Integrated Hydrological Modelling for Water Management in Southwest Florida

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Abstract

This paper describes application of integrated surface-ground water model MIKE SHE (MS) in support of water supply planning, basin water management, sustainability of natural resources and ecosystem maintenance in south Florida watersheds. A brief description of applied models at different sites is provided to illustrate the flexibility of integrated models to describe various hydrologic settings and management schemes in relation to basin water resource assessment. A more detailed discussion of two of the models (TCRB and PSRP) at a rapidly urbanizing site in southwest Florida will be presented. TCRB implementation includes various land uses (13), irrigation routine, surface water abstraction, groundwater withdrawal (public water supply), and control structures to manage flooding/water supply and ecosystem needs.

MIKE SHE is a deterministic, distributed and physically based modelling system for simulation of hydrological processes in the land phase of the hydrological cycle. The model is applicable to a wide range of water resources and environmental problems related to surface water and groundwater systems, and the dynamic interaction between the two regimes. The modelling package comprises a number of pre- and postprocessors to facilitate the input of data and the analysis of simulation results; among others are: spatial interpolation routines; graphical editing; and plots of the variations in space and time of any variable, as well as animation tools.

MIKE SHE simulates the variations in hydraulic heads, flows and water storage on the ground surface, in stream/rivers, and in the unsaturated and saturated subsurface zones. The spatial variation of meteorological data and watershed characteristics are represented in a network of grid squares. Within every grid square the soil profile is divided into a series of vertical layers. The model structure and components are illustrated in Figure 1 below.

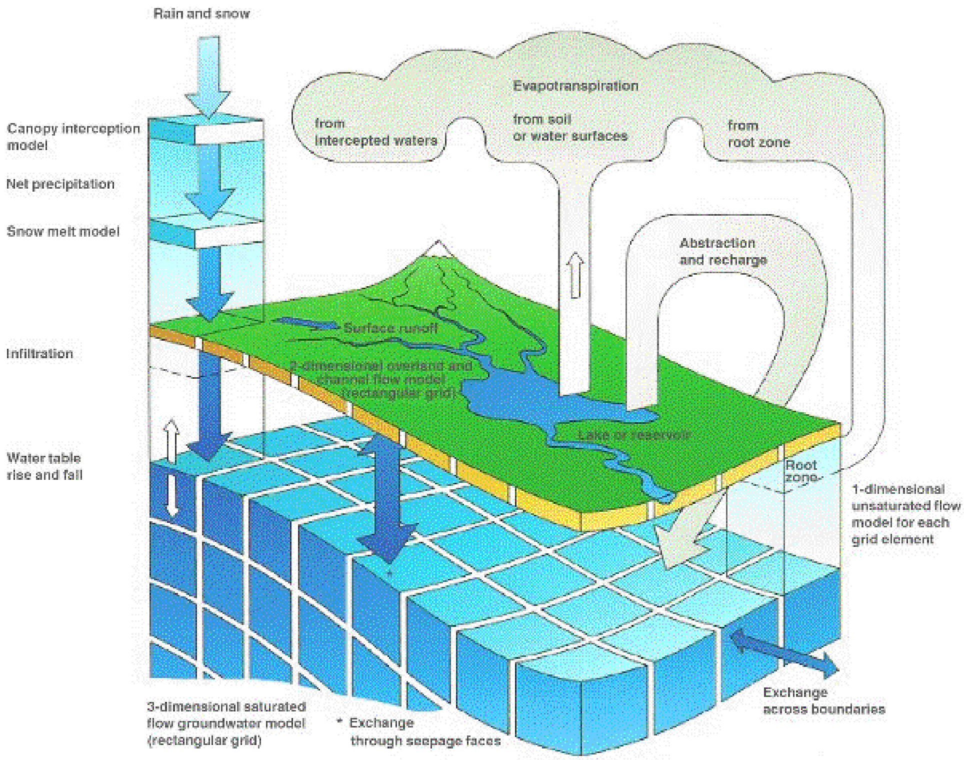


Figure 1: The MIKE SHE Model Structure

INTRODUCTION

MIKE SHE (MS) has been applied in four basins in southwest Florida to assess flooding issues of urban high water table areas, water supply management for both urban and agriculture, and sustainability of natural resources for developments and analysis of alternative scenarios for environmental restoration. The basins modelled include Tidal Caloosahatchee River Basin (TCRB), Estero Bay (EB), Big Cypress Basin (BCB), Freshwater Caloosahatchee (C-43), and the Picayune Strand Restoration Project (PSRP). Modelling results will be presented for a couple of the basins (TCRB) and PSRP to illustrate the model's capability for conjunctive use/management of regional water resources and environmental restorations. The extent of each model and the overlapped areas among the models are shown in Figure 2 below.

AS shown in the figure the physical needs are the basis for individual model boundaries. There are surface and/or groundwater features that require establishment of the individual model boundaries for proper characterization and representation of the flow systems. During the course of the project the modelers noticed that specification of boundary condition had profound effect on simulation results especially for monitor wells close to the boundaries. To improve calibration of sub-models, later the four models were merged to develop a regional model that can be used to simulate regional behavior and develop more accurate boundary conditions for sub-models. Future improvement of sub-models

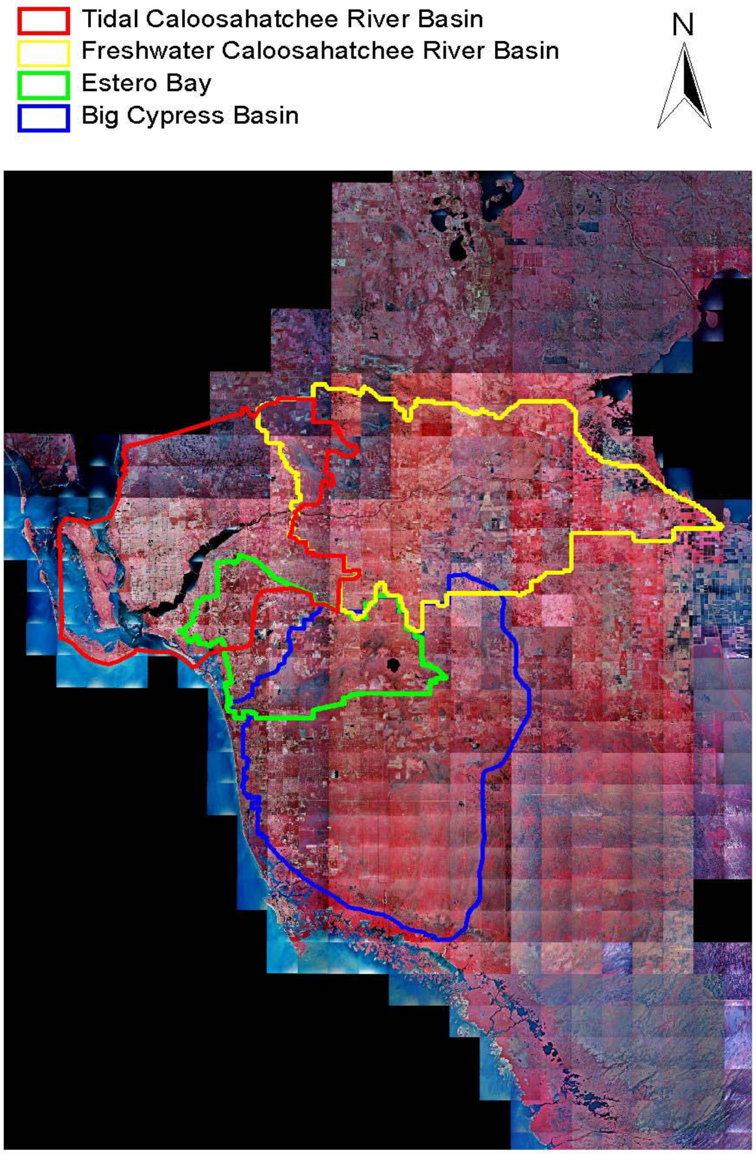


Figure 2: Model Boundaries in MIKE SHE Applications

is being considered using results from the regional model. The process of merging the smaller domain model into a larger regional model is a fairly straight forward procedure in the MIKS SHE modeling environment. All of the models use the same temporally and spatially varied data base for rainfall and ET, and spatially variable hydrogeology and soil/vegetation properties. These data are grid based and individual models use these data based on their domain size. There are tools that allow merging of surface water networks, irrigation command areas, and other hydrologic and soil property databases. The model also has advanced modules for routine tasks of database manipulation, extension, and reduction to meet the needs of users. It also has extensive links with GIS and allows conversions of GIS shape files and MIKE SHE grid files (dfs2). This features enables the users to use regional shape files and make sub-regional shape files to go from a larger scale model to a smaller scale model and vice versa. Since the GIS shape files and MIKE SHE dfs2 files that represent the grids (where the calculations are made), allow convertibility, this option facilitates database construction for any change in the model domain going from a smaller to a larger scale or larger to a smaller scale. In a recent project there was a need for a more detailed assessment of surface water features for restoration activities in the Everglades of South Florida. The existing regional model had a coarse grid (1500 feet) that was not suitable for detail analysis of design storms (100-year) to assess the effect of spreader canals that would distribute flows during such events for extending the wetland hydro-periods and impact of channel plugs on restoration plans. Reduction of model grid size from 1500 feet to 750 feet would be computationally prohibitive as well as economically infeasible because of a need for new topography maps for the larger domain. However, using a smaller domain model that focused on the region in question would allow faster and less costly efforts in field works for a refined topography map and shorter simulation time using boundary conditions from the larger model to analyze flow dynamics in the smaller domain model. The following figure shows the domain of both models. As can be seen the model's foot prints are within the BCB domain shown above and a couple of iterations were required to firm up the final PSRP domain. In the following sections, the calibration results from these models are presented.

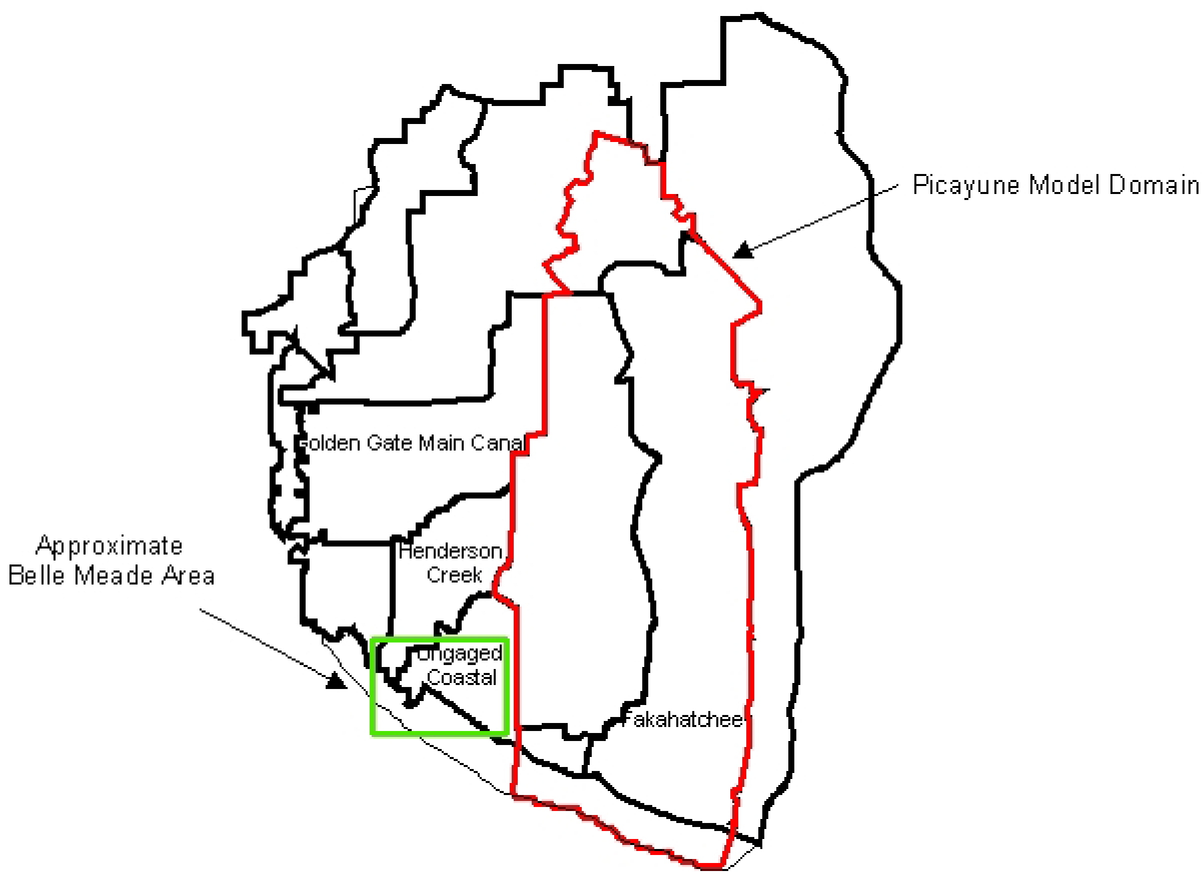


Figure 3: BCB Model Domain and the PSRP sub-model Domain

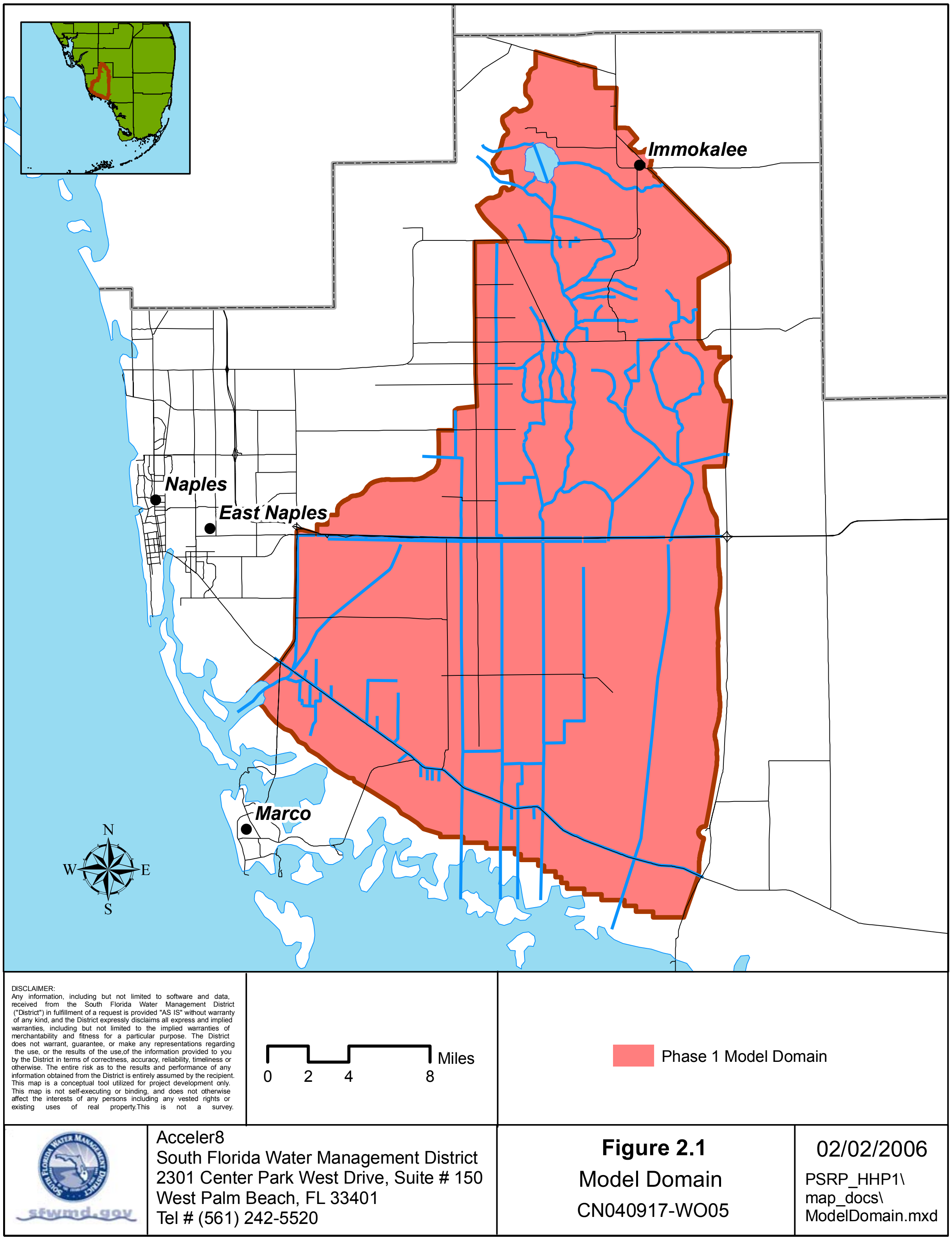


Figure 4: Final PSRP Model domain after inclusion of Belle Meade and Henderson Creek

DESCRIPTION OF TCRB MODEL

The TCRB model domain covers the Caloosahatchee River basin downstream of the Franklin Lock. The objective of the project was to develop a simulation model that incorporates major components of the water budget in the hydrological cycle including: precipitation, irrigation, evapotranspiration, runoff, flow control structures, lakes, rivers and canals, groundwater flow, and urban water supply impacts to the aquifers. The boundary of the model is shown in the Figure 2 above in red.

Surface water from the upstream portion of the Caloosahatchee River basin (C-43) is discharged to the TCRB at the Franklin Lock, which separates the freshwater and saline water parts of the basin. The TCRB model domain covers a little less than approximately 400 mi^2 (1,036 km^2). The TCRB model domain may be further subdivided into six major sub-basins, as described and shown in Figure 5 below.

The MS model of the TCRB is capable of simulating the following major flow processes:

- Overland sheet flow and depression storage
- Infiltration and storage in the unsaturated zone
- Dynamic exchange between the unsaturated zone and groundwater (recharge)
- Dynamic exchange between aquifers and rivers/canals (seepage)
- Groundwater flow, storage and potential changes in head
- River/canal and floodplain flow and water levels
- Evapotranspiration losses
- Effects of drainage
- Effects of irrigation water allocation
- Dynamic flow exchange between floodplains, rivers, overland and wetlands.

The Saturated Zone (SZ) components of all models consist of three calculation layers. The calculation layers contain the following geological layers:

Layer 1:
- Holocene
- Pliocene Pinecrest
- Ochopee Limestone, where Bonita Springs Marl is not present
- Bonita Spring Marl confining layer

Layer 2:
- Lower Tamiami aquifer (Ochopee Limestone where Bonita Springs Marl is present)
- C1, confining layer between LT and SS

Layer 3:
- Sandstone aquifer (net confined sand)
- C2, confining layer between SS and Mid-Hawthorne (MH)

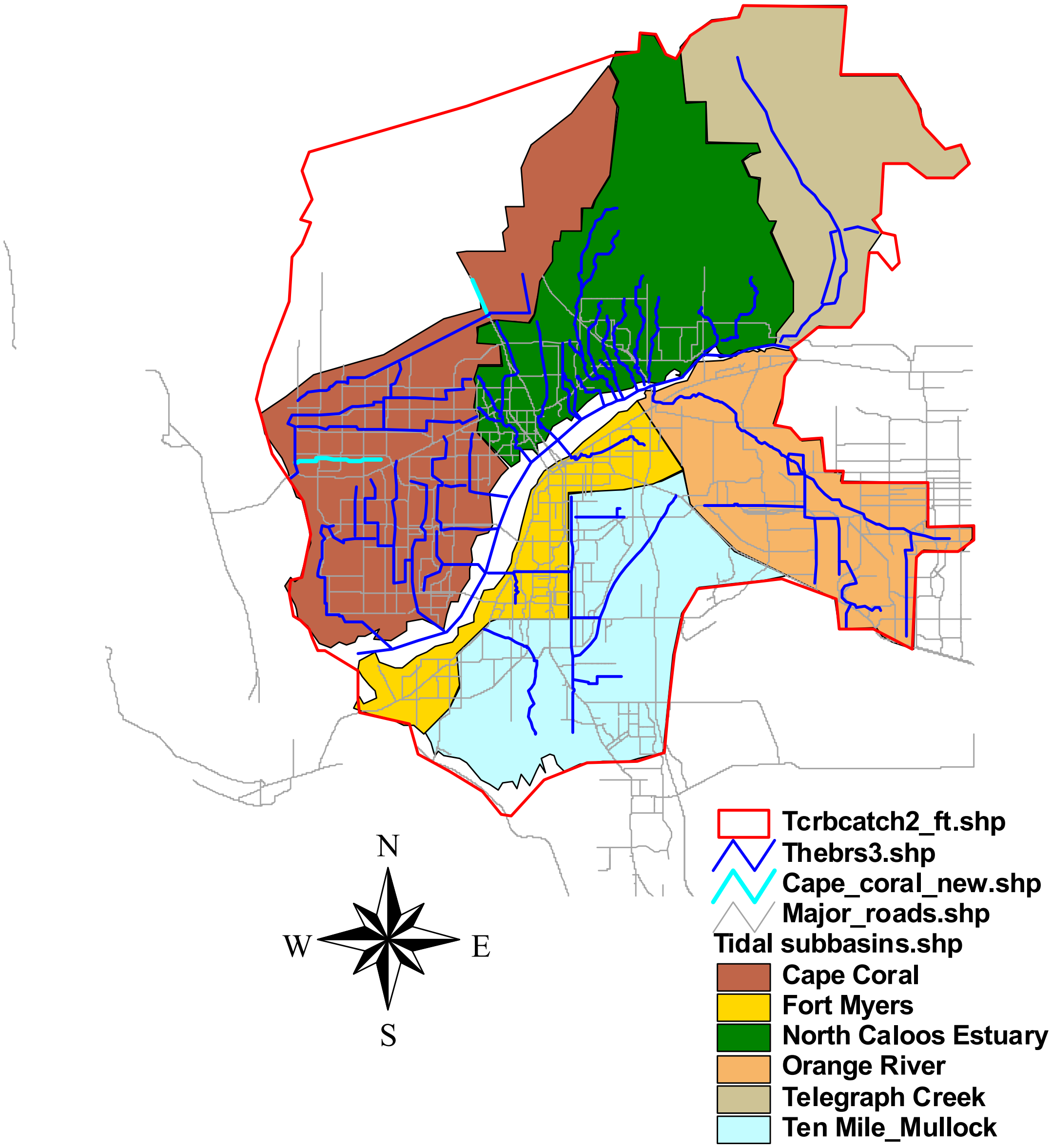


Figure 5: TCRB Surface Water Network and Individual Sub-Basins

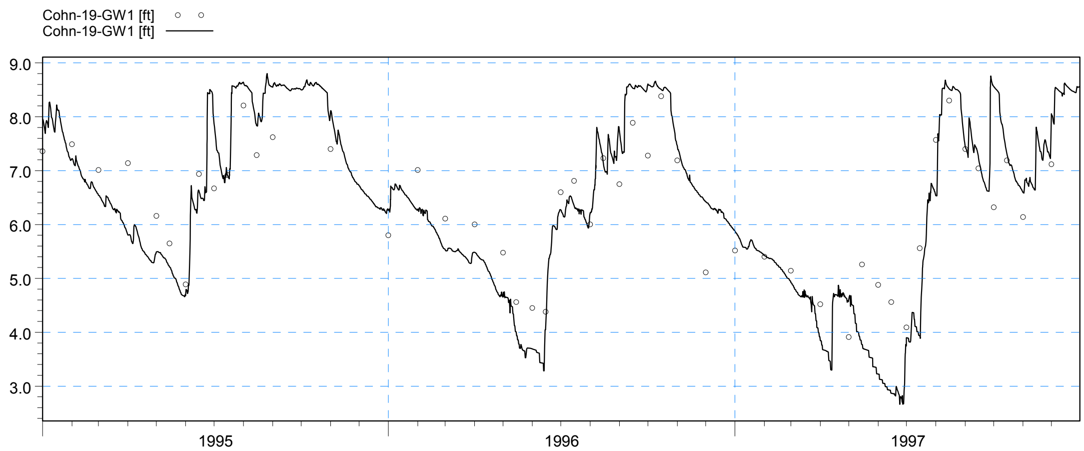
TCRB CALIBRATION

The calibration process of integrated model TCRB consists of modifying model parameters and coefficients to improve the correlation between the measured and predicted parameter values. For the Surface Water component the quality of calibration often relies on comparisons of measured and simulated flow relative to the following:

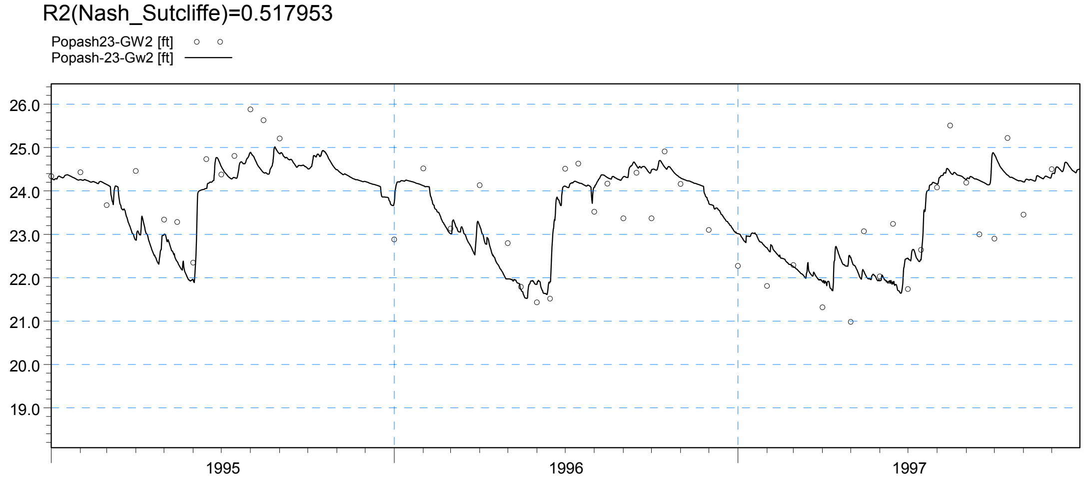
- Magnitude and timing of stage and discharge
- Accumulative discharge
- Canal and river stage

- Flow recession and low-flows
- High flows in general
- Simulation of peak flows for specific events

For integrated models, the surface water results is expected to be better correlated than single regime models because of the dynamic links between the groundwater and surface water components of the system, especially in high water table regions. Groundwater and surface water calibration plots are show below for a few of the stations. For many of the calibration stations the metrics are within the accepted range established for the project. The metrics for the validation period (1998-2000) were similar and met the criteria established for the project.

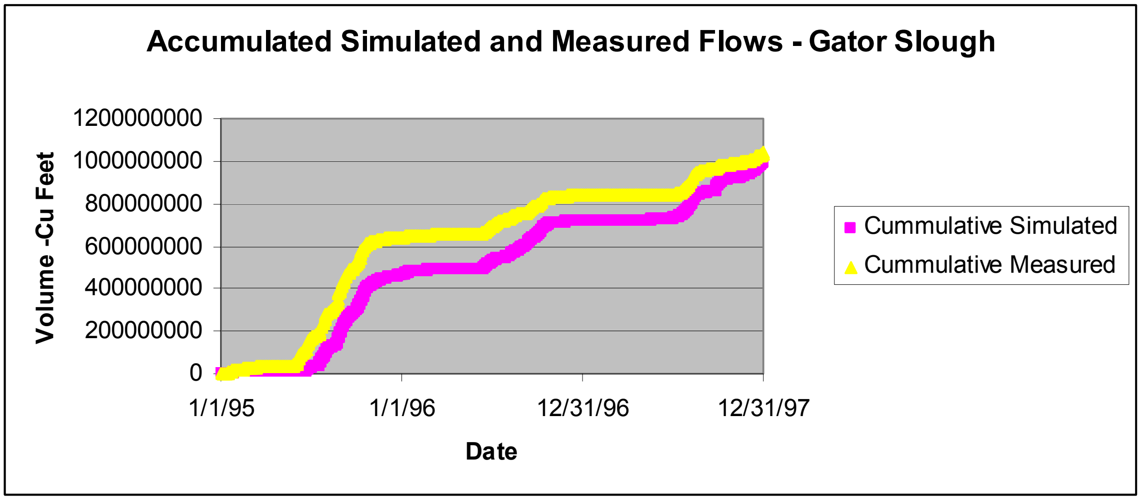


ME=0.0476143
MAE=0.649822
RMSE=0.821315
STDres=0.819934
R(Correlation)=0.881664
R2(Nash_Sutcliffe)=0.517953



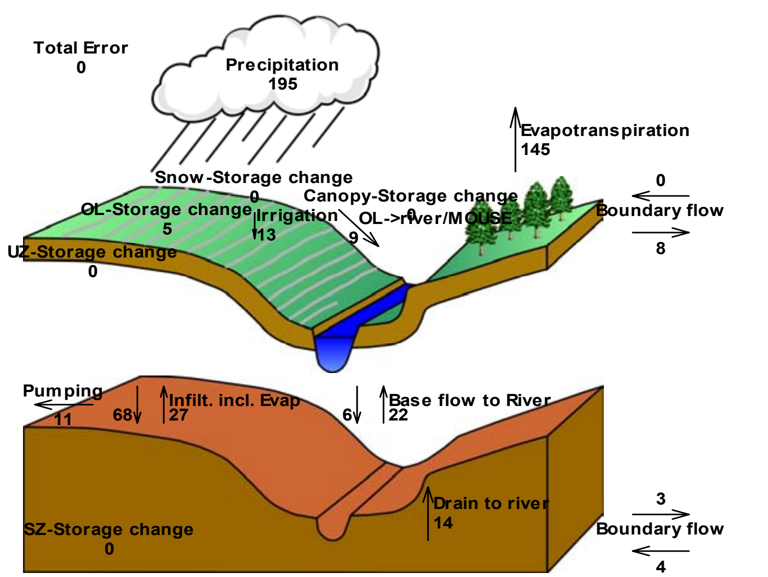
ME=0.0195196
MAE=0.611756
RMSE=0.761378
STDres=0.761128
R(Correlation)=0.785213
R2(Nash_Sutcliffe)=0.612927

The figure below shows accumulated simulated and measured flows at a station that are very close. The slight deviations may be due to inaccurate data on the operation of the control structures upstream of the gauge.



Water Budget

The chart below shows the total water budget for the calibration period. This kind of charts can be generated for various components of the model that are very helpful during the calibration process.



Accumulated waterbalance from 1/1/1995 to 12/30/1997. Data type : Storage depth [inch].
Flow Result File : E:\Projects-TCRB\Caloosa\MSHE_Model\Tidal_Caloo_1-95-To12-97-Cal27\Tidal_Caloo_1-95-To12-97-Cal27
Title : Tidal Caloosahatchee River Basin (TCRB) MIKE SHE Enhancements Text : Recalibartion of the 2001Model using new data anc

PARAMETER SENSITIVITY

As part of performance analysis of the model, a number of model parameters were varied within an accepted range to assess the impacts on the simulation results. The most sensitive parameter was determined to be the crop coefficient (K_c). Drain Level and Soil Moisture Deficit were also sensitive parameters (but less sensitive than K_c) for irrigation, infiltration of agricultural lands, drain flow to rivers from agricultural lands, River Contribution to Groundwater, and Groundwater Contribution to River. Manning's coefficient influenced overland flow and flows in rivers/canals draining wetlands and selected agricultural lands.

The sensitivity simulations clearly showed that varying key model parameters have a significant influence on model performance. It is clear that K_c, a crop coefficient affecting evapotranspiration (ET), has a strong influence on model performance. This was observed during calibration of the TCRB and C-43 models. We also had done some sensitivity analyses of this parameter during calibration runs and the findings of these runs reaffirmed our past experiences. Moisture Deficit seems to be a sensitive parameter especially in agricultural lands since this parameter influences irrigation demand.

PICAYUNE STRAND RESTORATION PROJECT (PSRP) MODEL

The PSRP model, a sub-model of the BCB domain includes the watersheds for the Picayune Strand, Henderson Creek and the Belle Meade area as shown in Figures 3 and 4 above. This model will serve as a Hydraulic Design Tool (HDT) to assess alternative scenarios for restoration activities in the basin. The above domain shown in Figure 4 was selected because it met two conditions. First, it includes all locations where flow depth and/or flow rate is needed for design purposes. Second, it contains all areas that are necessary boundaries to enable computation of flows at design locations.

The chosen domain of the HDT is about half the size of the BCB model domain. This size enabled use of a finer grid size, since computational times would be reduced relative to the larger model. The chosen grid size is 750 feet, which is half that used in the BCB model. As a result, the HDT tool simulation run time is about 8 hours per storm event period. The benefit of this change is that it delivers information at a finer resolution and is more closely associated with design locations.

A one (1) minute time-step was used for the hydraulic component (MIKE 11) of the model. A maximum time-step of 15-minutes, 1 hour, and 4 hours was used for the overland flow, unsaturated zone, and saturated zone domains. The simulation time-step for the overland flow, unsaturated zone, and saturated zone domains was dynamically reduced during model execution when the rainfall exceeded approximately 0.6 inches (15 mm) per time-step in any model grid-cell. When the rainfall exceeded the specified threshold of approximately 0.6 inches per time-step, the time-step length was reduced by a factor equal to 0.6 inches ÷ actual rainfall amount.

Calibration Events

Hourly rainfall records were used for calibration and validation of the HDT model. Where disaggregation of daily data was necessary to obtain hourly data, this was done by determining the fraction of daily rainfall data occurring each hour at the closest gauge with hourly data and disaggregating the daily rainfall data using the appropriate hourly percentage.

Hourly data was available at the BCB Field Station, Collier WWTP, and Golden Gates at I-75 (GGI75) gages in 1995. Daily data was available at the Collier-Seminole, Conservancy, Corkscrew HQ, Immokalee, Immokalee Landfill, Marco Island, Miles City Tower, and Silver Strand rainfall gauges in the HDT model domain. The hourly and disaggregated hourly rainfall data was distributed over the HDT model domain using a Thiessen polygon network developed from the locations of the available hourly and daily data in 1995.

Hourly data was also available at the Courthouse, Golden Gates at I-75 (GGI75), and Golden Gates Fire Station gages in 1999. Daily data was available at the Collier-Seminole, Corkscrew HQ, Immokalee, Immokalee Landfill, Marco Island, Miles City Tower, and Silver Strand rainfall gages in the HDT model domain. The hourly and disaggregated hourly rainfall data was distributed over the HDT model domain using a Thiessen polygon network developed from the locations of the available hourly and daily data in 1999.

Model Calibration Approach

The model calibration was undertaken by successive adjustment of model parameters from their initial starting points. The sequence of runs and parameter changes was adapted during the calibration process, as interim results generated insights into model behavior. The initial focus in calibration was to ensure that overall mass balance was appropriate. Evapotranspiration rates, infiltration volume, runoff volume and other key terms were checked to ensure that gross movement of water between major system compartments was reasonable and within expected ranges for the area.

Subsequent steps in the calibration process concentrated on adjusting parameters so that time varied flows were simulated in a way that matched the flows and stages observed at gauging stations located throughout the model domain. At this stage, the emphasis is to enable simulation of the dynamics of surface water flow as affected by control structure operations and runoff processes during high-intensity events.

Two major storm periods were available for this activity, one in 1995 and one in 1999. The 1995 rainfall dataset was used for model calibration, and the 1999 rainfall dataset for model validation. Key factors that were considered in evaluating model behavior included:

- Timing of peaks – verification that events occurred at the time observed
- Magnitude of peaks – verification that events had maximum flow rates consistent with what was observed
- Shape of event – verification that events discharge in a pattern that is consistent with what was observed

- Base level – verification that conditions between events, and the progression towards those conditions, is consistent with what is observed
- Temporal trends – verification that the long term movement of the system does not demonstrate a positive or negative bias
- Spatial trends – verification that the model is not positively or negatively biased in a systematic pattern across the domain
- Maximum errors – evaluation of the greatest error observed in the model's predictive ability

The key requirement in calibration was to ensure that the magnitude and timing of peaks is accurately represented, since this will be the critical factor for the design storm simulations. When long term model behavior is at issue, other factors will need to be addressed, particularly volume of runoff and base levels, in order to have confidence that the model is capable of accurately simulating long-term conditions.

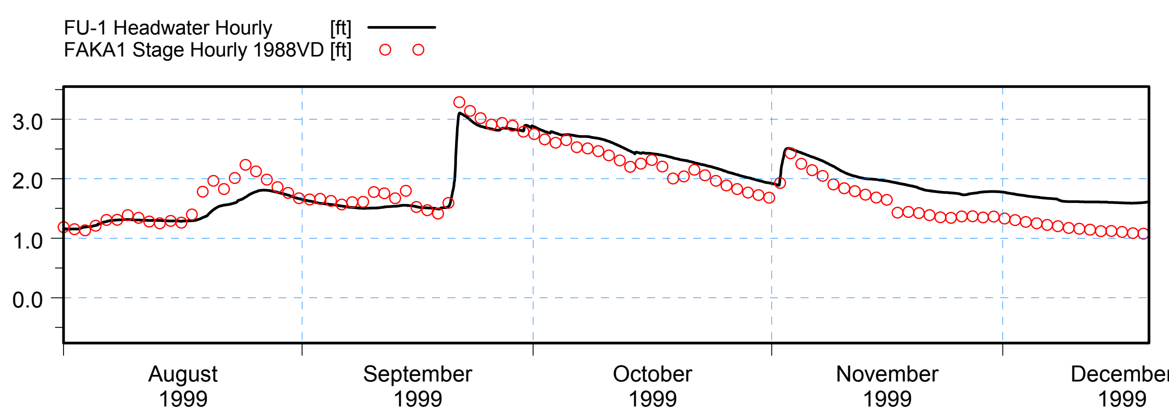
The model behavior is reasonably good from a hydraulic standpoint. It shows very close agreement in event timing and recovery, and peaks match in many areas to a reasonable degree of fit. Overall, the basic rainfall/runoff phenomenon was well represented.

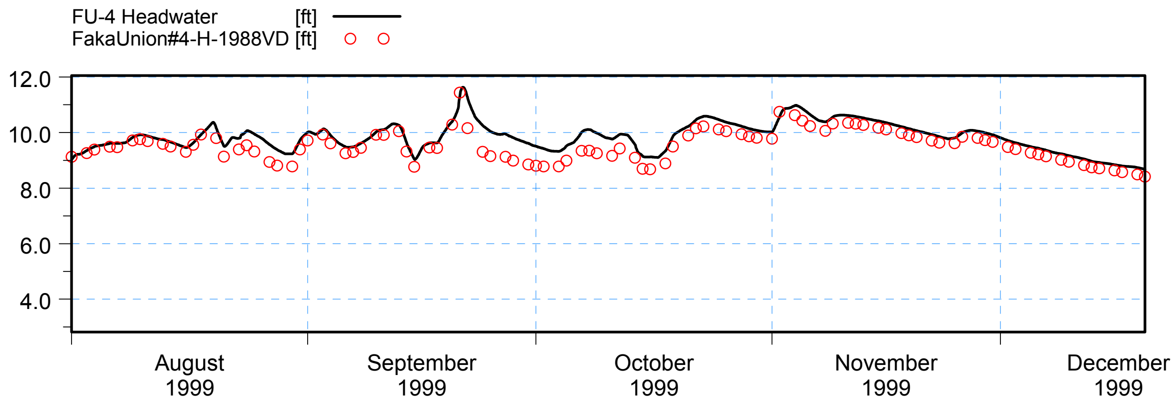
The validation set displayed a very good agreement with the calibration set. There were no consistent trends in differences between the two, and the degree of fit was comparable. Therefore, to the extent possible with the available data, the model has been validated.

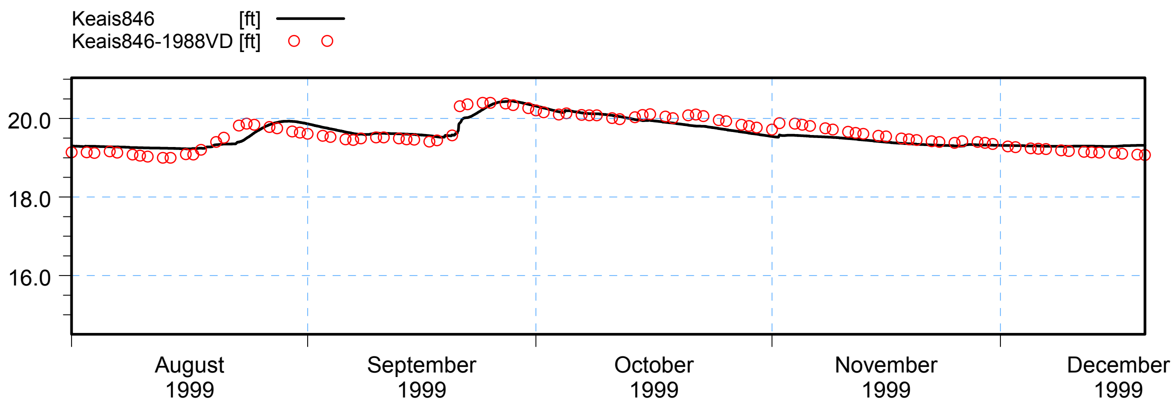
Detailed Results

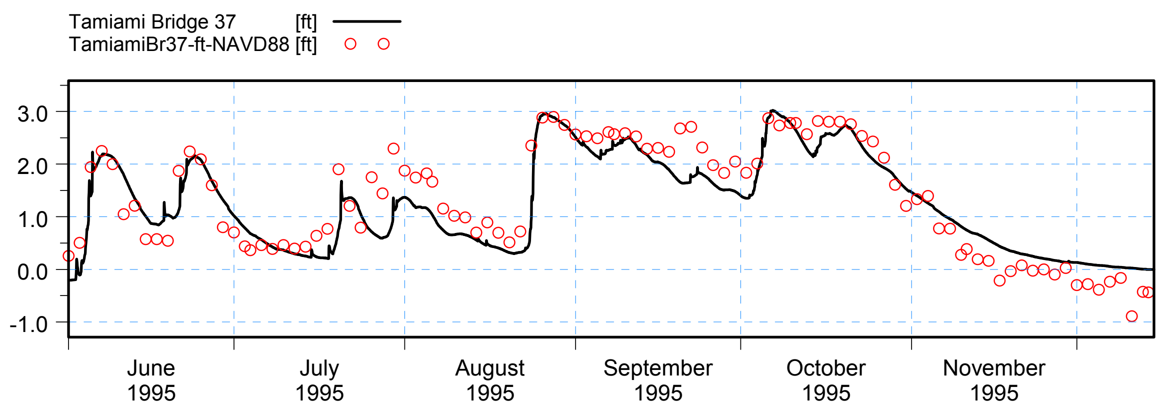
The following plots show results of the model at available calibration locations within the model domain. In each figure, a time series plot is provided for the calibration set. Several points should be noted:

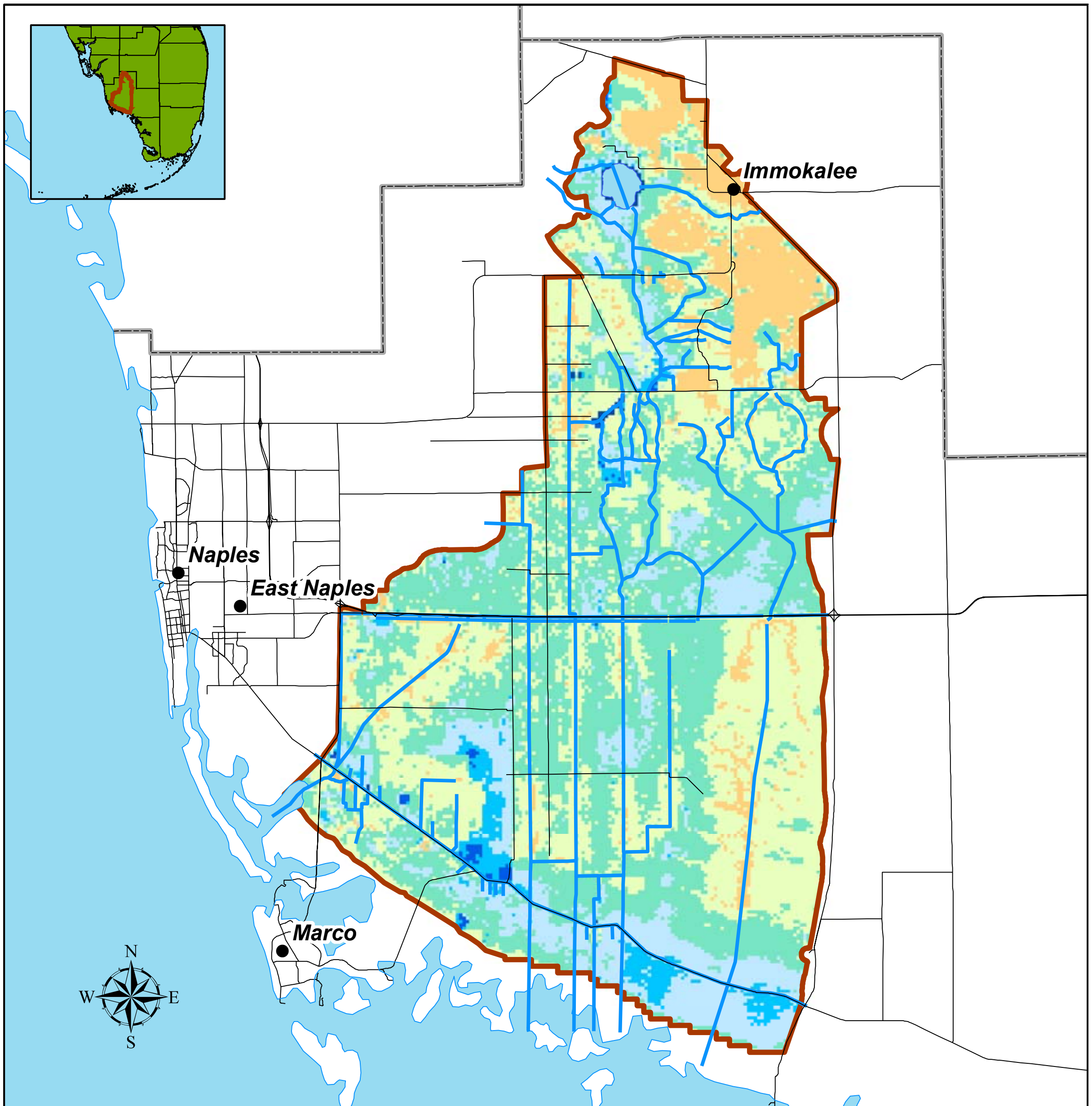
- Behavior exhibited in the warm-up period at the beginning of the plot was ignored in this evaluation
- The focus of evaluation was the major event during the simulation period
- Because the tool will be used to estimate design event responses, relative peak rates were examined, not absolute rates




FU-4 Headwater [ft]
FakaUnion#4-H-1988VD [ft]
12.0
10.0
8.0
6.0
4.0
August 1999
September 1999
October 1999
November 1999
December 1999


Keais846 [ft]
Keais846-1988VD [ft]
20.0
18.0
16.0
August 1999
September 1999
October 1999
November 1999
December 1999


Tamiami Bridge 37 [ft]
TamiamiBr37-ft-NAVD88 [ft]
3.0
2.0
1.0
0.0
-1.0
June 1995
July 1995
August 1995
September 1995
October 1995
November 1995



Miles
0 2 4 8

feet

0 - 0.2	1 - 2	4 - 5
0.2 - 0.5	2 - 3	> 5
0.5 - 1	3 - 4	

Acceler8
South Florida Water Management District
2301 Center Park West Drive, Suite # 150
West Palm Beach, FL 33401
Tel # (561) 242-5520

sfwmd.gov

Figure 3.25
Simulated 1995 Maximum
Overland Water Depth
CN040917-WO5

02/02/2006
PSRP_HHP1\
map_docs\
MaxOLDepth95.mxd

Conclusions and suggestions for model improvement

The model set-up and calibration phase of the PSRP hydrologic modeling effort was completed in a satisfactory manner. Several key areas have been addressed:

- The HDT itself has all the features necessary to address the requirements of the design analysis which will be undertaken in subsequent model steps. The physical scope of the tool is appropriate, and it performs in a stable and effective way.
- Calibration has been completed to a degree that will enable application of the model for that purpose.
- The calibrated model has been validated against an independent data set, and shown to perform effectively against those data.
- The MIKE SHE model can effectively be used to analyze various water management needs.

It is noted that additional work could be done to improve model calibration and performance. It is possible that the HDT model can be improved further during development and execution of the design-event simulations. If additional calibration of the HDT model cannot be performed during current phase of the project, it should be kept in mind that the model will be extended, improved, and further calibrated in the next phase of the project. The objective of future phase is to be able to represent long term time varied flows under normal rainfall conditions and calibration activities associated with this phase will include close attention to the groundwater system.

For restoration design purposes, however, the HDT is complete from a hydraulic perspective and, with minor revisions of the topography it will be ready for adaptation and computations of flow diversions during intense storms (wet season) to improve wetland hydro-periods. As with all models there are additional activities that could improve model performance. Some suggested improvements include:

- Acquisition and incorporation of tidal data more representative of conditions in Florida Bay. Currently the model is using observed tailwater conditions from either the Henderson Creek 1 tailwater gage or the FU-1 tailwater gage.
- Improvement of the DEM is recommended. Based on the simulated maximum overland flow depths it appears the model is under-simulating depths in Fakahatchee Strand and Henderson Strand, and over-simulating depths east of Belle-Meade. These discrepancies may impact the ability to use the model with confidence in these areas or areas downstream of these locations.