

**CENTRAL AND SOUTHERN FLORIDA PROJECT
COMPREHENSIVE EVERGLADES RESTORATION PLAN**



**G.1 – WATER QUALITY MODELING
G.1.1 – RESERVOIR PHOSPHOROUS
UPTAKE MODEL**

**EVERGLADES AGRICULTURAL AREA
STORAGE RESERVOIRS - PHASE 1**



**US Army Corps of Engineers
Jacksonville District**



**South Florida Water
Management District**

Assisted By:
 **Kimley-Horn
and Associates, Inc.**
(SFWMD Consultant Task 2.1.1)

TABLE OF CONTENTS

G.1.1 Reservoirs Phosphorus Uptake

FORWARD.....	ii
G.1.1.1 Introduction.....	1
G.1.1.2 Model Selection Criteria.....	2
G.1.1.3 Model Shortlist Description and Evaluation.....	3
G.1.1.3.1 DMSTA.....	4
G.1.1.3.2 CE-QUAL-R1.....	6
G.1.1.3.3 CE-QUAL-W2.....	9
G.1.1.3.4 LOWQM.....	12
G.1.1.3.5 WQRRS.....	14
G.1.1.3.6 MIKE 3, 11, 12 and 21.....	16
G.1.1.3.7 WAP6.....	19
G.1.1.3.8 HydroQual Wetlands.....	22
G.1.1.4 Model Selection Approach.....	24
G.1.1.4.1 Identify Water Quality Parameters of Concern.....	24
G.1.1.4.2 Assess Availability of Water Quality Data.....	25
G.1.1.4.3 Establish Water Quality Modeling Objectives.....	26
G.1.1.4.4 Identify Physical, Chemical and Biological Processes to be Modeled.....	27
G.1.1.4.5 Identify and Rank Candidate Water Quality Models.....	27
G.1.1.5 Conclusions and Recommendations.....	28

REFERENCES

ATTACHMENTS

Attachment G.1.1.1 – Modeling Steering Committee Members and Participants

FORWARD

The purpose of this interim document is to present the results of the Everglades Agricultural Area Storage Reservoirs – Phase 1, Water Quality Model Steering Committee discussions between September, 2002 and April, 2003. The process of identifying candidate models and methodologies was interrupted to allow for a broader discussion of the water quality parameters and spatial limits of the model needed to meet the project’s objectives. It is anticipated that this document in its current form will not be included in the Draft or Final PIR. It will serve as the basis for on-going discussions on this vital topic.

G.1.1 Reservoir Phosphorus Uptake

G.1.1.1 Introduction

The Everglades Agricultural Area (EAA) Storage Reservoirs – Phase 1 Project Implementation Report (PIR) requires that a hydrologic, hydraulic and water quality 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 (USACE and the SFWMD 2002) goals and objectives are as follow:

1. Reduction of the Lake Okeechobee regulatory releases to the estuaries and back pumping from the EAA into Lake Okeechobee by sending the water to the south and into the proposed 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 Stormwater Treatment Area (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; and
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 hydrologic and hydraulic model selection and approach are address in Appendix B.2.1 – Model Evaluation Report and Appendix B.2.2 – Hydrologic Modeling/Methodology Report, respectively. The development of an approach to modeling the water quality benefits of the EAA Storage Reservoirs and to optimize STAs performance is a critical element in the development of the PIR. The water quality model and approach must be capable of the following functions:

1. Provide a tool for evaluating alternative plans and simulating the interaction between alternative configurations of the EAA Storage Reservoirs and the STAs.
2. Assess phosphorus impacts related to water depths and dry-out periods that will be typical of the EAA Storage Reservoirs.

The water quality model and approach must also be able to meet the requirements outlined in the final Comprehensive Everglades Restoration Plan (CERP) Guidance Memorandum Number 023: Water Quality Considerations for Project Management Plans and Project Implementation Reports (CGM 023). This guidance memorandum addresses water quality considerations necessary for the formulation, evaluation, and design of project alternatives during the PIR development. A draft of this memorandum has been prepared by the Florida Department of Environmental Protection (FDEP 2003), dated February 4, 2003, and it is in the process of being finalized.

To clarify the intent of WRDA with respect to attaining Everglades water quality restoration objectives, the Draft CGM establishes three categories of CERP Projects. Category A, B, and C projects must not attain their primary water quantity performance objectives by degrading water quality. For a Category B project, design or operational alternatives with net water quality benefits must also be pursued, as long as this does not

compromise the attainment of its primary water quantity performance objectives. A Category A project is designed to meet one or more water quality performance objectives in addition to its water quantity performance objectives. The EAA Storage Reservoirs meet the CGM definition of a Category B project.

The SFWMD and US Army Corps of Engineers (USACE) Project Managers formed a Model Steering Committee (MSC) to provide guidance throughout the EAA Basin modeling activities. A list of the MSC members is included in Attachment G.1.1.1. The following sections describe the water quality model selection criteria defined to date and potential models that could meet these criteria. Recommendations of an approach to be implemented in selecting the ultimate water quality model and methodology for this project are also presented.

G.1.1.2 Model Selection Criteria

The selected water quality model(s) or tool(s) must be able to meet the objectives identified in the PMP and final CGM 023, and it must assess water quality performance of the alternative plans. The MSC identified 16 models that could potentially meet these objectives:

1. Dynamic Model for Stormwater Treatment Areas (DMSTA)
2. HSPF
3. BATHTUB/FLUX/PROFILE
4. CE-QUAL-R1
5. CE-QUAL-W2
6. HEC-5Q
7. EUTROMOD
8. WAMVIEW
9. EAAMOD
10. Lake Okeechobee Water Quality Model (LOWQM)
11. Water Quality for River-Reservoir System (WQRRS)
12. XP-SWMM
13. MIKE 3, 11, 12 and 21
14. Water Quality Analysis Simulation Program (WASP6)
15. QUAL2E
16. Hydroqual Wetlands

The MSC reduced this list of models to a list of eight models, based on the capability of the models to meet the following criteria:

1. Ability to simulate water quality dynamically
2. Ability to account for spatial extent in analysis
3. Model comprehensiveness
4. Ability to simulate water quality in reservoirs

The eight models that could potentially meet these criteria are as follows:

1. DMSTA
2. CE-QUAL-R1
3. CE-QUAL-W2
4. LOWQM
5. WQRRS
6. MIKE 3, 11, 12 and 21
7. WASP6
8. Hydroqual Wetlands

The MSC also identified 12 proposed water quality model selection criteria as follows:

1. Capable of estimating reservoir water quality treatment performance
2. Capable of estimating STA water quality performance or integrating with DMSTA
3. Capable of simulating surface water quality
4. Capable of simulating groundwater quality
5. Capable of simulating pollutants of concern
6. Capable of being integrated with selected hydrologic/hydraulic model(s)
7. Capable of simulating reservoir design alternative design features (internal cells, submerged areas, operational scenario, etc.)
8. Extensively used to simulate conditions similar to those found in the EAA
9. Reasonable model set-up and execution times to meet project schedule
10. Data needs can be met with available data or with a minimum of additional research, special studies, or monitoring
11. Available model documentation
12. Licensed for public use

These criteria may need to be modified and/or refined after water quality evaluation criteria and CGM 023 are finalized. In addition, following discussions by the Modeling Steering Committee, it was decided that, for purpose of optimizing STA performance in conjunction with EAA Reservoir operation, the real-time routing of extreme flow events to maximize removal of particles and particle-bound pollutants and to minimize particle resuspension and export would not be considered. This eliminates the need for modeling of particle transport as a function of particle size, density, and flow and the associated water quality dynamics and kinetics. For purposes of addressing the effects of changes in design or operation on the water quality impacts from a range of meteorological and hydrological events, a steady state EAA runoff model run in probabilistic mode will feed a reservoir water quality model joined to an STA water quality model joined to the receiving water body model under mass budget constraints.

G.1.1.3 Model Shortlist Description and Evaluation

The following sub-sections provide a brief overview of each of the eight models short listed by the MSC as potential models that could meet the model selection criteria. These sub-sections also provide a summary of the model formulation, required input parameters, capabilities, limitations and developer/distributor.

G.1.1.3.1 DMSTA

DMSTA Overview

DMSTA is currently being used to support the evaluation of STAs, as part of the Everglades Construction Project (ECP) Basin-Specific Feasibility Studies. DMSTA provides a framework for integrating experimental and field-scale monitoring data for designing the next generation STAs. The phosphorous removal performance of the STAs has also been evaluated with DMSTA. This model was prepared by William Walker and Robert Kadlec for the U.S. Department of Interior (Walker and Kadlec 2002).

The DMSTA model has been prepared to provide a single platform for estimating the performance of a variety of treatment wetland options, including wetlands dominated by emergent macrophytes (classic STA), submerged aquatic vegetation (SAV), and periphytic algae (PSTA). This model provides an extremely flexible set of options for parameter selection, water balance issues, water flows, and internal hydraulics, and cell configurations.

DMSTA Formulation

DMSTA simulates daily water and mass balances in a user-defined series of wetland treatment cells, each with specified morphometry, hydraulics, and phosphorus cycling parameters. Up to six treatment cells can be linked in series and/or parallel to reflect compartmentalization and management to promote specific vegetation types. Each cell is further divided into a series of continuous stirred tank reactors (CSTR's) to reflect residence time distribution. Water-Balance terms for each cell include inflow, bypass, rainfall, evapo-transpiration, outflow, seepage in, and seepage out. Parameter estimates for the phosphorus cycling model have been developed for various vegetation types. The model is coded in Visual Basic for applications; the user interface is an Excel workbook.

The DMSTA phosphorus cycling model contains three parameters that require calibration to each vegetation type. Two parameters (C0, C1) define the effective concentration range and scale of biomass phosphorus (P) storage. These are calibrated using biomass P and water column P data from several systems. Another key parameter (Ks) reflects the turnover rate of biomass P. Turnover rate is calibrated to outflow concentration time series data.

DMSTA Required Input Parameters

A list of the DMSTA model input data requirements includes the following:

- Morphometry (Length, Width, Area, Cell Configuration)
- Hydraulic Efficiency (Number of Stirred Tanks in Series)
- Daily Time Series:
 - Inflow and Outflow Volume
 - Inflow and Outflow Concentration

- Mean Depth
- Rainfall
- Evapotranspiration
- Descriptive Data:
 - Seepage Rates
 - Community Description
 - P Storage (metadata: macrophytes, periphyton, soil)

Daily time series data used for model calibration include:

- Outflow Volume
- Depth
- Velocity
- Inflow Concentration (flow-weighted, un-weighted)
- Outflow Load (using observed or predicted flows)

DMSTA Capabilities

The DMSTA can simulate the phosphorus load reduction of wetland systems. DMSTA can be used to model flows and phosphorus through existing and modified STAs. DMSTA can also be used to route flows through flow equalization basins and other components associated with chemical treatment facilities. The DMSTA model offers the following factors that are not included in a steady-state STA design model:

- Temporal Variations in Inflow Volume, Load, Rainfall, and ET
- Hydraulic Compartments (Cells, Internal Levees for Flow Redistribution)
- Hydraulic Efficiency (Number of Stirred Tanks in Series)
- Cell Aspect Ratio (Length/Width)
- Water Level Regulation
- Outflow Regulation (Discharge vs. Water Level)
- Compartmentalization of Biological Communities
- Dry-Out Frequency and Supplemental Water Needs
- Bypass Frequency, Quantity, and Quality
- Seepage Collection and Management

DMSTA Limitations

The following are some know limitations of the DMSTA model:

- DMSTA lacks level of detail in modeling reservoir hydrology.
- One important limitation of the DMSTA model is that certain SAV types that may have relatively low uptake rates (such as hydrilla) are not represented in the data sets. Therefore, they cannot be represented properly with DMSTA.
- The model is bound by the limitations of the available datasets (e.g., spatial scale, duration, and/or relatively steady inflows), so, for example, it cannot currently model reservoir performance

- DMSTA has not been calibrated for deep-level pools as those associated with reservoirs.
- DMSTA can only model phosphorus removal by a generalized (lumped) process of transfer from a labile pool to a refractory pool. It cannot model phosphorus removal by the individual processes of particle settling, biological uptake and net refractory biomass storage, or chemical precipitation as a function of pH, alkalinity, redox, or temperature. It cannot model release of labile phosphorus from the sediment back to the water column as a function of wind, flow, depth, redox, or temperature.
- Although the model can be run on a daily time step, the empirically derived coefficients are long-term annual average values.
- It systematically overestimates the TP removal efficiency and underestimates the TP outflow concentrations in the low TP concentration range (< 50 ppb), e.g., STA-2.

DMSTA Developer/Distributor

William Walker
Department of Interior
<http://www.walker.net/dmsta/>

G.1.1.3.2 CE-QUAL-R1

CE-QUAL-R1 Overview

CE-QUAL-R1 is a spatially, one dimensional model that simulates vertical distribution of thermal energy, biological materials, and chemical materials in reservoirs. This model can simulate pre- and post-impoundment water quality and the effects of reservoir management operations on water quality. The model can also simulate water quality problems associated with reservoir eutrophication with possible anaerobic conditions. CE-QUAL-R1 can model the dynamics of 27 water quality variables and can calculate both vertical in-pool and downstream releases. The model can also simulate 11 other variables, which represent materials in sediments.

CE-QUAL-R1 Formulation

In CE-QUAL-R1, the reservoir is conceptualized as a vertical sequence of horizontal layers where thermal energy and materials are uniformly distributed in each layer. The mathematical structure is based on a set of differential equations that express conservation of mass and energy in each horizontal layer. Solution of these equations provides material or energy concentrations as functions of time and depth. Temperature and concentration gradients are computed only in the vertical direction. Variable layer thicknesses permit accurate mass balancing during periods of inflow and outflow. The distribution of inflowing waters among the horizontal layers is based on density differences. Simulations of surface flows, interflows, and underflows are possible. Similarly, out flowing waters are withdrawn from layers after considering layer densities, discharge rates, and outlet configuration.

The thermal analysis portion of CE-QUAL-R1 is provided as an independent model (CE-THERM-R1) to simplify simulation of water budgets and temperature profiles. CE-THERM-R1 includes the variables of temperature, suspended solids, and total dissolved solids. Algorithms representing physical processes are the same as in CE-QUAL-R1.

A number of utilities are also provided with CE-QUAL-R1. These include preprocessors, which are aids in assembling a usable data set, two graphic utilities, statistics for comparing measured and predicted data, and a flux model. The flux model calculates and lists the rates of change for all biological processes, which should aid the user in correctly predicting variable concentrations.

The vertical transport of thermal energy and materials occurs through entrainment and turbulent diffusion. Entrainment is a transport process that sharpens gradients and determines the depth of the upper mixed region and the onset of stratification. It is calculated from the turbulent kinetic energy influx generated by wind shear and convective mixing. Turbulent diffusion is a transport process that reduces gradients and is calculated using a turbulent diffusion coefficient that is dependent on wind speed, inflow and outflow magnitudes, and density stratification.

CE-QUAL-R1 Required Input Parameters

CE-QUAL-R1 requires an extensive amount of data including initial conditions, reservoir geometry, physical coefficients, biological and chemical reaction rates, and time sequences of hydrometeorological and inflowing water quality concentrations.

CE-QUAL-R1 Capabilities

CE-QUAL-R1 can simulate the interaction of numerous factors in both aerobic and anaerobic environments. The following are some of the physical, chemical and biological factors that can be simulated:

Physical Factors

- Shortwave and longwave solar radiation at the water surface.
- Net heat transfer across the air-water interface.
- Convective and radiative heat transfer within the water body.
- Convective mixing due to density instabilities.
- Placement of inflowing water at depths with comparable density.
- Withdrawal of outflowing waters from depths influenced by the outlet structures, discharge rate, and density stratification.
- Conservative substance routing.
- Suspended solids routing and settling.

Chemical and Biological Factors

- Accumulation and depletion of dissolved oxygen through aeration, photosynthesis, respiration, and organic decomposition.

- Uptake-excretion kinetics and regeneration of nitrogen and phosphorus and nitrification-denitrification processes under aerobic and anaerobic conditions.
- Carbon cycling and dynamics and alkalinity-pH-CO₂ interactions.
- Dynamics and trophic relationships of phytoplankton and macrophytes.
- Transfer through higher trophic levels of the food chain.
- Accumulation, dispersion, and decomposition of detritus and sediment.
- Coliform bacteria mortality.
- Accumulation, dispersion and reoxidation of manganese, iron, and sulfide when anaerobic conditions prevail.

The model can also address the following water quality problems:

- Onset, extent and duration of thermal stratification.
- Location of selective withdrawal ports required to meet a downstream temperature objective.
- Effect of structural modifications on water quality.
- The development of anoxic conditions.

In addition, the model can perform stochastic simulations using Monte Carlo methods. Statistical data describing biological and chemical coefficients are used to provide probabilistic estimates of key output variables. Reservoir outflows can be simulated to take place according to a specified schedule of port releases. Alternately, specification of total release and desired release temperatures can be made. In this case, the model will select port flows. In addition, both continuous (normal) and scheduled operations can be simulated. Continuous operation refers to normally uninterrupted port and weir outflows. Scheduled operation refers to fluctuating generation outflows or pumpback inflows.

CE-QUAL-R1 Limitations

The one-dimensional representation of reservoirs limits simulation to a vertical series of well-mixed horizontal layers. This assumption cannot predict longitudinal and lateral variations in water quality and requires the assumption of instantaneous dispersion of all inflow quantities and constituents throughout the horizontal layers.

The model assumes that the dynamics of each physical, chemical and biological component can be described by the principal of conservation of mass. Because the equations are not solved in closed form, minor errors concerning the conservation of mass can occur.

CE-QUAL-R1 Developer/Distributor

Dorothy H. Tillman
Environmental Laboratory
U.S. Army Engineer Research and Development Center

Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
tillmad@wes.army.mil

G.1.1.3.3 CE-QUAL-W2

CE-QUAL-W2 Overview

CE-QUAL-W2 is a longitudinal-vertical hydrodynamic and transport model built for long-term, time-varying water quality simulations of lakes, reservoirs, and estuaries. CE-QUAL-W2 accurately reproduces vertical and longitudinal water quality gradients and is capable of multi-decade simulations. CE-QUAL-W2 presently includes water quality routines for 22 parameters: suspended solids, coliforms, total dissolved solids, labile DOM, refractory DOM, algae, detritus, phosphorous, ammonia, nitrate-nitrite, dissolved oxygen, CBOD, sediment, inorganic carbon, alkalinity, pH, carbon dioxide, bicarbonate, carbonate, iron, and a numerical tracer. Other parameters and formulations are easily accommodated in the modular code. CE-QUAL-W2 can be used to infer changes in circulation and water quality as well as provide boundary condition data to embedded 3-D models or to near-field models such as PLUMES or CORMIX.

CE-QUAL-W2 Formulation

CE-QUAL-W2 is based on the laterally averaged equations of momentum, continuity, and transport. The formulation includes the vertically varying, longitudinal momentum balance, vertical momentum in the form of the hydrostatic approximation, local continuity, vertical integration of the continuity equation based on a free surface condition as one of its boundaries, and longitudinal and vertical transport of any number of constituents. Constituents that determine density such as temperature and salinity are related to momentum through an equation of state. The vertically varying, longitudinal momentum balance includes local acceleration of horizontal velocity, horizontal and vertical advective momentum transfer, the horizontal pressure gradient, and horizontal and vertical shear stress. Included in the latter are the surface wind stress and the bottom stress caused by friction. The horizontal pressure gradient includes the barotropic surface slope and the baroclinic vertical integral of the horizontal density gradient which is the dominant term in density-induced, convective circulation.

The time-varying solution technique of the model is based on an implicit, finite difference scheme that results from the simultaneous solution of the horizontal momentum equation and the free-water surface equation of vertically integrated continuity. This technique results in the surface long wave equation that is solved on each time step to give the water surface profile, from which the vertical pressure distribution can be determined. The horizontal momentum is then computed, followed by

internal continuity and then constituent transport. The QUICKEST finite difference scheme is used for the advective processes in the constituent transport balances. Vertical turbulent transfer of momentum and constituents is determined from the vertical shear of horizontal velocity and a density gradient-dependent Richardson number function.

The boundary conditions at the open ends of the branches can be any combination of either flux or elevation conditions. The fluxes or elevations are specified from boundary data. The elevation boundary condition enters the formulation through the implicit long wave surface equation. Fluxes at the elevation boundary are computed from a reduced form of the longitudinal and vertical momentum equations which include the baroclinic, barotropic, vertical shear, and local acceleration terms but do not include the longitudinal spatial acceleration.

CE-QUAL-W2 Required Input Parameters

CE-QUAL-W2 requires an extensive amount of data including:

- Geometric data
- Topographic map and/or sediment range surveys
- Project volume-area-elevation table
- Bathymetric data
- Initial conditions
- Boundary conditions
- Hydraulic parameters
- Kinetic parameters

CE-QUAL-W2 Capabilities

The following is a summary of the CE-QUAL-W2 capabilities:

- **Hydrodynamic.** The model predicts water surface elevations, velocities, and temperatures. Temperature is included in the hydrodynamic calculations because of its effect on water density.
- **Water quality.** The water quality algorithms incorporate 21 constituents in addition to temperature including nutrient/phytoplankton/dissolved oxygen (DO) interactions during anoxic conditions. Any combination of constituents can be simulated. The effects of salinity or total dissolved solids/salinity on density. Hydrodynamics are included only if they are simulated in the water quality module. The water quality algorithm is modular allowing constituents to be easily added as additional subroutines.
- **Long term simulations.** The water surface elevation is solved implicitly which eliminates the surface gravity wave restriction on the time step. This permits larger time steps during a simulation resulting in decreased computational time. As a result, the model can easily simulate long-term water quality responses.
- **Head boundary conditions.** The model can be applied to estuaries, rivers, or portions of a waterbody by specifying upstream or downstream head boundary conditions.

- **Multiple branches.** The branching algorithm allows application to geometrically complex waterbodies such as dendritic reservoirs or estuaries.
- **Variable grid spacing.** Variable segment lengths and layer thicknesses can be used allowing specification of higher resolution where needed.
- **Water quality independent of hydrodynamics.** Water quality can be updated less frequently than hydrodynamics, thus reducing computational requirements. However, water quality kinetics are not decoupled from the hydrodynamics (i.e., separate, stand-alone code for hydrodynamics and water quality where output from the hydrodynamic model is stored on disk and then used to specify advective fluxes for the water quality computations). Storage requirements for long-term hydrodynamic output to drive the water quality model are prohibitive for anything with a large number of computational cells. Additionally, reduction in computer time is minimal when hydrodynamic data used to drive water quality are input every time step.
- **Autostepping.** The model includes a variable time step algorithm ensuring numerical stability requirements for the hydrodynamics imposed by the solution scheme are not violated.
- **Restart provision.** The user can output results during a simulation that can subsequently be used as input. Execution can then be resumed at that point.
- **Layer/segment addition and subtraction.** The model will adjust surface layer and upstream segment locations for a rising or falling water surface during a simulation.
- **Multiple inflows and outflows.** Provisions are made for inflows and inflow loadings from point/nonpoint sources, branches, and precipitation. Outflows are either specified as releases at a branch's downstream segment or as lateral withdrawals. Although evaporation is not considered an outflow in the strictest sense, it can be included in the water budget.
- **Selective withdrawal calculations.** The model can calculate the vertical extent of the withdrawal zone based on outlet geometry, outflow, and density.
- **Time-varying boundary conditions.** The model accepts a given set of time-varying inputs at the frequency they occur independent of other sets of time-varying inputs.
- **Outputs.** The model allows the user considerable flexibility in the type and amount of output.
- **Frequency of outputs.** Output is available for the screen, hard copy, plotting, and restarts. The user can specify the model output, when during the simulation output is to begin, and the output frequency. The present version requires the user to develop output plotting/visualization capabilities.

CE-QUAL-W2 Limitations

CE-QUAL-W2 has the following limitations:

- Does not include transfer to higher trophic levels of zooplankton and fish.
- Does not account for substances accumulated in the sediments other than organic matter.
- Contains only one algal group rather than three.

- Does not include macrophytes.
- Does not allow the release and oxidation of sulfur and manganese when anaerobic conditions prevail, although it does allow specification, as a boundary condition, of flux from the sediments of iron, ammonia nitrogen, and phosphate phosphorus during anaerobic conditions.

In addition to these limitations, the model has a large prediction error, which is characteristic of all water quality models addressing complex processes of eutrophication in an estuary. Natural phenomena such as algae blooms are difficult to predict with reliability. The CE-QUAL-W2 model, as with most eutrophication models, has difficulty in assessing responses such as fishkills. In addition, this model requires extensive amount of data for calibration and verification. The model is also complicated and time consuming model requiring knowledge in hydrodynamics, aquatic biology, aquatic chemistry, numerical methods, Fortran coding, and statistics.

CE-QUAL-W2 Developer/Distributor

Thomas M. Cole
Environmental Laboratory
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180
tcole@lasher.wes.army.mil

G.1.1.3.4 LOWQM

LOWQM Overview

The LOWQM was developed to evaluate effects of nutrient loading, regulation of water storage and other management activities on lake water. This model uses the U.S. Environmental Protection Agency's Water Quality Analysis Simulation Program (WASP) to simulate eutrophication processes in both the water column and underlying sediments. The original WASP framework includes the oxygen cycle, phosphorus cycle, nitrogen cycle, and one algal group that represent a generic green algae. This framework was modified to include three algal groups: representing green algae, diatoms, and cyanobacteria, including suspended solids and processes related to sediment resuspension, the silica cycle, and nitrogen fixation. External forcings that drive the model include solar radiation, temperature, wind induced sediment resuspension, surface discharges into and out of the lake, rainfall, evaporation, and nutrient loads. This is a one-box model that simulates average, lake-wide phosphorus, nitrogen, and phytoplankton concentrations.

LOWQM Formulation

The LOWQM uses an enhanced version of the EUTRO5 model (which is part of WASP) that simulates the transport and kinetics of nine variables. These variables encompass the phosphorus (P), nitrogen (N) and oxygen cycles, and phytoplankton dynamics. The

model simulates organic N (ON) and P (OP) as particulate forms. The model also accounts for dissolved organic nutrients by reducing settling rates for particulate organic nutrients. Sediment and nutrient resuspension are explicitly modeled. In-lake water movement is simulated by a separate hydrodynamic model and input to the LOWQM.

LOWQM Required Input Parameters

To run LOWQM, the following parameters are needed:

- model segmentation
- advective and dispersive transport
- boundary concentrations
- meteorological data
- point and diffuse source waste loads
- kinetic parameters, constants, and time functions
- initial concentrations for the following parameters:
 - Soluble Reactive Phosphorus (SRP)
 - Total Phosphorus (TP)
 - Ammonia (NH₄)
 - Nitrate+nitrite (NO_x)
 - Total Nitrogen (TN)
 - Total Suspended Solids (TSS)
 - Silica (SI)

Since LOWQM is based on WASP, the WASP graphical user interface can be used for data input, modeling, and model output. WASP has a good graphical user interface that is Windows-based. Input screens are available, and post-processing graphics routines are available. WASP is supported by US EPA and a number of users, both public and private.

LOWQM Capabilities

LOWQM can be used to identify acceptable lake or reservoir loading targets and to predict how valued components of the lake or reservoir ecosystems will respond to pollution load reductions and other restoration measures. The SFWMD intends to link the lake models with watershed models so that for any proposed change in land use or pollution control strategy, managers can predict: (a) benefits in terms of reduced phosphorus loading; (b) economic impacts; and (c) water quality and ecological improvements in the lake. This model can also be operated on a whole-lake scale and can compute average lake-wide nutrient concentrations. The model can also explicitly simulate sediment resuspension.

LOWQM Limitations

One of the main limitations of the model is that it is currently under development and is not well documented. The model also requires a separate hydrodynamic model to

simulate flow. In addition, a large number of parameters are required to calibrate and verify the model.

LOWQM Developer/Distributor

Thomas James
South Florida Water Management District
Okeechobee Systems Research Division
987 Gaines School Road
561-682-6356

tjames@sfwmd.gov

G.1.1.3.5 WQRRS

WQRRS Overview

WQRRS is a comprehensive model that allows the simulation of the water quality in a reservoir, hydraulics of a river, and water quality of the river itself. Each component is modeled in a separate module: reservoir module (WQRRSR), stream hydraulic module (SHP) and stream water quality module (WQRRSQ). The three components of the system may be used in combination or independently. The reservoir module assumes a one-dimensional system representation of stratified or well-mixed reservoir, and it may be used in deep reservoirs with long residence times. This module takes into account the effects of mass transport due to outflow in the various layers and may model different quality parameters. The stream hydraulic module routes flow using several different methods (St. Venant equations, Kinematic Wave, Muskingum, Modified Puls) and is able to model both steady and unsteady flow regimes. The river quality module simulates aerobic degradation as well as simple dispersion of non reactive pollutants.

WQRRS Formulation

Fate and transport of water quality constituents in WQRRS are modeled based on the principles of conservation of heat energy and conservation of mass. The reservoir is discretized into a series of layers or elements. Each element is assumed to be completely mixed. For the typical element, mass may enter or leave via advection or diffusion from adjacent elements (vertical), may enter via inflow from tributary contributions to the reservoir (lateral), and /or may be removed through reservoir withdrawal (lateral). Exceptions occur at the surface and bottom elements where air-water interface and sediment-water interfaces, respectively, may play a role. Conservative water quality parameters are modeled using the advective-dispersion equation. The source and sink term in the equation is limited to external heat fluxes for temperature. It includes settling, first-order decay, reaeration, chemical transformation, biological uptake and release, growth, respiration and mortality including predation.

WQRRS Required Input Parameters

As for most comprehensive water quality models, WQRRS requires an extensive amount of data including:

- Geometric data
- Meteorological
- Initial conditions
- Boundary conditions
- Hydraulic parameters
- Kinetic parameters

WQRRS Capabilities

The WQRRS model can simulate 18 different physical, chemical and biological water quality parameters in a river or reservoir or a river-reservoir system. WQRRS can simulate temperature, inorganic suspended solids, organic sediments, inorganic sediments, BOD, total coliform, total inorganic carbon, ammonia, total nitrogen, total phosphorus, dissolved oxygen, alkalinity, pH and suspended solids. The biological constituents that can be simulated include fish, aquatic insects, benthic animals, zooplankton, phytoplankton, benthic algae and detritus. The Stream Hydraulics Package (SHP) and Stream Water Quality (WQRRSQ) programs simulate flow and quality conditions for stream networks which can include branching channels and islands. The Reservoir Water Quality (WQRRSR) program is a one-dimensional model used to evaluate the vertical stratification of physical, chemical, and biological parameters in a reservoir. The SHP provides a range of optional methods for computing discharges, velocities, and depths as a function of time and location in a stream system. The hydraulic computations can be performed optionally using input stage-discharge relationships, hydrologic routing, kinematic routing, steady flow equations, or the full unsteady flow St. Venant equations.

WQRRS Limitations

Similar to the CE-QUAL-R1 model, WQRRS one-dimensional representation of reservoirs limits simulation to a vertical series of well-mixed horizontal layers. This assumption cannot predict longitudinal and lateral variations in water quality and requires the assumption of instantaneous dispersion of all inflow quantities and constituents throughout the horizontal layers.

The model assumes that the dynamics of each physical, chemical and biological component can be described by the principal of conservation of mass. Because the equations are not solved in closed form, minor errors concerning the conservation of mass can occur. The model simplifies ecological relationships and interactions. Therefore, the model does not consider competition between individual species, predict precise number of species, and consider all ecological processes occurring in a reservoir.

WQRRS Developer/Distributor

Hydrologic Engineering Center
US Army Corps of Engineers
609 Second Street
Davis, CA 95616
Tel. (916) 756-1104

G.1.1.3.6 MIKE 3, 11, 12 and 21

MIKE 3, 11, 12 and 21 Overview

MIKE 3, 11, 12, and 21 are a suite of hydrodynamic, hydraulic, and water quality models that can be used for a range of water quality simulation problems. MIKE 11 is one dimension both horizontally and vertically. MIKE 12 is one dimension horizontally, two dimensions vertically (for stratified reservoirs). MIKE 21 is two dimensions horizontally and one dimension vertically (a wetland). MIKE 3 is used for three dimension problems such as stratified estuaries. Each of these programs has integrated advection and dispersion routines for solution of mass balance problems, again with different levels of detail. Single contaminants can be modeled with a first-order decay, for water quality (nutrients and DO/BOD), basic eutrophication (nutrients and chlorophyll-a), extended eutrophication (nutrients, chlorophyll-a, SAV, and sediment nutrient dynamics, heavy metals including mercury, and xenobiotics (organic chemicals such as DDT).

The MIKE 11 model network is a set of cross sections that define a river system, as in HEC-RAS or XP-SWMM. MIKE 12 uses the same cross sections but the vertical segmentation is either user-defined or based on a heat budget. MIKE 21 and 3 models are either finite difference (fixed square grid), curvilinear finite difference, or finite element (variable mesh triangular grid). MIKE 3 finite difference models can be created with two-way nested grids, allowing for greater detail in portions of the model area. These models can be used in a range formulations, ranging from complex three dimensional water quality/vegetation nutrient uptake/sediment nutrient flux models to simple riverine reservoirs with simple linear or first order decay of constituents

The suite of hydrodynamic numerical models from includes a wide range of water quality add-on modules (WQ Solver) for simulating the transport, transformation, interaction and fate of water quality components (temperature, dissolved oxygen, organic matter, chlorophyll-a, metals etc.). Traditionally they have been divided into three main groups based on the category of water quality study conducted:

- WQ: BOD/DO relationship, nutrients (nitrogen and phosphorus) and bacteria.
- EU: Algae growth, chlorophyll-a, nutrient dynamics and benthic vegetation.
- ME: Simulation of dissolved and particle bound metals in water column and the sediment.

These water quality modules consist of a set of coupled differential equations describing the relevant processes for each of the three types of water quality models. The equations

are based on 20 years of experience and numerous worldwide applications. However, there is an increasing demand for a more open and flexible system, where models can be customized to the specific study area. Sometimes a specific process description is required to be used by the end user, or a site specific developed process descriptions or empirical relationships are required.

The user can modify and build environmental models. A customized water quality model will be interpreted by the MIKE system during the model set-up procedure. The user will be prompted for the required input to drive the water quality models, such as model coefficients or function functions (temporal and/or spatially varying external data).

MIKE 3, 11, 12 and 21 Formulation

The model mass transport equations are based on the key principle of the conservation of mass. This principle requires that the mass of each water quality constituent being investigated must be accounted for in one way or another. The transport routines trace each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time. The eutrophication model is a complex model with many coupled relations and consists of 12 coupled first order differential equations describing eutrophication processes. The transport process (AD model) for the pelagic components and the biological processes (EU model) are coupled in a Solution Scheme and solved simultaneously using an Integration Routine.

The water quality modules of MIKE 11 consist of coupled differential equations. In order to solve these equations a numerical integration is applied taking the interactions between each differential equation into account.

Three different build-in integration routines exist in MIKE 11:

- RKQC (Fifth order Runge-Kutta with Quality Control)
- RK4 (Fourth order Runge-Kutta)
- EULER (Euler or Linear Solution)

The accuracy (and the computing time) varies for the three integration routines:

High accuracy ?-----? Low accuracy

RKQC -----RK4-----EULER

This means that the most accurate results will be calculated when using RKQC (Default routine). However, in many cases the same results are obtained when using the other two routines. At the same time the computing time can be reduced by using RK4 or EULER.

The Xenobiotics module explicitly handles most of the physical, chemical, and biological processes that affect synthetic organic compounds, excluding reduction and precipitation-dissolution. If the kinetics of these reactions are described by the user, they also can be included as an extra reaction. The MIKE 21 and 3 models can handle mixing zones or near field effects using the nested grid option.

MIKE 3, 11, 12 and 21 Required Input Parameters

To run MIKE 11 to MIKE 3 pollutant models, the user must first insert the following data:

- simulation and output control
- model segmentation
- advective and dispersive transport
- boundary concentrations
- point and diffuse source waste loads
- kinetic parameters, constants, and time functions
- initial concentrations

MIKE 3, 11, 12 and 21 Capabilities

Water quality modules simulate the fate and transport of conservative or linearly decaying constituents, eutrophication processes including nutrient cycling, phytoplankton, zooplankton, and benthic vegetation growth, processes affecting dissolved oxygen, exchange of metals between the bed sediments and the water column, and sediment transport/deposition/erosion.

There are two forcing functions for the MIKE 11 EU (eutrophication) model: the temperature and the light irradiance. The temperature has an influence on all biological processes, e.g. the photosynthesis and all the mineralization processes. The annual variability of the temperature is one of the factors resulting in a strong annual variability of the eutrophication processes.

A summary of the parameters that can be simulated with MIKE 11 Eutrophication include:

- temperature
- salinity
- coliform bacteria
- nitrogen
- phosphorus
- detritus
- BOD
- algae, macro algae, and submerged aquatic vegetation
- zooplankton
- dissolved oxygen
- cohesive sediments
- noncohesive sediment
- sediment diagenesis
- conservative tracer
- user-defined constituent
- metals

- pesticides
- synthetic organics
- sediment fluxes of nutrients and oxygen demand
- any set of water quality equations and parameter (EcoLab)

The MIKE 3, 11, 12 and 21 models provide the following input/output features:

- ▶ Graphical data input/editing
- ▶ Simultaneous input/editing of various data types
- ▶ Copy and paste facility for direct import from spreadsheet programs
- ▶ Fully integrated tabular and graphical windows
- ▶ Importing of topographic data and other survey data from ASCII text files
- ▶ User defined layout of all graphical views (colors, font settings, lines, marker types, etc.)

On the output side, advanced presentation facilities are available, including:

- ▶ Colored horizontal and vertical plan graphics for the data and results
- ▶ Animated presentation of results in 2D plot, line series plots and time series plot
- ▶ Slice plot presentations in perspective view
- ▶ ADCP plot presentations
- ▶ Synchronized animation of results
- ▶ Copy and paste facility for exporting result tables or the presentation graphics into other applications (spreadsheet, word processing or others)

MIKE 3, 11, 12 and 21 Limitations

When modeling complex 3D nutrient impacts on eutrophication and aquatic vegetation, the models require extensive amount of data for calibration and verification.

MIKE 3, 11, 12 and 21 Developer/Distributor

DHI Water and Environment
4119 S. MacDill Avenue
Tampa, FL 33611
(813) 254-9427
www.dhigroup.com

G.1.1.3.7 WASP6

WASP6 Overview

WASP6 is a dynamic compartment model that can be used to analyze a variety of water quality problems in such diverse water bodies as ponds, streams, lakes, reservoirs, rivers, estuaries and coastal waters. It is a receiving water model that is used to assess the fate and transport of both conventional and toxic pollutant. The model network is a set of expanded control volumes, or "segments," that together represent the physical configuration of the water body. The network may subdivide the water body laterally and vertically as well as longitudinally. Segments in WASP may be one of four types: epilimnion layer, hypolimnion layers, upper benthic layer, and lower benthic layers.

Segment volumes and the simulation time step are directly related. As one increases or decreases, the other must do the same to insure stability and numerical accuracy. The size of the segments is determined by the spatial and temporal scale of the problem being analyzed.

WASP6 Formulation

The equations solved by WASP6 are based on the key principle of the conservation of mass. This principle requires that the mass of each water quality constituent being investigated must be accounted for in one way or another. WASP6 traces each water quality constituent from the point of spatial and temporal input to its final point of export, conserving mass in space and time. To account for the spatial and temporal change in concentration of the constituent a finite-difference equation is applied to each segment. For simplicity, the derivation of the finite-difference form of the mass balance equation is for a one-dimensional reach. Concentration is calculated for each segment. The initial value used for each segment at time zero is the final concentration calculated from the previous segment.

These equations represent the three major classes of water quality processes: transport, loading, and transformation. Of these three terms, three important components that play the largest part with concentration variability throughout the river reach are the processes of advection, dispersion, and kinetic transformation. Advection refers to the advective movement or velocity of the water mass and the pollutants within the river water. The higher the velocity the faster the pollutant is transported. Dispersion is the amount of concentration spreading of the contaminant. Advection greatly promotes dispersion but only in the longitudinal direction (parallel to water flow). When advection is larger there will be a larger amount of longitudinal dispersion. Kinetic transformation is an important process because it determines the magnitude of contaminant degradation. Factors that will influence the degradation are temperature, initial pollutant concentration, and in many cases oxygen content in terms of the biodegradation of an organic pollutant.

WASP6 Required Input Parameters

To run WASP6 the user must first insert the following data.

- simulation and output control
- model segmentation
- advective and dispersive transport
- boundary concentrations
- point and diffuse source waste loads
- kinetic parameters, constants, and time functions
- initial concentrations

WASP6 Capabilities

WASP6 is based on the flexible compartment modeling approach, and can be applied in one, two, or three dimensions. WASP6 includes two submodels for water

quality/eutrophication and toxics, referred to as EUTRO5 and TOXI5, respectively. EUTRO5 can be operated by the user at various levels of complexity to simulate some or all of nutrients, phytoplankton, carbonaceous material, and dissolved oxygen and the interactions between these variables and with the benthos.

In TOXI5, the transport of up to three user-defined types of sediment can be simulated. Because sediment deposition and erosion are not functions of sediment shear strength and water column shear stress, the sediment transport model should be considered descriptive. TOXI5 also simulates the transport and transformation of one to three chemicals that may be independent or they may be linked with reaction yields, such as a parent compound-daughter product sequence.

WASP6 explicitly handles most of the physical, chemical, and biological processes that affect synthetic organic compounds, excluding reduction and precipitation-dissolution. If the kinetics of these reactions are described by the user, they also can be included as an extra reaction.

The WASP modeling system consists of two stand-alone computer programs, DYNHYD and WASP that can be run in conjunction or separately. The unsteady flow hydrodynamic program DYNHYD simulates the movement of water, and the water quality program WASP simulates the movement and interaction of pollutants within the water. The flows that determine advective transport can be supplied directly, or calculated by a hydrodynamic model. The easiest linkage is with a link-node model running on an equivalent spatial network.

A summary of the parameters that can be simulated with WASP6 include:

- temperature
- salinity
- coliform bacteria
- nitrogen
- biochemical oxygen demand
- algae
- phosphorus
- silica
- dissolved oxygen
- cohesive sediments
- noncohesive sediment
- sediment diagenesis
- conservative tracer
- user-defined constituent
- pesticides
- synthetic organics

WASP6 Limitations

The WASP6 model does not handle mixing zones or near field effects. The model also does not handle sinkable/floatable materials. WASP6 also requires extensive site-specific linkage efforts to couple with multi-dimensional hydrodynamic models. The model requires extensive amount of data for calibration and verification.

WASP6 Developer/Distributor

US Environmental Protection Agency (EPA)
Center for Exposure Assessment Modeling
Environmental Protection Agency
Athens, Georgia
706-355-8400
ceam@epamail.epa.gov

G.1.1.3.8 HydroQual Wetlands

HydroQual Wetlands Overview

The HydroQual Wetlands model was developed for the SFWMD by HydroQual, Inc. and is comprised of a hydrodynamic and water quality model. The hydrodynamic model computes changes in surface water elevation and horizontal water movement that result from inflows and outflows to and from the wetland. The model was developed for and applied to Water Conservation Area (WCA) 2A. The hydrodynamics are affected by precipitation and evaporation.

The water quality model computes the temporal and spatial distributions of both dissolved and particulate nutrients within WCA-2A as affected by horizontal transport, uptake by periphyton and emergent vegetation, recycle by microbial processes, chemical precipitation and inputs associated with the inflow structures and atmospheric precipitation. There are four submodels: a periphyton or eutrophication model, a chemical equilibrium sub-model, a sediment nutrient flux submodel, and an emergent vegetation model.

HydroQual Wetlands Formulation

The hydrodynamics are two-dimensional using the EFDC code. The water quality model is quasi-three-dimensional in that there is a floating periphyton mat, a water column layer, a benthic periphyton mat, a detrital litter layer, and a sediment layer. The floating and benthic periphyton mats, the litter layer, and the sediment layer are fixed in space and are not directly influenced by transport as computed by the hydrodynamic model, as in the water column. Rather the only movement of the water quality constituents within the periphyton mats, the litter layer, and the sediment layer considered in the model framework is via vertical diffusion or vertical exchange between the periphyton mats and the water column, between the litter layer and the water column, and between the benthic periphyton mat/litter layer and the sediment layer. In addition, there is an exchange of appropriate water quality constituents between the sediment layer and emergent

vegetation. The benthic periphyton mat is divided into two layers, in an attempt to reproduce the vertical gradients in water quality that have been observed in the field between the surface and bottom of the periphyton mats.

A tracer is included in the water quality modelling framework to insure that the wetlands water quality model is coupled properly to the wetlands hydrodynamic model. Water column temperature is calculated in the model and the temperature controls chemical and biological processes and dissolved oxygen saturation.

HydroQual Wetlands Required Input Parameters

To run the HydroQual Wetlands model, the user must first insert the following data.

- simulation and output control
- model segmentation
- advective and dispersive transport
- boundary concentrations
- point and diffuse source waste loads
- kinetic parameters, constants, and time functions
- initial concentrations

HydroQual Wetlands Capabilities

The eutrophication submodel includes two functional periphyton groups and considers the interactions between periphyton biomass (as indicated by carbon, phosphorus, nitrogen, and chlorophyll-a), nutrients (phosphorus and nitrogen), and dissolved oxygen. The chemical equilibrium model includes state variables for total inorganic carbon, alkalinity, calcium, solid phase calcium carbonate, and co-precipitation of phosphorus with calcium carbonate. The sediment nutrient flux model considers the deposition of particulate organic matter, its subsequent decay, and the flux of resulting end-products back to the overlying water column. Finally, the vegetation model considers above- and below-ground biomass (carbon, phosphorus, and nitrogen), as well as fallen dead biomass, and the models the interactions between sediment nutrients, plant growth, and plant nutrient composition. Each of the aforementioned water quality submodels is linked to one or more of the other submodels.

A summary of the parameters that can be simulated with HydroQual Wetlands include:

- temperature
- nitrogen
- phosphorus
- alkalinity
- carbon
- algae,
- floating periphyton mats
- benthic periphyton mats

- detrital litter
- macrophytes
- dissolved oxygen
- sulfate, hydrogen sulfide
- iron
- sediment diagenesis
- sediment fluxes of nutrients and oxygen demand

HydroQual Wetlands Limitations

When modeling nutrient impacts on eutrophication and aquatic vegetation, the models require extensive amount of data for calibration and verification.

HydroQual Wetlands Developer/Distributor

HydroQual, Inc.
One Lethbridge Plaza
Mahway, NJ 07430
(201) 529-5151
www.hydroqual.com

G.1.1.4 Model Selection Approach

Prior to selecting the water quality model(s) and/or tool(s) to assess alternative plans for the EAA Storage Reservoirs – Phase 1 project, it is critical that a model selection approach is clearly defined. The MSC has identified the following model selection approach:

1. Identify the water quality parameters that need to be evaluated.
2. Assess the availability of water quality data needed in developing, calibrating and validating the model.
3. Define purposes and objectives of the water quality modeling.
4. Identify the physical, chemical, and biological processes to be modeled.
5. Identify and rank candidate models that are capable of meeting the water objectives of the project.

The following sub-sections provide a summary of each element of the proposed approach.

G.1.1.4.1 Identify Water Quality Parameters of Concern

FDEP has defined the primary canals within the EAA (Miami, Hillsboro, North New River, West Palm Beach, Bolles and Cross canals) as Class III waters with a designated use of “recreation, propagation and maintenance of healthy, well-balanced population of fish and wildlife.” Section 62-302.530, Florida Administrative Code, and FDEP define the key water quality constituents for discharges to Class III waters as follow:

1. Dissolved oxygen (DO)

2. Conductivity
3. pH
4. Turbidity
5. Total nitrogen
6. Alkalinity
7. Iron
8. Total phosphorus
9. Calcium
10. Sulfate
11. Sodium
12. Chloride
13. Mercury
14. Pesticides/Herbicides
15. Total suspended solids (TSS).

The MSC concurred that these constituents be established as the pollutants of concern to evaluate the potential cause or contribution to violations of water quality standards in receiving water from EAA Storage Reservoir discharges.

G.1.1.4.2 Assess Availability of Water Quality Data

The ability of a water quality model to assess water quality benefits or impacts is directly proportional to the quality of the available data to develop, calibrate and verify the model. The existing water quality data for EAA region must be compiled, screened, reviewed, analyzed and interpreted. The interpretation of the analyzed data is in the context of applicable water quality standards and frequency of monitoring for both short- and long-term basis. The MSC recommends that the review and analysis of available data would include screening and grouping of data, checking data quality, evaluating trends and impact of management changes, and verifying chemical/ hydrodynamic processes.

The EAA best management practices (BMP) program implemented in 1995 has improved storm water quality in the EAA region. Therefore, data review and analysis should consider impact of this management on the water quality. Presently, a statement of work for this water quality analysis is being developed by the SFWMD. It is anticipated that the draft copy of the water quality analysis will be available in July or August 2003.

G.1.1.4.3 Establish Water Quality Modeling Objectives

The primary objective of water quality modeling is to forecast the water quality under various alternatives, project design and operating conditions. For the EAA Storage Reservoirs project, the MSC proposed to group modeling objectives into four categories:

1. Planning and Site Selection

During the plan formulation of the EAA Storage Reservoirs project, the results from water quality modeling could be used to assist in the evaluation of

alternatives and the selection of the most appropriate alternative to accomplish the goals of the project.

2. Design

Refinement of the water quality modeling approach will be needed for design purpose. This refinement could be based on adjustments using more detailed data, and results would be used for assisting in the ultimate project design. Specifically, the water quality model would be instrumental in the determination of the optimal foot print areas and reservoir depths required to achieve pre-established numeric targets for the selected water quality parameters. The model could also be needed in the determination of the design parameters of the project, such as optimal depth range, intake and outflow locations.

3. Operation

The water quality model could be used to simulate the operation of the EAA Storage Reservoirs. Modeling various scenarios based on a sensitivity analysis will be extremely important, as the results will determine optimal gate operation, retention time and other operation parameters.

4. Monitoring for Compliance

Short- and long-term water quality monitoring during the operation of the EAA Storage Reservoirs will be needed. Water quality modeling results could be used in the determination of the optimal monitoring location sites and water quality parameters to be monitored for each site and monitoring frequency. Short- and long-term water quality monitoring could also be used as a feedback of information for periodical adjustment and re-calibration of the model.

For the planning phase of the project, the MSC considers it useful if the modeling approach selected is capable of dynamically modeling the following water quality parameters:

- DO
- Chlorophyll- a
- Phosphorus cycle (details not determined at this point)
- Nitrogen cycle (details not determined at this point)
- TSS
- TOC

However, the remaining water quality parameters, which have been identified as pollutants of concern, could be evaluated using a method other than a dynamic model (such as mass balance equations), unless the selected dynamic model is also capable of simulating those pollutants without extensive data needs.

G.1.1.4.4 Identify Physical, Chemical and Biological Processes to be Modeled

The MSC recognizes that it is important to understand and recognize which physical, chemical and or biological processes are essential and required to be modeled in order to

achieve the modeling objectives. A detailed assessment and evaluation of the physical, chemical and or biological processes are needed for the EAA Storage Reservoirs. The MSC has proposed that the following processes can be simulated by the selected model(s) and/or tool(s):

- Pollutant disposition among dissolved, particle-sorbed, and DOC-sorbed phases
- Reservoir re-aeration rate as a function of water depth, wind, and Temperature (T^0)
- Light penetration for photo-active wavelengths (PAR) as a function of depth, TSS, and DOC
- Internal organic particle production as function of P, PAR, and T^0
- Canal and reservoir particle erosion, advection, and deposition by type and size category
- Reservoir organic particle oxygen demands, and aerobic and anaerobic decomposition rates as a function of T^0

G.1.1.4.5 Identify and Rank Candidate Water Quality Models

A list of models capable of meeting the selected modeling criteria and objectives must then be developed. The MSC has established a shortlist of models that could potential meet the preliminary criteria identified:

1. DMSTA
2. CE-QUAL-R1
3. CE-QUAL-W2
4. LOWQM
5. WQRRS
6. MIKE 3, 11, 12 and 21
7. WASP6
8. Hydroqual Wetlands

The final criteria established for the project must be weighted based on the relative level of significance in relation to the objectives of the project. A matrix should be established to evaluate how well each model meets each of the specified criteria. The model that meets the most critical criteria should be selected.

G.1.1.5 Conclusions and Recommendations

For the EAA Storage Reservoirs project, the water quality evaluation criteria have not been finalized. In addition, the CGM 023 has also not been finalized. Therefore, at this time, water quality model(s) and/or tool(s) selection and approach cannot be finalized. After the water quality evaluation criteria and CGM are finalized, the model selection criteria and model selection approach currently identified by the MSC must be re-evaluated and refined to be able to meet the ultimate project water quality objectives.

References

ACE, 1978: WQRRS User's Manual. Hydrologic Engineering Center. CPD-8.

Wlosinski, J.H. and Collins, C.D., 1985: Confirmation of the Water Quality Model CE-QUAL-R1 Using Data from Eau Galle Reservoir, Wisconsin, US Army Engineer Waterways Experiment Station Vicksburg, MS. Environmental Lab Final Report. Technical Report E-85-11, 72 p.

Environmental Laboratory, 1986: CE-QUAL-R1: A Numerical One-Dimensional Model of Reservoir Water Quality; Users Manual, Instruction Report E-82-1 (Revised Edition), US Army Engineer Waterways Experiment Station, Vicksburg,

SFWMD, 2001: Goals and Performance Measures: Lake Okeechobee Sediment Management Feasibility Study, Technical Report C-11650. South Florida Water Management District West Palm Beach, Florida.

USACE and SFWMD, 2002, Everglades Agricultural Area Storage Reservoirs – Phase 1, Project Management Plan.

W. Walker and R.Kadlec, 2002. Dynamic Model for Stormwater Treatment Areas. U.S. Department of Interior.

Thomas M. Cole, 2002: CE-QUAL-W2: A Two-Dimensional, laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.1 User Manual. Environmental Laboratory, U.S. Army Corps of Engineers and Department of Civil and Environmental Engineering, Portland State University.

FDEP, February 4, 2003. CERP Guidance Memorandum

Water Quality Analysis Simulation Program (WASP) Version 6.0 Draft: User's Manual. By Tim A. Wool, US Environmental Protection Agency, Atlanta, GA, Robert B. Ambrose, Environmental Research Laboratory, Athens, GA, James L. Martin, USACE-Waterways Experiment Station, Vicksburg, MS and Edward A. Comer, TetraTech, Inc. Atlanta, GA.

Attachment G.1.1.1 – Modeling Steering Committee Members and Participants

EAA SR Water Quality Model Steering Committee Members

Michael Chimney	mchimney@sfwmd.gov
Larry Fink	lfink@sfwmd.gov
Chandra Pathak	cpathak@sfwmd.gov
Tracey Piccone	tpiccone@sfwmd.gov
Yongshan Wan	ywan@sfwmd.gov
Mark White	Mark.A.White@saj02.usace.army.mil

Other Participants in the Evaluation Process

Angela Prymas	aprymas@sfwmd.gov
Robert Tucker	robert.c.tucker@usace.army.mil