

CENTRAL AND SOUTHERN FLORIDA PROJECT
COMPREHENSIVE EVERGLADES RESTORATION PLAN



B.2 HYDRAULICS
FINAL MODEL EVALUATION REPORT

EAA STORAGE RESERVOIRS – PHASE 1



US Army Corps of Engineers
Jacksonville District



South Florida Water
Management District



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B.2.1 Model Evaluation Report

B.2.1.1 Introduction

The South Florida Water Management District (District) retained the Kimley-Horn and Associates, Inc. Team (KHA Team) to assist the District in developing portions of the Everglades Agricultural Area (EAA) Storage Reservoir – Phase 1 Project Implementation Report (PIR). The Statement of Work for this project requires that a modeling approach or methodology be identified to meet the goals and objectives of the project as stated in the Project Management Plan (PMP). The PMP goals are as follows:

1. Reduction of the Lake Okeechobee regulatory releases to the estuaries and backpumping from the EAA into Lake Okeechobee by sending the water to the south and into the reservoirs
2. Improved environmental releases through the storage of water and release to the Everglades during the dry season
3. Flow stabilization and optimization of treatment performance of STA-2, STA-3/4, STA-5, and STA-6 by capturing peak storm event discharges within the reservoirs for slow release to the STAs
4. Improved flood control and regional water supply for the agricultural community currently served by the EAA canals and other areas served by Lake Okeechobee

The development of an approach to model the hydrologic and hydraulic characteristics of the primary and secondary basins within the EAA is a critical element in the development of the PIR. Because of the PMP's multiple hydrologic and environmental goals for this project, comprehensive computer modeling of these basins is needed. As outlined in the KHA Team project Statement of Work (SOW), the modeling approach that is selected must be capable of producing the following results:

1. General water budgets for the entire EAA region and individual primary and secondary basins;
2. Information that can be used for water reservations and for compliance with the Water Resources Development Act (WRDA) of 2000 Savings Clause (601(h)(5));
3. Predictions of average annual economic flood damages (based on flood routings for 2-, 5-, 10-, 25-, 50-, and 100-year return periods, as well as the Standard Project Flood) for the existing and future without project conditions as well as for alternative plans under the future conditions;
4. An evaluation of water supply availability within the EAA basin for the existing conditions, as well as for future conditions with alternative plans;
5. An evaluation of water availability for environmental releases;
6. Design criteria for canal conveyance, reservoir storage capacities (for each cell), and pump/structure capacities by performing flood routings, water supply deliveries and period of record simulations (36 years);
7. An estimate of the frequency and volume reduction of back pumping into Lake Okeechobee for alternative plans;
8. An assessment of operational flexibility within the EAA to move water within primary basins to meet the needs of agricultural and environmental stakeholders;

9. An evaluation of potential interim benefits attributable to early implementation of canal improvements in advance of construction of the storage reservoir;
10. A tool for evaluating alternative plans relative to performance measures, opportunities, and impacts; and
11. An assessment of phosphorus impacts related to water depths and dry out periods that will be typical of the EAA reservoirs.

The District and US Army Corps of Engineers (USACE) Project Managers formed a Model Steering Committee (MSC) to provide the KHA Team with guidance throughout the EAA Basin hydrologic/hydraulic modeling activities, as defined in the Statement of Work. A list of the MSC members is included in Attachment A.

Through meetings with the KHA Team, the MSC provided direction on the model selection tasks. The MSC met on August 9, 2002 and a list of 15 models to be considered was generated. During the meeting a list of criteria was agreed upon by which the models should be evaluated. These criteria were primarily from the PMP and SOW. On August 22, 2002 written information on the 15 models was presented to the MSC. As a result of the information and ensuing discussion, additional criteria was provided by the MSC. The models were then evaluated based on the criteria from the PMP, SOW, and the MSC and the three models (or combination of models) that best satisfied the requirements of the project were chosen. An additional six factors to be considered were presented at the August 22, 2002 meeting by the MSC. The three remaining models were evaluated based on the six factors. At the September 26, 2002 meeting the MSC recommended the model that best satisfied the criteria and factors.

The following sections describe the hydrologic and hydraulic model evaluation and selection methodology implemented by the MSC. A recommendation of the proposed model to be used to perform the modeling tasks associated with this project is also presented.

B.2.1.2 Subregional Model / Methodology Selection Criteria

The MSC concurred that the criteria outlined in the KHA Statement of Work should be used in selecting the most appropriate model(s) for this project. These criteria are as follows:

1. Provide accurate and reliable information
2. Enable results to be available within the delivery dates identified in the established PIR schedule. The modeling information shall be made available to allow sufficient time for the necessary follow-up planning work
3. Address the entire EAA study area
4. Utilize available data to the maximum extent practical
5. Provide input/output that is compatible with the South Florida Water Management Model (SFWMM) which will be utilized for the regional evaluation of alternative plans
6. Be consistent and compatible with other related modeling performed by the District and USACE for the EAA

7. Be available for licensed public use and have been used by the engineering/scientific/professional communities for similar applications
8. Enable both flood event and period of record simulations
9. Simulate the major hydrologic and hydraulic processes in the EAA, including overland flow, canal flows, water control structure operations, evapotranspiration (ET), and groundwater flows
10. Be based on best available science (CERP Draft Programmatic Regulations 385.26)

To successfully accomplish the required goals, the model(s)/methodology would need to meet each of these criteria. In addition, the MSC concurred that the selected model(s) must be usable in subsequent work required to evaluate the water quality performance of alternative plans. It must allow for simulating the interaction between alternative configurations of the EAA Storage Reservoirs and the Stormwater Treatment Areas (STAs). Furthermore, the methodology must assure that the selected model(s) be compatible with the Dynamic Model for Stormwater Treatment Areas (DMSTA) or a water quality model of similar capabilities. In this manner, the integrated models would enable simulation of the interaction of the reservoirs with the STAs to assess ways to optimize the water quality performance of the STAs.

As stated in the PMP, the South Florida Water Management Model (the SFWMM or 2x2 model) will be used for establishing system-wide effects of Comprehensive Everglades Restoration Plan (CERP) project elements. The 2x2 model is referred to as the regional model. The 2x2 model is accepted as the best available model for assessing the impacts of CERP project elements on a regional scale. The 2x2 model has been developed and calibrated specifically for the south Florida water management system and has undergone extensive peer review. It is accepted by the agricultural community, the environmental community, state and federal agencies, and the general public. The 2x2 model has been adopted by REstoration COordination & VERification (RECOVER) as the modeling tool for periodic checks on the progress of all CERP projects with respect to overall CERP restoration goals. However, because the 2x2 model is a regional model, the MSC concurred that the large scale and daily time step of the regional model limits its ability to adequately evaluate local scale or relatively marked transient events. This makes it difficult to evaluate a number of sub-regional issues in the EAA, such as determination of flood levels, duration of flooding in EAA farms, canal capacity, and seepage to and from reservoirs and canals. The reasons identified for not using the 2x2 model for the detailed hydrologic/hydraulic modeling of the EAA storage reservoirs are listed in Table 1.

The model to be used for evaluating the effect on the EAA of the storage reservoirs will be referred to herein as the sub-regional model. The MSC also concurred that the sub-regional model will need to be capable of receiving boundary conditions from the regional model and, if feasible and necessary, provide more detailed results back to the regional model. The sub-regional and the regional model will be used concurrently to evaluate the effect of the EAA storage reservoirs at both the regional and the sub-regional levels. For example, the 2x2 model will provide a flow time series for major structures from Lake Okeechobee to the EAA. If the sub-regional model determines that the reservoir can reduce the need for water from the lake while still meeting water demands

from the EAA farms, the WCAs, and the urban areas, then this information will be passed back to the 2x2 model for re-evaluation.

Table 1 – SFWMM (2x2 Model) Shortfalls

Modeling Goal/Performance Measure	Ability of 2x2 Model to Assess the Goal or Performance Measure
Simulate groundwater impacts of reservoir on nearby farms	The 2x2 model will not be able to accurately assess seepage impacts to numerous farms less than 640 acres (1x1 mile).
Intra-day variation groundwater levels	The 2x2 model cannot assess this because the time step is one day.
Capable of FEMA-approved storm event modeling	<ul style="list-style-type: none"> • The 2x2 model simulates canal water levels using a one day time step, which is too long for simulating flood elevations. • The Cross and Bolles Canals are not in the 2x2 model. • The change in storage in the non-primary EAA canals cannot be estimated using the 2x2 model.
Canal/aquifer seepage impacts on canal conveyance	The 2x2 model or the 2x2 model in combination with HEC-RAS or UNET does not handle two-way canal-stage-dependent canal-aquifer exchange in the EAA.
Accurate water budgets	The 2x2 cells in the EAA can either have an irrigation requirement or excess water for a day, not both. Adjacent EAA farms that are smaller than 2x2 miles, can be irrigating and discharging water simultaneously within a day.
Capable of modeling structures in the EAA with more than one on-and-off cycle within a day	The 2x2 model is limited to a daily time step, and structural discharges change rapidly during a day.

The MSC members agreed that the sub-regional model must also be capable of achieving certain key goals in addition to the model criteria outlined in the KHA Team Statement of Work. The following 11 goals are a combination of goals established by the SOW plus goals identified by the MSC:

1. Capable of simulating groundwater levels surrounding storage facilities at an acceptable confidence level
2. Capable of simulating rapidly changing groundwater levels and flow and two-way aquifer-channel seepage
3. Capable of providing a water budget with high confidence (pump discharge flows, seepage losses, ET, rainfall, water supply, etc.)
4. Capable of easily exchanging data with the 2x2 model (in a grid format) and water quality models
5. Capable of Federal Emergency Management Agency (FEMA) approved storm event modeling and continuous modeling for 36 years
6. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, levee heights, etc.)
7. Capable of modeling canal geometry versus grid simulation only.
8. Capable of exchanging data with Decision Support Systems (DSS)

9. Has a graphical user interface with comprehensive pre- and post-processing capabilities
10. Extensively used to simulate conditions similar to those found in the EAA
11. Reasonable model set-up and execution times to meet project schedule

FEMA-approved storm event modeling requires a fully-dynamic hydraulic model with the ability to model two-way flows, structures, bridges, and predict water surface elevations at accuracy standards established by FEMA. Models have to be approved by FEMA prior to use for determining flood plain elevations.

The MSC agreed that the overall modeling approach will not require use of a single subregional model to supplement the regional (2x2) modeling. Several different models may be used in combination to achieve these goals. However, it would be desirable to have a single model, because it will streamline the amount of time required to interact between models.

The MSC identified 15 models or combinations of models that could potentially achieve these goals:

1. adICPR
2. BASINS with FEQ
3. HSPF
4. FEQ
5. HEC-HMS/HEC-RAS with UNET
6. InHM
7. ISGW
8. MIKE SHE/MIKE 11
9. MODBRANCH
10. MODFLOW
11. MODHMS
12. MODNET
13. SFRSM including HSE
14. EPA SWMM/XP-SWMM 2000
15. WASH123D

The following subsections describe the features of the models that were considered. Both advantages and limitations of each model are summarized. The advantages and limitations listed for each model are those that are pertinent to the key selection criteria developed for the EAA project and are not meant to be applied to other modeling studies.

B.2.1.3 Description and Evaluation of Models

B.2.1.3.1 adICPR

The Advanced Interconnected Pond Routing (adICPR, Version 3) model is a one-dimensional (1D), unsteady-state stormwater management model. This model has the capability to route runoff hydrographs through complex drainage networks including

dendritic, diverging, and looped systems. The adICPR model has been applied in projects in south Florida, primarily for analysis of urban systems. A comprehensive graphical user interface is available for adICPR.

The adICPR model can simulate a full range of structures (weirs, culverts, gates, etc.) with either horizontal or vertical alignment. A number of rating curves can be used for structures including time-discharge, head-discharge, and stage-discharge without variable tailwater conditions. On-off elevations can be used to simulate pump stations. Bridges can be simulated using the same algorithms as Federal Highway Administration (FHWA) Water-Surface PROfile (WSPRO) and a dam breach procedure similar to the National Weather Service's DAMBRK model is included.

Overland flow can be simulated in adICPR using runoff hydrographs that can be generated by the Soil Conservation Service (SCS) unit hydrograph method, the Santa Barbara urban hydrograph method, or the kinematic overland flow method. The adICPR model also allows the importing of external hydrograph files generated using other programs.

Unsaturated zone flow, groundwater flow, evapotranspiration, and irrigation capabilities are not included in adICPR. Pollutant loading cannot currently be simulated with adICPR.

Advantages of adICPR

1. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
2. Able to model canal geometry versus grid simulation only
3. Has a graphical user interface with comprehensive pre- and post-processing capabilities

Limitations of adICPR

1. Cannot simulate rapidly changing groundwater levels surrounding storage facilities
2. Cannot simulate groundwater flow and two-way aquifer-channel seepage
4. Cannot provide a water budget with high confidence (pump discharge flows, seepage losses, ET, rainfall, water supply, etc.)
5. Not capable of easily exchanging data with the 2x2 model and water quality models
6. Not capable of FEMA-approved storm event modeling and continuous modeling for a number of years
7. Not capable of exchanging data with DSS

2.1.3.2 BASINS with FEQ

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources with Full Equations Model) is a modeling system that was developed by the United States Environmental Protection Agency (EPA) to facilitate examination of environmental data, support analysis of environmental systems, and provide a framework for examining management alternatives. BASINS was also conceived as a system for supporting the development of total maximum daily loads (TMDLs). The integrating framework for

BASINS is a geographical information system (GIS). BASINS is composed of nine components which include:

1. Nationally derived databases with data extraction tools and project builders
2. Assessment tools (TARGET, ASSESS, and Data Mining) that address large- and small-scale characterization needs
3. Utilities to facilitate organization and evaluation of data
4. Tools for watershed delineation
5. Tools for classifying digital elevation models (DEMs), land use, soils, and water quality data observations
6. Watershed characterization reports that facilitate compilation and output of information on selected watersheds
7. An in-stream water quality model, QUAL2E
8. Two watershed loading and transport models, Hydrological Simulation Program – Fortran (HSPF) and Soil and Water Assessment Tool (SWAT)
9. PLOAD, a simplified GIS based model that estimates non-point loads (NPS) of pollution on an annual average basis

Within BASINS, HSPF, and the tools for classifying digital elevation models (DEM), land use, soils, and water quality data observations are most appropriate for the EAA project. HSPF contains simplified reach routing routines but can be coupled with Full Equation (FEQ) to simulate unsteady, fully dynamic channel flow. FEQ is not a component of BASINS version 3.0 and requires generation of FEQ data sets and operation of HSPF coupled with FEQ external of the BASINS environment.

HSPF has been applied in south Florida and HSPF/FEQ was used in the C-24 watershed in the upper east coast of south Florida. This model did not meet calibration targets. According to SFWMD staff, problems were encountered in representing interior farm canal drainage and automatic gate operations.

Use of HSPF and FEQ relative to the EAA project is discussed further below.

B.2.1.3.3 HSPF

HSPF is a lumped parameter watershed model that simulates non-point source runoff and pollutant loadings for a watershed and performs flow and water quality routing in reaches. All pertinent hydrologic processes can be simulated with HSPF but many of the parameters that control system responses are empirical (non-physically based) and are determined through calibration. Spatially distributed land use, reach, meteorological, and water quality data can be used to develop HSPF data sets but they must be reduced to a surface water sub-basin discretization to be used in HSPF.

All of the hydrologic processes, except for reaches, can be conceptualized as storage reservoirs connected by a number of pipes with controlling valves. Operation of the valves is controlled by empirical parameters and addition or subtraction of water from storage reservoirs is controlled by a combination of the valves and empirical parameters that are a function of storage in one or more of the reservoirs.

The kinematic wave approximation is used to route water in the reaches and may lead to significant errors when dealing with low channel slopes, significant backwater conditions, and/or reversals in channel flow. Surface water structures can be simulated using fixed stage-discharge-storage relationships. Currently, the stage-discharge-storage relationships cannot be dynamically changed during a simulation. The kinematic wave approximation is used to route overland flow to reaches in HSPF and requires that surface water sub-basins be significantly discretized in order for specified overland flow parameters to be appropriate.

The unsaturated zone is approximated in HSPF using a single storage reservoir (Lower Zone Storage). Inflow to the unsaturated zone is controlled by the ratio of actual storage to a specified nominal storage. Evapotranspiration is the only way for water to leave the unsaturated zone. The water in the unsaturated zone does not actually flow out of the control volume due to limitations in model code. The only way to decrease unsaturated zone water content is to reduce the user-defined fraction of rainfall that enters the unsaturated zone.

Groundwater for each surface water sub-basin is simulated as two storage reservoirs (active and deep). Three-dimensional (3D) groundwater flow cannot be simulated with HSPF but simple linear routing of groundwater in the active groundwater storage reservoir can be simulated and controlled with an empirical routing parameter.

Evapotranspiration and irrigation can be simulated with HSPF but requires use of several different empirical relationships to control removal of water from the various storage reservoirs.

Because of the simple formulation used for the surface water processes in HSPF, the code is very efficient and runs very quickly for large applications and long periods of time.

B.2.1.3.4 FEQ

FEQ is a fully dynamic unsteady, 1D flow package that can be used to simulate flow in open channels and through control structures. Surface water control structures include junctions, bridges, culverts, dams, waterfalls, spillways, weirs, side weirs, and pumps. FEQ can be applied to a wide range of stream configurations (including loops), lateral inflow conditions, and special features. FEQ can be linked to HSPF through “Diffuse Time Series Files” (DTSF) and can also use standard HEC DSS files. FEQ has capabilities to simulate the dynamic operation of structures using logical operands and one or two stage or flow control points. Water quality cannot be simulated using FEQ.

All overland flow, unsaturated zone, and groundwater flow processes are handled by HSPF.

Advantages of HSPF with FEQ

1. Can provide a water budget for most components of the hydrologic cycle
2. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)

3. Able to model canal geometry versus grid simulation only

Limitations of HSPF with FEQ

1. Cannot simulate groundwater levels surrounding storage facilities because ground water is modeled as a simple large underground reservoir
2. Cannot simulate groundwater flow and two-way aquifer-channel seepage
3. Not capable of easily exchanging data with the 2x2 model and water quality models
4. Not capable of FEMA-approved storm event modeling
5. Not capable of exchanging data with DSS
6. Does not have a graphical user interface with comprehensive pre- and post-processing capabilities

B.2.1.3.5 HEC-HMS/HEC-RAS with UNET

HEC-HMS and HEC-RAS (Hydraulic Engineering Center Hydrologic Modeling System and River Analysis System) are two models developed by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Centers (HEC) for simulating hydrologic and hydraulic conditions, respectively, and are typically used in combination and the specific attributes of each are discussed below. Several comprehensive graphical user interfaces with pre- and post-processing capabilities are available. HEC-HMS, HEC-RAS, and [UNsteady Flow through a Full NETWORK of Open Channels \(UNET\)](#) have been applied in south Florida, including the EAA. These three models have not been used in combination in south Florida.

Hydrologic elements are connected in a dendritic network to simulate runoff processes. A number of options for runoff event modeling are available and include use of initial and constant conditions, the SCS curve number method, a spatially distributed (grid-based) SCS curve number method, and Green and Ampt calculations.

Different methods are available to simulate infiltration losses. A one-layer deficit and constant model or a five-layer soil moisture storage algorithm that accounts for evapotranspiration from different horizons can be used for continuous modeling.

HEC-HMS has some limited channel routing capabilities that can be used if HEC-RAS is not used. In HEC-HMS, channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge method, channels with overbank areas can be modeled with the Muskingum-Cunge method and an eight-point cross section. Routing with no attenuation can also be modeled with the lag method and the modified Puls method can be used to model a reach as a series of cascading, level pools with a user-specified storage-outflow relationship.

Channel interaction with groundwater is accounted for using a linear reservoir method. Channel-groundwater interaction in HEC-HMS is always from the aquifer to the channel.

There are currently no water quality simulation capabilities in HEC-HMS.

Steady flow surface water profiles, unsteady flow conditions, and sediment transport/movable boundary conditions are simulated with HEC-RAS and are discussed further below. DSS data files from HEC-HMS are used as hydrograph inputs to HEC-RAS models. There are currently no water quality simulation capabilities in HEC-RAS with UNET.

Steady Flow Water Surface Profiles

This component of the modeling system is intended for calculating water surface profiles for steady, gradually varied flow. The system can handle a fully looped network of channels, a dendritic system, or a single river reach. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles.

Unsteady Flow Simulation

This component of the HEC-RAS modeling system is capable of simulating 1D unsteady flow through a full network of open channels. The unsteady flow equation solver was adapted from UNET (Barkau, 1992; HEC, 1993). This unsteady flow component was developed primarily for sub-critical flow regime calculations. The hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures that were developed for the steady flow component have been incorporated into the unsteady flow module. Additionally, the unsteady flow component has the ability to model storage areas, navigation dams, tunnels, pumping stations, and levee failures.

Advantages of HEC HMS/HEC RAS with UNET

1. Can provide a water budget for most components of the hydrologic cycle; however these components are solved by three separate programs
2. Capable of FEMA-approved storm event modeling and continuous modeling for a number of years
3. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
4. Able to model canal geometry versus grid simulation only
5. Capable of exchanging data with DSS
6. Has graphical user interface with comprehensive pre- and post processing capabilities

Limitations of HEC HMS/HEC RAS with UNET

1. Cannot simulate groundwater levels surrounding storage facilities because these models do not simulate groundwater flow
2. Cannot simulate groundwater flow and two-way aquifer-channel seepage
3. Not capable of easily exchanging data with the 2x2 model and water quality models

B.2.1.3.6 InHM

InHM (Integrated Hydrology Model) was initially developed by J.E. VanderKwaak as part of his Ph.D. dissertation (VanderKwaak, 1999) and has been further enhanced by VanderKwaak (e.g., VanderKwaak and Loague, 2001). InHM is a physically based, spatially distributed, finite element, integrated surface water and groundwater model. Chemical transport in surface water and groundwater is also possible with InHM. A

Graphical User Interface is not available for InHM. InHM has not been applied in south Florida.

Channel and overland flow are simulated in two dimensions using the diffusive wave approximation. The model uses a two-dimensional (2D) representation to simulate the flow field and the channel cross-section as well as chemical mixing on the overland flow plane. In order to do this, the model requires that the surface mesh be adequately discretized to capture channel geometry. No channel structures or bridge options are available in InHM.

Variably saturated flow is simulated with a comprehensive representation of unsaturated zone soil properties. To reduce numerical problems solving the nonlinear Richard's Equation, InHM automatically switches the primary variable from pressure to saturation depending on the degree of saturation of the element. The groundwater component of InHM allows for detailed simulation of porous media, fractures, subsurface conduits, macro-pores, and perched water tables. Groundwater quality can be simulated in the subsurface components.

The specifics of the evapotranspiration capabilities of InHM were not available in available documentation.

InHM uses a mass-conservative control volume finite element technique and a fully coupled, fully-implicit, physically based flux coupling to link surface and subsurface flow processes. Discretization of the model domain utilizes flexible finite elements with different element types to represent surface and subsurface features and influence coefficients instead of Gaussian integration to reduce numerical overhead. The surface and subsurface flow and transport equations are assembled and solved in the same matrix. A time-stepping algorithm that allows implicit coupling or a hybrid implicit/explicit intermediate procedure to reduce run times is available in InHM.

Advantages of InHM

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for the full hydrologic cycle

Limitations of InHM

1. Not capable of easily exchanging data with the 2x2 model and water quality models
2. Not capable of FEMA-approved storm event modeling for a number of years
3. Not capable of exchanging data with DSS
4. Not capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
5. Not able to model canal geometry versus grid simulation only
6. Does not have a graphical user interface with comprehensive pre- and post-processing capabilities

B.2.1.3.7 ISGW

ISGW (Integrated Surface and Groundwater Model) is a model which couples HSPF and MODFLOW to simulate integrated surface water and groundwater problems. ISGW was initially developed jointly by BCI, Schreuder Davis Inc., and the University of South Florida. Since 1994, ISGW has been developed further by SDI Inc. and more recently by Intera and AquaTerra. A comprehensive graphical user interface is not available for ISGW but datasets can be developed using a combination of BASINS, Groundwater VISTAS, and text editors. ISGW has been applied in west-central Florida.

ISGW uses the EPA version of HSPF, which is discussed under BASINS above, and the standard version of MODFLOW which is discussed below. The coupling between HSPF and MODFLOW in ISGW is explicit and restricted to groundwater recharge. Groundwater recharge is calculated in HSPF and is a function of simulated MODFLOW water levels from the last stress period, and fluxes between the HSPF reaches and MODFLOW river cells.

Advantages of ISGW

1. Can simulate groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for most of the hydrologic cycle using an empirical representation of the hydrologic system
4. Capable of easily exchanging data with the 2x2 model and water quality models
5. Able to model canal geometry versus grid simulation only

Limitations of ISGW

1. Not capable of FEMA-approved storm event modeling and not currently able to use a time step less than one day
2. Not capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
3. Not capable of exchanging data with DSS
4. Does not have a graphical user interface with comprehensive pre- and post-processing capabilities

B.2.1.3.8 MIKE SHE/MIKE 11

MIKE SHE/MIKE 11 is a physically-based, spatially-distributed, finite difference, integrated surface water and groundwater model. MIKE SHE is based on the European Hydrological System that was developed in a joint effort by the Institute of Hydrology (United Kingdom), SOGREAH (France), and the Danish Hydraulic Institute. Since 1987, the SHE model has been further developed independently by the three respective organizations, which are now the University of Newcastle (United Kingdom), Laboratoire d'Hydraulique de France, and DHI, Inc. (DHI). DHI's version of MIKE SHE/MIKE 11 includes a comprehensive user interface, additional process descriptions, and a coupling to the MIKE 11 hydraulic model. MIKE SHE and MIKE 11 have been applied in south Florida, including a portion of the EAA.

MIKE SHE, coupled with MIKE 11, is capable of modeling open channel flow and closed pipe flow using the kinematic wave, diffusive wave, and dynamic wave approximation. MIKE 11 can simulate a full range of structures (dams, weirs, culverts, gates, etc.), many of which can be operated according to a known time series or dynamically based on logical rules driven by simulated hydraulic conditions. MIKE 11 is capable of simulating a range of water quality parameters. Overland flow is simulated using the diffusive wave approximation and special provisions are available for flow between the overland flow plane and channels that depend on channel bank geometry and user selected flooding options.

MIKE SHE utilizes three methods to simulate flow in the unsaturated zone but assumes that flow is vertical in all three methods. The basis for this assumption is flow is primarily vertical at the scale typically simulated with MIKE SHE (catchment scale). Once infiltrated water enters the surficial aquifer, the 3D ground water equations take over. Two of the available unsaturated zone methods in MIKE SHE are 1) the full Richard's equation and 2) a simplified Richard's equation that neglects capillary tension. The full and simplified Richard's equation methods use real soil properties and soil moisture-relationships that can be developed using Brooks and Corey or Van Genuchten relationships. A simplified wetland module that uses a linear relationship between depth to the water table and average soil moisture content and a linear infiltration equation can be used in place of the full and simplified Richard's equation modules.

MIKE SHE includes a 3D saturated zone model. Available boundary conditions are comparable to those available in MODFLOW (i.e., wells, drains, etc.). Groundwater quality in the overland, unsaturated, and saturated components can be explicitly modeled with MIKE SHE.

Interception and evapotranspiration can be simulated in combination with the full or simplified Richard's equation unsaturated zone modules using an empirical evapotranspiration module (Kristensen and Jensen, 1975). If the wetland unsaturated zone module is used, evaporation is determined using a top-down approach (interception storage, detention storage, unsaturated zone, and groundwater) until potential evaporation is satisfied, if possible, or water levels are below a specified seasonally- and spatially-varying evapotranspiration extinction depth.

The overland, unsaturated, and saturated zone modules and MIKE 11 are explicitly coupled which allows the time step of each component to be determined based on the response time of the component processes. The explicit coupling allows simulations to be tailored to particular problems but requires extreme diligence to ensure that mass balance errors do not occur. Special provisions are available in MIKE SHE to adjust the time step during a simulation based on changes in input fluxes (i.e., rainfall). The rainfall time step can vary from 15 minutes to one hour to one day, and a mix of time steps is possible. Thus, one-day time steps can be used for most of the period, with a one-hour time step during critical rainfall periods.

Advantages of MIKE SHE/MIKE 11

1. Can simulate rapidly changing groundwater levels surrounding storage facilities

2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for the full hydrologic cycle
4. Capable of easily exchanging data with the 2x2 model and water quality models
5. Capable of FEMA-approved storm event modeling and continuous modeling for a 36-year period of record
6. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
7. Able to model canal geometry versus grid simulation only
8. Has a graphical user interface with comprehensive pre- and post-processing capabilities

Limitations of MIKE SHE/MIKE 11

1. Not capable of exchanging data with DSS
2. Does not have the ability to handle variable grids
3. Model is proprietary

B.2.1.3.9 MODBRANCH

MODBRANCH (MODFLOW coupled with BRANCH) represents an implicit coupling of the 3D groundwater flow model MODFLOW and the 1D unsteady hydraulic model BRANCH (Swain and Wexler, 1993). Input data and model results can be processed using the commercially available Groundwater Modeling System (GMS) initially developed by the Department of Defense. GMS includes GIS capabilities that allow existing data coverage to be used to develop model input files. MODBRANCH has been used in south Florida by the USGS and USACE and was developed to address channel-groundwater interactions in south Florida.

Channel flow is simulated using BRANCH. BRANCH can simulate steady or unsteady flow in a system of branches connected in a branched or looped pattern. MODBRANCH has been improved to more-accurately simulate flow conditions in south Florida (Evans, 2000). Some of these improvements include dynamic operation of operational structures. MODBRANCH cannot simulate overland runoff directly. Others have approximated overland flow using MODFLOW and saturated hydraulic parameters that approximately mimic overland flow (e.g., Evans, 2000).

MODBRANCH is not capable of simulating flow in the unsaturated zone.

MODBRANCH has all of the capabilities of MODFLOW discussed below including the available ET options. MODBRANCH does not contain any irrigation options beyond those available in MODFLOW (i.e., recharge and well package).

Advantages of MODBRANCH

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Capable of easily exchanging data with the 2x2 model and water quality models
4. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)

5. Has a graphical user interface with comprehensive pre- and post-processing capabilities

Limitations of MODBRANCH

1. Cannot provide a water budget for the full hydrologic cycle because overland flow and the unsaturated zone are not simulated
2. Not capable of FEMA-approved storm event modeling
3. Not able to model canal geometry versus grid simulation only
4. Not capable of exchanging data with DSS

B.2.1.3.10 MODFLOW

MODFLOW (MODular 3D Finite-Difference Ground-Water FLOW Model) is a 3D groundwater flow model developed by the United States Geological Survey. MODFLOW is a widely used groundwater flow model that has been used extensively in South Florida. MODFLOW's wide use is partially a result of its modular nature that allows additional functionality to be added easily. A number of comprehensive graphical user interfaces are available for MODFLOW.

Simplified river channels can be simulated using the MODFLOW stream package. The MODFLOW stream package is not actually a surface water package but does calculate channel-aquifer interaction and channel stage using the Manning's equation. Overland flow cannot be simulated in the USGS version of MODFLOW. The Wetlands package created by SFWMD can be used to simulate overland flow in natural areas. The Wetlands package has been applied in south Florida.

MODFLOW does not have any capabilities to simulate flow in the unsaturated zone.

The groundwater capabilities of MODFLOW are numerous, well-tested, and have been applied extensively in south Florida. The available packages that may be appropriate for the EAA project are the well package (WEL), the river package (RIV), the general head boundary package (GHB), the time varying constant head package (CHD), the drain package (DRN), the drain with return flow (DRT1), the lake package (LAK3), and the recharge package (RCH). Groundwater quality can be simulated with MODFLOW96 and MODFLOW-2000.

The MODFLOW drain with return flow (DRT1) or SFWMD MODFLOW return drain flow (RDF) packages may also be useful for simulating agricultural management in the EAA project area. Evapotranspiration can be simulated using either the evapotranspiration package (EVP), or the segmented evapotranspiration package (ETS1). The evapotranspiration packages only account for evapotranspiration from the land surface or the saturated zone.

A number of numerical solution techniques are available. MODFLOW-2000 also has parameter estimation capabilities.

Advantages of MODFLOW

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Capable of easily exchanging data with the 2x2 model and water quality models
4. Has a graphical user interface with comprehensive pre- and post- processing capabilities

Limitations of MODFLOW

1. Cannot provide a water budget for the full hydrologic cycle because overland flow and the unsaturated zone are not simulated
2. Not capable of FEMA-approved storm event modeling
3. Not capable of modeling common type surface water hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
4. Not able to model canal geometry versus grid simulation only
5. Not capable of exchanging data with DSS

B.2.1.3.11 MODHMS

MODHMS (MODFLOW Hydrologic Modeling System) is based on MODFLOW and includes additional modules to simulate overland flow, channel flow, and solute transport. MODHMS was developed by HydroGeoLogic Inc. Prior to development of MODHMS, HydroGeoLogic developed a number of codes to deal with variable saturated, variable density, and multi-phase flow and transport. MODHMS is a physically based, spatially distributed, finite difference, integrated surface water and groundwater model. Datasets for an earlier version of MODHMS, MODFLOW-SURFACT, can be generated using Groundwater VISTAS and can be used to generate a basic framework for a MODHMS simulation. MODHMS is currently being used by St. Johns River Water Management District.

MODHMS is capable of modeling open channel flow and closed pipe flow (Priesmann slot) using the diffusive wave approximation. MODHMS can simulate structures (dams, weirs, culverts, and gates) with levels that vary between stress periods. Dynamic structure operations are not currently available in MODHMS. Overland flow is simulated using the diffusive wave approximation and special provisions are available for flow between the overland flow plane and channels that depend on channel bank geometry. The surface water components have not been extensively applied to watershed scale and design problems. Water-quality capabilities are currently not available for the surface water components in MODHMS.

The groundwater flow component of MODHMS solves the 3D Richard's equation for variably saturated flow. Real soil properties, using Brooks and Corey or Van Genuchten relationships, or simplified linear permeability-saturation relationships (Pseudo Soil Function) can be used to simulate unsaturated flow processes. All of the standard MODFLOW packages are available in MODHMS. Complete water-quality capabilities are available for the groundwater components in MODHMS.

Comprehensive interception and ET calculations are also included, with various potential ET formulas (from bare ground or vegetated surfaces) that may be applied in different regions of a model domain.

MODHMS has an adaptive time step algorithm that tailors time steps to convergence of the iterative solver and user specified parameters. Newton-Raphson schemes, a modified PCG solver, and an ORTHOMIN solver are available in MODHMS. Techniques to allow sequential, explicit surface and groundwater flux coupling are available to reduce run times when interactions between surface water and groundwater components are limited. As in InHM, the flow and transport equations are assembled in a single matrix and solved simultaneously.

Advantages of MODHMS

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for the full hydrologic cycle
4. Capable of easily exchanging data with the 2x2 model and water quality models

Limitations of MODHMS

1. Not capable of FEMA-approved storm event modeling
2. Not capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
3. Not able to model canal geometry versus grid simulation only
4. Not capable of exchanging data with DSS
5. Does not have a graphical user interface with comprehensive pre- and post processing capabilities

B.2.1.3.12 MODNET

MODNET (MODFLOW coupled with UNET) represents a coupling of the 3D groundwater flow model MODFLOW and UNET developed by the USACE. MODNET was developed for SFWMD by West Consultants, Inc. and Gartner Lee Ltd. (Walton et al., 1999). A comprehensive graphical user interface is not available for MODNET, but MODNET has been used by South Florida Water Management District.

Channel flow is simulated using UNET. UNET capabilities and disadvantages are discussed above with HEC-HMS/HEC-RAS with UNET. UNET is coupled with MODFLOW through channel bed flux interaction. MODNET cannot simulate overland runoff directly. Another program would be required (e.g., HEC-HMS) to generate runoff and groundwater recharge.

MODNET is not capable of simulating flow in the unsaturated zone.

MODNET has all of the capabilities of MODFLOW discussed above including the available ET options. MODNET does not contain any irrigation options beyond those available in MODFLOW (i.e., recharge and well package).

In addition to the individual numerical features of MODFLOW and UNET, they can be either explicitly or implicitly coupled. Use of the implicit coupling insures mass conservation but is less stable than the explicit coupling option.

Advantages of MODNET

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Capable of easily exchanging data with the 2x2 model and water quality models
4. Capable of FEMA-approved storm event modeling and continuous modeling for a number of years
5. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
6. Capable of exchanging data with DSS

Limitations of MODNET

1. Cannot provide a water budget for the full hydrologic cycle because overland flow and the unsaturated zone are not simulated
2. Not able to model canal geometry versus grid simulation only
3. Does not have a graphical user interface with comprehensive pre- and post-processing capabilities

B.2.1.3.13 SFRSM including HSE

The SFRSM (South Florida Regional Simulation Model including the Hydrologic Simulation Engine) is an advanced hydrologic and hydraulic model that will eventually replace the SFWMM (commonly called the 2x2). It is currently being developed by SFWMD and is composed of four major elements, the Hydrologic Simulation Engine (HSE), the Management Simulation Engine (MSE), the Graphical User Interface (GUI), and the DataBase (DB). The MSE and GUI are still under development, while the HSE and DB are currently being used for a number of regional modeling exercises. HSE has a number of features that are not available in the 2x2 and is based on Object-Oriented model development techniques that facilitate easy incorporation of modifications to existing functions and incorporation of additional processes (Lal, 1998). SFRSM currently does not have a comprehensive graphical user interface with pre- and post-processing capabilities.

HSE can simulate the major components of the hydrologic cycle as well as the complex water management rules and policies in south Florida. The overland flow process is the weighted implicit finite volume method. This is a more advanced implementation of the 2D diffusive wave equations, which reduces model run time. HSE also includes a channel routing process module with structure capabilities, a representation of unsaturated processes, evapotranspiration processes, and a 2D groundwater flow process module.

HSE uses an unstructured mesh that allows discretization to be tailored to the specific problem. HSE is designed for regional, long-term applications and is not intended for local-scale, decision-making support. Initial applications of the model for Everglades National Park and the southwest Florida area (Caloosahatchee River to the Big Cypress

Basin) have yielded comparable model accuracy to the 2x2 (for ENP) and short run times.

Advantages of SFRSM

1. Can dynamically simulate groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for the full hydrologic cycle
4. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.), however this aspect is still in development
5. Able to model canal geometry versus grid simulation only

Limitations of SFRSM

1. Not capable of easily exchanging data with the 2x2 model and water quality models
2. Not capable of FEMA-approved storm event modeling and continuous modeling for a number of years
3. Not capable of exchanging data with DSS
4. Does not have a graphical user interface with comprehensive pre- and post processing capabilities.

B.2.1.3.14 EPA SWMM/XP-SWMM 2000

The EPA SWMM (EPA Storm Water Management Model) is a comprehensive dynamic model for simulating urban runoff quantity and quality. XP-SWMM 2000 (XP Software Storm Water Management Model) was developed by XP Software and is based on EPA SWMM version 4.4. XP Software had made extensive refinements to the calculation algorithms of the EPA SWMM to improve and extend the simulation capabilities. EPA SWMM is in the public domain and XP-SWMM 2000 is a proprietary version of SWMM. Both versions have been used in south Florida.

EPA-SWMM and XP-SWMM 2000 are capable of modeling open channel flow and closed pipe flow using the dynamic wave approximation and can simulate a full range of structures (dams, weirs, culverts, gates, etc.). Dynamic pump operations can also be simulated using XP-SWMM 2000. EPA-SWMM and XP-SWMM have several methods for simulating runoff including Laurenson, EPA, Time Area, Rational, SCS, Santa Barbara Unit Hydrograph (SBUH) and numerous others.

Unsaturated zone infiltration can be simulated in XP-SWMM 2000 with a number of techniques including SCS, Horton, and Green-Ampt methods. Groundwater flow is approximated in XP-SWMM using a lumped storage parameter and baseflow is simulated using a power function. XP-SWMM 2000 has the ability to simulate evapotranspiration.

Water quality can be simulated with XP-SWMM 2000.

Advantages of XP-SWMM

1. Can provide a water budget for surface water portion of the hydrologic cycle – XP SWMM 2000 only

2. Capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
3. Able to model canal geometry versus grid simulation only
4. Has a graphical user interface with comprehensive pre- and post-processing capabilities

Limitations of XP-SWMM

1. Cannot simulate groundwater levels surrounding storage facilities
2. Cannot simulate groundwater flow and two-way aquifer-channel seepage
3. Not capable of easily exchanging data with the 2x2 model and water quality models
4. Not capable of FEMA-approved storm event modeling and continuous modeling for a number of years
5. Not capable of exchanging data with DSS
6. It is proprietary

B.2.1.3.15 WASH123D

WASH123D (WaterSHed Systems of 1D Stream-River Network, 2D Overland Regime, and 3D Subsurface Media) is a public domain model developed by the Waterways Experiment Station for United States Environmental Protection Agency (USEPA). The USEPA and the USACE endorses WASH123D for modeling of comprehensive watershed management plans. WASH123D is a physically based, spatially distributed, finite element, integrated surface water and groundwater model. Input data and model results can be processed using the commercially available Groundwater Modeling System (GMS) initially developed by the Department of Defense. GMS includes GIS capabilities that allow existing data coverages to be used to develop model input files. WASH123D has been applied in south Florida.

WASH123D is capable of modeling flood control, water supply, water quality, structures, weirs, gates, junctions, evapotranspiration, and sediment transport for both event and continuous simulations. 1D and 2D surface flows can be simulated using dynamic wave equations. WASH123D uses an innovative technique to automatically choose between the kinematic, diffusive, and dynamic wave approximations depending on the conditions in each computational element. This approach allows the kinematic wave approximation to be used where slopes are steep and the full dynamic wave approximation where slopes are low and backwater conditions can exist. A variety of surface water structures can be simulated with WASH123D and provisions are available to simulate dynamic structure operations based on time series or operation rules.

The groundwater flow component of WASH123D solves the 3D Richard's equation for variably saturated flow. Variably saturated flow is simulated using real soil moisture relationships that can be developed using either Brooks and Corey or Van Genuchten relationships. Groundwater quality can be simulated with WASH123D.

Evapotranspiration and irrigation can be simulated using WASH123D. WASH123D is capable of simulating dynamic irrigation from internal sources based on soil moisture conditions.

WASH123D can be run in the following combinations: 2D overland flow; coupled 2D overland flow and 3D subsurface flow; coupled 1D channel flow and 3D subsurface flow; and coupled 1D canal, 2D overland, and 3D subsurface flow. Three different time scales are used for 1D channel flow, 2D overland flow, and 3D subsurface flow to reduce the computational burden. Water quality is simulated using a hybrid Lagrangian-Eulerian approach.

Currently, WASH123D cannot be practically used on workstation class machines or PCs when there is a strong coupling between 1D channels and the 3D subsurface, (Richards et al., circa 2000). USACE is currently exploring parallel versions of WASH123D as a method to reduce run times but the need for cutting edge computer technology (parallel super computers) is expected to remain a requirement even if WASH123D is successfully parallelized.

Advantages of WASH123D

1. Can simulate rapidly changing groundwater levels surrounding storage facilities
2. Can simulate groundwater flow and two-way aquifer-channel seepage
3. Can provide a water budget for the full hydrologic cycle
4. Is capable of modeling common type hydraulic control structures with appropriate on-off triggers (weirs, gates, pumps, etc.)
5. Is able to model canal geometry versus grid simulation only
6. Has a graphical user interface with comprehensive pre- and post-processing capabilities

Limitations of WASH123D

1. Is not capable of easily exchanging data with the 2x2 model and water quality models
2. Is not capable of FEMA-approved storm event modeling and continuous modeling for a number of years
3. Is not capable of exchanging data with DSS
4. Run times for WASH123 are very long and require the use of parallel super computers

B.2.1.4 Model Selection Decision Matrices

The models discussed above have varying levels of capability for modeling the hydrology and hydraulics of the EAA. Table 2 represents a comparison of these models relative to the 11 goals defined by the MSC. HSPF and FEQ were combined with BASINS, because these models are typically used in combination. The MSC concurred that the models or combinations of models that meet the greatest number of goals should be considered further. Table 3 includes the total number of criteria met by each model or combination of models. Table 3 also identifies the models suggested by the MSC to be considered further and justification for reducing the number of potential models from 14 to three.

Table 2 - Model Selection Matrix

CRITERIA	1	2	3	4	5	6	7	8	9	10	11
Hydrologic Model	Capable of simulating groundwater levels surrounding storage facilities	Capable of simulating rapidly changing groundwater levels and flow and two-way aquifer-channel seepage	Capable of providing a water budget (pump discharge flows, seepage losses, ET, rainfall, water supply, etc.)	Capable of exchanging data with the 2x2 model in a grid format	Capable of FEMA-approved storm event modeling and continuous modeling for a number of years	Capable of modeling common type hydraulic control structures with on-off triggers (weirs, gates, pumps, etc.)	Capable of modeling canal geometry versus grid simulation only	Capable of exchanging data with DSS	Has a graphical user interface with pre- and post-processing capabilities	Used to simulate conditions similar to those found in the EAA	Model set-up and execution times to meet project schedule
AdICPR						●	●		●		●
BASINS 3.0 (incl. HSPF, FEQ)			● ¹			●	●				●
HEC-HMS and HEC-RAS with UNET			● ¹		●	●	●	●	●	●	●
InHM	●	●	●								
ISGW (incl. HSPF and MODFLOW)	●	●	●	●			●				●
MIKE SHE/ MIKE 11	●	●	●	●	●	●	●		●	●	●
MODBRANCH (incl. MODFLOW and BRANCH)	●	●		●		●			●	●	●
MODFLOW	●	●		●					●	●	●
MODHMS	●	●	●	●							●
MODNET (incl. MODFLOW and UNET)	●	●		●	●	●		●		●	●
SFRSM	●	●	●			●	●				●
EPA SWMM			●			●	●		●	●	●
WASH123	●	●	●			●	●		●		
XP-SWMM2000			● ¹		●	●	●		●	●	●

1 – Does not include seepage from the channel to the aquifer

Table 3 - Models Comparison

Model	Number of criteria met	Consider Further?	Comment
adICPR	4	No	No groundwater
BASIN 3.0 (incl. HSPF and FEQ)	4	No	No groundwater, not FEMA approved, one SF study with poor calibration
HEC-HMS and HEC-RAS with UNET	8	No	Merge with MODNET
InHM	3	No	Common hydraulic control structures not available
ISGW (incl. HSPF and MODFLOW)	6	No	Although 6 criteria are met by this model, the model structure routines too simple to assess the EAA watershed complexity
MIKE SHE/ MIKE 11	10	Yes	
MODBRANCH (incl. MODFLOW and BRANCH)	7	No	Although 7 criteria are met by this model, the model is not capable of FEMA approved storm event modeling
MODFLOW	6	No	Merge with XP-SWMM
MODHMS	5	No	Dynamic structure routines not currently available
MODNET (incl. MODFLOW and UNET)	8	No	Merge with HEC-HMS/HEC-RAS with UNET
SFRSM	6	No	Management Simulation Engine not finished
EPA SWMM	5	No	XP-SWMM selected
WASH123	6	No	Excessive run times
XP-SWMM2000	7	No	FEMA Approved, merge with MODFLOW
HEC-HMS, HEC-RAS with UNET, and MODNET	11	Yes	
XP-SWMM2000 and MODFLOW	10	Yes	

The three models or combinations of models recommended by the MSC to be considered further are as follows:

1. MIKE SHE/MIKE 11
2. Combination of HEC-HMS, HEC-RAS with UNET, and MODNET
3. Combination of XP-SWMM2000 and MODFLOW

The process of selecting a model or combination of models for the EAA Basin Modeling Task is a balance of model features, ability to set up the model(s) within the available project schedule, ability to evaluate alternative reservoir configurations, and ease of use after completion of the PIR. The MSC agreed that these model(s) must also be able to assess the applicable CERP Programmatic Regulations or performance measures:

1. Additional quantity, timing, distribution of water for subsequent projects
2. Improvements to water quality (WQ) for natural system
3. Water needs for natural system
4. Document 2000 level of flood protection
5. No loss of quantity, flood protection, water distribution

6. Document impacts to wetlands
7. Evaluate last-added increments
8. Can describe regulation schedules, water control and operating criteria
9. Can describe water fluctuations
10. Distribution of water during droughts

Items 2, 3, and 6 are CERP Programmatic Regulations performance measures that can be evaluated with a number of the models being considered in the evaluation. Evaluation of wetlands impacts within the EAA is important because there are substantial wetland areas within the EAA (e.g. Holey Lands, Rotenberger Tract) that may be affected by the operation of the EAA storage reservoirs.

Table 4 shows a summary of the ability of these models to assess these CERP Programmatic Regulations and the number of regulations that could be assessed by each model. From this comparison, the MIKE SHE/MIKE 11 can assess the most performance measures (nine total), while the other two models meet a total of six regulations. Tables 2 - 4 were developed and refined in meetings of the MSC, and the ranking of the models is a result of discussions by the MSC.

Table 4 - Additional Model Comparison Criteria

No.	CERP Performance Measure	HEC-HMS HEC-RAS with MODNET	MIKE SHE/MIKE 11	XP-SWMM2000 and MODFLOW
1	Additional quantity, timing, distribution of water for subsequent projects	●	●	●
2	Improvements to WQ for natural system		●	●
3	Water needs for natural system	2x2	2x2	2x2
4	Document 2000 level of flood protection	●	●	●
5	No loss of quantity, flood protection, water distribution	●	●	●
6	Document impacts to wetlands		●	
7	Evaluate last-added increments	●	●	●
8	Can describe regulation schedules, water control and operating criteria	●	●	●
9	Can describe water level fluctuations	●	●	
10	Distribution of water during droughts		●	
Number of Bullets:		6	9	6

Note: Criteria 3 will be evaluated by the 2x2 model and is a RECOVER function.

The MSC agreed that additional model selection factors should be considered. The factors the MSC considered to be important for this project are as follows:

1. Level of effort to set up model
2. Required iterations during scenarios
3. One model for water quality/hydrology/hydraulics/structures
4. Difficulty of use by agencies after project is done

5. Level of effort to coordinate water quality/hydrology groundwater/hydraulics/structures
6. Extensive documentation, peer reviewed

Table 5 lists the ability of each model to meet these factors in relation to High, Moderate and Low. Determination of level of model conformance (High, Moderate and Low) was based on the MSC and KHA Team members’ prior professional experience with these models.

Table 5 - Additional Factors to Consider in Model Selection

No.	Criteria	HEC-HMS HEC-RAS with MODNET	MIKE SHE/MIKE 11	XP-SWMM2000 and MODFLOW
1	Level of Effort to Set up Model	Low	High	Moderate
2	Required iterations during scenarios	High	Low	High
3	One model for WQ/Hydrology/Hydraulics/Structures	No	Yes	No
4	Difficulty of use by agencies after project is done	Low	Moderate ¹	Moderate ²
5	Level of effort to coordinate WQ/hydrology groundwater/hydraulics/structures	High	Low	High
6	Extensive documentation, peer reviewed	Moderate	Moderate	Low

1 – USACE, SFWMD, and NPS ENP have MIKE SHE/MIKE 11
 2 – USACE and many resource agencies do not have XP-SWMM2000
 - Indicates Best

From this comparison, MIKE SHE/MIKE 11 can achieve the most number of factors with the highest performance relative to the other models.

B.2.1.5 Merits of Final Models

B.2.1.5.1 Model Input Requirements, Analysis Tools, and Pre- and Post-Processing Capabilities

The schedule outlined for the EAA project is extremely aggressive with a short duration defined for the hydrologic/hydraulic modeling component (A CALIBRATED MODEL IS DUE IN MID-JANUARY, 2003). Therefore, to be able to meet this schedule the selected model should have an effective graphical user interface for data entry, analysis of results, and presentation of model output.

The SOW for the preparation of the PIR for the EAA project lists five factors that will affect the model selection:

1. Input data requirements, formats, and tools available to pre-process raw data
2. Tools to generate model grids and boundaries
3. Analysis tools and requirements, including proprietary software necessary to manipulate and display output data
4. Output data requirements, formats, and availability to be used in other software packages like GIS

5. Animation capabilities

The following five sections provide additional detail for these evaluation factors.

1. Input data requirements, formats and availability. The required input data, data formats, and availability is defined in the Table 6. Note that data collection is ongoing, and that requests for data known to be available are outstanding.

Table 6 – MIKE SHE/MIKE 11 Model Data Input Requirements

MIKE SHE - general data			
Input	Basic data requirement	Preferred format	Availability?
Rainfall distribution	Point/Polygon data (x,y) of rainfall stations or precipitation zones	ArcView GIS coverages, MIKE SHE .T2	Adequate data available
Rainfall time series	Time series of precipitation	Excel spreadsheet, MIKE SHE .T0	Adequate daily data available. Still checking for hourly data
Model area	Horizontal extent of model area, polygon data (x,y)	ArcView GIS coverages, MIKE SHE .T2	Available

MIKE SHE OL - overland flow component			
Input	Basic data requirement	Preferred format	Availability?
Digital elevation model (DEM)	Contoured data or point data (x,y,z) of surface elevation.	ArcView GIS coverages	Must be synthesized from a variety of sources. Data collection ongoing
Mannings surface roughness numbers	Land use map	ArcView GIS coverages	Available from the SFWMM

MIKE 11 - river hydraulics model			
Input	Basic data requirement	Preferred format	Availability?
Digitized river/canal network	Point/line/polyline data (x,y) of river branches	ArcView GIS coverages	Available from SFWMD GIS data base
Digitized horizontal extent of surface water bodies	Point/line/polyline data (x,y) of horizontal surface water body extent	ArcView GIS coverages	Available from SFWMD GIS data base
Digitized river and surface water body cross sections	Cross section data (x,z) of main river, flood plains, lakes and reservoirs	Excel spreadsheet, MIKE11 ASCII format, MIKE11 cross section database (.xns11), or HEC-RAS	Available for Miami River, N New River, Cross, Bolles, & some L canals. Still looking for Hillsboro, W. Palm Beach Canals and L-1,4,5,6,7. L-5 data should be in STA-3/4 files (still checking)

Hydraulic structure data	Location and geometry (x,z) of all structures, rivers, operational rules/schedules	Excel spreadsheet, MIKE11 input (.nwk11)	Available from SFWMD Structure Book
Surface water use data	Location (x,z) of diversion points, time series of water use	Excel spreadsheet, MIKE11 input (.nwk11)	Available from SFWMD permit files
Water stage and gauged flow data	Location and ID of gauging station, time series of data	Excel spreadsheet, MIKE11 input (.dfs0)	Available from DBHYDRO for daily, still checking for hourly

MIKE SHE UZ - unsaturated zone

Input	Basic data requirement	Preferred format	Availability?
Soil map - distribution of characteristic soil columns	Polygon data (x,y) of surface soil type.	ArcView GIS coverages	Available
Hydraulic conductivity data	Hydraulic conductivity curve, $K(\Theta)$ for the soils	Excel spreadsheet, MIKE SHE UZ database	Some data found in studies for portions of EAA, still checking other sources
Soil water retention data	Retention curve, $\Theta(pF)$ for the soils	Excel spreadsheet, MIKE SHE UZ database	Available from C-43 Watershed MIKE SHE Model - S-4 Basin

MIKE SHE ET – evapotranspiration

Input	Basic data requirement	Preferred format	Availability?
Potential ET distribution	Point/Polygon data (x,y) of ET stations or ET zones	ArcView GIS coverages, MIKE SHE .T2	Available from the SFWMM
Potential ET time series	Time series of potential ET	Excel spreadsheet, MIKE SHE .T0	Available from the SFWMM
Land use map	Polygon data (x,y) of land use / vegetation cover	ArcView GIS coverages	Available from the SFWMD GIS data base
Vegetation data	Time series of leaf area index (LAI) and root density function (RDF)	Excel spreadsheet, MIKE SHE vegetation database	Available from C-43 Watershed MIKE SHE Model - S-4 Basin

MIKE SHE SZ - ground water

Input	Basic data requirement	Preferred format	Availability?
3-D geological model	Point/contours (xyz) of upper and lower surfaces of all geological units	ArcView GIS coverages, MIKE SHE .T2	Some data found in studies for portions of EAA, still checking other sources
Hydraulic properties	Points/polygons/contours (xyz) of transmissivity based on e.g. pump test data	ArcView GIS coverages	Some data found in studies for portions of EAA, still checking other sources
Groundwater withdrawal	Location of pumping wells (x,y), aquifer unit, time series of withdrawal	Excel spreadsheet, MIKE SHE (.T0)	Available from SFWMD permit files

Drainage	Polygon or line (x,y) map of drain systems and drained/non-drained areas	ArcView GIS coverages, MIKE SHE .T2	Available from SFWMD permit files
Observed head data	Location of observation wells (x,y), aquifer unit, time series of heads	Excel spreadsheet, MIKE SHE (.T0)	Available from DBHYDRO, USGS, and IFAS

The data needs of MIKE SHE/MIKE 11 are similar to the other two models being considered. A comparison of the data needs of the three modeling approaches is provided in Table 7.

Table 7 Input Data Requirements of Final Models

Input Data	MIKE SHE/MIKE 11	HEC-HMS HEC-RAS MODNET	XP-SWMM/ MODFLOW
1. Hourly or daily rainfall	R	R	R
2. Evapotranspiration	R	R	R
3. Stream/canal cross sections	R	R	R
4. Topographic data/digital elevation model	DEM	Slope	Slope
5. Land use	R	R	R
6. Crop-specific ET	R	N/A	N/A
7. Interior Farm Drainage Coefficients	R	N/A	N/A
8. Overland Manning's Coefficient (n)	R	R	R
9. Channel Manning's Coefficient (n)	R	R	R
10. Pump details	R	R	R
11. Gate details	R	R	R
12. Culvert dimensions	R	R	R
13. Groundwater layers	R	R	R
14. GW layer thickness	R	R	R
15. GW hydraulic parameters	R	R	R
16. Boundary conditions	R	R	R
17. River channel-groundwater exchange	2-way	Uncoupled 2-way	1-way
18. Calibration Data (rivers, groundwater)	R	R	R

Legend: R – required
 N/A - not applicable
 DEM - Digital Elevation Model

The key differences among these models are related to Items 4, 6, 7 and 17 outlined in Table 7. The boundary conditions (Item 16) in MIKE SHE/MIKE 11 must be selected carefully so that the interaction of the EAA with Lake Okeechobee and the WCAs is handled properly. The differences, advantages and disadvantages of each model associated with these items are described in the following subsections.

Item 4: MIKE SHE/MIKE 11 requires an accurate digital elevation model (DEM) that allows for accurate flood inundation mapping, as shown in Figure 1. The other models do not have flood inundation linked directly to a DEM; however, flood inundation maps can be created with a significant level of effort during post-processing of the results. Topography is limited in the EAA; however, a

reasonable DEM can be generated by merging land surface elevation data from a number of sources such as permits, previous surveying efforts and available data from the landowners.

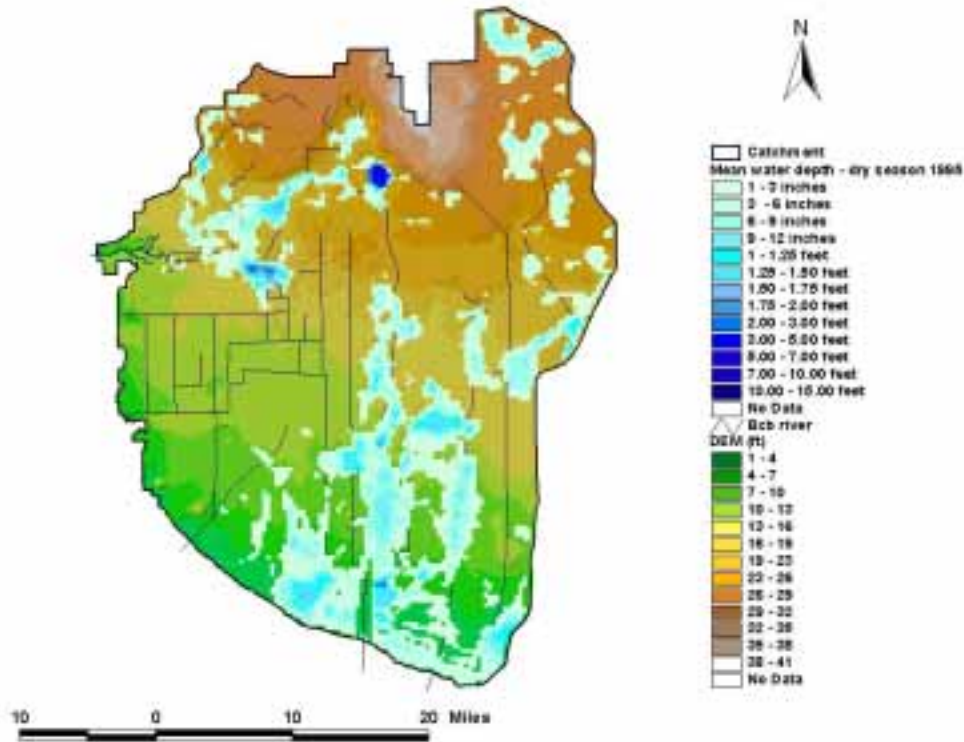


Figure 1 – Flood Inundation Map for Big Cypress Basin from MIKE SHE/MIKE 11 model

- Item 6: Crop specific ET can be handled by all three models; however only MIKE SHE/MIKE 11 has the ability to have the crop uptake directly linked to the groundwater dynamics. Crop specific ET parameters are available from the muck-farm sugar cane areas for the C-43 Basin watershed that are directly west of Clewiston.
- Item 7: Interior farm drainage coefficients are used in MIKE SHE/MIKE 11 to represent minor interior canals. The drainage feature in MIKE SHE/MIKE 11 allows for conveyance of water from the unsaturated zone to the farm discharge point. This can be simulated to a degree in UNET and/or MODNET; however, the interior farms are represented by a single storage element, not a set of grid cells with varying levels of drainage. Farms often have areas of poor drainage. A multi-cell farm representation will better represent interior farm flooding than a single cell representation of the farm. Therefore, MIKE SHE/MIKE 11 will represent interior flooding of farm fields due to high ground water conditions better than either UNET or XP-SWMM.
- Item 16: Boundary conditions will be selected so that the model will be able to handle flows in and out of the EAA. Lake Okeechobee inflows will be provided from either measured data (for calibration) or the 2x2 (for scenarios). The model grid will be set to lay right on top of the 2x2 grid so that data can be readily

exchanged, plus the grid will extend into WCA 1, 2, and 3. Measured and 2x2 water levels will be utilized for simulations. One potential grid option for MIKE SHE/MIKE 11 is presented in Attachment B.

The 2x2 boundary on the west side of the EAA is east of the L canals. The 2x2 therefore cannot represent the dynamics of a proposed EAA storage reservoir next to the L-canal. If the western domain of the MIKE SHE model of the EAA is exactly the same as the 2x2 (to facilitate concurrency), then the MIKE SHE model may have a similar problem. Data from STA 5 and 6 will be reviewed to determine if seepage extends to the west of the L-2 and 3 canals. If this is the case, some extension of the western boundary of the MIKE SHE model may be appropriate.

Item 17: River channel-groundwater exchange in MIKE SHE/MIKE 11 is a two-way process where the river accepts groundwater inputs if the water elevation in cells adjacent to the river are higher than the river elevation. The river discharges to the aquifer if the river level is higher than the water surface elevation in cells adjacent to the river. Figure 2 illustrates how these results are provided from MIKE SHE. The other models allow for watershed groundwater inflows to the river, but this discharge is not limited by higher river elevations. MODNET can handle two-way river-aquifer interactions, but infiltration in HEC-HMS and subsequent discharge to a river segment takes place regardless of the river elevations. SWMM river segments do not drain to MODFLOW. River channel-groundwater exchange coefficients can be selected with previous values used in adjacent watersheds and empirical information available from EAA land managers.

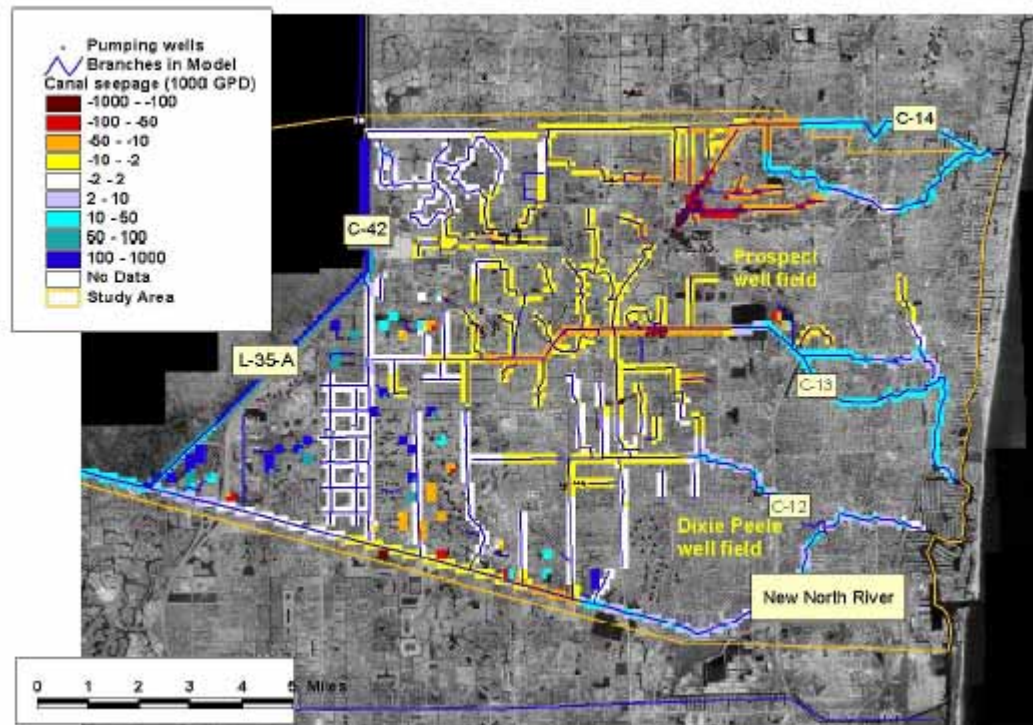


Figure 2 – Canal-Aquifer Exchange of the Central Broward MIKE SHE/MIKE 11 Model

Data Formats. The HEC models and UNET use DSS data formats, which are commonly used. MODFLOW data formats are ASCII, and are commonly used. SWMM input files are ASCII, and are commonly used.

The MIKE SHE/MIKE 11 format for data is dfs0 (an ASCII data storage format), however MIKE 11 and MIKE SHE have the capability to exchange data from a number of sources, including ASCII, and spreadsheets. Routines can be written for formats such as DSS and the 2x2 model.

Pre-process Raw Data. The raw data can be processed from sources such as ASCII and spreadsheets using standard cut-and-paste techniques. The cross section files can be converted from SWMM or HEC-RAS format directly into the format used by MIKE 11. GIS tools are available to view spatial data and to convert a combination of raw topography and survey points into a DEM.

- Tools to generate model grids and boundaries. The HEC models and XP-SWMM do not use a grid-based representation of the watershed. This limits the ability of these models to exchange information with the SFWMM. MODFLOW uses a variable grid which allows for a higher resolution near canals and reservoirs. Groundwater Vistas is a proprietary Graphical User Interface (GUI) that is commonly used for generating MODFLOW grids. Other GUIs are also available including GMS and some customized ArcView utilities. MODFLOW grids can be set up to be consistent with the SFWMM 2x2 grid.

MIKE SHE/MIKE 11 has GIS tools for generating model grids (fixed square grid only) and boundaries. These tools can also be used to import model grids from other programs such as the HSE grid and the 2x2 grid.

- Analysis tools and requirements, including proprietary software necessary to manipulate and display output data. HEC HMS and HEC-RAS have analysis tools for manipulating and displaying output data. Free software or low-cost graphical user interface programs are available for these programs. XP-SWMM results can be analyzed and displayed with a built in graphic user interface. Common output for HEC-RAS and XP-SWMM includes river profiles and hydrographs.

Reviewing the flux of infiltration to groundwater and to the river, and from the river to the groundwater will require a significant amount of data manipulation for the HEC models and for XP-SWMM/MODFLOW. There are no common tools used for analysis of this type of information. As stated above, MODFLOW results can be reviewed using Groundwater Vistas. Groundwater Vistas cannot display all results provided by MODNET, and a graphical user interface for MODNET was not identified.

MIKE SHE/MIKE 11 is propriety software from DHI. This software has been purchased by SFWMD, USACE, and Everglades National Park. A number of consultants in Florida also have licenses, including Brown and Caldwell, ADA

Engineering, CDM, and Ayres Associates. MIKE SHE/MIKE 11 has basic statistical processing routines to calculate parameters such as mean, minimum, maximum, mean error, mean absolute error, root mean squared error, standard deviation, and the Nash Sutcliff statistic.

MIKE SHE/MIKE 11 output data can be displayed in the following formats: tabular, time series graphs, cross section plots, and profile plots for both surface water and ground water layers. Plan-view flood plain maps can be displayed for the model area (see Figure 1). An initial listing of the model output relative to performance measures is listed below in Table 8. Additional information will be provided after performance measures are defined beyond the generic performance measures listed in the CERP Programmatic Regulations.

Table 8 – MIKE SHE/MIKE 11 Model Output and Intended Use

Output data	Description	Intended Use
Canal elevation	Canal elevation, depth, peak depth and top of bank as a profile, cross section, or time series	<ul style="list-style-type: none"> • Compare peak elevation to levee height to determine flooding potential • Determine wetland hydroperiods • Compare to elevation of plant communities to determine benefit of restoration scenario
Depth to groundwater and elevation above ground	Time series of depths at specific points, plan view maps of watershed, animations of plan view maps	<ul style="list-style-type: none"> • Wetland hydroperiod assessments • Farm field drought and flood impacts • Reservoir dry-out assessments
Canal velocity	Time series of velocity at specific points, spatial maps of velocity	<ul style="list-style-type: none"> • Assess sediment re-suspension potential
Flows in and out of Lake Okeechobee	Annual, monthly, weekly, or daily water budgets for in/out of Lake Okeechobee	<ul style="list-style-type: none"> • Assess ability of reservoirs to reduce discharges to or demand from Lake Okeechobee
Water Budgets	Annual, monthly, weekly, or daily water budgets for farms, drainage basins, or multiple drainage basins	<ul style="list-style-type: none"> • Track demand from farms. • Impacts to Lake Okeechobee, WCAs, Holey Land and Rotenberger WMAS. • Verify no change of flows to STAs • Savings/reservations • Impacts on urban water supply

4. Output data requirements, formats, and availability to be used in other software packages like GIS Output of time series data from all three possible modeling packages can be copied and pasted directly into Excel and other databases. Groundwater Vistas can generate results for use in GIS, and some GIS processing of HEC and XP-SWMM results is possible.

MIKE SHE/MIKE 11 ground water input and output files can be converted directly to MODFLOW format using standard Windows-based file store pull-down menus. Spatial output from MIKE SHE/MIKE 11 can be saved in GIS format (shape files) using standard Windows-based pull down menus.

5. Animation capabilities MIKE SHE/MIKE 11 has animation routines available for viewing results in a variety of formats. MIKE SHE/MIKE 11, and HEC-RAS, and XP-SWMM have animations capabilities for river flow and water depth in time series, profile, and cross section formats. However, MIKE SHE/MIKE 11 also provides animated results (calculated using the integrated surface/ground water model) in plan view. In MIKE SHE/MIKE 11, animations of flood inundation on top of a DEM can be created for user-defined time periods (e.g. an animation of water depth for the year of 1995). Animations of integrated surface/ground water model results for HEC-HMS/HEC-RAS/MODNET and XP-SWMM MODFLOW are not possible without extensive post-processing of model results.

B.2.1.5.2 MIKE SHE/MIKE 11

MIKE SHE/MIKE 11 is a proprietary model that has the ability to meet the majority of the modeling requirements within a single integrated model. This will save time and effort during calibration and scenario analysis. MIKE SHE/MIKE 11 has been applied to approximately 6,500 square miles in Florida (Watersheds: C-43, Tidal Caloosahatchee River, Estero and Imperial Rivers, Big Cypress Basin, ENR, Lake Toho watershed, central Broward County, and the Bennett Swamp watershed in Volusia County). The MIKE SHE/MIKE 11 model of the Everglades Nutrient Removal Project (now STA-1W) was able to reproduce measured water levels in surface and ground water both inside and outside the ENR. Significant effort will be required during model development. SFWMD, USACE, and ENP are currently using the software, but it may be difficult for other stakeholders to obtain access to the code to conduct a thorough peer review. DHI has in the past made temporary licenses (for 3 to 6 months) available at no cost for peer review, and will do so for this project. Further, DHI will assist peer reviewers in understanding the structure of input files.

B.2.1.5.3 HEC-HMS, HEC-RAS with UNET, and MODNET

The HEC-HMS, HEC-RAS with UNET, and MODNET models are firmly within the public domain and are commonly used for many hydrologic/hydraulic studies within Florida and across the U.S. Models exist for much of the study area for both UNET and MODFLOW. However, the hydrologic model and the hydraulic model of the surface water system are separate models which require iteration to make sure that lumped parameters within the two models are consistent. Evaporation is relatively simple in HEC-HMS, and is based on monthly averages. Seepage from the watershed to canals is not limited by high canal stages. The groundwater is modeled by MODNET. This necessitates another level of iterations between HEC-RAS/UNET and MODNET to make sure that parameterization of surface/ground water interactions is consistent. These two iteration steps will increase the cost and time necessary for both calibration and scenario analysis.

B.2.1.5.4 XP-SWMM 2000 and MODFLOW

XP-SWMM 2000 is a proprietary version of SWMM that is commonly used by many government agencies and consultants in south Florida and throughout the U.S. MODFLOW is a public domain software program that has been used throughout south Florida and the U.S. XP-SWMM 2000 has been linked to MODFLOW by a consultant in a study in northeast Broward County, and weak linkages have been used in other watersheds, such as the Bennett Swamp in Volusia County. The linked XP-SWMM/MODFLOW model used in Broward County allows for infiltration from SWMM to MODFLOW, but seepage back to canals from MODFLOW is not possible. Unsaturated zone dynamics are less comprehensive than MIKE SHE, which has led to calibration challenges (James et al., 2000).

B.2.1.6 Conclusions and Recommendations

The MSC outlined 11 key modeling goals that should be met by the model or combination of models selected to support the EAA project PIR development. The MSC also identified ten CERP performance measures that are crucial to be assessed by selected model(s) and a total of six key factors that can be met by the model(s). Of the 14 models or combinations of models identified by the MSC, the MIKE SHE/MIKE 11 model is the model that can meet the most modeling selection goals, assess the most CERP performance measures, and meet the most key modeling factors. The MIKE SHE/MIKE 11 model also has the most comprehensive analysis tools and pre- and post-processing capabilities to provide the results included in the KHA Team SOW.

Based on the model selection approach identified by the MSC, the MIKE SHE/MIKE 11 model is the recommended model to address the EAA Sub-Regional modeling requirements. This model will complement the SFWMM (2x2 model) which is the selected regional modeling tool to support the EAA Reservoir – Phase 1 Project PIR development. This conclusion is derived from the superior capability of this model to address key goals, criteria and factors identified by the MSC within the available project schedule. This approach provides a comprehensive, integrated surface water and ground water model that will easily exchange boundary condition results with the existing Regional Model. It will provide sufficient detail to adequately represent the interaction of the secondary (farm) drainage basins and the primary canal system within the EAA. MIKE SHE/MIKE 11 will also support the development of flood damage assessments and the evaluation of alternative plans. Additionally, it can be developed and calibrated with available existing data within the time frame of this project.

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ATTACHMENT B

POTENTIAL MIKE SHE/MIKE 11 GRID OPTIONS

