6) generation of a comprehensive model development report and a user's guide for FTMR applications; and 7) use of recently collected high-resolution land-surface elevation data in the DWRM2 and FTMR models.

Relative to the defined objectives of the peer review, the panel has determined that DWRM2 is:

- well suited to evaluate ground-water withdrawal impacts to the UFA,
- may be limited for evaluating SAS water-level impacts in areas with high errors and/or appreciable surface-water boundary condition exchange,
- may be limited for evaluating water-level impacts in PZ2, PZ3, and the lower Floridan aquifer (LFA) because of limited data availability,
- is limited for evaluating changes in surface-water flows (base flow and spring flow) because of poor calibration of these water-budget components,
- is not suitable for particle-tracking analyses in coastal areas to determine changes in the position of the freshwater/saltwater interface, and
- should not be used to evaluate water-quality changes without additional vertical discretization, development of appropriate parameters (porosity, dispersivity, and others), and calibration of transport parameters.

Introduction

Within the Southwest Florida Water Management District (SWFWMD or the District), potential water users applying for water-use permits for new or additional ground-water withdrawals must either submit an evaluation of the effects of the proposed withdrawals on other legal users, rivers, lakes, wetlands, and water quality, or accept a SWFWMD staff evaluation. To aid in this evaluation, a numerical ground-water model, District-Wide Regulation Model (DWRM), was developed in 2003, and was first applied in 2004. DWRM was intended to provide a technically and conceptually sound resource and impact evaluation model for estimating the cumulative and incremental effects of proposed withdrawals, and provide a consistent and reliable tool for evaluation of permit applications. The model was prepared by Environmental Simulations, Inc. (ESI), using the MODFLOW family of numerical model codes and the Groundwater Vistas (GWV) modeling shell. MODFLOW is a widely used and well accepted numerical ground-water flow code in the United States. MODFLOW was developed by the U.S. Geological Survey and has been extensively applied and tested since its introduction in the early 1980s. MODFLOW and related codes are under continuous development by the U.S. Geological Survey. GWV is a commercially available modeling graphical user interface developed and maintained by ESI. GWV is a graphical preprocessor that prepares input files for MODFLOW simulations and also provides a graphical platform for evaluation of model-output files.

The hydrologic conceptualization of DWRM follows the conceptualizations and hydrostratigraphic units incorporated in previous flow models and publications (Miller, 1986; Andrews, 1990; Sepulveda, 2002; Arthur and others, 2008), updated with more recent data. The basic hydrologic conceptualization of DWRM follows the "Mega Model" of Sepulveda (2002), with the exception of utilizing an active surficial aquifer in place of specified heads in layer one of the model and the subdivision of permeable zones of the intermediate aquifer system (IAS). The model area in DWRM includes portions of the Mega Model within District boundaries, plus a buffer zone around the District within the SFWMD, SJRWMD, and SRWMD; DWRM2 was supplemented with data from the Southern District (SD) model (Beach, 2003). Because DWRM is intended to provide a tool to assess impacts on water levels in the surficial aquifer system (SAS), the upper Floridan aquifer (UFA), and the lower Floridan aquifer (LFA), DWRM differs from the Mega Model in that the SAS, model layer 1, is fully active and the two laterally extensive permeable units of the IAS (PZ2 and PZ3) have been included. The initial version of DWRM was calibrated to a steady-state period based on data from August 1993 to July 1994. Development of DWRM continued, and various enhancements and data updates were added. DWRM was also recalibrated to a new steady-state period, calendar year 1995, and a transient calibration from January 1996 to December 2002 was completed. The updated model version is designated DWRM2.

DWRM2 contains a module called FTMR. This module creates a small cell size, local (focused) MODFLOW model within the larger, 5,000 x 5,000 feet (ft) cell size DWRM2 regional model. The heads generated in the regional model are used as external boundary conditions for the local model. FTMR allows a fine grid, finite-difference model to be focused on an area of interest, while preserving the calibration contained in the regional model, and also using all of the stresses (ground-water withdrawals) contained in the regional model. This procedure allows the cumulative and incremental effects of proposed withdrawals to be assessed on a local scale.

In the summer of 2008, the District initiated a voluntary peer review of DWRM2. The purpose of the peer review was to provide a critical, constructive, technical evaluation of DWRM2 and the FTMR procedure. The peer review was performed to determine the model's capacity to accurately simulate impacts to water resources of the District. Because DWRM2 was developed specifically for use in FTMR applications for water-use permit applications, the panel focused on the model's capacity to accurately simulate drawdown and changes in surface-water boundary condition flows at a combination of regional and FTMR scales instead of the model's capacity to simulate absolute water-level elevations. Specific peer review objectives stated in the scope of work (SWFWMD, 2008) for the peer review include determining whether DWRM2 is:

- suitable for accurate simulation of ground-water withdrawal impacts to the SAS, wetlands, lakes, rivers/streams, and springs (water levels and flows);
- suitable for evaluation of ground-water withdrawal impacts to defined permeable zones of the IAS (heads, flows, water quality);
- suitable for evaluation of impacts to the UFA and LFA (heads, flows, water quality);
- suitable for accurate simulation of water levels in uplands and coastal wetlands;
- suitable to perform particle-tracking analysis along the freshwater/saltwater interface, and
- adequately documented.

The purpose of this report is to present the findings of the peer review as specifically defined in the peer review objectives. This report is intended to be reviewed in conjunction with reports developed for version 1 (ESI, 2004) and version 2 (ESI, 2007) of DWRM. Readers of the peer review report are referred to ESI (2004 and 2007) for discussion, maps, and information unrelated to specific peer review objectives.

The Peer Review Panel consisted of three members: Dr. Joseph Hughes – U.S. Geological Survey, Dr. Mark Stewart – University of South Florida, and Mr. Patrick Tara – INTERA. The panelists represent governmental, academic, and consulting perspectives (respectively). All of the panelists have extensive experience with numerical models of ground-water flow and all have experience with and knowledge of the hydrology of the District.

Model Conceptualization

District staff asked the Peer Review Panel to evaluate DWRM2 as a base model for finer scale models developed using FTMR, and, specifically, whether the modeling techniques and methodologies are appropriate for the scale of the model. The techniques applied with the FTMR procedure establish a fine grid centered on a single ground-water well or cluster of ground-water wells. The fine grid encompassing the selected ground-water well or cluster of ground-water wells is surrounded by a zone (buffer area) with increasing grid spacings, which expand using a multiplication factor of 1.5, to cover the user defined extent of the FTMR model. The boundary conditions are established by extrapolation from DWRM2 at the boundaries of the local model grid. FTMR is intended to provide a procedure that can be used by the District and applicants for evaluating water-use permits in the District. The intent is

to use FTMR models to evaluate drawdown in the pumped aquifer and the SAS, UFA, and LFA in addition to changes in surface-water flows represented by river and drain boundary conditions.

As stated previously, the vertical discretization of DWRM2 is based on the approach used by Sepulveda (2002) with the exception of further refinement of the IAS. Specifically, DWRM2 has been vertically discretized into five (5) defined aquifer units. The five aquifers are the SAS, the middle permeable unit of the IAS (PZ2) that is considered to be regionally extensive, the lower most laterally extensive permeable unit of the IAS (PZ3), the UFA, and freshwater portions of the LFA.

In general, DWRM2 is a reasonable base for the local-scale models created with FTMR. The 5,000 × 5,000 ft grid spacing of DWRM2 is coarse, but the density of available data, such as aquifer performance tests (APT) and head measurements, may not justify a finer grid for the regional model at this time. The use of the FTMR allows a smaller grid spacing to be used to assess local- scale effects of proposed withdrawals, while maintaining the calibration of DWRM2 regional model and the pumping stresses included in DWRM2. It should be noted, however, that whereas the finer grid used in the FTMR procedure can allow better spatial representation of sinks and sources, the overall parameter distribution in DWRM2 is interpolated into the finer grid with no increase in spatial resolution of hydraulic parameters.

DWRM2 includes most of the important hydrologic processes required to perform accurate simulation of the ground-water impacts resulting from ground-water withdrawals. Ground-water withdrawal data used in DWRM2 were determined by the SWFWMD, the SJRWMD, the SRWMD, and the SFWMD and are based on a combination of metered and estimated water use within these water management districts. Net ground-water recharge estimates were defined from the Southern District (SD) model (Beach, 2003), as well as other sources. Boundary conditions were defined using equivalent freshwater heads along the coast, as well as general head boundaries (GHB) to simulate the ground-water flow at external boundaries. The topography used to define the model parameters is from the U.S. Geological Survey digital elevation model (DEM) (ESI, 2004). Although the current DEM topography can include appreciable errors, it represents the best available data at the time DWRM2 was developed.

Hydrographic data used to define river and aquifer interaction is adequate, but could be improved. The land-use/land-cover map provided a good base to define the aerial extent of the hydrography, but further classification was made using the 1:250,000 scale quadrangle digital line graph (DLG). The selection of hydrographic features digitized in the 1:250,000 DLG, however, does not reflect the hydraulic significance or the hydraulic interaction with aquifer units represented in DWRM2. The 1:250,000 DLG was used to define the hydrography elements that received higher conductance rates (Figure 1). River features represented in DWRM2 are restricted to the SAS (model layer 1). Various rivers in the DWRM2 model domain intersect permeable units of the IAS (model layers 2 and 3) or the UFA (model layer 4). These river connections with deeper units should be represented in the model because of the effect these connections have on water levels and base flow. An alternative approach would be to restrict river features to the SAS, as is currently done in DWRM2, but use appropriate IAS or UFA hydraulic properties in grid cells with river features that are in direct connection with aquifer units underlying the SAS; scaling of the horizontal extent of IAS or UFA properties would have to be

considered in FTMR applications to accurately represent the actual horizontal extent of the rivers connected to the IAS or UFA. Consideration should be given to whether horizontal IAS or UFA properties should be used in the SAS for grid cells with a direct connection to underlying permeable units if this alternative approach is used. Furthermore, the approach used to define river cell parameters should be improved; suggested improvements are discussed in detail in the following sections.

Surface-water features that are missing in the model conceptualization include Cypress Creek and the Tampa Bypass Canal (TBC) (Figure 1). These and other surface-water features are missing because they were not included on the 1:250,000 DLG. These features are hydrologically important, and should be included to represent ground-water/surface-water interactions at these locations. The TBC is a major hydrologic feature with an average SAS and UFA base-flow discharge of approximately 40 cubic feet per second (ft^3/s). The TBC is also an example of a surface-water feature that needs to be represented as a direct connection between the UFA and the surface water system, as the confining unit (ICU) overlying the UFA was breached when the TBC was constructed.

Crystal Springs is another major hydrologic feature that was not included in the conceptualization of DWRM2 (Figure 1). The spring is a second magnitude spring with an average flow rate of 60 ft^3/s (Scott and others, 2004) and is a major source of base flow in the Hillsborough River. Hillsborough River base-flow targets are affected because the spring was not included in the model conceptualization. The spring flow also has a prominent effect on UFA water-levels in the vicinity of the spring that is not accounted for in the current model conceptualization.

The selection of MODFLOW-2000 (Harbaugh and others, 2000) is appropriate for DWRM2 and applications of the model in the FTMR process. MODFLOW-2000 includes packages required to simulate the important hydrologic processes necessary to meet the objectives of the DWRM2 and associated FTMR process. In the future, consideration should be given to updating the model to MODFLOW-2005 (Harbaugh, 2005) because of the expanded capabilities that may improve model calibration, performance, and defensibility. Examples of additional functionality that could improve DWRM2 and FTMR applications include the unsaturated zone flow (UZF) package (Niswonger and others, 2006), streamflow routing (SFR) package (Niswonger and Prudic, 2005), and the local grid refinement (LGR) package (Mehl and Hill, 2005 and 2007). The UZF package was designed to simulate infiltration of rainfall into the unsaturated zone, evapotranspiration, and implicitly handles saturation and infiltration excess conditions; this approach would potentially eliminate issues related to specification of net ground-water recharge rates under steady-state and transient conditions that are discussed below. The SFR package was designed to simulate simple hydrologic or hydraulic routing, aquifer-river exchanges, and can receive excess recharge from the UZF package as a lateral inflow term. A combination of the UZF and SFR packages could be used to develop an integrated surface-water and ground-water tool that includes all of the major hydrologic processes except for hydraulic routing of water on the overland flow plane. Use of the UZF and SFR packages, however, would increase model run-times and limit the ability to use the Parameter ESTimation (PEST) software package (Doherty, 2001) for parameter optimization of transient simulations. However, if the District requires a tool to evaluate changes in surface water runoff and base flow, use of the UZF and SFR package would be a reasonable approach and would likely have shorter run-times than other fully integrated ground-water/surface-water models (Integrated

Hydrologic Model (IHM) – Ross and others (2004); GSFLOW - Markstrom and others (2008)). Use of the LGR package would improve mass conservation between the regional DWRM2 and FTMR applications as discussed in the following section.

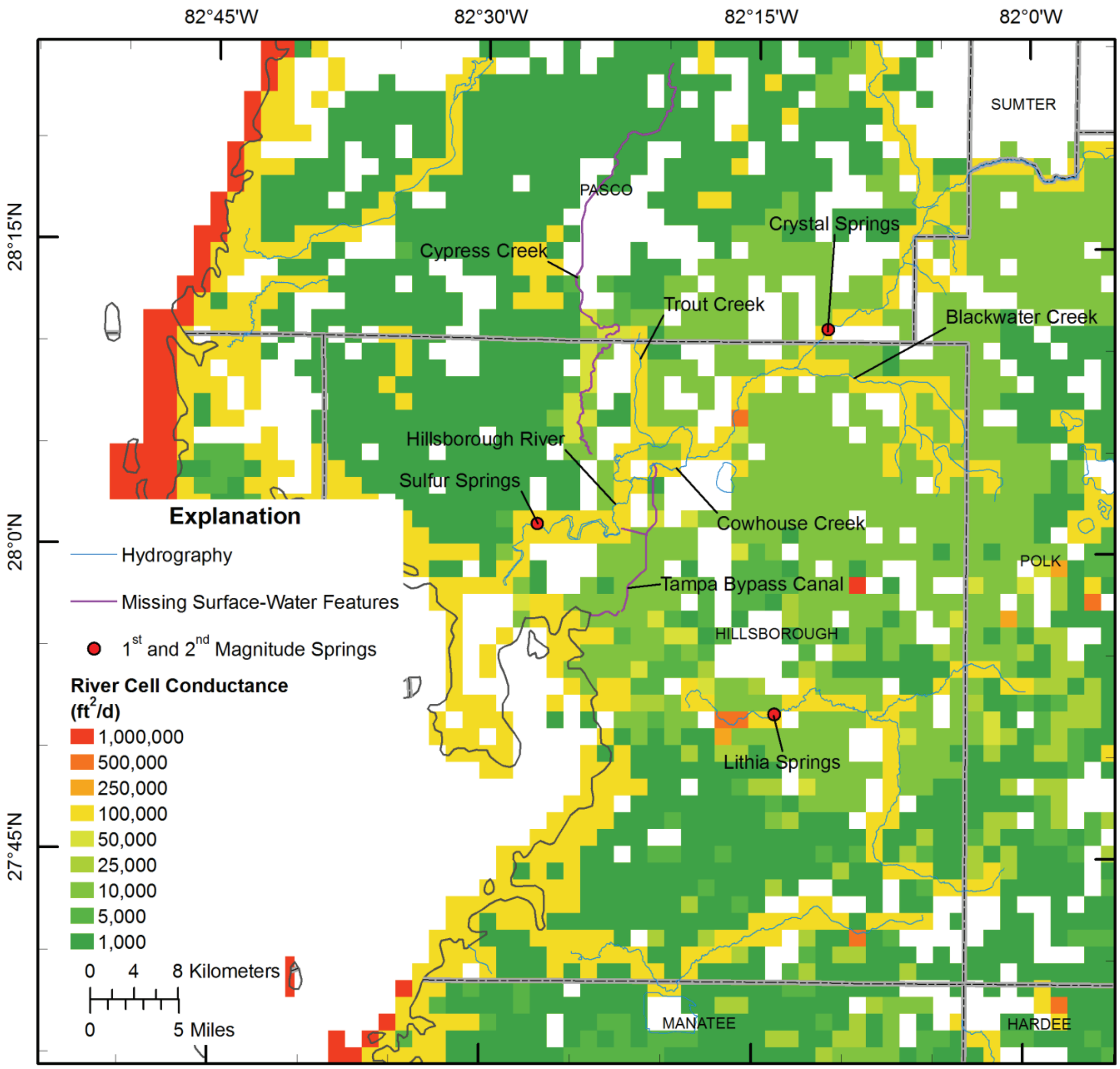

Figure 1 **DWRM2 river cells in the Hillsborough River Basin near Crystal Springs, Blackwater Creek, Trout Creek, and Cypress Creek. Varying river cell conductance values are shown along with the 1:250,000 DLG hydrography. The location of 1st and 2nd magnitude springs are also shown for reference. River conductance values equal to 1,000,000 ft^2/d are used in offshore ground-water discharge areas. Missing surface water features represent features not represented in DWRM2.**

Model Development

The technical Peer Review Panel reviewed DWRM2 documentation, model-input files, and model results to evaluate the approach used to calibrate DWRM2. Calibrated model parameters were also evaluated and compared to available aquifer parameter data.

Calibration Approach

DWRM2 was calibrated with PEST using preferred value regularization with pilot points. Smoothness regularization was used in DWRM1 (ESI, 2004). Preferred value regularization was constrained by APT data provided by the District. APT data were reviewed by District staff and ranked based on data quality. During calibration of DWRM2, APT data classified as good, fair, and poor were allowed to vary by 10%, 25%, and 50%, respectively, from interpreted values. UFA transmissivity was also bounded to be greater than 40,000 feet squared per day (ft^2/d) and less than 10,000,000 ft^2/d, except in Pinellas County where values as low as 10,000 ft^2/d were permitted.

Pilot points were defined to calibrate the hydraulic conductivity/transmissivity of the SAS, PZ2, PZ3, and the UFA. Pilot points were also defined to calibrate leakance from the SAS to PZ2, from PZ2 to PZ3, and from PZ3 to the UFA. The transmissivity of the LFA and leakance between the UFA and the LFA were not calibrated in DWRM2 but were kept at values determined during calibration of DWRM1. Storage parameters were distributed using a zone approach and manually calibrated for transient simulations.

A triangulation approach was used to distribute pilot points used to calibrate DWRM2. Water levels were primary calibration targets used by PEST. Base flow and spring flow were not used by PEST but were evaluated as part of the calibration process. A manual calibration approach was used to adjust model parameters controlling simulated base flow and spring flow.

The use of parameter estimation software and application of regularization to calibrate model parameters is a major improvement over manual calibration approaches. Furthermore, use of preferred value regularization in aquifer units with aquifer performance test data (APT) validated by District staff is an improvement over the smoothness regularization approach used to calibrate the DWRM1. A smoothness, equal value, or other such constrained regularization approach may be more appropriate for units where parameters are not expected to change significantly over small horizontal distances (for example, SAS). One major limitation of the approach used in DWRM2 is that surface-water flow data were not explicitly incorporated in the parameter estimation process. Furthermore, the current approach allows minimization of the objective function without explicitly defining the interdependence of aquifer water levels and ground-water flow between aquifer units. Use of processed water-level and flow data can be critical for constraining model parameters in the parameter estimation process. Examples of processed data that should be considered include 1) SAS-UFA water-level differences to refine intermediate confining unit (ICU) or IAS leakance parameters; 2) DTW, vertically adjusted SAS water level data, or DTW data developed using regression analysis of available data (Beach, 2003) to refine simulated SAS water levels, reduce areas with water above land surface, and minimize the impact of grid size based topographic data sampling issues; and 3) base flow data developed using the base-flow separation approach of Weber and Perry (2006), digital filter techniques (Nathan and McMahon,

1990), or the conductivity mass-balance method (Stewart and others, 2006). PEST includes utilities to digitally filter surface water data that can be incorporated in the parameter estimation process (Watermark Numerical Computing and University of Idaho, 2007). Vertical adjustment of SAS water level data is discussed in the **Rivers and Drains** section.

Because storage parameters will have a major effect on simulated drawdown, PEST should be used to minimize the objective function for data related to hydraulic conductivity, transmissivity, leakance, ground-water/surface-water exchanges, and storage parameters. Although the magnitude of water-level and surface-water flow measurement units (ft vs. ft^3) differ appreciably, appropriate weights could be developed to reduce the likelihood that unit differences (for example, water level elevations and discharge) and number of observations do not adversely affect minimization of calibration target errors. A simple approach to include base flow data in the parameter estimation process would be to convert simulated results to ft^3/s. This conversion would result in flow units with residuals comparable to water-level residuals. Simulated and observed annual base flow could be converted to inches per year (in/y), which would result in flow residuals with similar magnitudes to water-level residuals. PEST also includes two utility programs (PWTADJ1 and ADJOBS) that can be used to adjust observation weights so that they appropriately contribute to the objective function (Doherty, 2008).

It is important to correctly position target pilot points in order for the optimization approach to develop calibrated data sets that are consistent with the information contained in target data sets. DWRM2 water-level target pilot points are positioned between water-level targets and are appropriately placed to fit observed horizontal hydraulic gradients. Furthermore, pilot points for leakance and storage parameters, which were not included in the PEST optimization approach, should be placed at the observation locations because water-level changes and vertical ground-water flow are a function of local model parameters. Calibration targets should also be limited to no more than one per model grid cell because this is the limit of spatial resolution of model-generated information; representative or average observation data should be used for model grid cells with more than one observation of the same data type.

Calibration Criteria

The calibration criteria used to evaluate the fit of the steady-state model include the mean error (ME - residual mean), mean absolute error (MAE - absolute residual mean), root mean square error (RMSE - standard deviation), normalized mean error (residual mean over the range), normalized mean absolute error (absolute residual mean over the range), and the normalized root mean square error (standard deviation over the range). These criteria are adequate for the steady-state model. Addition of the correlation coefficient (R) and/or the Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) would give a statistically-based measure of the model capacity to accurately simulate hydrologic conditions.

Quantitative calibration criteria were not defined for the transient simulation. The ME, MAE, and RMS should be used to quantitatively assess the quality of the transient calibration for each observation location in addition to calculation of global statistics. R and the Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) should be calculated for each observation location.

Model Parameters

The Peer Review Panel reviewed DWRM2 parameters for all aquifer layers of the model including the SAS, ICU/IAS, UFA, and LFA. These parameters are discussed below.

Hydraulic Conductivity/Transmissivity

Calibrated SAS hydraulic conductivities are heterogeneous. There appears to be little correlation of hydraulic conductivity/transmissivity to the physiographic regions of White (1970) or soil type. Scaled sensitivities (Figure 3.1 in ESI, 2007) and the sensitivity analysis (Figure 3.30 in ESI, 2007) of the SAS suggest that model results are not sensitive to the SAS hydraulic conductivity. Because it is expected that there would be correlation of SAS hydraulic conductivity with physiographic regions and/or soil type, it may be appropriate to use smoothness or equal value constrained regularization for the SAS.

IAS transmissivities in DWRM2 do not correspond to the general transmissivity classifications in Knochenmus (2006) (see Figure 2). Low, moderately low, moderate, and moderately high permeabilities correspond to transmissivities less than 100, between 100 and 1,000, between 1,000 and 10,000, and between 10,000 and 100,000 ft^2/day, respectively. PZ2 and PZ3 in DWRM2 are predominantly in the moderate permeability range (see Figures 2 and 3), but the moderately low permeability range covers a major portion of the area described by Knochenmus (2006). Aquifer parameters for PZ2 and PZ3 should be revised to incorporate data from Knochenmus (2006) in the regularization process.

Comparison of UFA transmissivities in DWRM2 with Andrews (1990) are shown in Figure 4. In general, there is more heterogeneity in the transmissivity of the UFA in DWRM2 than the heterogeneity shown in Andrews (1990), but this is not necessarily a major concern for the model as a whole. Some areas that should be further evaluated and explained, if possible, are southern portions of the model domain with exceptionally high transmissivities, and areas in the vicinity of the Hillsborough River with relatively low transmissivities. It would also be beneficial if a depositional, post-depositional, diagenenetic, and/or hydrogeologic hypothesis could be put forward to explain the spatial transmissivity patterns observed in the central to southern portions of the model domain.

There are no calibration target data and little APT data for the LFA. The transmissivity values of the LFA are based on the model of Sepulveda (2002) and were not modified during development of DWRM2. This approach is reasonable given the limited amount of available APT data.

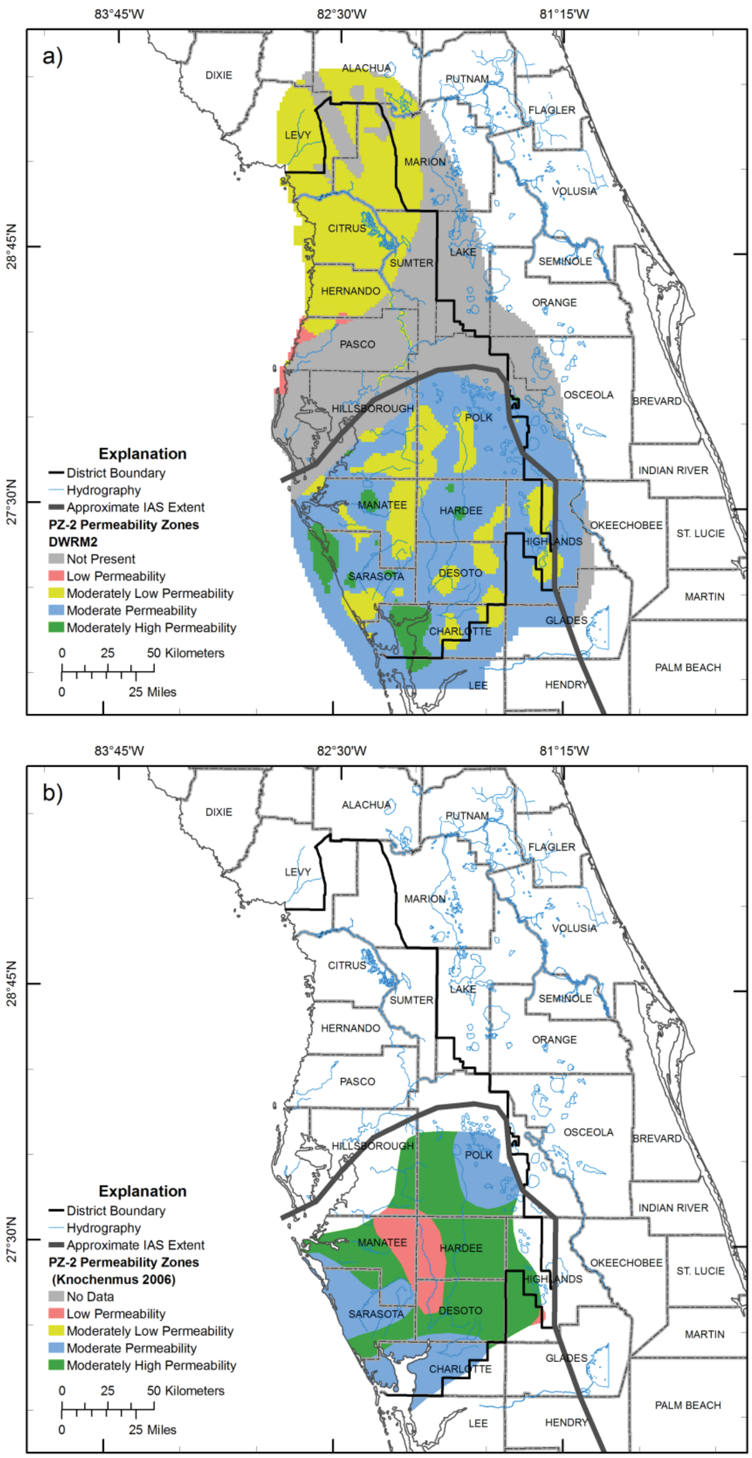

Figure 2 **IAS permeable zone 2 (PZ2) permeability ranges in a) DWRM2 and b) Knochenmus (2006). PZ2 extends throughout the model domain in DWRM2 but represents ICU or UFA properties outside of the approximate extent of the IAS.**

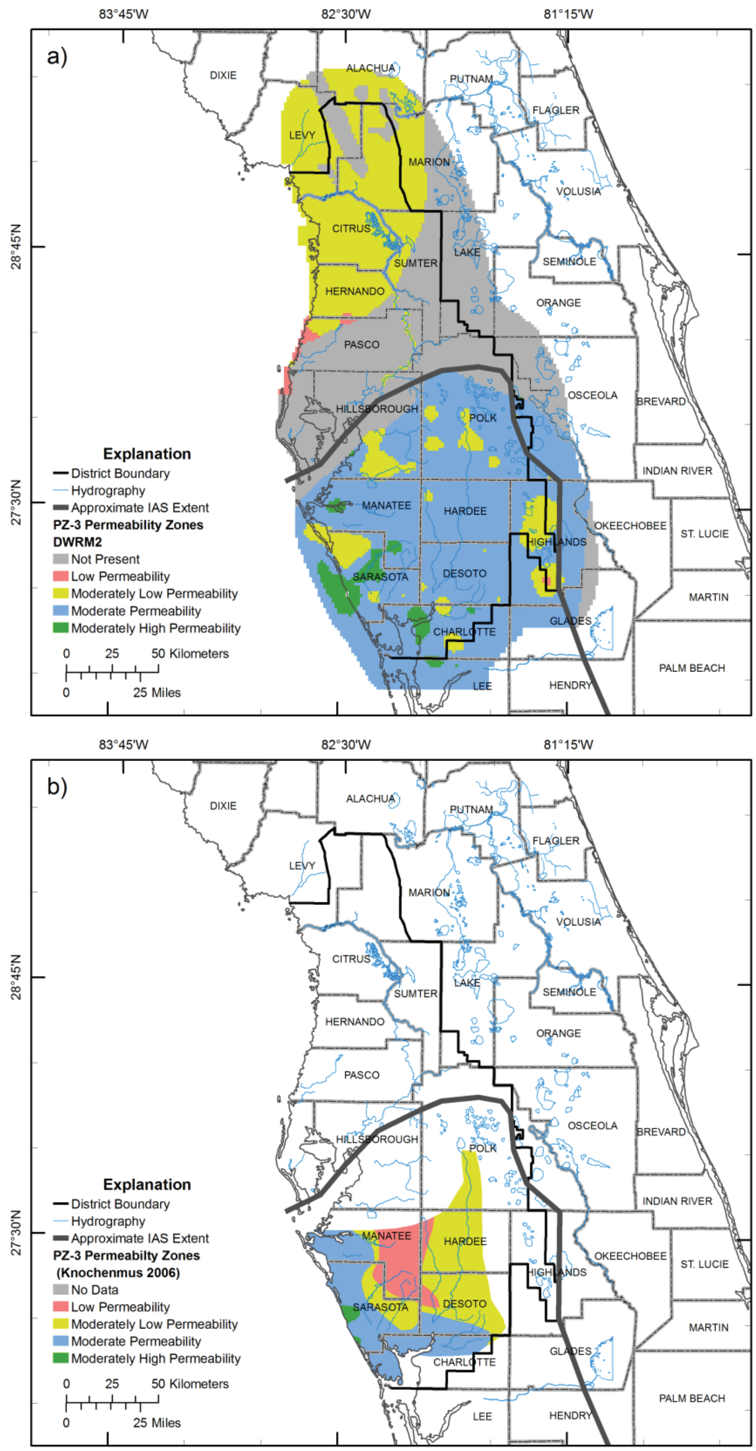

Figure 3 **IAS permeable zone 3 (PZ3) permeability ranges in a) DWRM2 and b) Knochenmus (2006). PZ3 extends throughout the model domain in DWRM2 but represents ICU or UFA properties outside of the approximate extent of the IAS.**

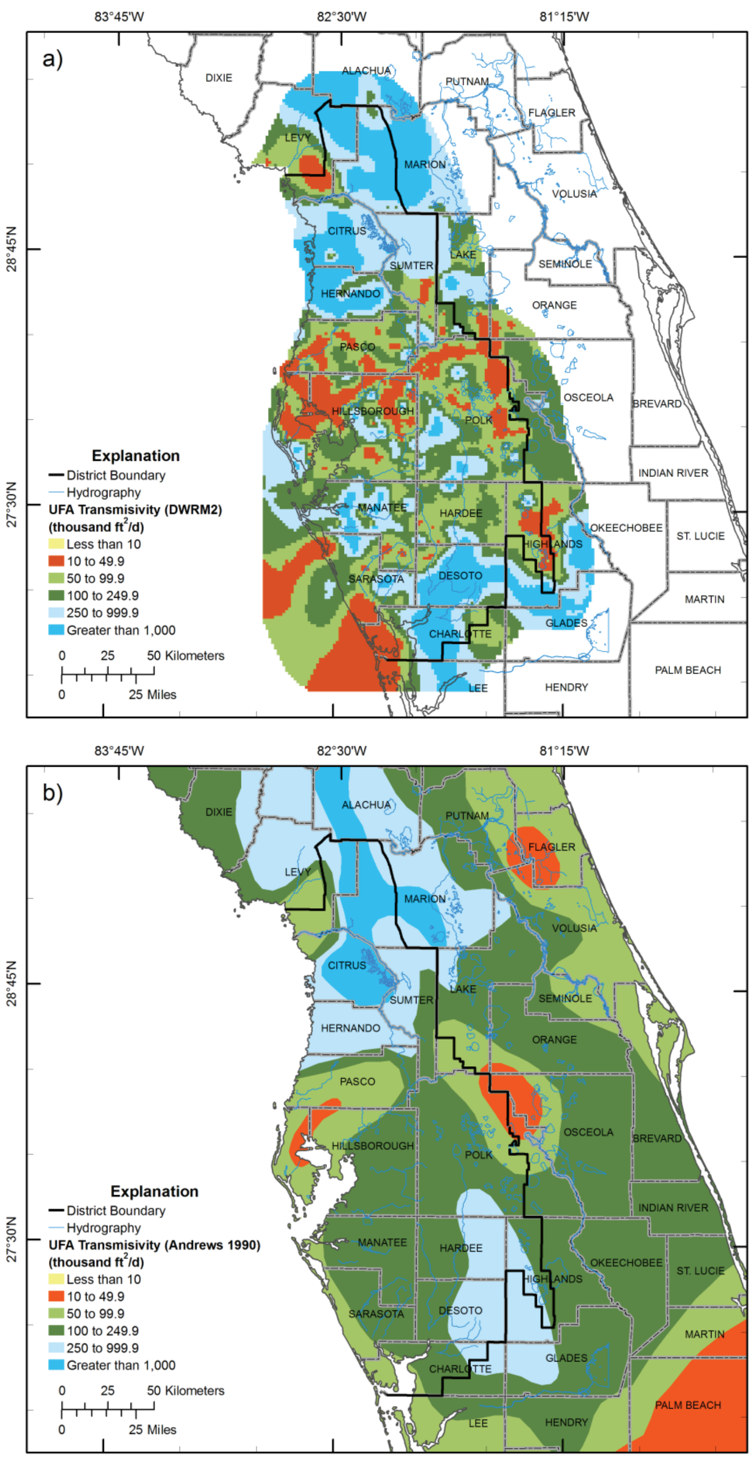

Figure 4 UFA transmissivity in a) DWRM2 and b) Andrews (1990).

Leakance

Leakance values used in DWRM2 vary over approximately six orders of magnitude. In general, leakance values between the SAS and UFA are highest in northern portions of DWRM2 where the UFA is unconfined to semi-confined. There are some areas of high leakance (1×10^{-3} to 1×10^{-2} day^{-1}) in semi-

confined areas (for example, western Hillsborough County) and confined areas (for example, eastern Polk County). It is expected that there would be a relation between ICU clay content and effective ICU leakance values (see Figure 12 in Knochenmus, 2006). Although the range of leakance values in DWRM2 may be reasonable, it is uncertain how well actual leakance values are simulated because observed water-level differences were not used directly in the calibration process. A detailed discussion of simulated and observed water-level differences is included in a following section (**Water Levels and Water Level Differences**).

Storage Parameters

The range of storage parameters used in DWRM2 appears to be reasonable, and storage is distributed using a zoned approach. Specific yields in the SAS are reasonable and are reported to correspond to APT data, but do not appear to be distributed based on either a soil or physiographic based approach. The accuracy of specific yield estimates from APT analysis is uncertain. It would be useful to determine if DWRM2 is sensitive to specific yield values. If DWRM2 is not sensitive to the current distribution of specific yield, it may be more defensible to use a soil-based approach to distribute storage parameters.

In general, storage values for PZ2, PZ3, and the UFA appear reasonable (10^{-5} to 10^{-3} ft/ft – Lohman, 1979), although there are some areas with values exceeding 0.01 ft/ft. Although the storage parameters in DWRM2 may be reasonable and based on APT data, it is uncertain how well the actual storage parameters are characterized in the model because transient data were not used directly in the automatic calibration process. Issues with development of transient recharge conditions may also compromise the calibration of storage parameters and are discussed further in the **Recharge and Evapotranspiration** section.

Boundary Conditions

Boundary conditions including recharge, rivers, drains, wells, and external model boundaries are discussed below.

Recharge and Evapotranspiration

Simulated steady-state recharge used in DWRM2 is shown in Figure 5. A net recharge approach was used in DWRM2 rather than combined use of the recharge and evapotranspiration (ET) packages. Although use of the ET package can be beneficial and appropriate in many cases, it was not used in DWRM2 because net ground-water recharge data were available from a watershed-scale rainfall runoff model (Hydrological Simulation Program--Fortran (HSPF)) developed for the SD model area by Geurink and others (2000). The watershed-scale rainfall runoff model was calibrated to target ET rates developed using the best available data and calibrated to observed streamflow data. As a result, it is expected that the net recharge approach used in DWRM2 is more appropriate and accurate than use of adjusted rainfall data and estimated ET package extinction depths and maximum ET rates. Recharge data for the period from August 1993 through July 1994 from the Mega Model were used in areas outside of the SD model domain and represent steady-state conditions in the Floridan aquifer system (Sepulveda, 2002).

As stated above, the study of Geurink and others (2000) simulated the surface-water budget from 1989 through 1998 and defined the flow components necessary to calculate the net recharge rate for DWRM2 in the SD model area. The surface-water components required to define net recharge from data contained in Geurink and others (2000) include inactive ground-water inflow (IGWI), active ground-water inflow (AGWI), and active ground-water evapotranspiration (AGWET). By adding the two inflow components and subtracting the ET component, net recharge can be determined for specific surface-water sub-basins. Calculated net recharge rates represent recharge to pervious upland areas of surface-water sub-basins. In DWRM2, net recharge data for pervious upland areas have been applied to both impervious and pervious areas of surface-water sub-basins.

To accurately apply net recharge data from Geurink and others (2000), net recharge rates in DWRM2 should be adjusted based on the proportion of impervious surface-water features in each sub-basin (approximately 25 to 30%). For example, net recharge used in the DWRM2 in northeastern Hillsborough County is shown in Figure 6 grouped according to net recharge rates. The net recharge data used in DWRM2 vary by sub-basin and are equivalent to net recharge rates for upland areas in Geurink and others (2000). Proper scaling of net recharge data would reduce net recharge rates applied in DWRM2 and would likely eliminate the need for many conceptual drains currently required to prevent conditions where water above land surface in DWRM2 is simulated erroneously. Drains and areas with water above land surface are discussed in more detail in the following sections. Two possible approaches for mapping net recharge data for surface-water sub-basins to DWRM2 grid cells are shown in Figure 7 and are described below.

Scaling to account for net recharge in pervious areas could be done on a cell-by-cell basis, as shown in Figure 7b, which would maintain volume at the grid scale. This scaling would cause the net recharge array to vary dramatically across the DWRM2 domain. The cells covered by surface-water features would, therefore, have no recharge assigned, whereas the cells covered by uplands would use the scaled upland rate. The net recharge for individual grid cells is calculated using

$$R_{NET} = \frac{\sum_{n=1}^{NLU} R_{n,i} A_{n,i}}{A_T} \qquad \textbf{(Eq. 1)}$$

where R_{NET} is the net recharge rate applied to a grid cell [L/T], NLU is the number of land-use types in grid cell i, R_n is the net recharge for land-use type n in grid cell i [L/T], $A_{n.i}$ is the area land-use type n in grid cell i [L^2], and A_T is the grid cell area [L^2]. Net grid cell recharge rates shown in Figure 7 were calculated using equation 1.

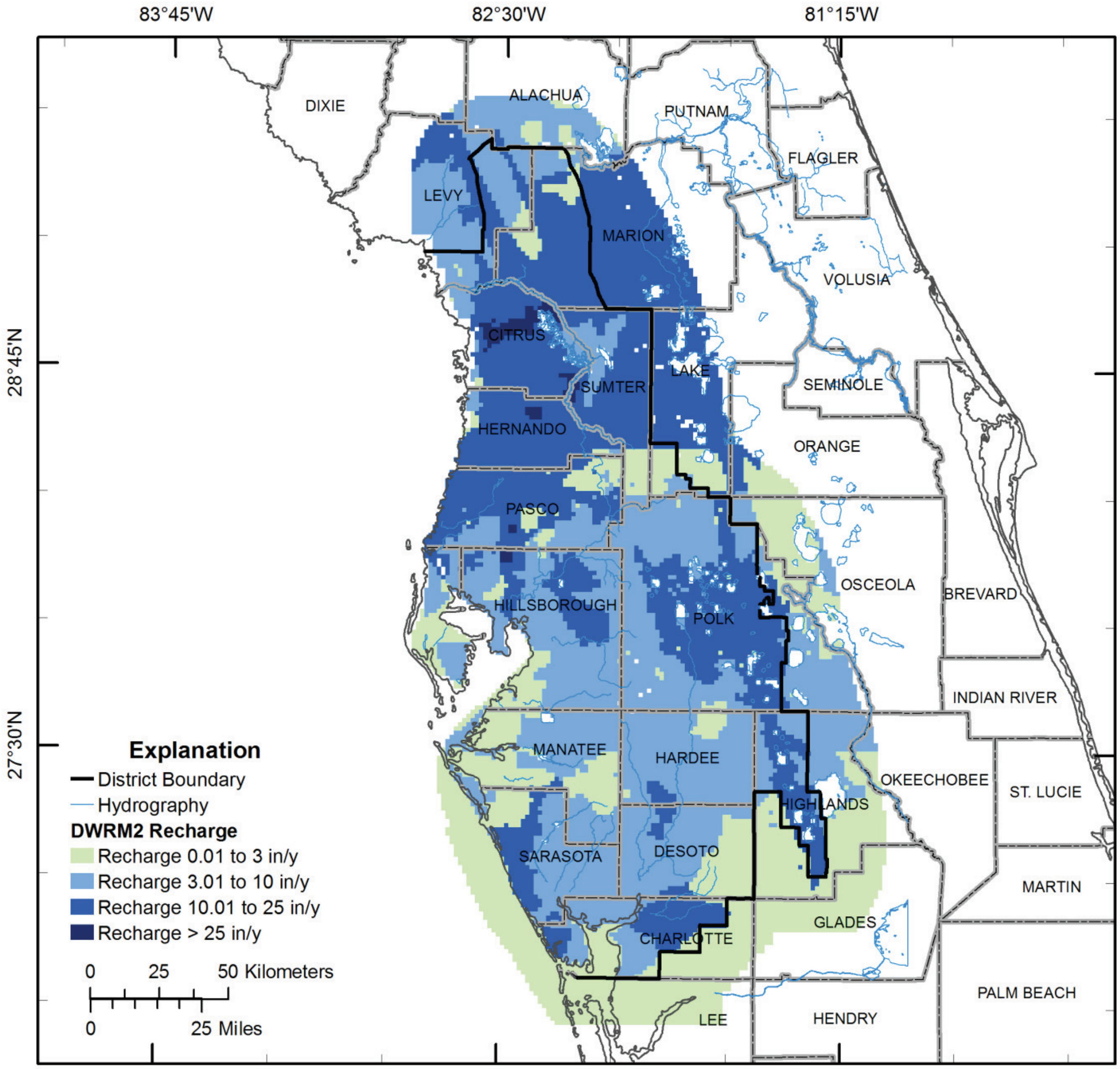

Figure 5 **Simulated steady-state recharge in DWRM2. Recharge is not applied to white areas.**

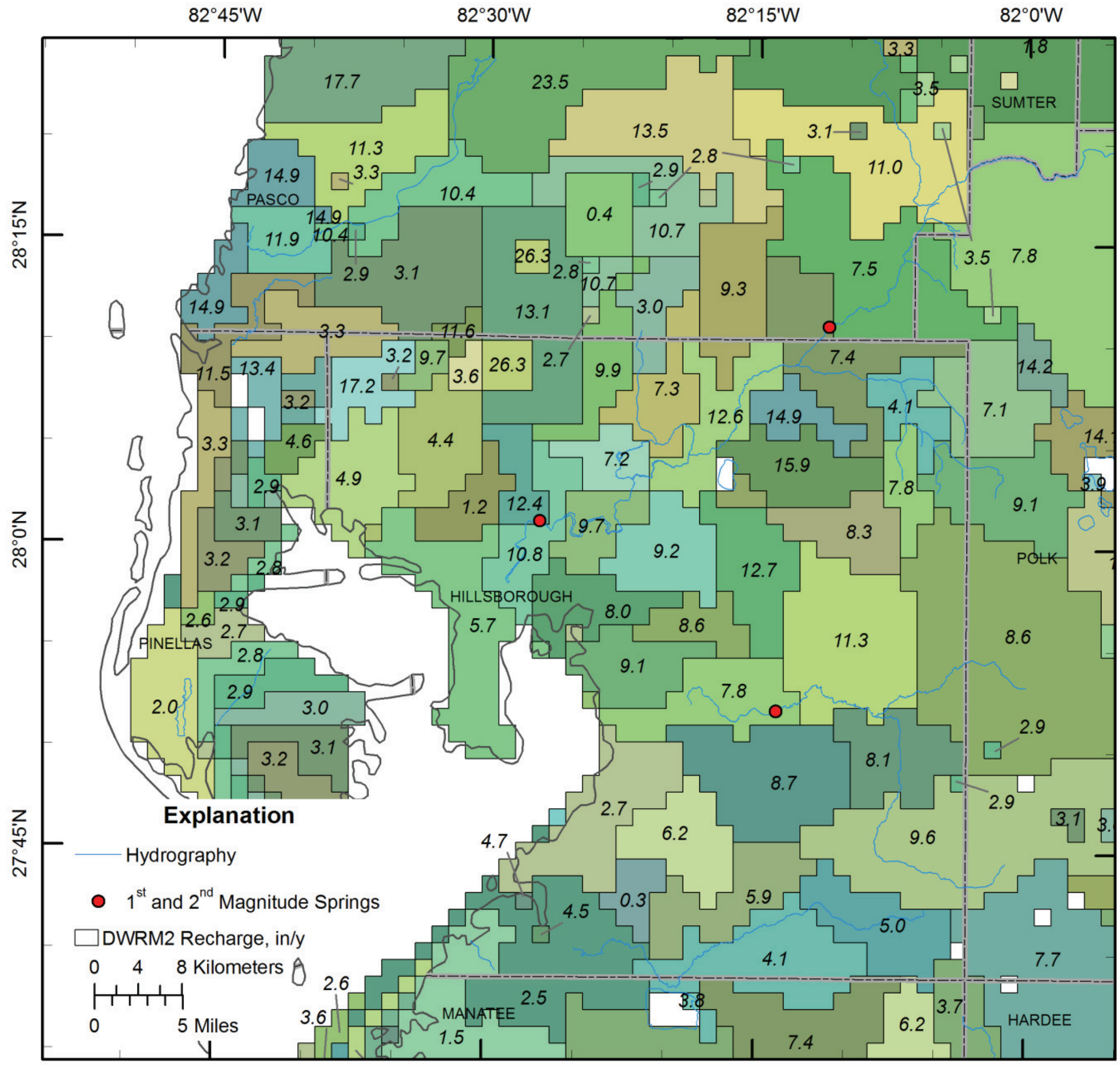

Figure 6 **Simulated steady-state recharge in Hillsborough County and surrounding areas in DWRM2. The location of 1st and 2nd magnitude springs is shown for reference and recharge is not applied to white areas. Unique recharge rates for DWRM2 grid cells have been grouped into unique polygons that can be related to surface-water sub-basins in Geurink and others (2000).**

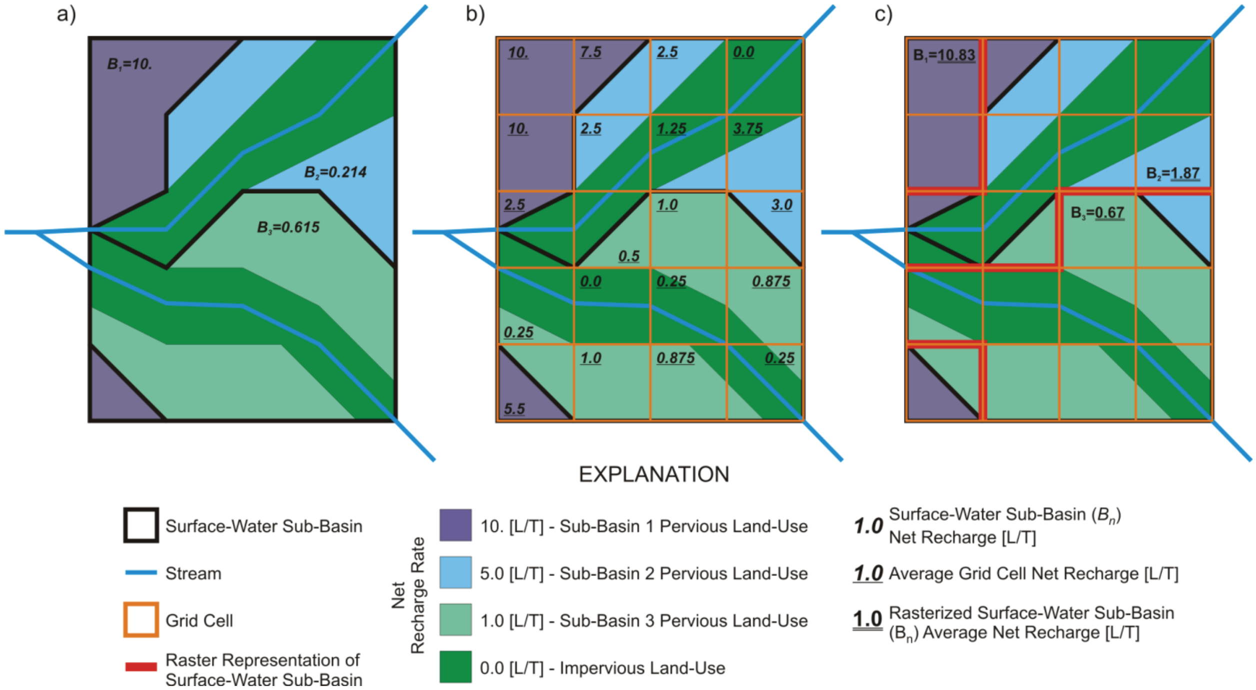

Figure 7 **General approach for mapping a) net recharge for surface-water sub-basins to b) DWRM2 grid cells on a cell-by-cell basis or c) DWRM2 based on a rasterized version of surface-water sub-basins. Cell-by-cell net recharge values shown in b) are calculated using the areal-weighted average of pervious and impervious area net recharge for surface-water sub-basins contributing to the grid cell (see equation 1). Rasterized surface-water sub-basin net recharge values shown in c) are calculated using average surface-water basin net recharge, surface-water sub-basin area, and the area of the rasterized surface water sub-basin (see equation 2). Impervious areas could include urban areas and wetlands.**

An alternative approach to distributing cell-by-cell net recharge data in DWRM2, as shown in Figure 7c, would be to scale sub-basin average areal-weighted pervious and impervious net recharge rates using sub-basin areas in the watershed-scale model and the rasterized form of the basins in DWRM2. The scaling required to conserve volume between the vector-based, sub-basin polygons and raster-based sub-basins in DWRM2 is

$$R_{DWRM2} = \frac{R_{P,n} A_{P,n}}{A_{DWRM2}} \qquad \textbf{(Eq. 2)}$$

where R_{DWRM2} is the net recharge rate applied in DWRM2 [L/T], $R_{P,n}$ is the net recharge calculated by Geurink and others (2000) for sub-basin *n* [L/T], A_P is the area of sub-basin *n* used by Geurink and others (2000) [L^2], and A_{DWRM2} is the area of the raster representation of the sub-basin in DWRM2 [L^2].

Because the proportion of upland and wetland land-use and the contribution of each surface-water sub-basin can be developed on a cell-by-cell basis, it is recommended that **equation 1** be applied in DWRM2. This approach will result in the most accurate representation of net recharge in DWRM2 and is

consistent with the approach used by Geurink and others (2000) to develop net recharge rates for the SD model area.

The current approach for distributing net recharge in the transient model assumes that there is a linear relation between monthly rainfall amounts and monthly net recharge. In reality, it is likely that low rainfall rates do not generate any recharge (for example, all of the rainfall is converted to evapotranspiration). Furthermore, net recharge rates may be a linear or non-linear function of rainfall rates. An example of such a relation between rainfall and net recharge rates is shown in Figure 8.

Use of an alternate approach for relating net recharge to rainfall would likely improve the ability to calibrate storage parameters and match low water levels in dry periods; accurate storage parameters and the ability to simulate water levels during dry conditions are both critical for transient FTMR simulations.

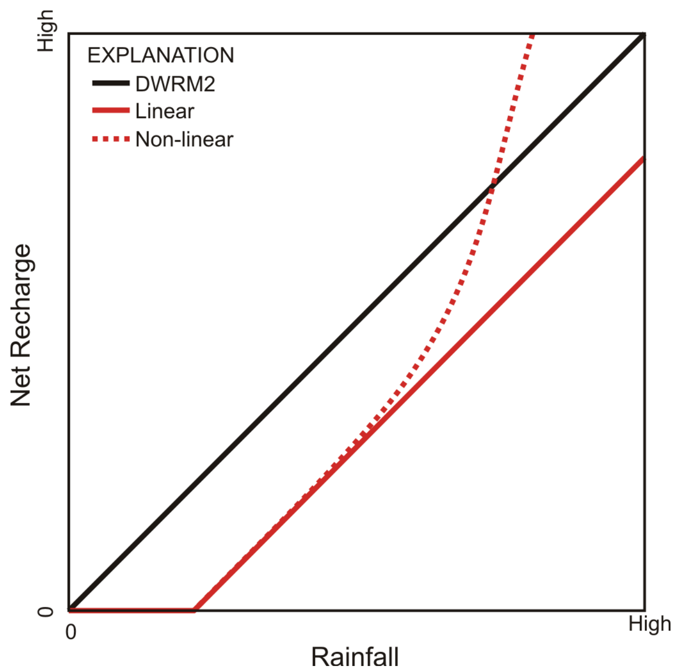

Figure 8 Conceptual response of net ground-water recharge to rainfall. Approach used in transient DWRM2 simulations is shown in black. Alternate linear and non-linear approaches are shown in red.

The Integrated Northern Tampa Bay (INTB) model may also yield another source of net recharge rates for the period after 1998 once final calibration activities and documentation are completed. The INTB was developed using the IHM that explicitly couples HSPF and MODFLOW to simulate integrated ground-water/surface-water processes (Ross and others, 2004). The IHM made many advances in the segmentation and computation of surface-water processes. The simulation period for the INTB extends through 2002 and could provide transient net recharge data for DWRM2 and eliminate the need to scale recharge rates using monthly rainfall data.

Rivers and Drains

A simple approach that uses the 1:250,000 DLG hydrography was used to assign river cell conductance in DWRM2. This approach does not accurately reflect differences between the connection of the ground-water system and surface-water system for these features. For example, the same conductance is used for Blackwater Creek, Trout Creek, Cowhouse Creek, and the Hillsborough River (Figure 1). In reality, base flow from the UFA to the Hillsborough River is much greater than base flow from the SAS to lower order streams (Blackwater Creek, Trout Creek, or Cowhouse Creek).

Although the approach used to develop river cell properties is reasonable, it does not accurately capture the variability in stream characteristics and is not easily scalable in the FTMR models. Currently, the majority of river cells in DWRM2 have been classified into four (4) types based on conductance: small rivers and creeks (conductance = $1{\times}10^3$ ft^2/d), moderate rivers and creeks (conductance = $1{\times}10^4$ ft^2/d), large rivers based on the 1:250,000 hydrography coverage (conductance = $1{\times}10^5$ ft^2/d), and coastal discharge areas (conductance = $1{\times}10^6$ ft^2/d). All of the river cells except coastal discharge rivers used an assumed incision depth of 1 ft and a water depth of 1 ft. Furthermore, calibrated conductance values were scaled by the grid size in the FTMR model, which does not guarantee conservation of conductance between the DWRM2 and FTMR models. If conductance is not conserved, simulated ground-water/surface-water exchanges in the FTMR may differ significantly from DWRM2 flows for the same river segment.

One approach that would minimize potential differences in river cell conductance would be to develop GIS-based coverage that includes physically based geometric and hydraulic parameters. One approach that has been used to assign hydraulic properties to river segments is to use a Strahler (1952) stream ordering approach to classify rivers. A diagram of the Strahler (1952) stream ordering approach is shown in Figure 9. Parameters, such as river width, river depth, stream bed depth below average grid cell topography (incision depth), and river bed leakance, could be assigned based on Strahler order. When mapped to the DWRM2 or FTMR model, a GIS-based polyline length in a grid cell, a width parameter (assigned via the Strahler reach order), and appropriate DEM data could be used to develop a grid-independent conductance value and appropriate stream bed elevation and river stage. The procedures needed to develop appropriate boundary condition elevations for a model grid are discussed in detail below.

Significant variations in the base elevations of boundary conditions (river and drains) are present in DWRM2 in model cells adjacent to rivers and drains. The juxtaposition of boundary condition elevations can create local inflows and outflows that are model artifacts and do not represent actual ground-water/surface-water exchanges. Because the grid cell elevation typically represents the average elevation within the cell, boundary condition heads (rivers and drains) should be defined in such a way that exchanges between aquifer units and these surface-water features are accurately represented. River or wetland elevations can vary significantly with respect to the average topography of a cell (see Figure 10). Wetland and river base flow would not be accurately simulated in DWRM2 or in associated FTMR models if base elevations for individual surface-water features are set at actual base elevations.

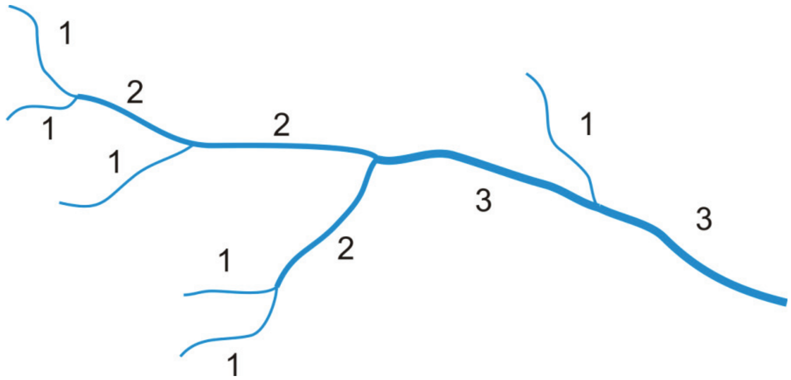

Figure 9 Strahler (1952) stream order approach for numbering streams based on flow from lower order tributaries (lower numbers) joining together to form higher order tributaries (higher numbers).

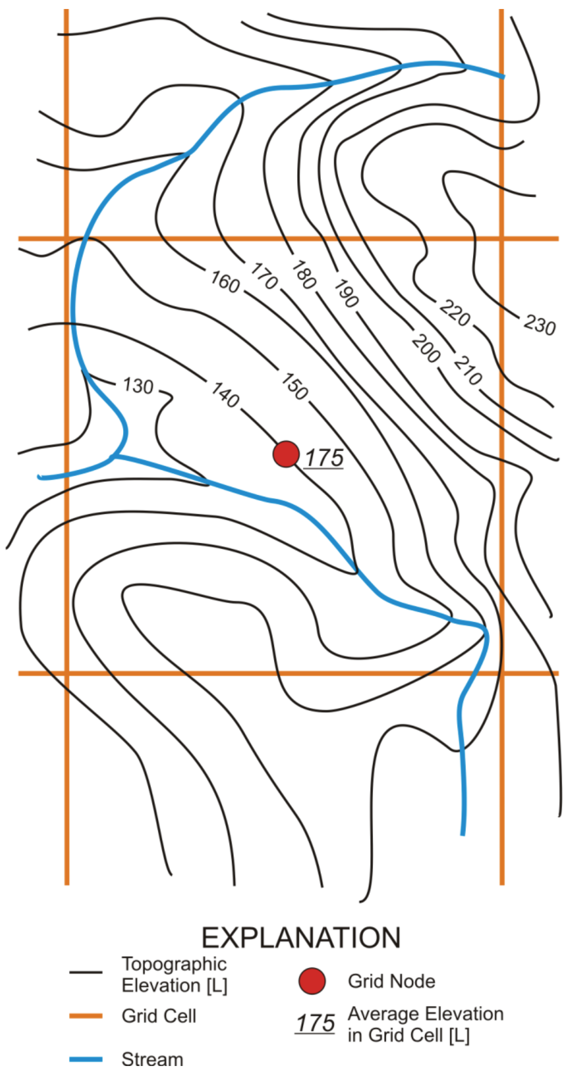

Figure 10 Conceptual illustration of the relation of actual and DWRM2 grid cell elevations. DWRM2 grid cell elevations represent the average topographic elevation within the grid cell. The intersection of topographic elevation contours and stream hydrography illustrate the difference between actual stream bed elevations and average grid cell elevations. In this example, stream bed elevations are significantly less than the average grid cell elevation and would result in over-prediction of aquifer-stream interactions.

To accurately simulate the connection between the ground-water system and surface-water features, the base elevation for surface-water boundary conditions should be vertically adjusted. The approach that should be followed to accurately simulate ground-water/surface-water exchanges is shown graphically in Figure 11. Without adjustment of the base elevation of boundary conditions, simulated flow may be under-predicted (simulated flow is less than observed flow) or over-predicted (simulated flow is greater than observed flow) and adversely affect simulated water levels and water budgets.

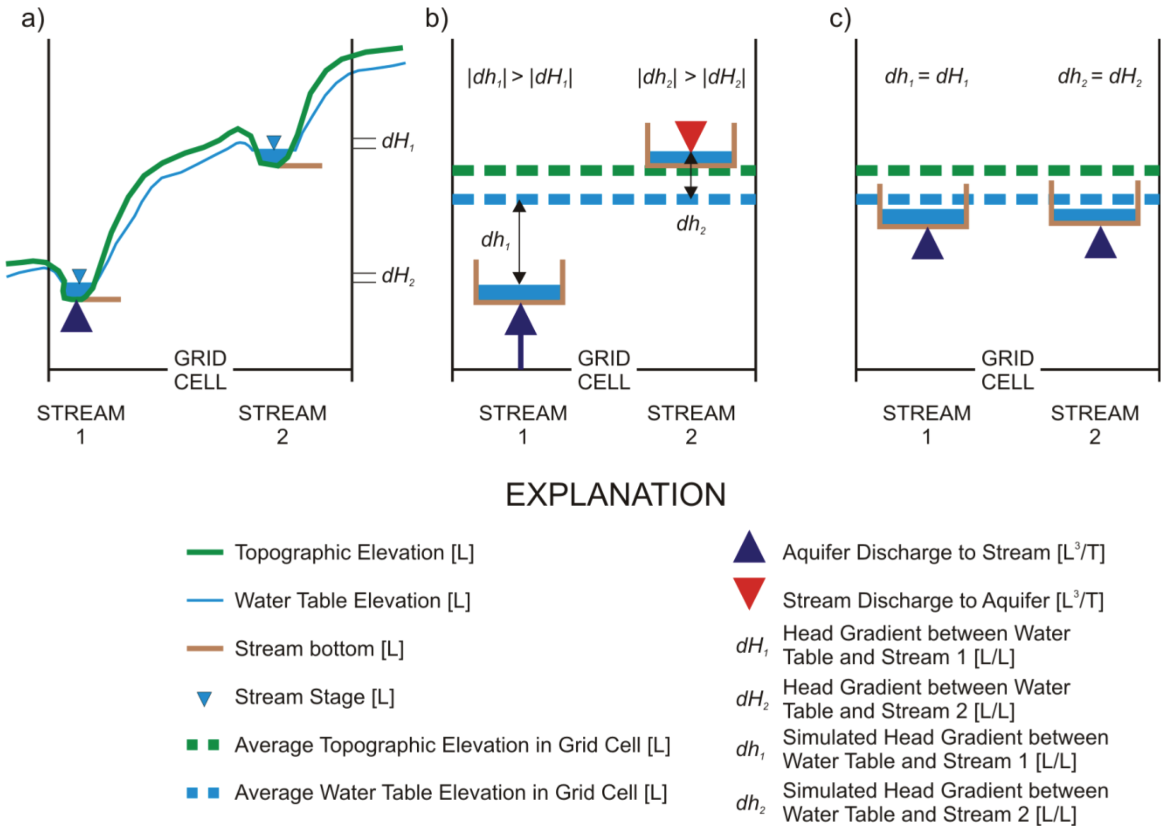

Figure 11 **a) Actual aquifer-stream exchanges within a grid cell, b) simulated aquifer-stream exchanges and associated errors before shifting boundary condition elevations, and c) simulated aquifer-stream exchanges after shifting boundary condition elevations. The length, color, and direction of the arrow denote the magnitude and direction of aquifer-stream exchanges.**

River cells were used in the SAS to represent discharge in coastal wetland areas in DWRM2. This approach is reasonable if water levels in the SAS always exceed the specified river stage. Because of the high conductance (1×10^5 to 1×10^6 ft^2/d) of these boundaries, they can add a significant volume of water to the DWRM2. This approach may be appropriate if these areas are a potential source of water to the SAS. However, it may be more appropriate to represent discharge areas in coastal wetlands as drains.

Drains were used in the SAS to represent wetland features and to control water levels that are above land surface. Many of these drains have high conductance values (1×10^5 ft^2/d) and can discharge a large quantity of water from the SAS out of the model. Representation of wetland features as drains is reasonable, but use of drains to control water levels above land surface is questionable. A better approach to control water levels above land surface is to identify and correct the factors that cause this

situation. As discussed earlier in the **Recharge and Evapotranspiration** section, the approach used to apply net recharge is one factor contributing to excess water above land surface.

A large number of drains are present in the UFA (model layer 4) in Citrus, Hernando, and Pasco Counties representing coastal springs. This representation is identical to the representation of Sepulveda (2002). This representation is not adequate here, however, because drains are not easily scaled for FTMR applications. A better approach would be to identify the location of discrete springs and develop a GIS coverage of spring locations and properties. The GIS-based coverage would be scalable for all future versions of DWRM2 and related FTMR applications.

Ground-water Withdrawals

Ground-water withdrawals in DWRM2 were obtained from the SWFWMD, SJRWMD, SRWMD, SFWMD, and the U.S. Geological Survey. This dataset is based on a combination of metered, permitted, and estimated water use within these water management districts and represents the best available data. In a recent review of ground-water withdrawal data, the SRWMD found that Sepulveda (2002) used permitted rates in the SRWMD. SRWMD is currently in the process of revising water use estimates and these revised estimates should be used when they become available. There are no other known data quality problems with this dataset.

External Model Boundaries

A combination of constant heads, river cells, and GHBs were used to define external boundary conditions in DWRM2. As discussed previously, river cells were used to represent surface-water features along coastal boundaries in the SAS and these features may require further evaluation to determine if they are appropriate. Constant-head cells were defined along the eastern boundary of the SAS and are considered appropriate because the domain boundary of DWRM2 does not correspond to surface-water basin boundaries. Equivalent freshwater constant heads, based on measured chloride concentrations, were defined in Tampa Bay and offshore in the Southern Water Use Caution Area (SWUCA – SWFWMD, 2006) for model layer 1. Chloride concentrations in these areas correspond to brackish to saline water conditions and equivalent freshwater constant heads should be calculated using reasonable chloride concentrations. There are also areas where river cells are specified offshore that are located between areas of specified equivalent freshwater constant heads (Figure 12). It is more defensible to specify equivalent freshwater constant heads for all offshore locations in DWRM2.

A number of discontinuous equivalent freshwater constant heads, based on measured chloride concentrations, are specified in PZ2 and PZ3 along the southern border of DWRM2. Justification for the equivalent freshwater constant heads in PZ2 and PZ3 is not given in the DWRM1 or DWRM2 documentation (ESI, 2004 and 2007). It is not clear why inflow or outflow would occur along some but not the entire southern model boundary.

Equivalent freshwater constant heads, with seawater chloride concentrations (approximately 19,400 milligrams per liter) and a water-level elevation of 0.0 ft (all levels are based on NGVD 1929), are specified in the UFA along the western boundary of DWRM2. Equivalent freshwater constant heads with measured chloride concentrations were specified along the southeastern boundary of DWRM2.

The approach used to define equivalent freshwater constant heads in the UFA is reasonable and appropriate. Additional information on the use and specification of equivalent freshwater heads is given in ESI (2004, 2007) and Guo and Langevin (2003).

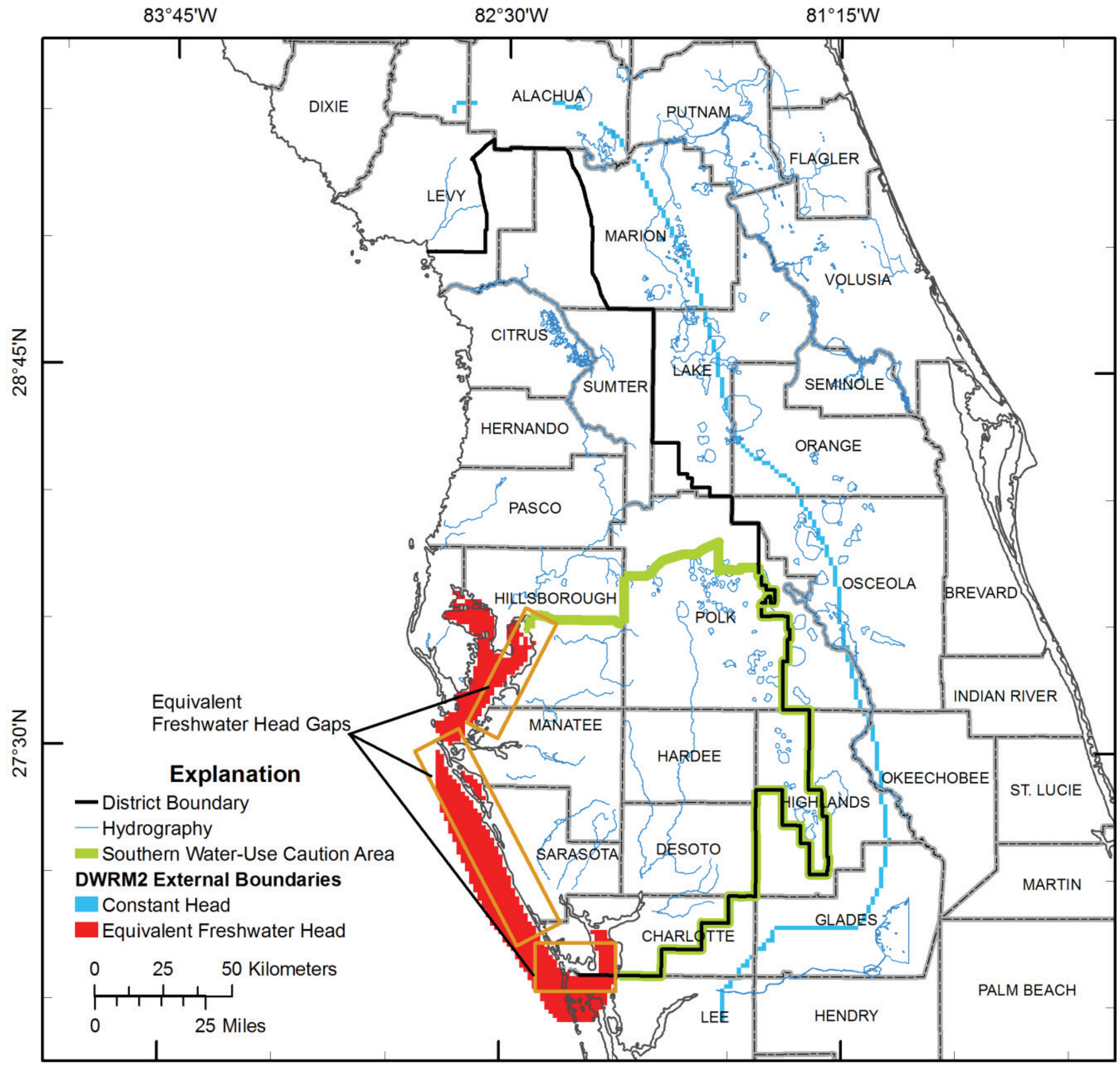

Figure 12 **Equivalent freshwater constant heads (red) in coastal areas of DWRM2 and specified constant heads (light blue) along the eastern boundary of DWRM2. The SWUCA is shown for reference and delineated in green. Note the gap between equivalent freshwater constant heads in Tampa Bay and western Manatee and Sarasota Counties highlighted within areas delineated in orange.**

GHBs were defined along the eastern boundary of DWRM2 in PZ2, PZ3, and the UFA. GHB heads and conductance were derived from simulated heads and the horizontal hydraulic conductivity used by Sepulveda (2002). The approach used is reasonable and appropriate. Two minor issues with the assignment of GHBs is the difference between the location of GHBs in PZ2 and PZ3 relative to the UFA and the appropriateness of simulated heads for 1993 from Sepulveda (2002) for the 1995 simulation

period of DWRM2. These issues should be addressed in the comprehensive model document described later.

Model Performance

Assessment of the calibration of DWRM2 relative to water levels, water-level differences, surface water flows, and water budgets is summarized below.

Water Levels and Water-Level Differences

A comparison of simulated UFA potentiometric-surface contours to the pre-development UFA potentiometric contours developed by Johnston and others (1980) is shown in Figure 13. The simulated UFA potentiometric surface is more than 5 ft lower than indicated by Johnston and others (1980) in portions of Alachua, Levy, and Putnam Counties and throughout much of the SWUCA. The simulated UFA potentiometric surface is more than 5 feet greater than indicated by Johnston and others (1980) in the Hillsborough and Withlacoochee River Basins and portions of Hardee, Highlands, and Polk Counties. Over-predicted UFA heads (simulated water levels higher than inferred levels) are a consequence of inaccurate application of the net recharge data of Geurink and others (2000) in DWRM2. Differences between simulated and inferred, contoured pre-development UFA water levels may also be an indicator of errors with calibrated model parameters in DWRM2.

Areas where simulated SAS water levels are above land surface during predevelopment and 1995 conditions are shown in Figure 14. As expected, areas where SAS water levels are above land surface are less extensive in 1995, as a result of ground-water withdrawals, than during pre-development conditions. Extensive portions of the SWUCA have simulated SAS water levels above land surface. Areas where SAS water levels are above land surface are important for FTMR cumulative analysis. These results indicate excess recharge is being applied in these areas and decreases in water levels resulting from increased ground-water withdrawals would likely be under-predicted in FTMR cumulative analysis. It is recommended that DWRM2 be further evaluated to determine defensible approaches (for example, revision of net recharge data, refined river cell development, incorporation of additional calibration target data types, and others) to eliminate areas where water levels are not expected to be above land surface.

The simulated difference between UFA and SAS water levels during 1995 conditions is shown in Figure 15. There is little difference between water levels in the UFA and SAS in northern portions of the SWFWMD even though topography varies appreciably in this area and the UFA is partially confined in northeastern portions of the DWRM2 model domain. In the SWUCA, simulated differences between SAS and UFA water levels are more than 50 ft (SAS water levels are more than 50 ft above UFA water levels) in many cells. The SAS-UFA water-level difference residuals (124 paired wells) are approximately normally distributed as a result of calibration to water-level targets (see Figure 16), although the dependence of water levels on leakance parameters was not explicitly incorporated in the calibration process. Large positive water-level differences (in recharge areas; see Figure 5) are under-predicted and large negative water-level differences (discharge areas) are over-predicted (see Figure 17a). SAS-UFA water-level difference residuals (Figure 17b) are generally greater than 10% of observed SAS-UFA water-

level differences (mean = 581%, median = 67%). For a defined leakance value, percent error shown in Figure 17b is a direct measure of absolute error in simulated vertical flow between the SAS and UFA. As a result, it appears there is significant bias in simulated SAS- UFA water-level differences and that calibrated leakance and/or specified recharge values may not be accurate.

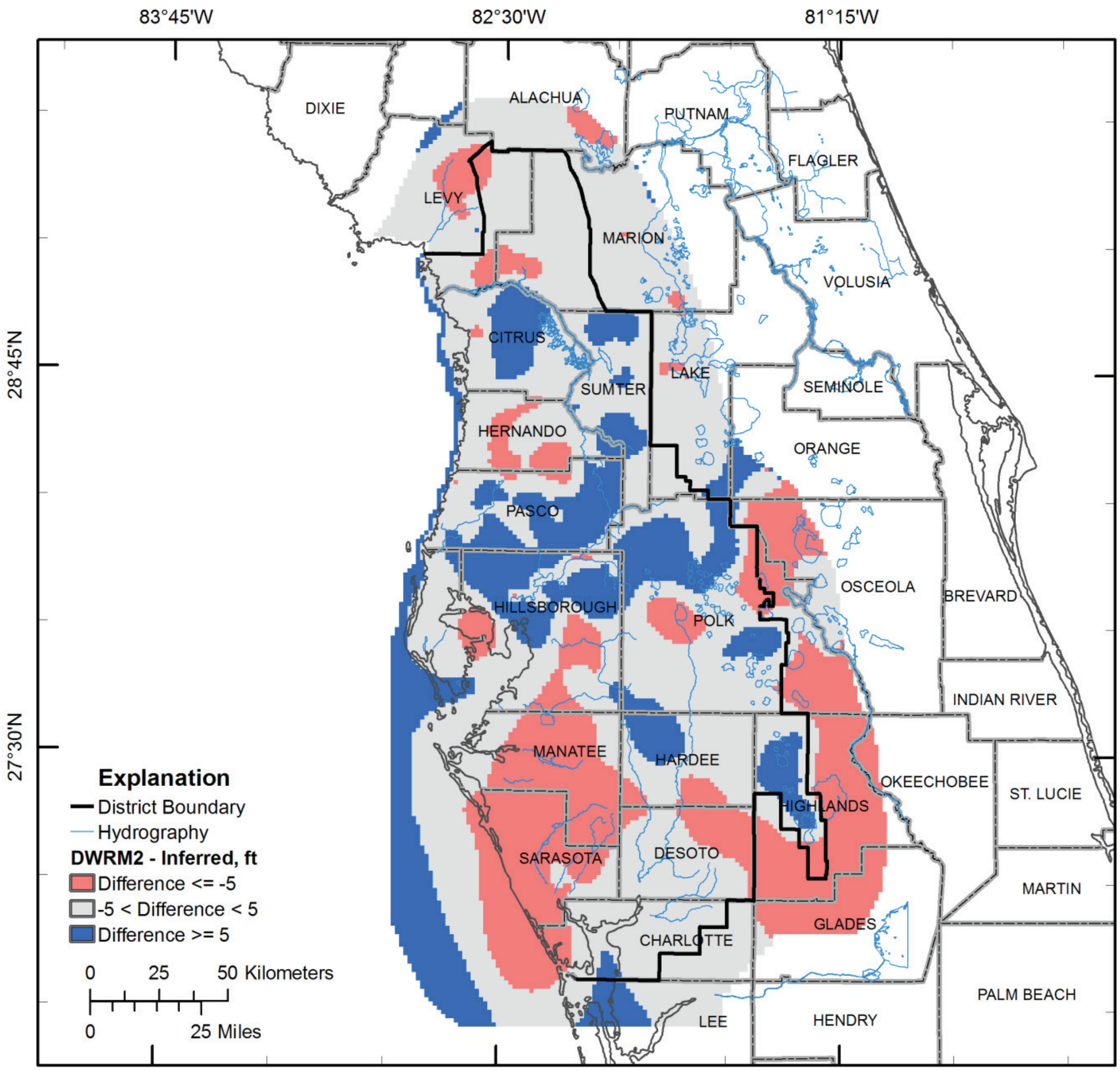

Figure 13 Differences between simulated and inferred predevelopment UFA potentiometric surfaces. Inferred predevelopment UFA potentiometric surface from Johnston and others (1980). The estimated error in the inferred predevelopment UFA potentiometric surface is 5 ft (one-half of the 10 ft contour interval).

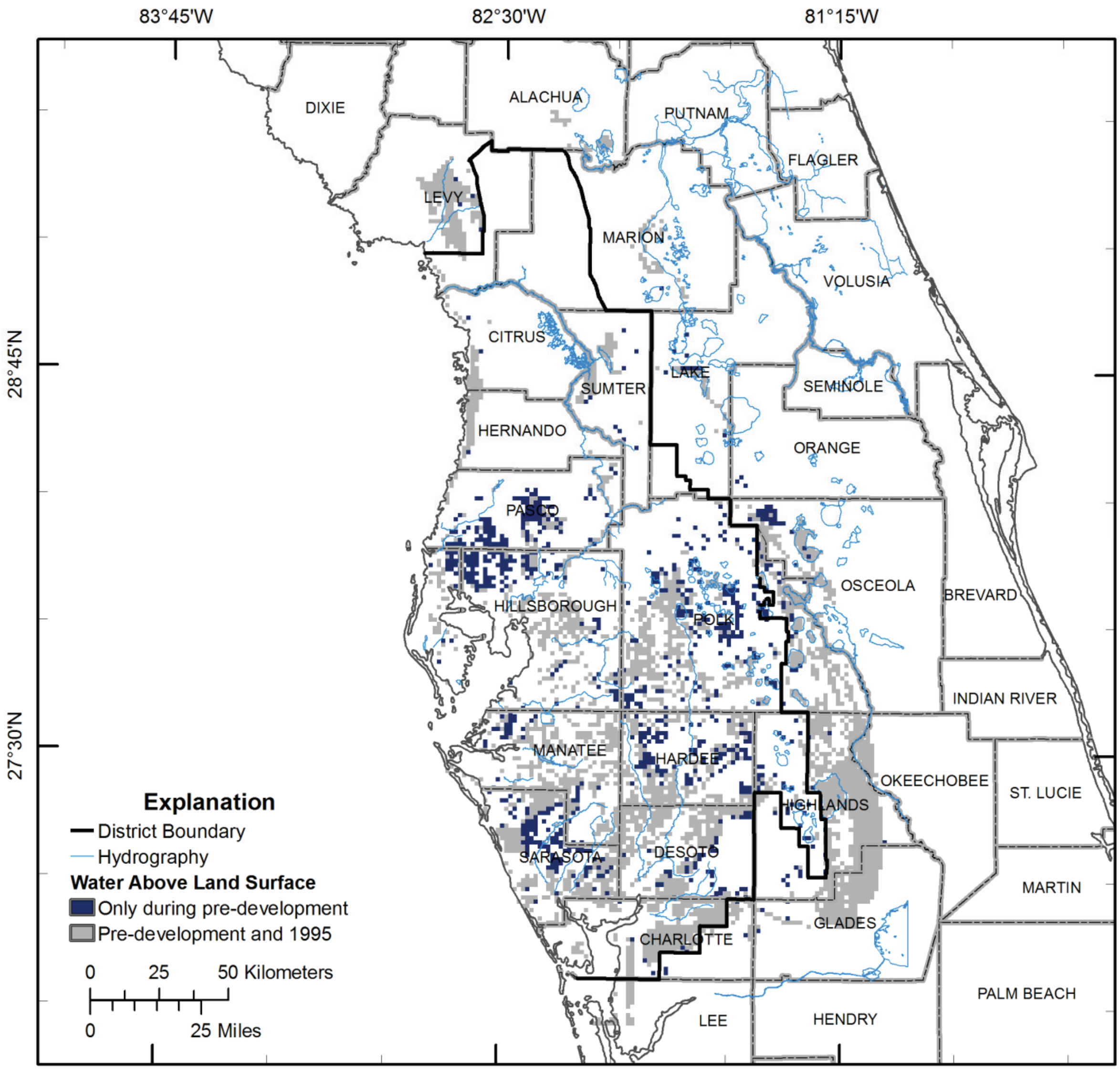

Figure 14 Cells with simulated water levels above land surface under pre-development and 1995 conditions. Areas with water levels above land surface during pre-development are indicated with blue and are located in areas with sizeable agricultural, industrial, and public supply ground-water withdrawals. Areas with water above land surface during pre-development and 1995 are indicated with gray and should correspond to lakes, rivers, or wetlands. Many of the areas with water above land surface during pre-development and 1995 correspond to upland areas of the model where water levels are expected to be below land surface.

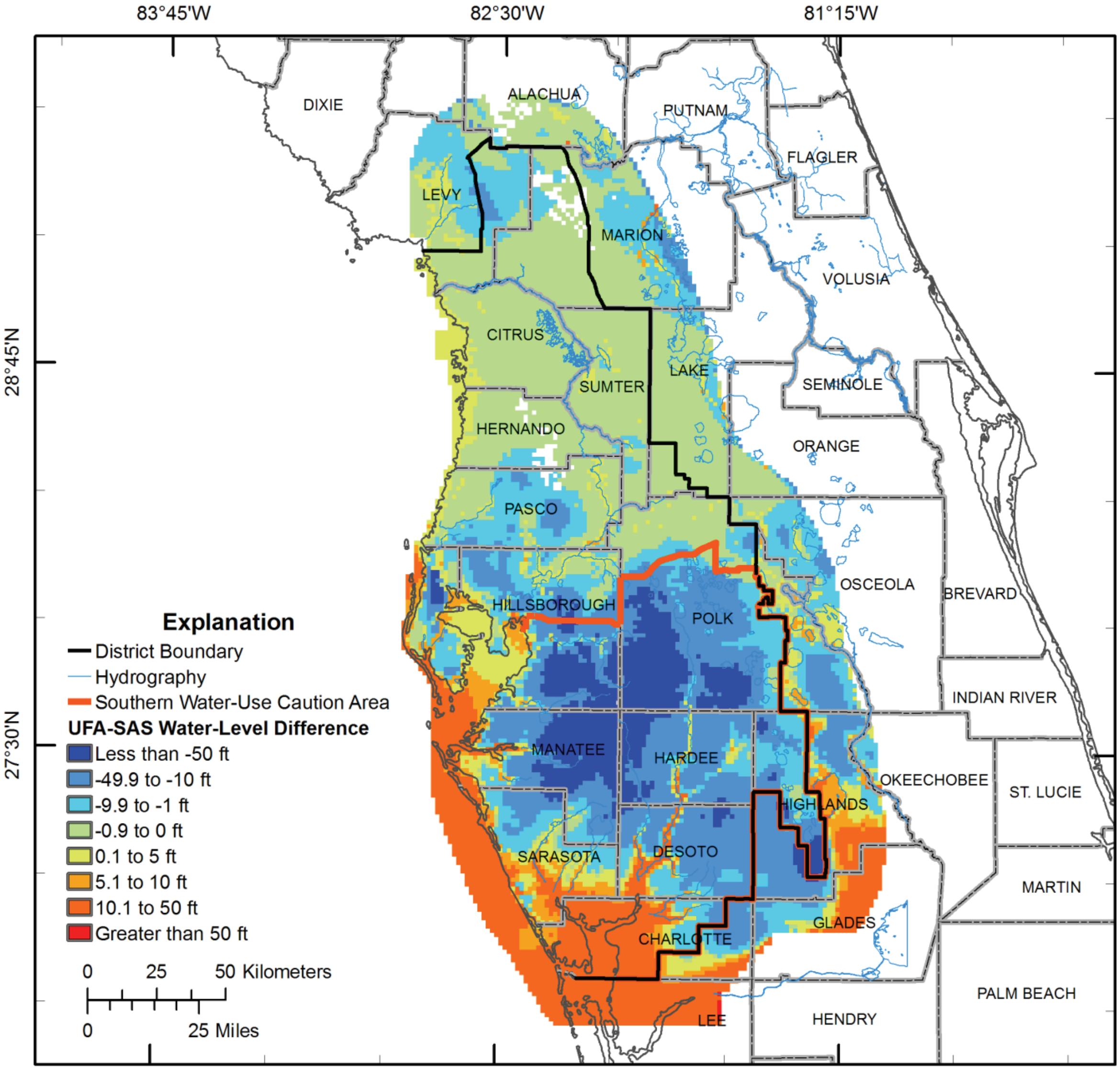

Figure 15 Simulated difference between UFA and SAS water levels during 1995. Positive values (yellow to red) indicate cells where UFA water levels are higher than SAS water levels and water flows from the UFA to the SAS (discharge conditions). Negative values (green to blue) indicate cells where SAS water levels are higher than UFA water levels and water flows from the SAS to the UFA (recharge conditions).

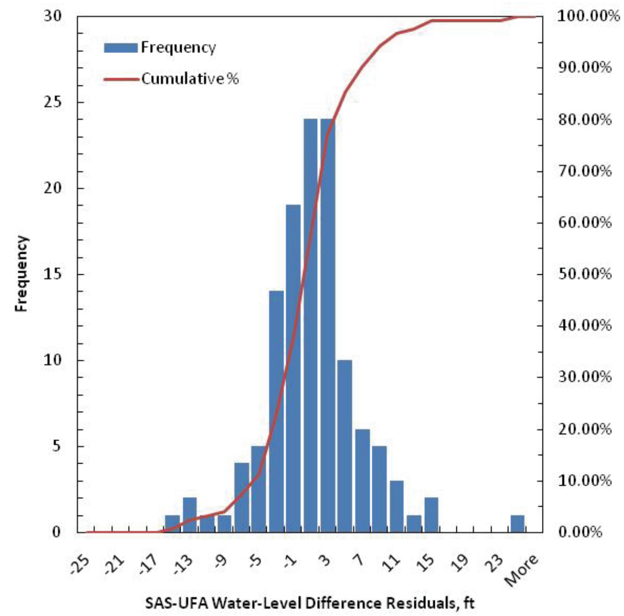

Figure 16 Distribution of SAS-UFA water-level difference residuals in DWRM2.

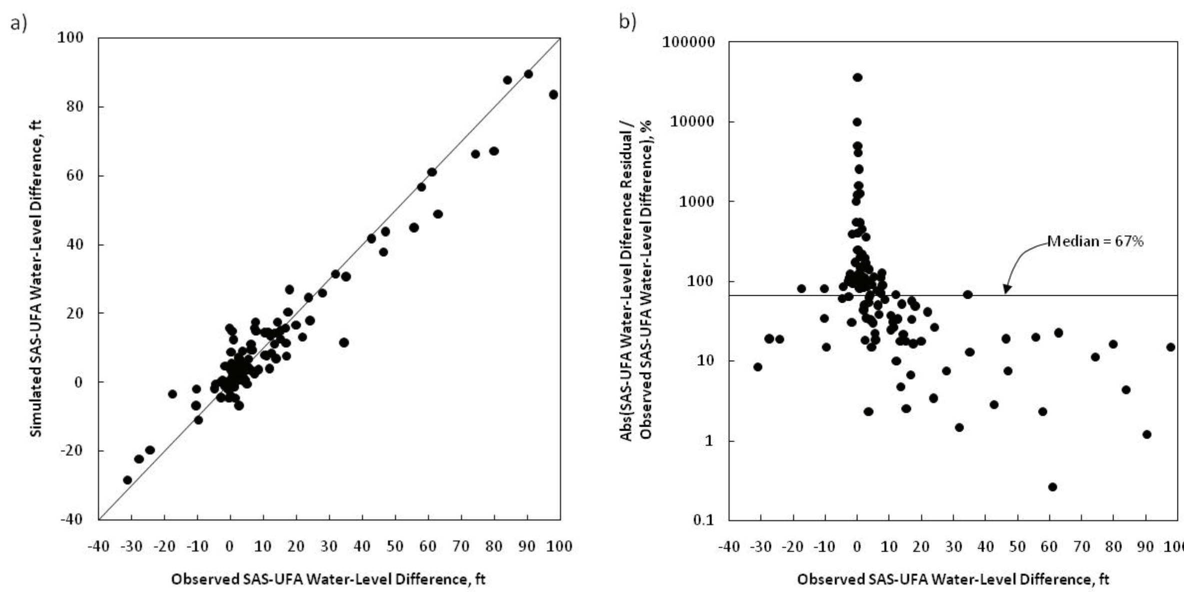

Figure 17 a) Difference between observed and simulated SAS-UFA water levels and b) absolute value of the percentage of the SAS-UFA water-level difference residual to observed SAS-UFA water-level difference. Percent errors shown in b) are a measure of absolute SAS-UFA vertical flow errors in DWRM2.

It is recommended that water-level differences be incorporated in the automatic calibration process to improve simulated SAS-UFA water-level differences. Furthermore, it is likely that use of SAS water-level elevation targets instead of DTW targets is introducing a positive bias into simulated SAS water levels. It is not uncommon for monitor wells to be located at relatively high elevations; therefore, in cases where water-level elevations measured in monitor wells are higher than the average water-level elevation assigned to a grid cell, water-level elevations higher than land surface will result with the use of the

automatic calibration process in DWRM2. It is recommended that water-level data should be shifted to the local grid cell datum (see Figure 11) or DTW targets be used instead of absolute SAS water-level elevations where DTW data are available.

Ground Water/Surface Water Exchanges

Simulated ground-water/surface-water exchanges in DWRM2 are discussed in the following sections relative to observed data or expected simulated values. Simulated ground-water/surface-water exchanges include river (base flow) and drainage flow. Drainage flow represents a combination of discharge from wetlands and conceptual losses representing ET.

Aquifer-River Exchange

The spatial distribution of SAS river cell base flow is shown in Figure 18. The range of base flow is summarized in Table 1 and varies from -1,684 to 175 in/y in individual grid cells. Based on observed data, the magnitude of the upper and lower range of base flow greatly exceeds expected ranges. Estimated base flow in the Hillsborough, Alafia, Little Manatee, and Peace Rivers is summarized in Table 2 and averaged 1,022 ft^3/s in 1995 (Geurink and others, 2000).

DWRM2 over-predicts base flow by 20% in 1995 and simulated base flow does not include drainage from wetland and drains used to limit water levels above land surface. Simulated SAS drainage flow should be combined with simulated SAS river flow to account for all base flow discharging to the surface-water system and lost from the system at the coast or as evapotranspiration. If this combination were done, simulated base flow would be over-predicted by more than 20% (see the **Aquifer-Drain Exchange** section). Furthermore, because base flow was not specifically incorporated in the automatic calibration process, there is significant uncertainty about how well the current distribution of model parameters and boundary conditions represents the ground-water system.

Daily measured streamflow for 1995 at the Hillsborough River at Morris Bridge near Thonotosassa, Florida station is shown in Figure 19 along with base-flow estimates using the algorithm of Weber and Perry (2006) and 60- and 120-day moving periods. This example was chosen because it represents the river segment with the largest percent error in DWRM2. Average streamflow and base flow calculated with a 60-day moving period for 1995 were 335 and 116 ft^3/s, respectively, whereas simulated base flow for the Hillsborough River Basin was 197 ft^3/s. Base flow calculated using a 60-day moving period represents 36% of the total flow measured at this location. Simulated base flow represents 59% of the total flow at this location and is approximately a factor of two (2) greater than computed values; the difference is even greater if the base flow calculated using a 120-day moving period (82 ft^3/s) is used or SAS drainage flow were included in the simulated DWRM2 base flow .

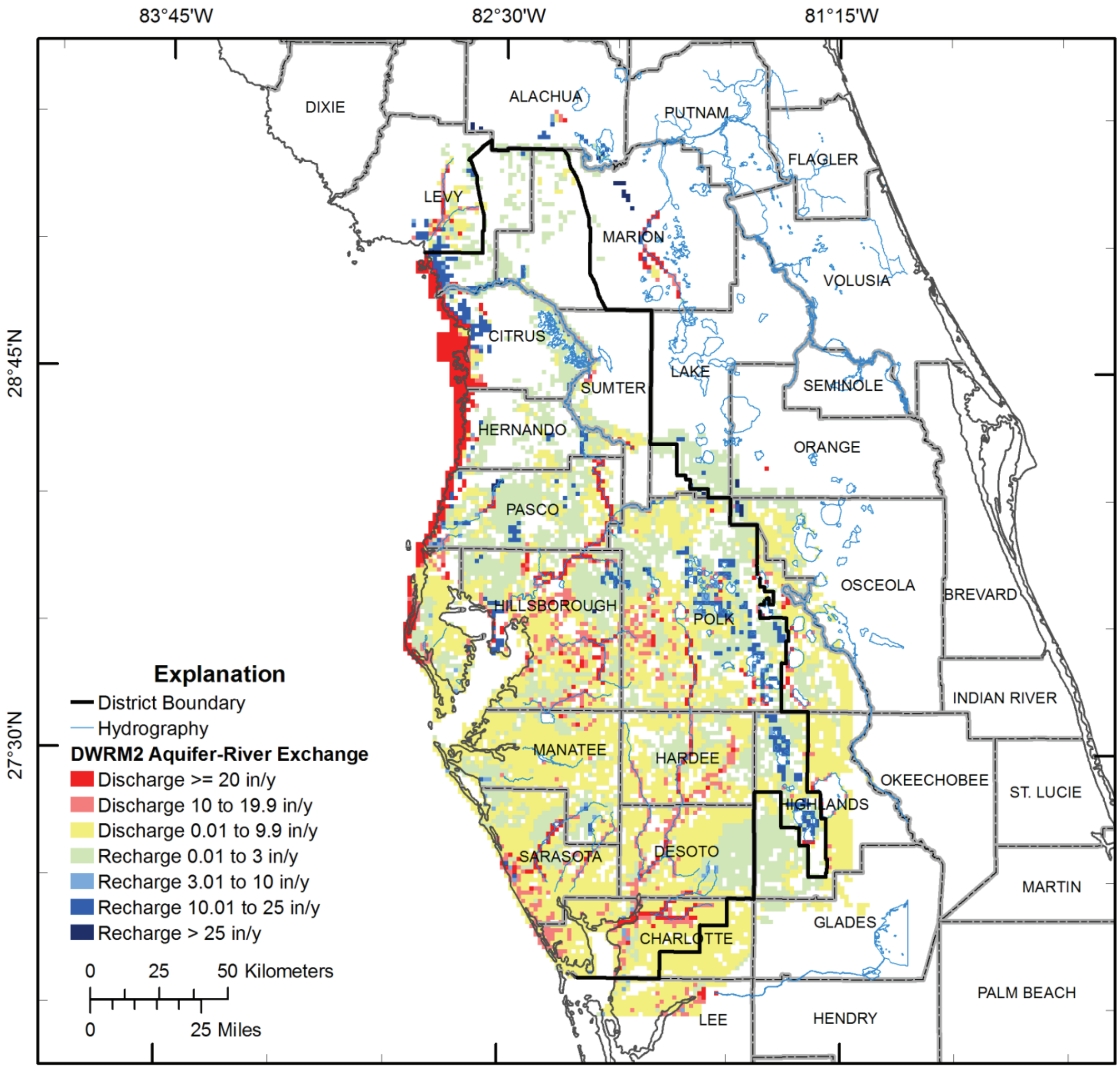

Figure 18 Simulated steady-state aquifer-river exchange in DWRM2. Discharge represents flow from the aquifer to surface-water features (base flow) and recharge represents flow from surface-water features to the aquifer (river seepage). Aquifer-river exchange is zero in white areas.

Table 1 Simulated range of recharge, SAS drain flow, river base flow, net recharge and discharge, and UFA spring flow in individual grid cells in DWRM2. Recharge represents recharge applied using the MODFLOW recharge package in DWRM2. Net recharge is the sum of recharge, SAS drain flow, and river base flow. Positive and negative values represent recharge and discharge from the aquifer, respectively.

Water-Budget Component	Cell-by-cell Flow Rate, in/y		
	Minimum	Maximum	Average
Recharge	0	29.68	8.05
SAS Drain Flow	0	280	1.57
River Base Flow	-1,684	175	-15.38
Net Recharge	-1,684	108	1.02
UFA Spring Flow	-10,368	0	-143

Table 2 Simulated base flow for selected drainage basins in DWRM2.

Basin	DWRM2, ft^3/d	Geurink and others (2000), ft^3/d	Difference, ft^3/d	Percent Error
Peace River	46,603,470	40,999,170	-5,604,300	-14
Myakka River	15,184,290	12,381,700	-2,802,590	-23
Manatee River	7,526,557	6,334,298	-1,192,259	-19
Little Manatee River	5,313,171	5,836,313	523,142	9
Alafia River	14,614,490	16,509,610	1,895,120	11
Hillsborough River	17,069,080	6,234,677	-10,834,403	-174
Total	106,311,058	88,295,768	-18,015,290	-20

Although base flow appears to be over-predicted, calibration criteria established for water-level data were met in the DWRM2 calibration. However, recharge and hydraulic conductivity/transmissivity are highly correlated when flow terms are not included in the calibration process. As a result, the ability to calibrate to heads without being able to simulate flows indicates that model parameters have been adjusted during the automatic calibration process to compensate for excess net recharge being applied in DWRM2. This result may limit the ability to accurately simulate impacts related to ground-water withdrawals, particularly in the vicinity of river boundary conditions.

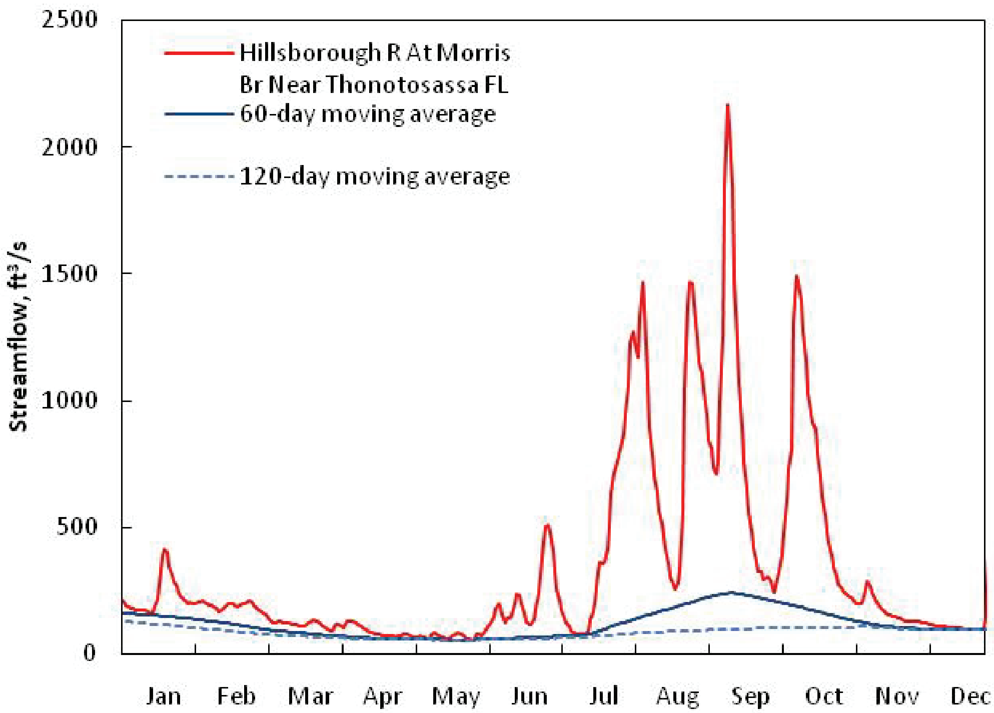

Figure 19 **Daily streamflow in 1995 at Hillsborough River at Morris Bridge near Thonotosassa, Florida. Calculated base flow using a 60- and 120-day moving average of minimum streamflow for the same moving period is also shown.**

Aquifer-Drain Exchange

The range of SAS drain discharge in individual grid cells is summarized in Table 1 (an average 1.57 in/y for all drain cells and maximum rate of 280 in/y). Simulated aquifer-drain exchange occurs over a large portion of the model domain (Figure 20). This result indicates that water levels would be above land surface in much of the model domain if these drains were not included in model simulation. Drain levels in the SAS are set at land surface. These levels are likely above actual water-table elevations in much of model domain. The pervasive nature and magnitude of SAS drain flow further supports the conclusion that excess aerial recharge is being applied in DWRM2. The combined simulated aquifer-river (1,390 ft^3/s) and aquifer-drain (694 ft^3/s) exchange for Charlotte, Desoto, Hardee, Hillsborough, Manatee, Polk, and Sarasota Counties is 2,084 ft^3/s. The simulated aquifer-river and aquifer-drain exchange is approximately a factor of two (2) greater than estimated base flow (1,022 ft^3/s) for 1995 for these counties (Geurink and others, 2000).

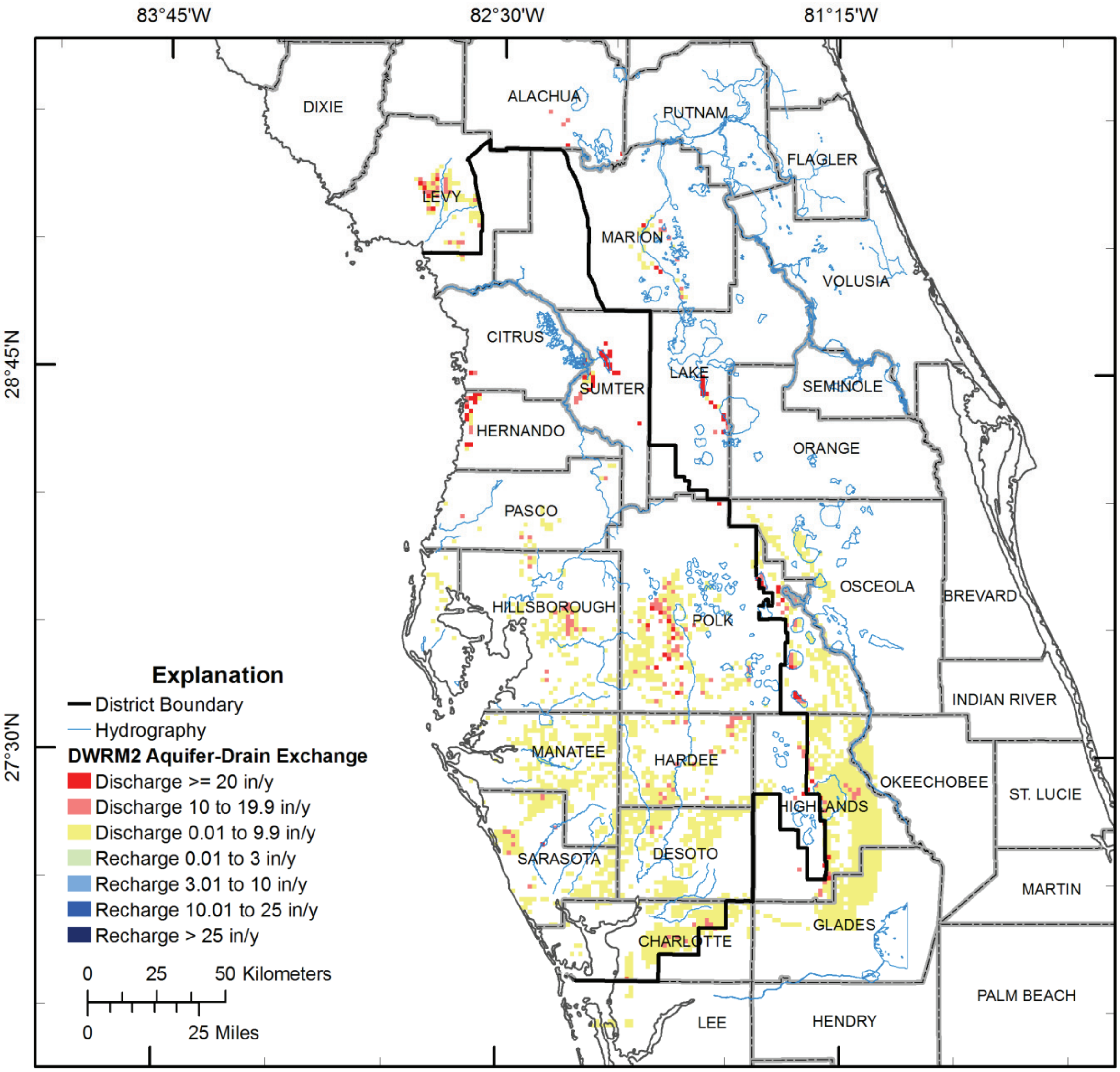

Figure 20 **Simulated steady-state aquifer-drain exchange from the SAS in DWRM2. Discharge represents flow from the aquifer to surface-water features (base flow). Recharge from drains does not occur and aquifer-drain exchange is zero in white areas.**

Spring flow from the UFA (model layer 4) represents a substantial loss of ground water from the UFA relative to typical ground-water recharge rates (average of -143 in/y for 304 drain cells) and flows are summarized in Table 1. Although the range of spring flow from the UFA is large, DWRM2 actually under-predicts spring flow from the UFA by 7.36% compared to measured spring flow (Sepulveda, 2002). The percent error reported in *DWRM2 Table 3.7* (ESI, 2007) does not preserve the correct sign of the error, although the magnitude of the flow weighted percent error reported in the table (7.36%) is correct. Because of the relative ease of calibrating to spring discharges, DWRM2 should be adjusted to better fit observed spring discharges in addition to adoption of the GIS-based spring coverage discussed previously.

Net SAS Ground-Water Recharge and Discharge

Net SAS recharge is shown in Figure 21 and, in general, appears to be reasonable over the model domain. The range of net SAS recharge is summarized in Table 1 and varies from -1,684 to 108 in/y in individual grid cells and averages 1.02 in/y in grid cells receiving recharge. Discharge is observed in the vicinity of most major rivers and along the coast. Areas where simulated net ground-water recharge or discharge exceeds expected ranges include Desoto, Highlands, southern Hillsborough, Manatee, Osceola, and eastern Sarasota Counties within the SWUCA. As simulated, these areas receive no net recharge and are discharge areas; discharge conditions are expected in coastal areas and in the vicinity of rivers, but are not expected throughout upland areas of the SWUCA.

Net UFA Ground-Water Recharge and Discharge

Net UFA ground-water recharge and discharge appears to be reasonable over the model domain when compared to pre-development UFA recharge estimated by Aucott (1988) (Figure 22). Coastal discharge in northern portions of the District and in Tampa Bay is consistent with expected discharge directions in DWRM2. Some areas where simulated net recharge differs appreciably in DWRM2 compared with Aucott (1988) include 1) relatively high recharge rates in northern portions of the District, 2) relatively low discharge rates in the lower Hillsborough River Basin, 3) relatively high discharge rates in isolated areas of Sarasota, Desoto, and Charlotte Counties, 4) anomalous discharge rates in ridge areas of Polk and Highlands Counties, and 5) relatively low discharge in the upper Kissimmee Basin. It is expected that many, if not all, of these differences will be resolved if the suggestions for improving the conceptualization of surface-water boundary conditions and use of additional calibration target data types are applied in DWRM2. High recharge rates in DWRM2 relative to pre-development estimates may be partially a result of use of net recharge data developed for post-development conditions and reflecting induced recharge related to ground-water withdrawals.

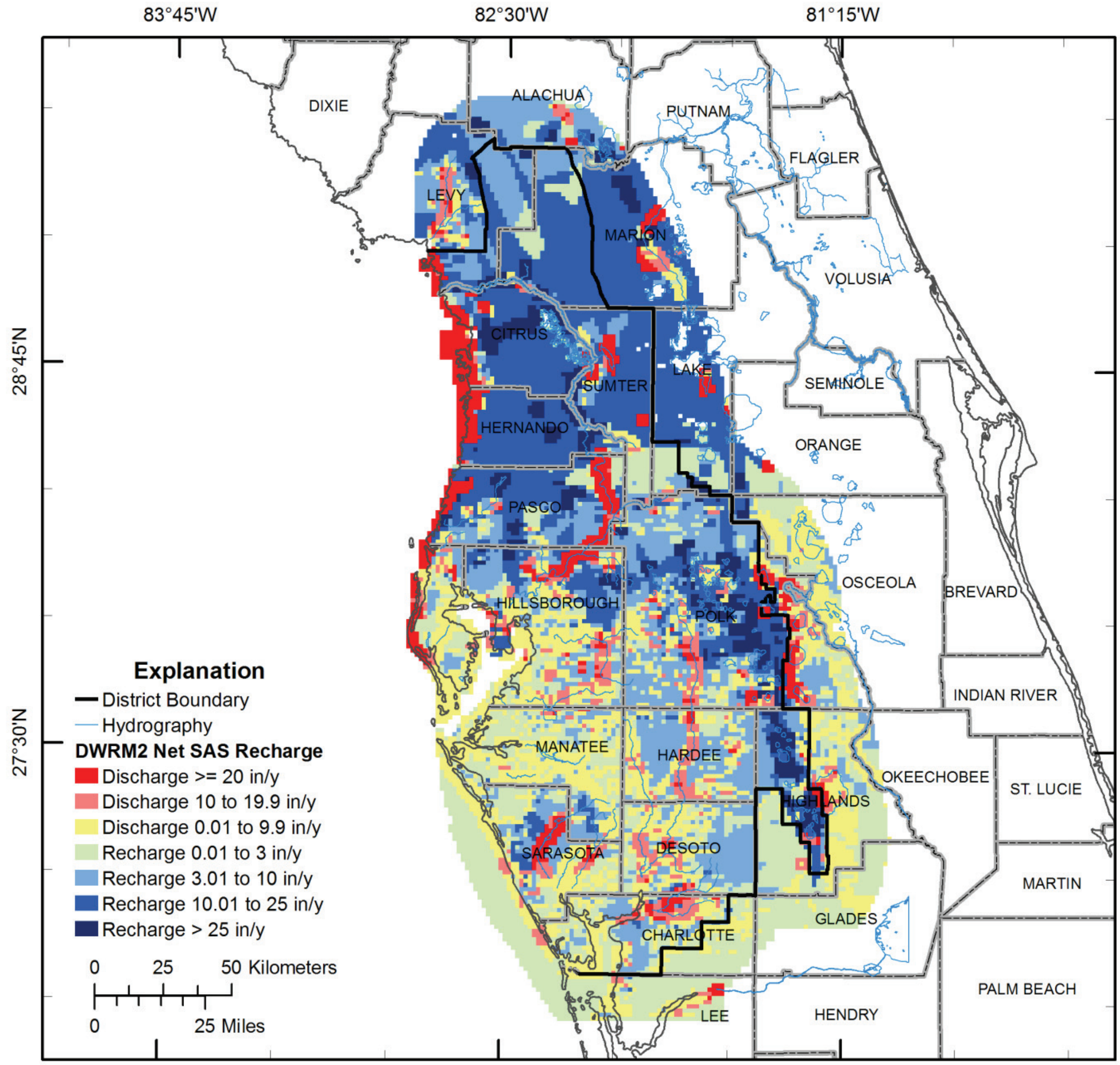

Figure 21 **Simulated steady-state net SAS ground-water recharge and discharge in DWRM2. Discharge represents flow from the aquifer to surface-water features and recharge represents the combination of new ground water recharge from rainfall and flow from surface-water features to the aquifer (river seepage). Net SAS recharge and discharge is zero in white areas.**

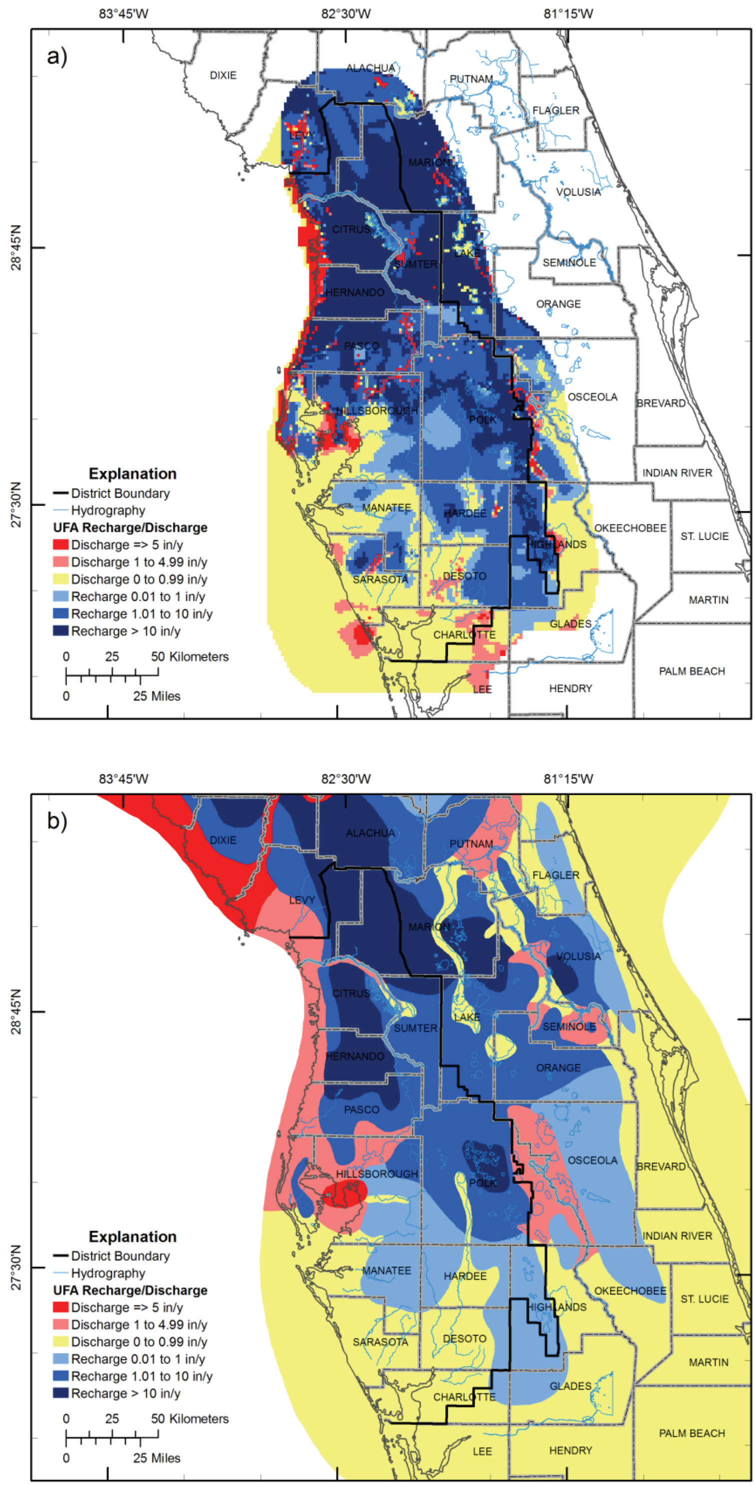

Figure 22 a) Simulated (DWRM2) and b) estimated UFA recharge and discharge in DWRM2. Estimated UFA recharge rates based on Aucott (1988). Data from Aucott (1988) represents pre-development conditions and are based on confining unit thicknesses from Miller (1986) and numerical modeling studies of Ryder (1985), Bush and Johnston (1988), Maslia and Hayes (1988), Krause and Randolph (1989), and Tibbals (1990).

Water Budgets

Simulated county water budgets for DWRM2 are summarized in Table 3. Boundary flows to coastal areas, to adjacent counties in the District, and to adjacent counties outside of the District are also summarized in county water budgets. In general, water budget terms are within expected ranges, except for specific water-budget terms in some counties (Table 3). Examples of analytical and numerical water budgets calculated for Florida watersheds can be found in Sumner (1999), and Swancar and others (2000), Knochenmus and Yobbi (2001), Spechler and Halford (2001), and Knowles and others (2002).

Net coastal flow in counties adjacent to the coast is shown in Figure 23a. Except for Pinellas County, net ground-water flow was to the coast. However, inflows from coastal boundaries were simulated in Charlotte, Citrus, Hillsborough, Manatee, Pasco, Pinellas, and Sarasota Counties. Except for Hillsborough and Pinellas Counties, coastal inflows were significantly less than coastal outflows. Coastal inflows are need to be carefully considered because it is expected that general ground-water flow direction in the ground-water system is towards the coast. Coastal inflows would appreciably affect the simulation of ground-water withdrawal impacts (specifically in FTMR model applications) near the coast.

Net recharge rates for counties within the District are shown in Figure 23b. Net recharge rates in Lake County are significantly less than rates for adjacent Sumter and Marion Counties. Net recharge rates in Highlands County are significantly higher than adjacent Desoto and Hardee Counties. Because of similarities in topography, soils, and confinement of the UFA, it is expected that net recharge in these adjacent counties would be similar. Net recharge in Pinellas County is significantly less than adjacent Hillsborough and Pasco Counties, but this difference is consistent with a higher degree of confinement in Pinellas County relative to Hillsborough and Pasco Counties.

Net inflow to coastal areas from constant-head cells is significant (75.14 in/y) and greatly exceeds both outflow to constant head cells and rainfall amounts. The majority of constant head inflows to coastal areas are discharge from river cells. Because of the magnitude of these flows, it is uncertain if they represent actual ground-water flow rates and it is expected that these boundary condition flows would limit the ability to use the model to evaluate the impact of ground-water withdrawals in the vicinity of coastal areas.

Table 3 Simulated county water budgets for DWRM2. Areas are in thousand-acres and only include the portions of the Counties within the model domain. All flows are in inches per year.

Northern Counties	Levy		Marion		Citrus		Sumter		Lake		Hernando	
Area	219.24		351.81		345.50		377.64		60.26		292.70	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Constant Head	0.00	0.00	0.00	0.00	2.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
River	1.11	0.28	0.18	0.03	1.27	1.08	0.40	1.61	1.66	0.24	0.87	1.97
Drain	0.00	1.34	0.00	13.28	0.00	17.03	0.00	5.95	0.00	0.00	0.00	8.67
GHB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Well	0.00	0.61	0.00	0.56	0.00	0.73	0.00	0.75	0.00	0.32	0.00	2.17
Net Recharge	8.34	0.00	14.79	0.00	18.42	0.00	12.71	0.00	4.66	0.00	17.47	0.00
Flow to Coastal Areas	0.00	0.54	0.00	0.00	0.43	10.45	0.00	0.00	0.00	0.00	0.00	14.18
Flow to Counties in SWFWMD	4.10	3.99	2.08	5.25	12.87	6.23	2.53	7.56	5.42	2.96	16.03	7.37
Flow outside of SWFWMD	1.43	8.22	4.81	2.75	0.00	0.00	1.75	1.52	1.74	9.96	0.00	0.00
Total	14.98	14.98	21.86	21.86	35.52	35.51	17.40	17.40	13.48	13.48	34.36	34.36

Central Counties	Pasco		Polk		Pinellas		Hillsborough		Manatee		Hardee	
Area	481.52		1,028.47		181.93		713.96		490.13		405.19	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Constant Head	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.18	0.00	0.00	0.00	0.00
River	1.10	3.62	1.31	2.33	0.13	3.28	0.81	4.94	0.20	2.64	0.10	3.03
Drain	0.00	0.81	0.00	0.95	0.00	0.13	0.00	1.40	0.00	0.51	0.00	1.16
GHB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Well	0.00	3.00	0.00	3.42	0.00	1.02	0.00	3.99	0.00	3.20	0.00	2.45
Net Recharge	11.07	0.00	9.86	0.00	3.33	0.00	7.90	0.00	4.06	0.00	6.72	0.00
Flow to Coastal Areas	0.07	0.95	0.00	0.00	2.12	1.31	0.24	0.66	0.65	0.40	0.00	0.00
Flow to Counties in SWFWMD	1.94	5.79	0.13	2.40	0.48	0.25	2.71	0.50	2.67	0.83	2.41	2.65
Flow outside of SWFWMD	0.00	0.00	0.09	2.30	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Total	14.18	14.18	11.39	11.39	6.06	6.06	11.67	11.67	7.58	7.58	9.29	9.29

Southern Counties	Sarasota		Desoto		Highlands		Charlotte		Non-SWFWMD		Coastal Areas	
Area	382.81		428.15		252.53		344.35		2,799.01		840.22	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Constant Head	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.90	0.42	75.14	1.02
River	0.17	4.60	0.11	3.27	2.62	1.77	0.08	6.68	0.43	1.39	0.23	84.01
Drain	0.00	1.01	0.00	0.93	0.00	0.88	0.00	1.59	0.00	3.72	0.00	2.44
GHB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	6.70	0.00	0.00
Well	0.00	1.40	0.00	2.91	0.00	3.41	0.00	0.78	0.00	1.03	0.00	0.06
Net Recharge	6.58	0.00	5.50	0.00	10.60	0.00	8.21	0.00	6.48	0.00	0.70	0.00
Flow to Coastal Areas	0.30	0.53	0.00	0.00	0.00	0.00	0.91	1.41	0.00	0.35	0.00	0.00
Flow to Counties in SWFWMD	1.61	1.13	1.56	1.18	0.07	1.36	0.45	1.17	2.85	1.51	11.82	1.77
Flow outside of SWFWMD	0.00	0.00	1.19	0.07	0.44	6.32	2.05	0.06	0.00	0.00	1.18	0.00
Total	8.66	8.66	8.36	8.36	13.74	13.74	11.69	11.69	15.12	15.12	89.05	89.30

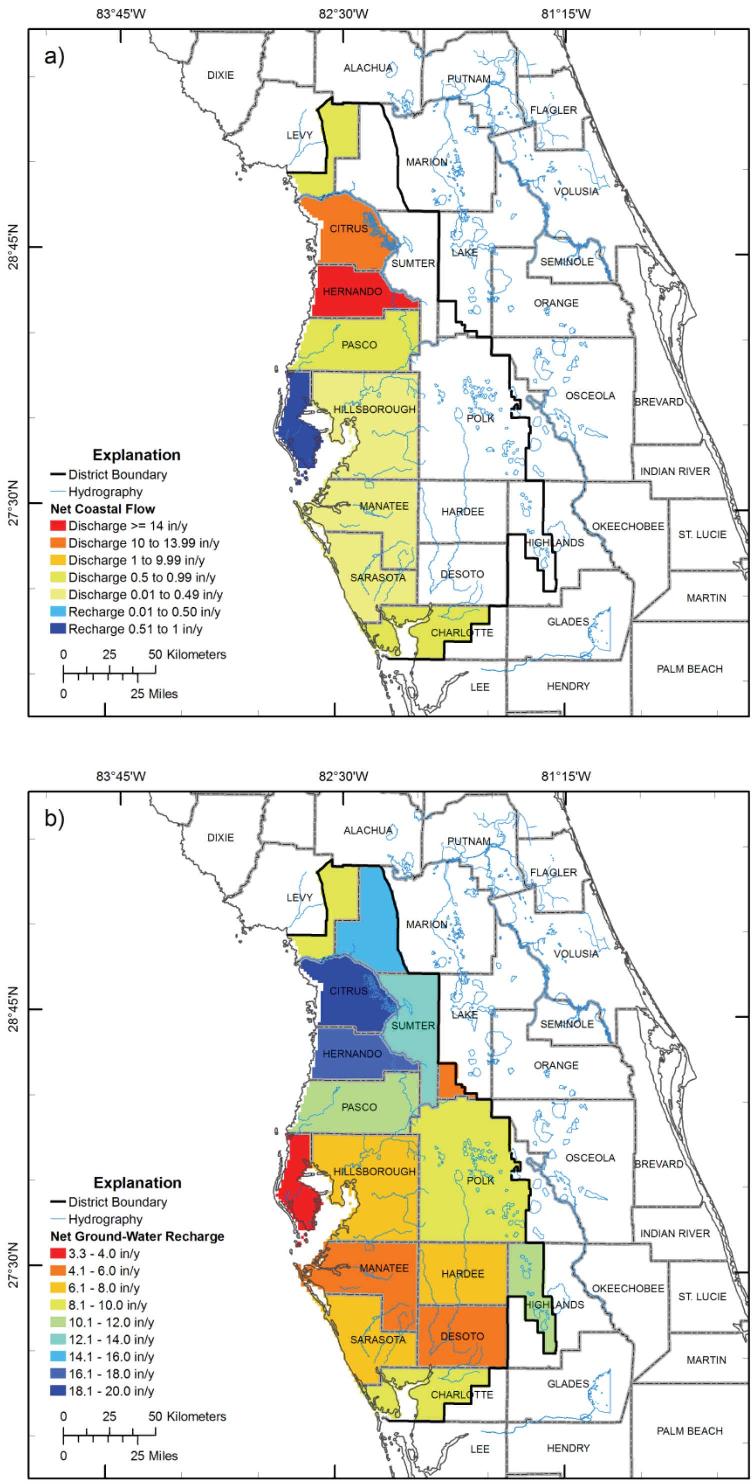

Figure 23 Simulated (DWRM2) county-wide a) net coastal flow and b) net ground-water recharge calculated from county water-budgets. County water budgets show there is a net contribution of water from coastal areas in Pinellas County and large differences in net ground-water recharge occur in adjacent counties.

Model Biases

Biases for the steady-state model have been briefly discussed previously and are summarized for the steady-state and transient models below.

Steady-State Model

DWRM2 is biased toward high values of simulated base flow, especially when simulated drain flow is also considered. DWRM2 is biased low for cumulative UFA spring flow. Simulated water levels do not appear to be biased, although there is a bias in simulated SAS-UFA water-level differences. Simulated SAS-UFA water-level differences are under-predicted at relatively high water-level differences corresponding to recharge conditions, and are over-predicted under discharge conditions (see Figure 17).

Transient Model

Transient water levels simulated in DWRM2, and presented in the appendices of ESI (2007), generally agree with observed water levels. However, for many of the observation wells, the total range of water levels over the transient simulation period was under-predicted in the UFA (model layer 4). Water levels were under-predicted during extremely wet periods and over-predicted during extremely dry periods. Examples of the transient response at two observation wells are shown in Figure 24 and 25. Temporal scaling of steady-state recharge based on monthly rainfall may contribute to errors in transient model responses (see **Recharge and Evapotranspiration** section).

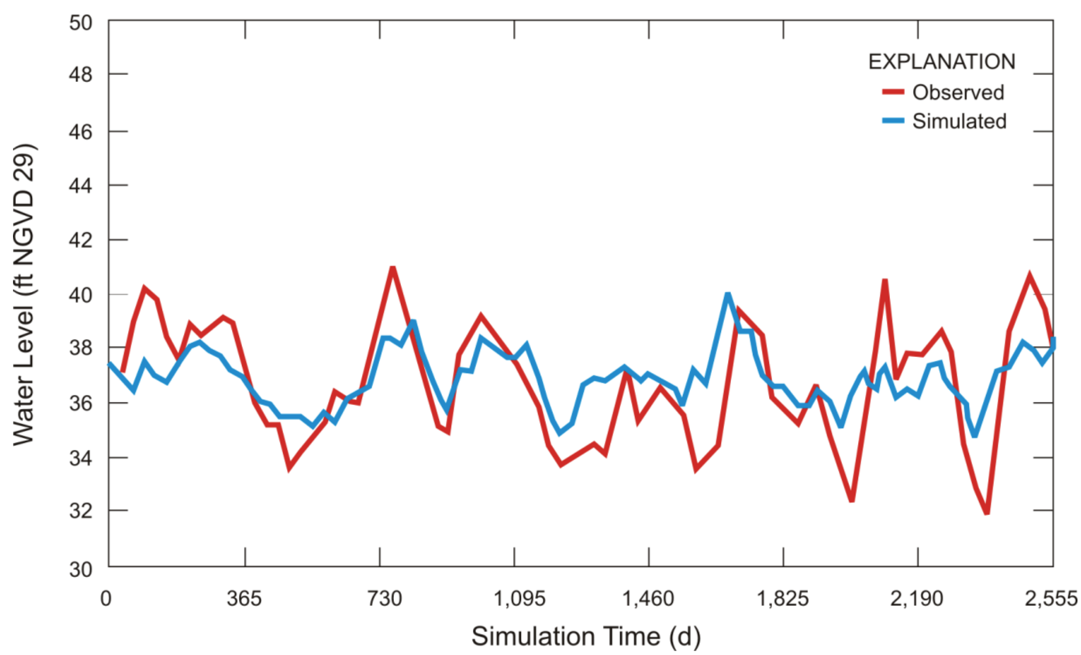

Figure 24 Simulated (DWRM2) and observed transient UFA water levels at STWF-1A-East.

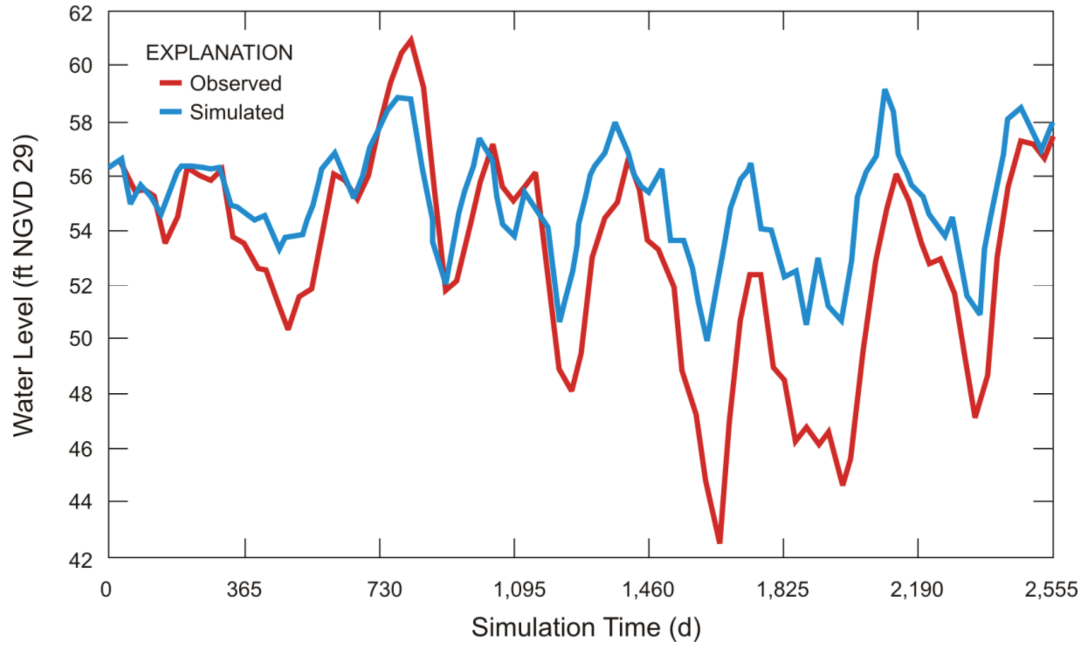

Figure 25 **Simulated (DWRM2) and observed transient UFA water levels at ROMP 59-SWNN-AVPK.**

Simulated ground-water/surface-water exchanges were manually adjusted during the calibration process as reported in ESI (2007). Base flow, calculated using base flow separation techniques and documented in Geurink and others (2000), and spring flow targets for many of the major river basins were not adequately reproduced and, in most cases, the simulated flows exceeded the estimates derived from the observed data. It is important to match as many of the external flow terms (for example, constant-head flow rates) as possible for accurate model simulation and to improve predictive capacities for FTMR applications.

Model Sensitivity

Model sensitivity was evaluated using scaled sensitivities calculated as part of the automatic calibration process, and a standard sensitivity analysis. An interpretation of the scaled sensitivities was not included in DWRM2 documentation (ESI, 2007). This interpretation could be valuable for identifying aquifer units where observed water levels and flows are not providing sufficient information to support highly parameterized aquifer properties in the SAS, PZ2, PZ3, UFA, and LFA (model layers 1, 2, 3, 4, and 5, respectively).

A traditional sensitivity analysis, based on independent adjustment of select model parameters, was performed on DWRM2 for the hydraulic conductivity of the SAS (Kx1), transmissivity of the PZ2 (Kx2), transmissivity of the PZ3 (Kx3), transmissivity of the UFA (Kx4), leakance between SAS and PZ2 (Leakance1), leakance between PZ2 and PZ3 (Leakance2), leakance between PZ3 and UFA (Leakance3), recharge (Recharge1), boundary conductance for minor streams (River Cond0), boundary conductance of major rivers (River Cond1), and boundary conductance of intermediate rivers (River Cond2). An analysis of sensitive parameters identified with the traditional sensitivity analysis is presented in ESI (2007).

Because of the importance of storage parameters in FTMR applications, these parameters should also be included in the sensitivity analysis. At a minimum, storage parameters of the SAS and UFA should be evaluated.

Particle tracking analysis in coastal areas

Particle tracking analyses are commonly performed to evaluate capture zones for pumping wells and general flow directions (Pollock, 1994). In a three-dimensional (3D) ground-water flow model, particle tracks can be used to characterize 3D advective transport of particles in a ground-water flow field and travel times if the porosity of the aquifer unit represented in the model is properly characterized. If adequately characterized, particle tracking could be used to evaluate the effect of ground-water withdrawals on particle tracks. One potential use of particle tracks in DWRM2 is to evaluate the movement of the freshwater/saltwater interface under different pumping scenarios. An assumption of this potential use is that a landward shift of particle tracks under increased ground-water withdrawals can be used as a surrogate for landward movement of the freshwater/saltwater interface. This approach is complicated by use of equivalent freshwater heads in coastal areas of DWRM2.

Forward particle paths in coastal areas of the model for pre-development conditions are shown in Figure 26. Particle paths in the vicinity of Tampa Bay and the SWUCA do not appear to be consistent with expected flow directions; paths appear to be adversely affected by UFA water levels that are lower in these areas than in surrounding areas as a result of differences in leakance parameters or equivalent freshwater heads (see Figure 13).

It is not reasonable to use particle tracking analysis with DWRM2 to evaluate changes in the position of the freshwater/saltwater interface resulting from ground-water withdrawals. Large boundary condition flows in coastal areas and use of equivalent freshwater constant heads offshore appreciably contribute to the limitations of the application of particle tracking analysis. It is possible that model parameters and boundary conditions could be revised to simulate more realistic particle tracks in coastal areas. Because use of equivalent freshwater heads in MODFLOW simulations does not account for buoyancy effects in the ground-water flow equation solved during simulation, inherent limitations to accurately simulate flow in coastal areas always will result.

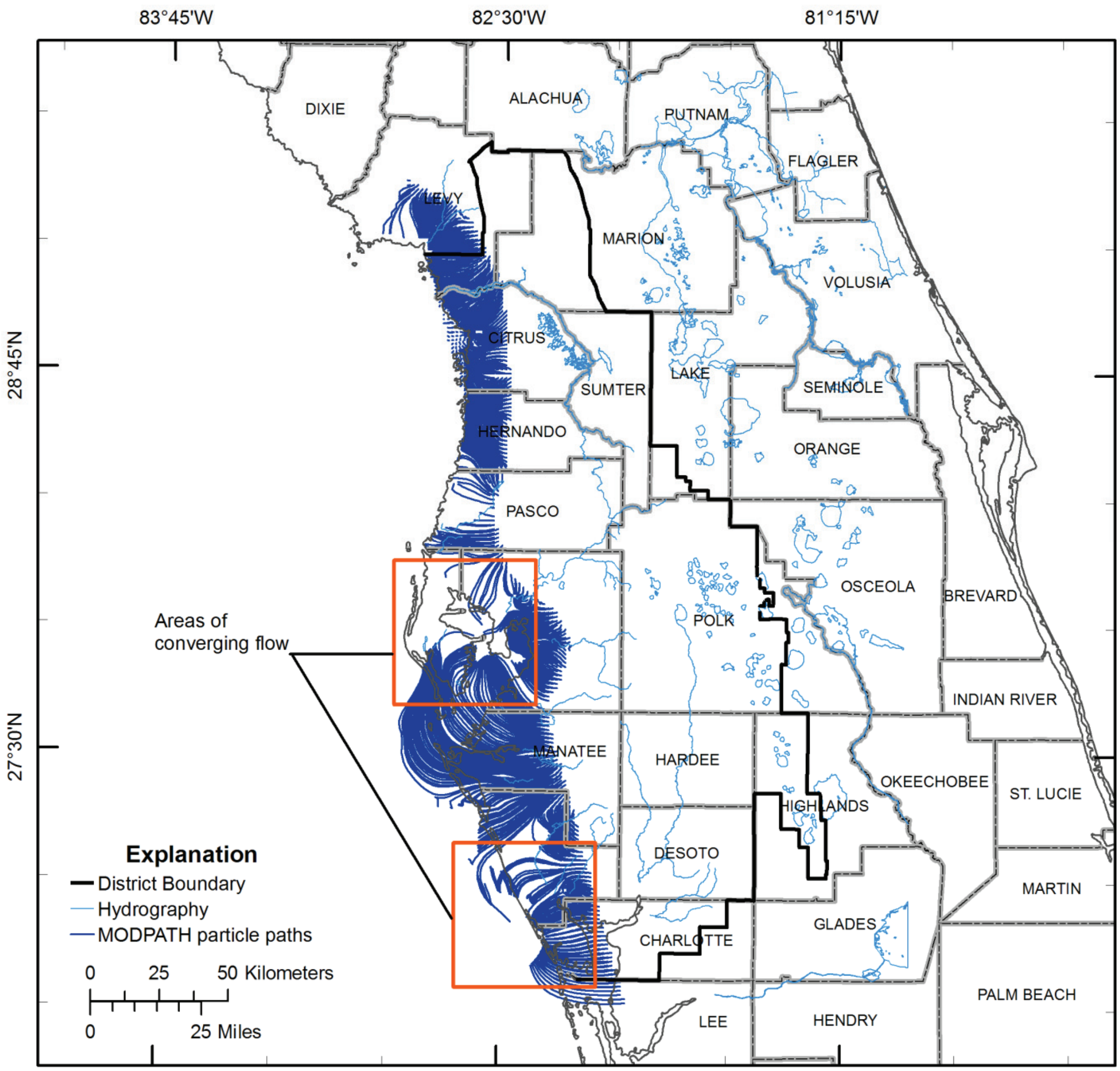

Figure 26 Simulated particle paths in coastal areas of DWRM2 under predevelopment conditions. A forward particle tracking analysis was performed and particles were released at the center of select UFA finite-difference cells approximately 10-15 miles from the coast. Two areas where particle paths are converging in offshore areas are highlighted by orange boxes.

Post audits of DWRM2

Post audits of ground-water flow models require a sufficient length of time from when a simulation is run to when additional field data are available to compare the simulation to the prediction. Post audits should be completed once sufficient field data have been accumulated to warrant such a comparison. For DWRM2, predictions of water levels and ground-water/surface-water exchanges are made for at least a year after the start of pumping. It may take for example, 5-10 years for permitted withdrawals to affect ground-water levels or ground-water/surface-water exchanges. For this reason, it is unlikely that post audits would be completed on an interval less than 2-3 years, and probably longer. However, it may become apparent that model predictions are not matching field results in some parts of the District on a time scale less than 2-3 years. In this case, re-evaluation of the model in those areas would be

appropriate. Whenever large scale APTs are completed within the District, the FTMR procedure should be applied and the model response compared to the APT results. This analysis would allow re-calibration of DWRM2 in areas when additional APT and water-level data become available.

Verification of DWRM water levels or flows does not require comparison of predictions with actual water-level and flow responses in order to improve the model response. For example, particle tracking analysis described in the previous section shows that ground-water flow patterns in the vicinity of the coastal boundary may be inaccurate. Improvements in the seaward boundary condition can be evaluated through examination of particle tracks and ground-water and boundary condition flow rates. Similar evaluations could be performed using other model results and qualitative hydrogeologic data such as UFA recharge and discharge rates, and other data.

Focused Telescopic Mesh Refinement Models

Water budgets were calculated for two focus areas of DWRM2 to evaluate the FTMR process (Figure 27). Comparison of water budgets for DWRM2 and two FTMR models is summarized in Table 4 and 5. DWRM2 water budgets were calculated using functionality available in GWV. FTMR water budgets are based on water-budget information in the MODFLOW listing (*.lst) file for the FTMR models. Water budgets were calculated for DWRM2 cells within the constant-head boundary cells in the FTMR models. DWRM2 water budgets were calculated for these areas because MODFLOW water-budgets exclude boundary conditions (for example, recharge, wells, rivers, and drains) in constant-head cells. Water budgets were compared for 2001 conditions (stress period 2) in both the regional DWRM2 and local FTMR models.

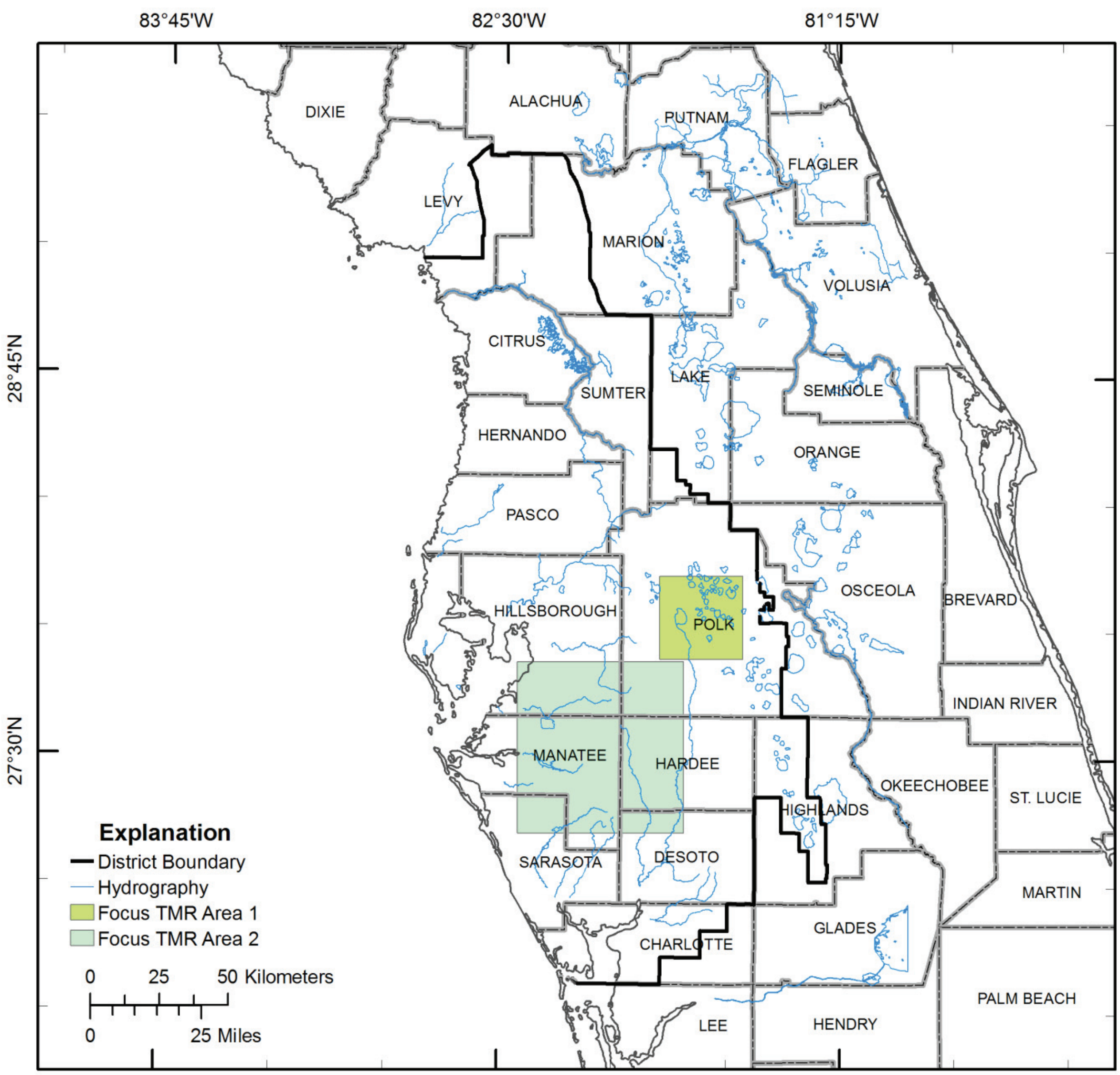

Figure 27 Areas where DWRM2 and FTMR model water budget comparisons were performed.

Differences in water-budget components between DWRM2 and the FTMR models are greater than expected; it is expected that ground-water withdrawals would be identical and other water budget components would be within ±10% of each other. Significant differences were observed between river, drain, and boundary condition flow in the DWRM2 and FTMR models; if differences in boundary condition flow rates exceed differences in proposed ground-water withdrawals it is questionable how reliable FTMR models will be in evaluating ground-water impacts. The overall FTMR water budget for Area 1 (Table 4) was closer to the DWRM2 water budget than for Area 2 (Table 5), although there were significant differences in river and aquifer-drain flow for Area 1.

It is difficult to determine how much of the differences in flow rates are a result of non-coincident grid extents and differences in boundary conditions (river stages and conductance). Reducing the potential sources of differences between the base DWRM2 and FTMR models as well as improving the FTMR process is discussed below.

Table 4 **DWRM2 and FTRM water budgets for FTMR Area 1 (see Figure 27). Positive %-differences indicate water budget components in DWRM2 are less than water budget components in the FTMR model. Negative %-differences indicate water budget components in DWRM2 are greater than water budget components in the FTMR model. FTMR Area 1 in DWRM2 is 8.1 x 10^9 ft^2; FTMR Area 1 is 7.94 x 10^9 ft^2; NA, Not Applicable.**

	FTMR Area 1					
	DWRM2		FTMR		Differences	
Water- Budget Terms	Inflow, in/y	Outflow, in/y	Inflow, in/y	Outflow, in/y	Percent Difference Inflow	Percent Difference Outflow
River	1.88	2.66	1.83	2.26	-2.95	-14.94
Drain	0.00	1.62	0.00	2.29	NA	40.74
Lake	0.00	0.00	0.11	0.11	NA	NA
Well	0.00	3.54	0.00	3.60	NA	1.72
Recharge	10.98	0.00	11.03	0.00	0.40	NA
Boundary	2.32	7.36	2.39	7.10	3.27	-3.51
Total Flow	15.18	15.18	15.25	15.25	1.18	1.16

Table 5 **DWRM2 and FTRM water budgets for FTMR Area 2 (see Figure 27). Boundary flow in DWRM2 includes 0.05 in/y of outflow from constant-head cells in Tampa Bay. Positive %-differences indicate water budget components in DWRM2 are less than water budget components in the FTMR model. Negative %-differences indicate water budget components in DWRM2 are greater than water budget components in the FTMR model. FTMR Area 2 in DWRM2 is 3.71 x 10^{10} ft^2; FTMR Area 2 is 3.64 x 10^{10} ft^2; NA, Not Applicable.**

	FTMR Area 2					
	DWRM2		Focus TMR		Differences	
Water-Budget Terms	Inflow, in/y	Outflow, in/y	Inflow, in/y	Outflow, in/y	Percent Difference Inflow	Percent Difference Outflow
River	0.09	3.22	0.95	3.94	945.19	22.32
Drain	0.00	0.99	0.00	0.98	NA	-0.90
Well	0.00	3.32	0.00	3.17	NA	-4.63
Recharge	6.14	0.00	6.13	0.00	-0.03	NA
Boundary	1.85	0.54	1.69	0.68	-8.97	25.60
Total Flow	8.08	8.08	8.77	8.77	8.60	8.60

In DWRM2, the head-dependent boundary conditions, such as river cells and drains, do not downscale with appropriate spatial resolution. River cells have fixed conductances rather than conductances calculated from river reach dimensions. If rivers are entered into DWRM2 from a GIS database, conductances can be calculated from a lookup table based on a conventional stream ordering scheme (for example, Strahler stream order) that contains characteristic river width and depth attributes. The reach length can be calculated from the stream segments in the GIS database. When river cells are downscaled to the local grid, the river conductances in each smaller, local model river cells can be calculated from reach length in the local cell and the stream-order based variables in the lookup table. This calculation should help prevent river cells in FTMR models from having an unrealistically large effect on calculated drawdown in the SAS. This approach is discussed in more detail in the “**Rivers and Drains**” section above.

At present, the FTMR grid is centered on a local center, such as a well, and then expanded appropriately. The result is that the local and regional grids do not necessarily coincide at the local model boundaries, and usually will not coincide. This non-coincidence can result in the mass balance of the equivalent area in the regional model not being conserved in the FTMR local model as indicated in Tables 4 and 5. If the center of the local grid were shifted to the nearest cell centroid of the regional grid, along with user-defined fixed grid expansion options, then the boundaries of the FTMR model could be made to coincide with the regional grid-cell edges. This approach would make assignment of boundary heads, specified boundary conditions, and head-dependent boundary conditions in the FTMR model more representative of simulated results in DWRM2. It would also help to preserve the mass balance between the corresponding areas of the regional and FTMR models. It is difficult to assess the effectiveness of the FTMR model in simulating the effects of proposed withdrawals if the mass balance of the regional DWRM2 model is not reasonably conserved when downscaling to the local FTMR model.

With regard to temporal scales, there is some uncertainty about the appropriate length of the simulation period of the FTMR models. Discussions with District staff suggest that a simulation time of one year is common, unless the model user feels that effects on the SAS have not yet reached a dynamic steady-state after one year. It is suggested that the District establish general guidelines for simulation times in transient simulations so that there is consistency when assessing the effects of a proposed withdrawal on the SAS, other aquifers, and surface-water features. For example, in Pasco and northern Hillsborough Counties, model results indicate that UFA water levels respond to new stresses on a scale of hours to days, whereas the full response of the SAS to new stresses in well-confined portions of the UFA may require a simulation time of over a year.

Regardless of whether the FTMR approach is revised, a water-budget analysis of the regional and FTMR model similar to the ones presented above should be included in the standard report generated as part of the FTMR process. A water-budget analysis will give users of DWRM2 the ability to evaluate if FTMR results are reasonable and adequate. For example, the user may find that differences in boundary condition flow rates are more than 10%. This result may indicate that the extent of the FTMR model should be expanded. The District should define general guidelines for acceptable differences in water-budget terms between the DWRM2 and FTMR models.

Model Documentation

Documentation was developed for DWRM Version 1 (DWRM1 – ESI, 2004) and Version 2 (DWRM2 – ESI, 2007). The intended use of DWRM2 is not fully defined in the documentation. The intended uses (model objectives) of DWRM2 have been provided to the Peer Review Panel, are summarized in the previous sections, and should be fully articulated in the documentation for DWRM2. Expected or known model limitations are not discussed in the documentation. Model limitations should be explicitly defined to prevent future model users from applying the model to applications outside of the expected model uses without additional data, evaluation, and/or model calibration.

Neither of the present documentations completely describes DWRM2, but, taken together, these two documents describe model development, calibration, and sensitivity analyses. Because DWRM2 documentation builds on the DWRM1 document, both need to be reviewed to fully understand the origin, development, and calibration of the current model. However, because there are major differences between the two versions, it is possible to confuse the approach used in DWRM2 with that used in DWRM1. It is suggested that a comprehensive stand-alone document be developed. The comprehensive document should fully describe Version 2. This document should only include a discussion of the different approaches used in Version 1 if there is a need to describe why one viable approach was selected over another (for example*,* use of pilot points with a regular or irregular grid spacing).

In general, figures in the documentation for DWRM1 and 2 are adequate. Explanations on many figures (for example *DWRM2 Figure 2.6 and DWRM2 Figure 7.1*) should be improved to make the figures more self-explanatory. The tables in the documentation for DWRM1 and 2 are adequate. Data source abbreviations listed in *DWRM2 Table 3.1* should be defined at the end of the table. *DWRM2 Table 3.2* lists weights for spring targets but the text (§3.4) indicates that spring flow targets were not weighted; the spring targets weights should be removed from *DWRM2 Table 3.2* or defined in the text (for example*,* weights used in Sepulveda (2002)). Where appropriate, units should be specified on figures and tables (for example*, DWRM2 Figure 3.14 and DWRM2 Table 3.1*). Water-budget tables (*DWRM2 Tables 4.1 and 4.2*) should be presented in units of inches per year (in/y).

ESI (undated) has prepared a tutorial that explains how to use the FTMR features that are part of GWV with DWRM2. The tutorial is easy to follow and highlights the functionality of the FTMR model for processing permit applications in the SWFWMD. Installation of the file swfwmd.org in the GWV installation directory to activate FTMR functionality is not detailed in the tutorial; this detail should be added to facilitate the application of the FTMR model outside of the SWFWMD. The tutorial is not dated and a version number has not been assigned to the document; this information should be added to the tutorial.

During the peer review process, development of two separate volumes for the DWRM documentation has been discussed and is recommended. The two documents would include the following:

1) Model Development Report
2) User's Guide - Information needed by users of the DWRM for permit applications.

Completion of the two documents would likely benefit the SWFWMD and end users of the model. The Model Development Report would contain information on model background, development, and calibration and be comparable to the current DWRM2 documentation. For typical permit applications, end users could rely primarily on the User's Guide that provides them with pertinent information for developing a FTMR model for a specific permit, the FTMR utility tutorial, and information on boundary conditions that might need to be modified as part of the FTMR process. It is likely that the User's Guide would need to be modified more frequently than the Model Development Report to include a description of additional functionality or approaches to applying the FTMR process to SWFWMD permit applications. Modifying only the User's Guide will limit the effort associated with updates.

Conclusions

Overall, DWRM2 represents an improved approach over previous ground-water regulation flow models developed in the District for evaluating permit applications in the District. The conceptualization has been improved over the approach used in previous models and includes active simulation of the SAS, use of recent hydrostratigraphic data developed by the Florida Geological Survey, and use of APT data reviewed by the District to constrain hydraulic parameters during the automatic calibration process. The FTMR process represents a unique approach to develop local-scale (FTMR) models for individual permit applications from a calibrated regional scale model (DWRM2).

After review of DWRM2 relative to the stated objectives of the model, the panel has determined that:

In general, the ability to assess impacts to the SAS and surface-water features may be limited in areas with high errors and/or appreciable boundary condition flow from rivers, springs, or conceptual drainage features. Until the calibration of the river cells is improved and drains removed, simulation of impacts to surface-water features (rivers, and other features) will not be accurate.

Lack of data may limit the ability to verify model predictions for permeable units of the intermediate aquifer (PZ2 and PZ3). The approach used in DWRM2 of assuming that PZ2 and PZ3 are laterally continuous may be best considering the data limitations, but this assumption would reduce local impacts and increase the regional impact of ground-water withdrawals in these units.

DWRM2 is appropriate for evaluating ground-water withdrawal impacts in the UFA. No calibration data are available for the LFA; as a result, the model can likely only be used to qualitatively assess impacts in the LFA. Because DWRM2 over-predicts UFA base flow and spring flow, its use to evaluate impacts to ground-water/surface-water exchanges resulting from ground-water withdrawals is likely limited in the vicinity of head-dependent boundary conditions with appreciable flow. DWRM2 would require additional calibration to improve model simulation of base flow and spring flow.

There is no basis for an assumption that the current DWRM2 could be used to evaluate ground-water quality changes; this evaluation would require development of appropriate parameters (porosity, dispersivity, and other parameters) and calibration of the transport model components. Because of relatively large flow rates near the coast resulting from specified equivalent freshwater heads and coastal boundary conditions, particularly in the SWUCA, DWRM2 is not suitable to perform particle tracking analysis along the freshwater/saltwater interface.

Although the DWRM2 and the FTMR process represent a major improvement over approaches used in the past and the model is generally well suited for evaluating impacts to UFA water levels, there are some specific changes that should be implemented to improve the capacity of the model to evaluate impacts to SAS water levels and ground-water/surface-water exchanges. Specific high-priority issues that should be addressed include 1) modification of the approach used to apply net ground-water recharge data from Geurink and others (2000) or Integrated Hydrologic Model (IHM) results; and 2)

incorporation of base flow, spring flow, DTW data, and SAS-UFA water-level difference data as calibration targets in the automatic calibration process.

A number of lower priority issues for improving the DWRM2 and FTMR approach also could be addressed. Proposed improvements, in order of priority, include 1) adoption of a consistent GIS-based, grid-scale independent approach to assign river boundary condition parameters based on a defined stream ordering scheme in the DWRM2 and FTMR model process; 2) adoption of a GIS-based, grid scale independent approach for defining UFA springs in the DWRM2 and FTMR models; 3) improvement of the approach for assigning base elevations for SAS boundary conditions; 4) removal of conceptual drain boundary conditions used to control water levels above land surface; 5) addition of DWRM2 and FTMR water-budget comparisons to standard reports generated by the FTMR process; 6) development of a comprehensive Model Development Report and a User’s Guide for FTMR model applications; and 7) incorporation of recently collected high resolution land-surface elevation data (for example, LIDAR data) in the DWRM2 and FTMR models.

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