WATER QUANTITY AND QUALITY IMPACTS OF THE PROPOSED EVERGLADES AGRICULTURAL AREA STORAGE RESERVOIR: PHASE 1

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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A model was developed to estimate water quality in the Everglades Agricultural Area Storage Reservoir (EAASR) and Stormwater Treatment Area (STA) 3/4 as part of the dynamic and challenging design process associated with the Everglades Restoration. The University of Florida Water Quality Design Tool is a steady-state mass balance model using the KC* model to simulate the total phosphorus (TP) concentrations of the outflows from the proposed EAASR and downstream STA 3/4. Performance under long-term average conditions was determined to be the most appropriate level of sophistication needed to provide key insights for the rapidly evolving EAASR designs. Water quantity boundary conditions were provided from output from the South Florida Water Management Model, a complex regional model that simulates daily flows and stages over a 36 year period.

Water quantity and quality inputs to the model were calculated for the base and STA scenarios for each configuration. The hydraulic residence time (HRT) of the

EAASR ranged from 39 to 107.5 days for various scenarios. The HRT of STA 3/4 was calculated to be 29 days for all scenarios. Inflow TP concentrations varied from 0.067 mg/L to 0.133 mg/L depending on the reservoir configuration. Lake Istokpoga was found to be the best comparable for parameter estimation. Data from 16 STAs were used as comparables to STA 3/4. The background TP concentration of the EAASR was determined to be 0.025 mg/L and 0.019 mg/L for the STA. The reaction rate calibration determined a rate of 0.016 per day of TP for the reservoir and 0.127 per day for the STA.

Output concentrations from the EAASR shared a significant treatment effect: concentrations reduced to 0.028 to 0.068 mg/L depending on the configuration. Variability in performance was greatly dampened in the STA 3/4 outflow with the outflow concentrations all in the 0.020-0.021 mg/L range. Results showed that compartmentalization of the reservoir and including an additional outflow structure from Compartment 2 to STA 3/4 in the two compartment configuration can provide additional operational flexibility and increase water quality improvements. Results suggest that simulated inflows to STA 3/4 could be increased to improve water quality even more in the EAASR/STA 3/4 storage/treatment train. The reservoir in its current simulation is not used for flow equalization. Actual performance of the EAASR/STA system could vary widely from our predictions for several reasons:

- Inflow quantities and water quality can be expected to vary over the next 50 years
- The SFWMM estimates of inflows and operations are not based on any kind of optimization for the EAASR/STA system but represent an estimate of their role in a regional water management scenario.
- Behavior and performance of the EAASR/STA can be expected to vary depending on how it is operated for flood control and water supply purposes as well as water quality enhancement.

CHAPTER 1
INTRODUCTION

The Everglades Agricultural Area Storage Reservoir (EAASR) is jointly operated for water supply, flood control, and to support water quality management. The multiple and sometimes competitive purposes of the reservoir provide significant design and operation challenges. Methods and guidelines for the design of reservoirs and levees with respect to water supply and flood control are well established. However, methods for incorporating water quality are less developed.

The United States Army Corps of Engineers (USACE) tasked the University of Florida, as a subcontractor to Water and Air Research Inc. (WAR), to develop and use a model for estimating of reservoir water quality. This model and prediction of water quality is to serve as one section of a larger report by WAR, who was tasked to create an Environmental Impact Statement for the EAASR.

The EAASR is one of the first and potentially the largest single Comprehensive Everglades Restoration Plan component to be included in the Acceler8 program. The Acceler8 program allows a dual-track process of design. The South Florida Water Management District (SFWMD) completes detailed design in parallel with the USACE meeting their prescribed requirements (South Florida Water Management District, SFWMD 2006). As a result, challenges have arisen throughout the project. The Acceler8 design evolved quickly, preempting USACE alternatives, and resulting in an iterative design formulation process that included multiple simulation and analysis efforts (Knight et al. 2006). Different modeling assumptions (between the project sponsors and updates to the simulation model) used to predict the water quantity created uncertainty when comparing current and previous results. To date, no Comprehensive Everglades Restoration Plan reservoir has been constructed. Therefore comparable existing lake or reservoir systems must be used to predict the performance of the proposed reservoirs. Choosing among these comparable systems is a significant challenge because of the wide range of operations.

Our aim was to create and use a model to estimate water quality in the EAASR and Stormwater Treatment Area (STA) 3/4. The model needed to be able to function in the dynamic and challenging EAASR design process. We hoped to gain key insights on the most current EAASR and STA 3/4 configurations.

CHAPTER 2
BACKGROUND AND PREVIOUS WORK

The Comprehensive Everglades Restoration Plan

The Comprehensive Everglades Restoration Plan (CERP) will deploy 63 water resource projects to help restore the Everglades, and provide water supply and flood control. CERP creates a partnership of USACE (the federal sponsor) and the SFWMD (the local sponsor) to restore, protect and preserve the South Florida ecosystem. The plan calls for cost-sharing between the state and federal sponsors. It will take approximately 30 years to implement all of the proposed CERP projects. The projects are focusing on getting the water right, which includes the quality, quantity, timing, and distribution of flows. This goal will be accomplished by all 63 projects working in unison (Central and Southern Florida Project 2005). Water quality benefits are an important part of CERP projects; however they are not the primary purpose of such projects.

Eight CERP projects where chosen by the SFWMD, including the Everglades Agricultural Area Storage Reservoir (EAASR), for accelerated funding, design and construction. This streamlined plan was termed Acceler8. Acceler8 allows a dual track process of design, where the SFWMD completes detailed design in parallel with the USACE meeting their prescribed requirements. The accelerated schedule allows the benefits to the system to be realized sooner and more cost-effectively (Figure 2-1) (SFWMD 2006a). The Project Implementation Report (PIR) details the reconnaissance, feasibility analysis, and selection of the preferred conceptual design.

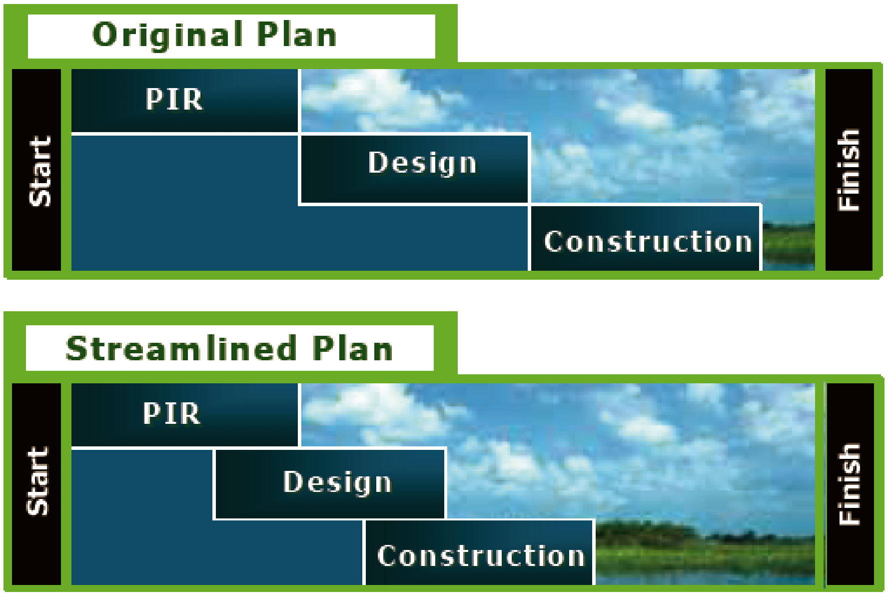

Figure 2-1. Accelerated CERP Projects (Central and Southern Florida Project 2005, Page 32)

Everglades Agricultural Area Storage Reservoir

Introduction and Previous Work

CERP uses extensive water storage systems, including surface and sub-surface reservoirs and aquifer storage and recovery (Central and South Florida Project 2006). These storage systems will be jointly operated for water supply, flood control, and water quality management. The multiple and sometimes competitive purposes of the CERP reservoirs provide significant design and operation challenges. Well-established methods and guidelines for the design of reservoirs and levees with respect to water supply and flood control purposes have been developed. However, methods for incorporating water quality are less developed.

The EAASR, a CERP project, aims to create a reservoir on land in the southern portion of the Everglades Agricultural Area (EAA) (Figure 2-2). The main goals and objectives of the EAASR Phase 1 project as stated in the 2002 Project Management Plan

(United States Army Corps of Engineers and South Florida Water Management District, USACE and SFWMD 2002) are as follows:

- Reduction of Lake Okeechobee regulatory releases to the estuaries and reduction of backpumping from the EAA into Lake Okeechobee by sending the water to the south and into the reservoirs.
- Improved environmental releases through the storage of water and release to the Everglades during the dry season demand.
- Flow equalization 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 subsequent release to the STAs.
- 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 USACE and SFWMD developed the 2002 Project Management Plan for the EAASR. Details on the background, purpose, scope, and initial planning of the EAASR are included in this document. The Conceptual Alternative report by USACE and SFWMD (2004a) presents 22 alternative designs for the EAASR, using any combination of Components A, B, and C in Figure 2-2. The area, depth, volume, water control structures, and additional features of each alternative are detailed. The Screening of Conceptual Alternatives report also by USACE and SFWMD (2004b) details the screening criteria and decision matrix for the initial conceptual alternatives. The screening results found five alternatives for further analyses. These analyses led to the development of conceptual alternatives utilizing only Component A, which where documented in the USACE and SFWMD (2005) Integrated Project Implementation Report and Environmental Impact Assessment (PIR/EIS). The PIR/EIS selects a single alternative, the tentatively selected plan (TSP), and provides detailed design information. An earlier version of the results and discussion presented in this thesis are also included in Appendix F of the PIR/EIS. SFWMD produced the Basis of Design Report (BODR)

(2006b) for the first phase of EAASR. The BODR provides greater design detail for phase 1 and an alternative water quality analysis.

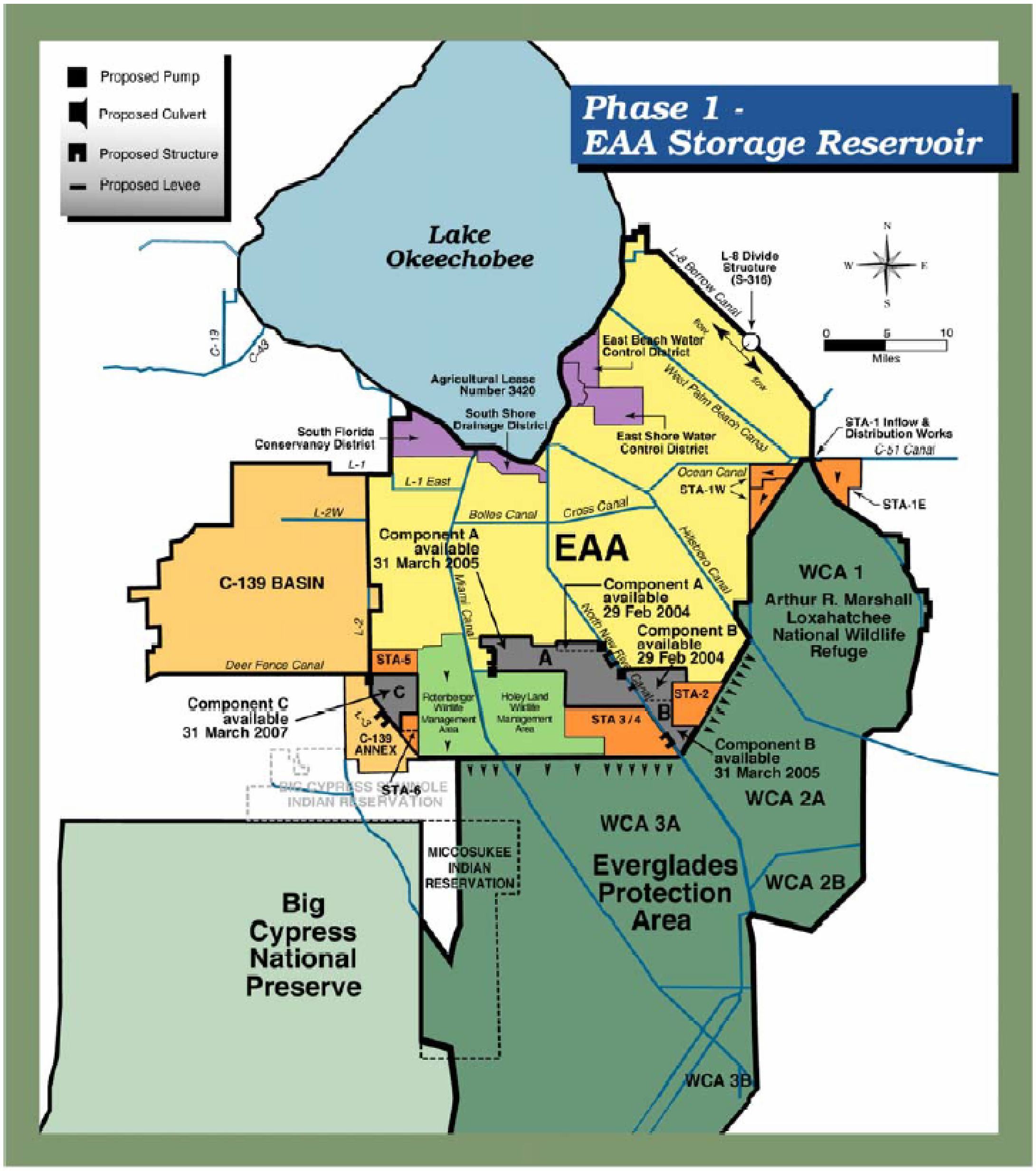

Figure 2-2. EAASR and Stormwater Treatment Area 3/4 Vicinity Map (USACE and SFWMD 2002, Page 7)

EAASR Planning and Design Challenges

The planning and design of the EAASR is one of the first and potentially the largest single CERP component to be accelerated. As a result, challenges have arisen throughout the project. Knight et al. (2006) reviewed the EAASR planning process in order to establish a cohesive approach to the design. They focus on the PIR/EIS where "the parallel process leads to the USACE examining and evaluating multiple alternatives while the SFWMD is beginning detailed design on a specific alternative" (Knight et al. 2006, Page 7). The USACE is attempting to incorporate the Acceler8 alternative, while meeting statutory requirements to evaluate a wide range of alternatives. The matter was complicated by USACE analyzing the entire 360,000 acre-feet of storage, while Acceler8 planned only the first phase, a 190,000 acre-foot reservoir. The resulting challenge arose as the Acceler8 design evolved quickly, preempting USACE alternatives that were in the processes of analysis for the PIR/EIS. The PIR/EIS alternatives were reformulated to meet the new conditions and provide a range of viable alternatives. The result was an iterative screening process for alternatives that included multiple simulation and analysis efforts. The iterative nature of the process is documented in the discussion EAASR configurations provided in Chapter 3.

Alternatives were simulated using the South Florida Management Model Version 5.4 (SFWMM). The SFWMM is a regional scale model used to simulate the hydrology and water management of the SFWMD area from Lake Okeechobee to Florida Bay. This 7,600 square mile area was partitioned into 1,900 two mile by two mile squares (2,560 acres) called cells in which surface water, groundwater, and their interactions are modeled. The model simulates the daily movement of water through the study area for 36 years from January 1, 1965 to December 31, 2000. The SFWMM is accepted as the best tool to model this area, because it incorporates the complex operating rules that govern the behavior of the system (SFWMD 2005a). Thus, a major simulation effort was required to run 36 years of daily activity for 1,900 grid cells in order to evaluate one project with 10 to 23 grid cells. As a regional model, changes to any component in the model could affect the behavior of the EAASR. Throughout the planning process, the model was continually updated, which improved the reliability of the results. USACE and Acceler8 alternatives were simulated on different networks and using different assumptions. For example, Acceler8 evaluated water quantity for the 2010 and 2015 land use projections, while USACE used 2050 land use projections (SFWMD 2006 and USACE and SFWMD 2005). These factors created uncertainty when comparing current and previous results, as well as results between agencies. The SFWMM can only be run by the sponsoring agencies and was not available for direct use by the study team. Thus, each run of the SFWMM required a requisition to the sponsoring agencies.

The EAASR may be actively operated in a wide range of hydraulic and hydrologic conditions, which affects the water quality of the reservoir. Empirical parameter estimates are required as part of the modeling exercise. No CERP reservoir has been constructed; therefore comparable existing lake and/or reservoir systems must be used to predict the likely performance of the proposed reservoirs. The choice of these comparable systems poses a significant challenge, due to the wide range of attributes of these lakes and reservoirs.

Engineering Design and the Systems Engineering Approach

Planning and design approaches exist to help meet the described challenges. This section provides an introduction to a systems engineering approach to engineering design. According to Hazelrigg (1996), engineering design is a decision-making process. He defines a decision as an irrevocable allocation of resources; hence the selection of design parameters by an engineer is a decision-making process. This outlook is a departure from traditional engineering design that is largely viewed as an exercise in problem solving. It creates the distinction that engineering is aimed at creating information, which is related to a specific decision, instead of knowledge, which is a set of agreed upon facts. Considering design in this manner is commonly called systems engineering (Hazelrigg 1996).

To develop a systems engineering approach independent of domain, Braha and Maimon (1998) performed an extensive literature review that found engineering design to share the following common properties:

- Design begins with an acknowledgement of an unmet need and a call for action to meet this need.
- Designing an artifact is used to transition from concepts and ideas to concrete descriptions.
- The designer is constantly faced with the problem of bounded rationality, i.e., the designer has limitations on his cognitive and information processing capabilities.
- The design specifications tend to evolve as part of the design process.
- Traditional engineering design methods tend to rely on satisfying rather than finding the true optimal solution.
- Alternatives and design solutions evolve as part of the design process.

Braha and Maimon (1998) view design as a sequential process with feedback. This process goes from general concept to preliminary and detailed design, production planning, production, operation, and final disposal. Hazelrigg (1996, Page 8) viewed the design process as

> three distinct activities: the identification of options, development of expectations on outcomes for each option, and use of values to select the option that has the range of outcomes and associated probabilities that are most desired.

A key concept of Hazelrigg's view is the need to produce information that provides a prediction of the accuracy or reliability of the design. Uncertainty is therefore intrinsic in information. Such uncertainty is commonly accounted for by conservative parameter estimations, factors of safety, or statistical design.

The general formulation of the engineering design problems and therefore models consists of two main parts; the objection function and constraints (Heaney, unpublished manuscript, 2006). Heaney (unpublished manuscript, 2006) defines the parts, where decision variables are one-time parameter decisions and/or operating rules, as:

- **Objective function:** Maximize or minimize some stated objective(s) by selecting the best values of the decision variables.
- **Constraints:** Physical, chemical, and/or biological process relationships and/or operational and regulatory constraints on the variables.

Traditionally design relies on constraining the system to separate the design into manageable and domain specific parts. Traditional design leads to a reductionism approach, where the outcome of the design is a function of the constraints. The systems engineering approach divides the design into disciplinary models, which are incorporated into a whole system model. This leads to a design that is less focused on constraints and may produce more optimal designs (Hazelrigg 1996).

Lee et al. (2005) document an approach to optimize the design urban stormwater storage-release systems. Urban approaches may also be applied to reservoir modeling as they are fundamentally both storage-release systems. Lee et al. approach uses cost as the objective for a design based on continuous simulation of water quantity and quality. Spreadsheets are utilized to link powerful optimization tools to transparent process models. Unlike traditional approaches, design may be optimized for 3 or more parameters.

Reservoir Modeling

Mathematical models are relied upon heavily for engineering design. They provide a prediction of the systems behavior for a given set of design or decision variables. These models strive to answer *what if* questions of the designer and if optimized can answer the question of *what is best*. Models are used to answer three fundamentally different types of questions (Hazelrigg 1996):

- Will the system work as designed?
- Which of the system alternatives are better?
- Do I properly understand the system?

To develop a model for the EAASR that focuses on the second question, which of the system alternatives is better, a review of water quality models was performed. The review included reservoir and lake models that have been developed and calibrated for the South Florida region. Results of the review are documented next.

Water Quality Models

The relatively shallow, actively controlled EAASR is more comparable to a lake or shallow reservoir system than a traditional reservoir. The general framework for both water quantity and quality models for lake or shallow reservoirs are well developed (Chapra 1996). Chapra and Auer (1999) reviewed management models to evaluate phosphorus loads in lakes. They classified phosphorus models in three general categories; empirical models, simple budget models, and nutrient food-web models.

Empirical models can be divided into phosphorus loading plots and trophic parameter correlations. Phosphorus loading plots are used to estimate the trophic level of the lake, or when linked to a simple balance model can predict in-lake total phosphorus concentrations. Trophic parameter correlations normally relate two trophic parameters or can be used in tandem with phosphorus loading plots. The main advantage of empirical models is the ease of use. These models are most accurate when calibrated for an individual lake.

Simple budget models focus on the mass-balance of a lake system. The most basic of these models uses inflow, outflow and one-way removal to characterize the system. These models provide a temporal response from the lake and can be easily adapted for different lake dynamics. Simple budget models are highly sensitive to the quality of input data. Therefore, they are best suited for long term trends or high quality data sets.

Nutrient and food web models are more complex models that aim to characterize the temporal and physical aspects of matter throughout a lake or reservoir (Chapra and Auer 1999, Page ?). These models require large amounts of data or assumptions and can provide a more detailed analysis than previous models.

Reservoir and Lake Modeling in South Florida

Empirical and simple balance models have been used in modeling CERP reservoirs and the EAASR. USACE and SFWMD (2003) reviewed 16 water quality models that predicted the uptake of phosphorus in lakes and reservoirs. DMSTA was at the top of the review's shortlist of models that met the reviewed criteria. DMSTA 2 (Walker and Havens 2005a), an improved version of DMSTA, is a mass balance model that is calibrated for CERP reservoirs. The model incorporates a first order kinetic model with a background concentration or a water column and sediment transfer model.

Wetland Solutions Inc. (WSI) developed water quality models to simulate 15 parameters of interest for a general CERP reservoir (WSI 2004). Each model was calibrated for Florida lakes and reservoirs and can be applied in a spreadsheet. The models include Eutromod (Reckhow 1979; Reckhow *et al.* 1992), the Vollenweider

Eutrophication Model (Vollenweider 1969, Kane 1999), and the U.S. Corps of Engineers Bathtub Model (Walker 2004). Additionally, WSI developed three regression models from Burns and McDonnell (2004b) based on comparable lakes and reservoirs. An earlier version of the University of Florida Water Quality Design Tool, which assesses TP uptake in the EAASR, is presented in the PIR/EIS (USACE and SFWMD 2005).

As stated previously, comparable lakes and reservoirs are necessary to estimate modeling parameters. Central and South Florida lakes and reservoirs have been relatively well studied. The restoration of the Everglades has driven recent area wide studies and model calibration efforts, such as Burns and McDonnell (2004a) and Walker and Kadlec (2006). Burns and McDonnell (2004a) completed a four-part project to create and analyze a database from lakes and reservoirs that were comparable to CERP reservoirs. They identified and acquired data for 36 potential comparable lake systems across Florida, which were refined to eight comparable lakes and a reservoir with sufficient data (Burns &McDonnell 2004). Walker and Kadlec (2006) developed an extensive database of lakes for their calibration effort for DMSTA 2. The DMSTA 2 calibration uses 19 lakes and reservoirs from Walker and Havens (2003), Wetland Solutions, Inc. (WSI) (2003), Walker (2000), and Burns and McDonnell (2004a) efforts.

Summary and Conclusions

CERP is an ambitious project to "get the water right" in the South Florida Ecosystem and restore the Everglades. The project goal will be accomplished by all 63 projects operating together. The Acceler8 project streamlines the CERP planning, design, and construction process to provide benefits to the system more quickly and cost-efficiently. The EAASR, a CERP and Acceler8 project, will provide storage for water supply, flood control, and flow equalization for water quality treatment areas. Water supply and flood control design approaches are well developed, while water quality approaches are less developed. The streamlining of the planning and design of the EAASR has posed several challenges resulting in an iterative design process with multiple conceptual alternative formulations and analyses. Due to differences in the simulation, uncertainty exists when these multiple formulations and analyses are compared.

The systems engineering approach to design provides a proven approach that can meet the challenges of the EAASR planning and design process. The approach incorporates disciplinary models that may produce a more optimal design than traditional approaches. A model in the water quality discipline was therefore sought to assess which of several alternatives are better. Simple empirical and mass balance models were found that can be used for the EAASR. Comparable lake and reservoir systems were used to provide parameter estimates for EAASR. Due to the wide range of possible operational conditions and planning and design challenges, a water quality model developed specifically for the EAASR will be necessary. The model must incorporate measures to meet the planning and design challenges of the EAASR. The iterative multiple conceptual design alternatives for the EAASR were reviewed. The model was then formulated in the context of this chapter and the conceptual design alternatives.

CHAPTER 3
DEVELOPMENT OF EAASR CONCEPTUAL DESIGN ALTERNATIVES

The hydrology of EAASR and STA 3/4 were simulated using the SFWMM Version 5.4. The complete water quantity dataset used in water quality modeling was developed from the simulations. Therefore, the EAASR conceptual design alternatives are presented in the contextual framework of the SFWMM. The physical layout of the reservoir is termed a configuration. The combination of a configuration and particular flow dataset is referred to as a scenario. All configurations simulated the levee walls as vertical and of insignificant area to affect the stage-area-volume relationship. The reservoir levees were also assumed to allow no seepage, though groundwater flow was included.

The selection of the configuration of the EAASR was an iterative process. The sizing of the EAASR, characterized by the area and depth, was first determined. For the chosen size, configurations to evaluate the compartmentalization of the EAASR were then developed. These configurations are used in the water quality analysis of this report and are described in full detail.

Sizing Configurations

Early configurations used a combination of Components A, B, and C of Figure 2-2 (USACE and SFWMD 2004a). A decision was made to reserve Components B and C to expand the capacity of adjacent Stormwater Treatment Areas. Alternatives were then developed using only the Component A location.

Three alternative reservoir sizes with storage capacities of 240,000, 360,000, and 480,000 acre-feet were evaluated in the early stages of Component A analysis, referred to as the original Alternative 1, the original Alternative 3, and the original Alternative 5, respectively (USACE and SFWMD, electronic correspondence, February 14, 2005, March 1, 2005, March 8, 2005, and April 5, 2005). The original alternatives were divided into two compartments of the same nominal depth. In the original alternatives, the first compartment, called C1, was configured to provide 90,000 acre-feet of storage for agricultural use. The second compartment, C2, varied in volume from 150,000 acre-feet to 390,000 acre-feet and was for environmental use. C1 was able to overflow to C2 (USACE and SFWMD, electronic correspondence, April 5, 2005). A conceptual view of the two compartment reservoir for the original Alternative 3 is provided in Figure 3-1. Subsequently, a decision was made that the total capacity of EAASR would be 360,000 acre-feet.

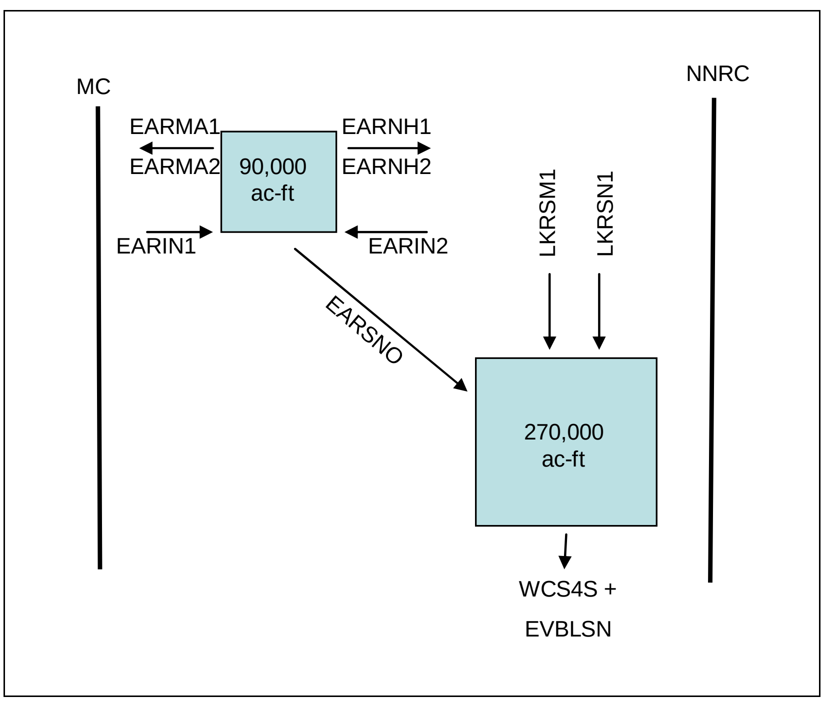

Figure 3-1. Conceptual Configuration of Reservoir for original Alternative 3 (USACE and SFWMD, electronic correspondence, April 5, 2005)

Design depth was the next key sizing decision. Four design depths were considered with nominal design depths of 6, 10, 12, and 14 feet. These alternatives were named Alt1R, Alt2R, Alt3R, and Alt4R, respectively (USACE and SFWMD, electronic correspondence, April 8, 2005). The compartments in all Alt_R configurations were termed C1 and C2, as in previous configurations. The depth and area used to achieve this total volume were varied in each alternative; however C2's area remained fixed at 17,920 acres. The associated areas of C1 were developed to yield a capacity of 360,000 acre-feet. The area, depth, and volume of the Alt_R configurations and the original Alt 3 simulation are presented in Table 3-1.

Table 3-1. Conceptual Configuration of Reservoir for Original Alternative 3

	C1			C2			Total	
Configuration	Area (ac)	Nominal Depth (ft)	Volume (ac-ft)	Area (ac)	Nominal Depth (ft)	Volume (ac-ft)	Area (ac)	Volume (ac-ft)
Alt 3 Orig.	7,500	12	90,000	22,500	12	270,000	30,000	360,000
Alt1R	40,960	6	250,000	17,920	6	110,000	58,880	360,000
Alt2R	17,920	10	180,000	17,920	10	180,000	35,840	360,000
Alt3R	12,800	12	150,000	17,920	12	210,000	30,720	360,000
Alt4R	7,680	14	110,000	17,920	14	250,000	25,600	360,000

A design depth of 12 feet was selected for the 360,000 acre-foot reservoir. Configurations to assess the effect of compartmentalization and the source of inflows were then developed. The configurations are presented in detail next.

Compartmentalization Configurations

Unlike previous configurations, the compartmentalization of the reservoir affects the inflow sources to STA 3/4. Therefore, details on both the EAASR and STA 3/4 are included for each configuration. The EAASR was modeled as 12 SFWMM cells incorporating 30,720 acres of area and STA 3/4 was modeled as 7 SFWMM cells incorporating 17,920 acres of area (USACE and SFWMD, electronic correspondence, February 2 and 3, 2006). The combined total area of the EAASR and STA 3/4 is 48,640 acres and the EAASR accounts for about 63% of this total area. Figure 3-2 displays the location of the EAASR and STA 3/4 in the SFWMM. The nominal depth of the EAASR was 12 feet for all configurations. The EAASR was assumed to have a level pool and flat bottom at an average elevation and therefore had a simple stage-area relationship. STA 3/4 was modeled with the same levee and pool assumptions as the reservoir.

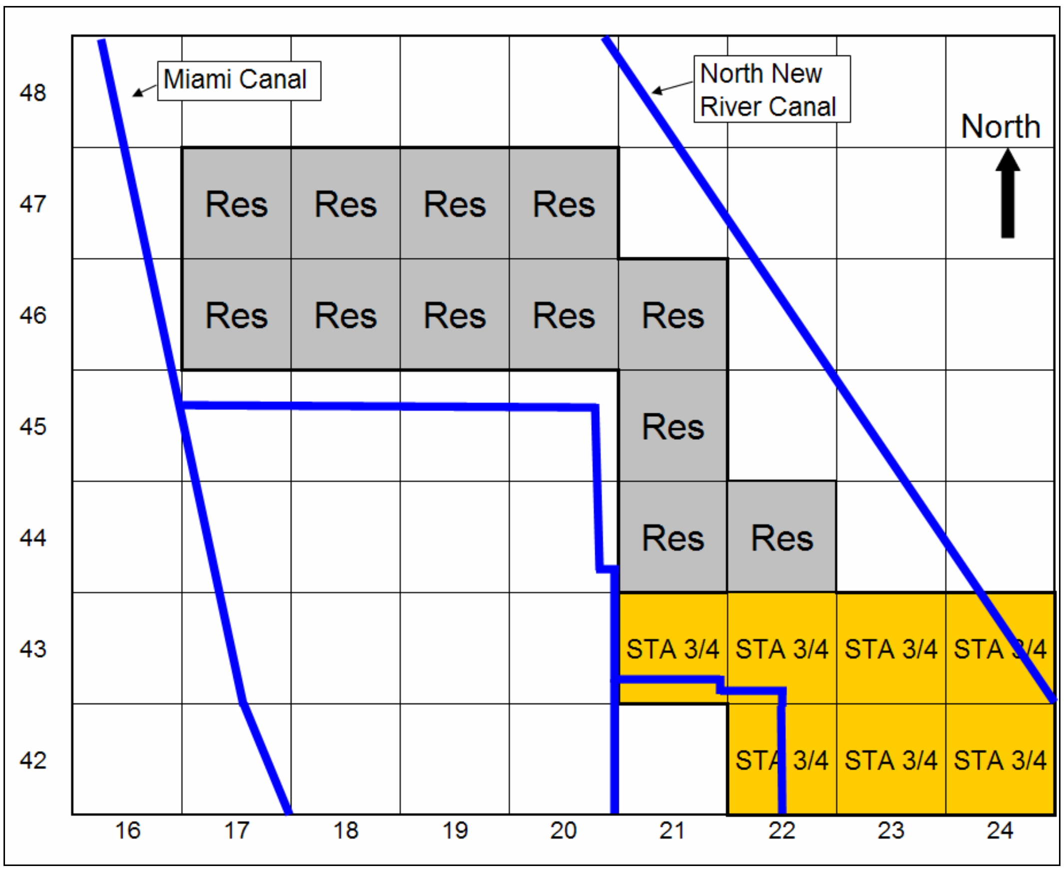

Figure 3-2. General Layout of EAASR and STA 3/4

Three following configurations of the EAASR were developed from the general layout presented in Figure 3-2:

1. Single Compartment
2. Two compartments
3. Four Compartments

A single SFWMM flow dataset (USACE and SFWMD, electronic correspondence, February 2 and 3, 2006) was used in modeling all three configurations. However, the quantity and source of flows to each compartment and STA 3/4 varied depending on the configuration. Each configuration will be described in detail in the remainder of this section.

Single Compartment EAASR

The single compartment EAASR configuration was modeled as presented in Figure 3-2. The single compartment used all of the 30,720 acres available. All possible inflows sources to the EAASR and STA 3/4 are represented in the configuration.

A flow diagram for the single compartment reservoir and STA 3/4 is presented in Figure 3-3. The EAASR and STA 3/4 receive inflows via the North New River (NNR) Canal and Miami Canal, which are shown on the east and west side of the EAASR in Figure 3-3. The EAASR receives inflows from four external sources: NNR basin runoff, Miami basin runoff, Lake Okeechobee (LOK) regulatory release through the NNR Canal, and LOK regulatory releases through the Miami Canal. Water is released to the agricultural basins or south to STA 3/4. STA 3/4 receives flow from NNR and Miami basin runoff, LOK through the NNR and Miami Canals, and the EAASR. The STA discharges to the water conservation Areas (WCA). Figure 3-3 and those like it represent the aggregation by source of SFWMM flow tags. All flows are actively operated in the SFWMM and are constrained by flow capacity and/or crest elevation.

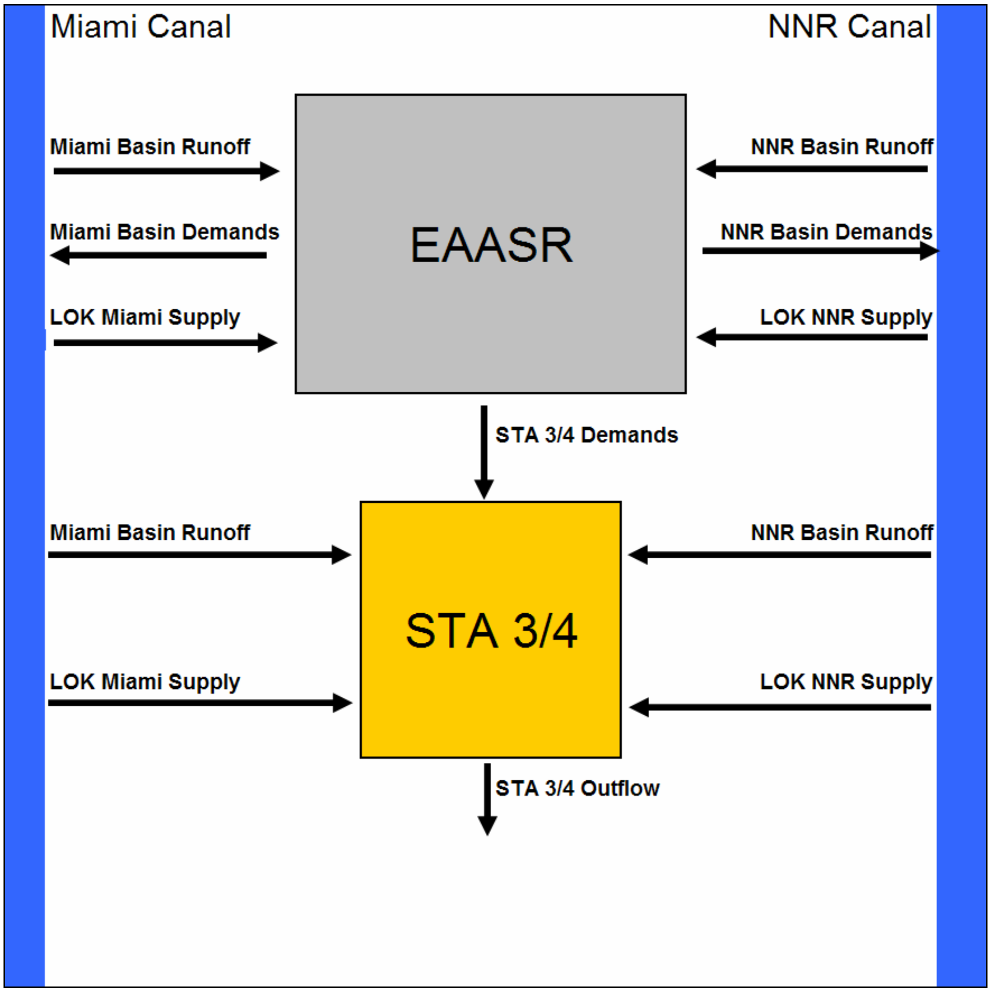

Figure 3-3. Single Compartment EAASR and STA 3/4 Flow Diagram

Two Compartment EAASR

In the second configuration, the EAASR is partitioned into two compartments (Figure 3-4). This configuration was considered to be comparable to the Tentatively Selected Plan (TSP) in the EAASR PIR/EIS (USACE and SFWMD 2005). The eastern compartment bordering the NNR Canal is referred to as Compartment 1 and the western compartment bordering the Miami Canal is referred to as Compartment 2. Each compartment was 15,360 acres and modeled as an independent level pool.

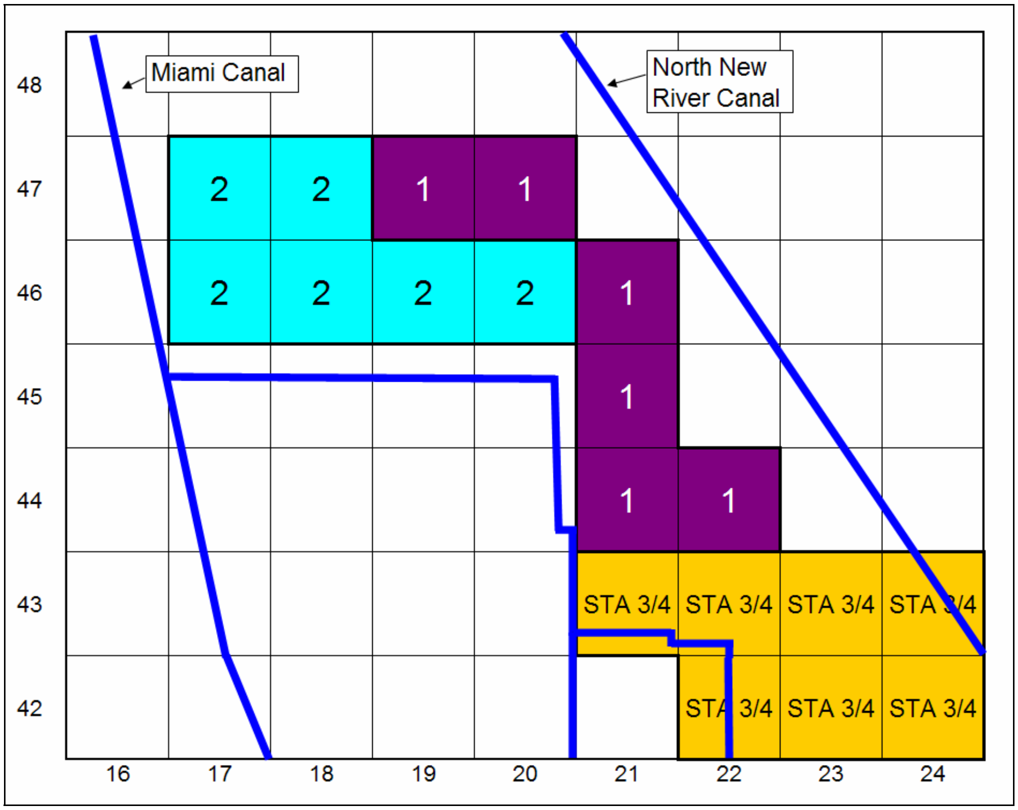

Figure 3-4. Two compartment EAASR and STA 3/4 Configurations

A flow diagram for the two compartment EAASR configuration and STA 3/4 is presented in Figure 3-5. The compartmentalization of the EAASR altered the ability of each compartment and the STA 3/4 to receive water from the sources presented in the single compartment configuration. Each compartment received external flow from the respective adjacent canal and through inter-compartmental transfers. It is important to note that unlike early configurations water can be transferred internally between both compartments. Water was released to the agricultural basins or south to STA 3/4 in the reservoir. Due to the location of the compartments, only Compartment 1 was able to release water to STA 3/4. STA 3/4 was not able to receive flow directly from the Miami Canal; therefore the Miami Canal flows were routed through the EAASR to the STA. The STA was able to receive inflow via NNR basin runoff, LOK through the NNR canal, and the EAASR. STA 3/4's discharge capabilities were not altered.

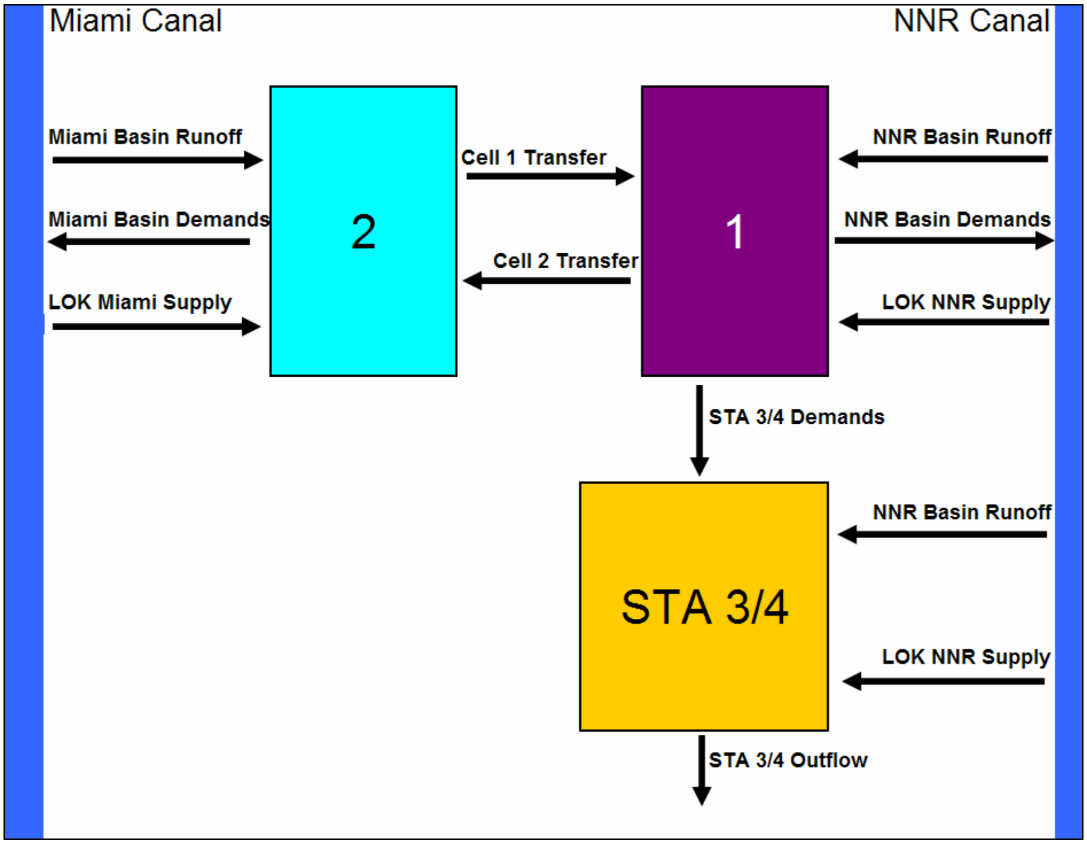

Figure 3-5. Two Compartment EAASR Configuration Flow Diagram

Four Compartment EAASR

The third configuration partitioned the EAASR into four compartments (Figure 3-6). This configuration was comparable to the Mixed/Segregated Plan (MSP) referred to in the January Work Tasks (USACE, electronic correspondence, January 26, 2006). The four compartments were labeled Compartments A through D. Compartment A and C are 5,120 acres and Compartments B and D are 10,240 acres. Each compartment is modeled as an independent level pool.

The four compartment flow diagram for the EAASR and STA 3/4 is presented in Figure 3-7. Each of the four compartments received flow from the adjacent canal and through inter-compartmental transfers. It is important to note that unlike early configurations water can be transferred internally between multiple compartments. The modeling of the four compartment configuration assumed that each compartment received flow from a single external source. Water was released to the agricultural basins through Compartments A or C. Due to the location of the compartments, only Compartments B and D were able to release water to STA 3/4. STA 3/4 was able to receive flow from both Miami and NNR Canals in this configuration. STA 3/4's discharge capabilities were not altered.

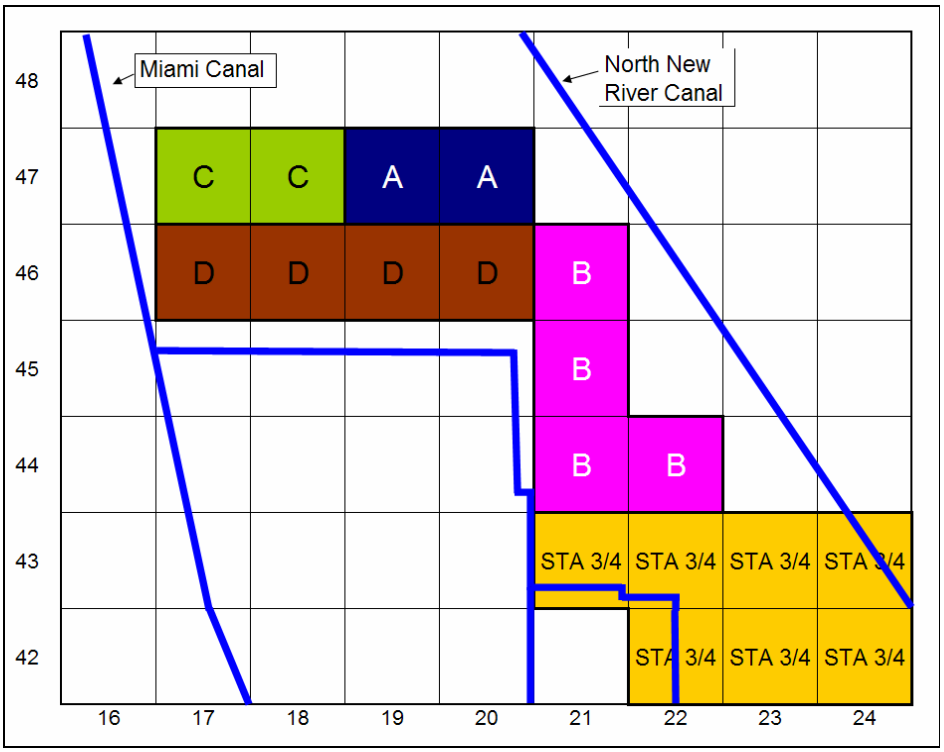

Figure 3-6. Four Compartment EAASR and STA 3/4 Configurations

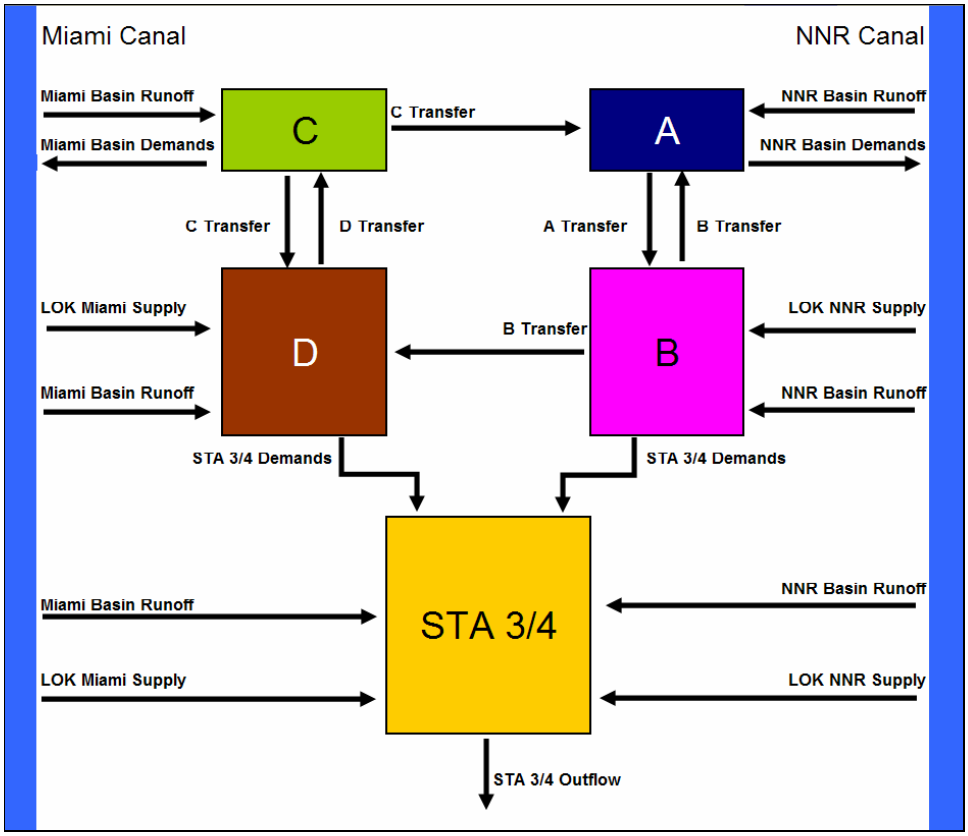

Figure 3-7. Four Compartment EAASR and STA 3/4 Flow Diagram

Summary and Conclusion

Several iterations of EAASR configurations have been developed. Early configurations used a combination of Components A, B, and C of Figure 2-2. Configurations were then formulated using only Component A. The sizing of the reservoir was evaluated first. Three configurations were developed to evaluate the volume of the reservoir. Four additional alternatives were developed to evaluate the depth of the reservoir. A 12 foot deep, 360,000 acre-foot reservoir was subsequently selected. Three configurations were then developed to assess the compartmentalization of the reservoir. The configurations were developed for one, two, and four compartments. The location of the compartments affected the source of water received for both the EAASR and STA 3/4. Unlike early configurations, internal transfers between the compartments occurred from multiple compartments.

The review of EAASR configurations was performed to provide the context within which the water quality model is developed. To use these configurations, a water quality model should include depth, area, and compartmentalization with varying area. Due to the inter-reservoir transfers, the model must be able to simulate reservoirs in series, with feedback loops. Additionally, the ability to include multiple inflows and outflows would be useful. The formulation and rationale of the water quality model is described in detail in the next section. The water quantity and quality values for the compartmentalization configurations, with an emphasis of modeling parameters, are detailed as well.

CHAPTER 4
SIMULATION MODEL FORMULATION AND INPUT

University of Florida Water Quality Design Tool

The EAASR is classified as a reservoir. Comparable systems in the area are called by a variety of names including:

- Lakes
- Reservoirs
- Emergent wetlands
- Pre-existing wetlands
- Submerged aquatic vegetation systems

Nominally, reservoirs and lakes provide storage while wetlands and STAs provide treatment. However, all of these systems can be viewed more generically as reactors that in fact provide a blend of these functions depending on how they are designed and operated. Accordingly, the word reactor will be used to describe the general modeling approach for these systems. The EAASR/STA 3/4 system is viewed as a treatment train with two reactors in series. EAASR and STA 3/4 simulations therefore incorporate both water quantity (storage) and quality. The water quality modeling of the EAASR focuses on Total Phosphorus (TP), the main water quality parameter of concern.

Mass Balance

A mass balance around the reactor is created to assure conservation of mass. For the reactor, the external sources of water and pollutants are the inflow and precipitation. The pollutant removal in the reactor is considered a final mass sink. The remaining pollutants exit the reactor in the outflow.

In steady-state mass balance analysis, the reservoir can be modeled as having inflows from the canals, Q_{in}, and outflow, Q_{out}, which are aggregates of the daily inflows, and outflows, and precipitation, P. A parameter of concern is assumed to enter at a constant concentration for each inflow, C_{in}, and from precipitation, C_P. The pollutant is removed as a function of detention time, t_d, initial concentration, C_{in}, and reaction rate, k_V. The pollutant exits the reactor to the surrounding system in the outflow at a calculated concentration, C_{out}. The conceptual view of the mass balance (Figure 4-1) and mathematical equation (Eqn. 4-1) also uses the concentration in each plug of water in the reactor (C), the depth (D), and the area (A).

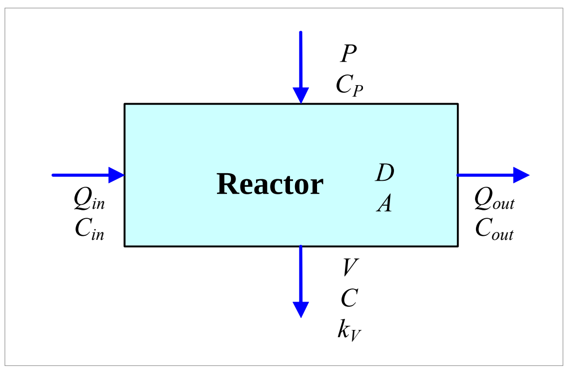

Figure 4-1. Block Mass-Flow Diagram of Modeled EAASR

$$Q_{in} \times C_{in} = V \times k_V \times C + Q_{out} \times C_{out} - P \times C_P \qquad (4\text{-}1)$$

Water Quantity Characterization

The water quantity characterization of the model is based on a volume balance of the system. The volume balance of the system is represented by the total inflows minus the total outflows equaling the change in storage ($\Delta S/\Delta t$). From the reservoir alternatives data provided by the IMC, the total inflows and outflows of the system are represented as rainfall (P), inflows (Q_{in}), groundwater inflows and outflow (GW_I *and* GW_O), ET, and outflows (Q_{out}) (Eqn. 4-2). The change in storage per unit time, $\Delta S/\Delta t$, is documented in the SFWMM by the stage or depth of the reservoir.

$$\Delta S / \Delta t = P + Q_{in} + GW_I - ET - Q_{out} - GW_O \qquad (4\text{-}2)$$

The volume balance components provide the inputs to calculate the hydraulic residence time (HRT), which represents the water quantity of the system. The HRT is a function of volume and flow (HRT = V/Q). For a given reservoir volume, V, HRT can be increased by reducing the inflow rate, Q_{in}. The other performance measure for the reactor is the mean operating depth, H. The above information is obtained from the output file for the SFWMM by aggregating the cell by cell data.

Water Quality Characterization

Water quality characterization of the system is based on the inflow concentration, C_{in}, the rate parameter, and the minimum concentrations. As storage and water quality changes are inseparable, the characterization of the water quantity affects the characterization of the water quality.

Inflow concentration

The inflow concentration, C_{in}, is a function of the source and quantity of inflows. The water quantity of the system uses an aggregate inflow, Q_{in}. Therefore, a single representative concentration is assigned to the aggregate inflow. If more than one inflow source exists, a flow weighted concentration is calculated from Equation 4-3 where Q_i is the flow, C_i is the concentration, and "i" designates the source.

$$C_{in} = \frac{\sum_{i=1}^{n} Q_i C_i}{\sum_{i=1}^{n} Q_i} \qquad (4\text{-}3)$$

Removal rate

The KC* removal rate equation is used to represent pollutant concentration profiles with time in a variety of reactor systems including wetlands (Kadlec and Knight

1996) and a wide variety of urban stormwater BMPs (CRC for Catchment Hydrology 2005). The KC* model uses a removal rate model with a background concentration (*C**). Removal is a function of the initial concentration (C_{in}), C* the overall rate constant, k_{V}, and the hydraulic residence time (HRT), t_d. The KC* equation is shown in Equation 4-4. The pollutant is removed more rapidly at first and then at a decreasing rate as HRT increases. Two-parameter calibration should be used for this model, where k_V and C* are calibrated simultaneously.

$$C_{out} = C^* + (C_{in} - C^*)e^{-k_v \cdot t_d} \qquad (4\text{-}4)$$

Model Rationale

The University of Florida Water Quality Design Tool (UF WQDT) was intended from the outset to be a simple spreadsheet model used to predict the behavior of TP in the EAASR. The storage-release framework described in Lee et al. (2005) was to be used to provide an optimal design, which included water quality considerations. It was decided that a basic mass balance and uptake rate model would provide a good representation of TP behavior. Initially modeling was expected to occur at three levels; steady-state simulation of the long-term average, frequency analysis, and daily time series analysis. However, as the design and planning challenges became evident the scope of the model was altered to best suit the needs of the project and the tight time schedule.

Steady-state simulation of long-term averages was deemed the most appropriate modeling level for the dynamic conditions associated with the design of the EAASR. A steady-state analysis can provide important insights and comparisons to design scenarios. The simple mass-balance model is easily adapted for new configurations and scenarios, while the steady-state nature allows for very fast run times. SFWMM updates and small model parameter alterations generally will not create significant changes in the long-term averages, where significant differences in the daily time series may be created. However, large changes to the configuration or operation of the EAASR, STA 3/4, or South Florida system will be reflected. Additionally, calibration efforts for the model could be performed at an appropriate level of significance, which is defined by the quality of the data. A description of the resulting model is provided in the next section.

Spreadsheet Model

The UF WQDT spreadsheet tool uses a flow and concentration calculator, a core reactor module, and a Solver objective and constraint section if a feedback between reactors exists. The basic UF WQDT for the SC base Scenario (Figure 4-2) does not include feedback and all values are in US units, except TP concentrations. Values highlighted in light blue are user entered, in white are calculated, and in orange are the results. The flow and concentration calculator, appearing first, aggregates multiple inflows generate a single representative flow and concentration. The core reactor module is broken into three sections: parameters, calculations, and results. The necessary parameters are entered into the parameter section. These values are used to calculate the volume, HRT, and hydraulic loading rate (HLR). The HLR is an alternate representation of the water quantity, which is nominally defined as the inflow, $Q_{in,}$ divided by the area, A. Appropriate given and calculated values are used to calculate the outflow concentration, C_{out}, using Equation 4-4. Percent removal of TP from the inflow concentration is calculated as well. The flow and concentration calculator and core reactor module are repeated for each reactor in the system (i.e. the EAASR compartments or STA 3/4) (Figure 4-2).

University of Florida Water Quality Design Tool

Cell 1 Influent Flow & Concentration	Flow source	Variable	Flow (ac-ft/d)	C_{in} (mg/L)
	NNR Basin	$Q_{NNR\ Basin}$	485	0.150
	LOK NNR	$Q_{LOK\ NNR}$	442	0.077
	Maimi Basin	$Q_{Maimi\ Basin}$	470	0.112
	LOK Miami	$Q_{LOK\ Miami}$	290	0.060
	Total	Q_{in}	1,686	0.105

Inputs	Parameter	Variable	Value	Unit
	Inflow	Q_{in}	1686	ac-ft/d
	Depth	D	5.90	ft
	Area	A	30,720	acres
	Inflow Concentration	C_{in}	0.105	mg/L
	Background Concentration	C^*	0.025	mg/L
	Removal Rate	k_V	0.02	day^-1
Calculations	Volume	V	181,306	ac-ft
	Hydraulic Retention Time	HRT, t_d	107.5	days
	Hydraulic Loading Rate	HLR, q	0.05	ft/day
Output	Reservoir	$C_{out\text{-}C1}$	0.040	mg/L
	Reservoir	$C_{out\text{-}C1}$	61.9%	Removal

STA 3/4 Influent Flow & Concentration	Flow source	Variable	Flow (ac-ft/d)	C_{in} (mg/L)
	NNR Basin	$Q_{NNR\ Basin}$	221	0.150
	LOK NNR	$Q_{LOK\ NNR}$	219	0.077
	Maimi Basin	$Q_{Maimi\ Basin}$	263	0.112
	LOK Miami	$Q_{LOK\ Miami}$	317	0.060
	EAASR	Q_{Res}	1,182	0.040
	Total	Qin	2,201	0.066

Inputs	Parameter	Variable	Value	Unit
	Inflow	Q_{in}	2201	ac-ft/d
	Depth	D	2.35	ft
	Area	A	17,920	acres
	Inflow Concentration	C_{in}	0.066	mg/L
	Background Concentration	C^*	0.019	mg/L
	Removal Rate	k_V	0.13	day^-1
Calculations	Volume	V	42,043	ac-ft
	Hydraulic Retention Time	HRT, t_d	28.9	days
	Hydraulic Loading Rate	HLR, q	0.12	ft/day
Output	Reservoir	$C_{out\text{-}C1}$	0.021	mg/L
	Reservoir	$C_{out\text{-}C1}$	68.2%	Removal

Figure 4-2. Spreadsheet Interface for UF WQDT

The two and four compartment EAASR includes feedback between compartments. In this configuration, the inflow concentration of one compartment is dependent on the inflow and performance of other compartments. The inflow concentration can be solved algebraically using a system of equations. However, this would require programming specific equations for each compartment. The Solver tool in Excel was used to iteratively solve for each concentration without altering the core reactor module.

For a design with feedback flow sources, the Solver objective and constraint section is used. Initial estimates of C_{in} are entered for each feedback. In the Solver section the difference of the feedback C_{in} cell and the appropriate compartment C_{out} cell are entered. The sum of the square differences are calculated for all feedback flows in the Total Difference cell and used as the objective in Solver. Each feedback concentration is constrained to the minimum achievable concentration, C*. Solver is then used to reduce the value of the objective function to zero, which calculates the correct concentrations. This methodology assumes full treatment of the feedback flows.

Water Quantity of EAASR and STA 3/4

The purpose of this section is to present the water quantity parameters necessary for water quality modeling. The reported inflows and outflows to the EAASR and STA 3/4 are based on output from the SFWMM. The water quality performance of the EAASR and STA 3/4 can be expected to vary depending on how the inflows are divided among compartments, how the individual compartments are operated as judged by the mean depth of storage in each compartment, and how water is transferred among compartments before discharge from the EAASR. Performance will also depend on whether inflows are routed to STA 3/4 directly or through the EAASR. This section provides background information and results for the compartmentalization configurations in Chapter 3.

Water Quantity Data Source and Information

A wide variety of options exist for directing water into the EAASR. The best projection of the expected inflows can be obtained by using the South Florida Water Management Model (SFWMM). The Interagency Modeling Center (IMC) modeled the EAASR and the downstream STA 3/4 using the SFWMM Version 5.4. The IMC provided data from their EAASR simulation to the University of Florida. All simulations were made with the assumption of 2050 land use projections and the reservoir as the "Next Added Increment" of the CERP project. The provided data included inflow and outflow for each control structure, the maximum capacity for the water control structures, rainfall, evapotranspiration (ET) and groundwater levels and the general modeling configuration and assumptions (USACE and SFWMD, electronic correspondence, February 2 and 3, 2006). Data were tabulated in 13,149 daily time steps for the 36 year period, starting on January 1, 1965 and ending on December 31, 2000. The data were provided for each of the EAASR's four square mile grid cells in the SFWMM for each time step. The total 2x2 grid is comprised of 1,900 2x2 grid cells. Thus, a major simulation effort was required to run 36 years of daily activity for 1,900 grid cells in order to evaluate one project with 19 grid cells (SFWMD 2005a). The IMC output provides the necessary information on the quantity and timing of the flows.

Water Balance of the FC Base EAASR and STA 3/4

A water balance (WB) was calculated from the SFWMM to ensure proper modeling results for the EAASR and STA 3/4. The output data from SFWMM provided a complete volume balance for the four compartment configuration, including stage data for each compartment and STA 3/4. Equation 4-2 was modified to include an imbalance term, which is attributed to ungaged flow. The imbalance term was attributed to either ungaged inflow or ungaged outflow by its sign and included in the WB (Eqn. 4-5) where Q_{inU} was ungaged inflow and Q_{outU} was ungaged outflow.

$$\Delta S / \Delta t = Q_{in} + Q_{inU} + P + GW_{in} - Q_{out} - Q_{outU} - ET - GW_{out} \qquad (4\text{-}5)$$

The long-term WB was calculated for each compartment and STA 3/4 separately. The average daily value of each WB component for the 36 year simulation period was used to represent the magnitude of each component. The averages are presented in units of ac-ft/day to allow comparison between the compartments and STA 3/4. The change in storage was calculated from the difference in volume between the first and last day of the dataset. The long term water balances for each compartment are presented in Table 4-1.

Several key insights may be gained from inspection of the 36 year water balance. The differences between natural WB components, rainfall, ET, and GW offset each other for the EAASR and STA 3/4. GW and ungaged flows can be assumed to be negligible on a long term average. The resulting simplified long term WB was used in the remainder of the report.

Table 4-1. Thirty Six Year Water Balance for EAASR and STA 3/4

WB Term	C1	C2	C3	C4	STA 3/4
Inflow (ac-ft/day)	485	470	442	290	2,201
Transfer (ac-ft/day)	105	318	83	280	NA
Ungaged (ac-ft/day)	0	0	0	2.1	0
Rainfall (ac-ft/day)	58	120	58	118	208
GW_I (ac-ft/day)	0.3	0.2	0.0	0.1	0.2
Total Inflow (ac-ft/day)	648	908	583	690	2,409
Outflow (ac-ft/day)	261	695	218	488	2,177
Transfer (ac-ft/day)	318	88	296	83	NA
Ungaged (ac-ft/day)	4.0	3.6	2.5	0	13.4
ET (ac-ft/day)	64	119	64	118	216
GW_O (ac-ft/day)	0.3	1.8	0.5	1.0	0.2
Total Outflow (ac-ft/day)	648	907	582	690	2,407
Storage Increase (ac-ft/day)	0.2	0.7	1.2	0.7	2.5
Net Error (ac-ft/day)	0	0	0	0	0
Average Depth (ft)	8.26	4.79	8.54	4.54	2.35

Single Compartment Reservoir Configuration Scenarios

The single compartment (SC) reservoir is the simplest scenario. Two scenarios were performed to provide a basis for further comparison in the two and four compartment analyses. The first scenario was the SC base scenario (Figure 4-3). The second scenario routed STA 3/4 inflows directly from the canal through the single compartment reservoir before entering the STA. The second scenario is referred to as the SC STA scenario (Figure 4-4).

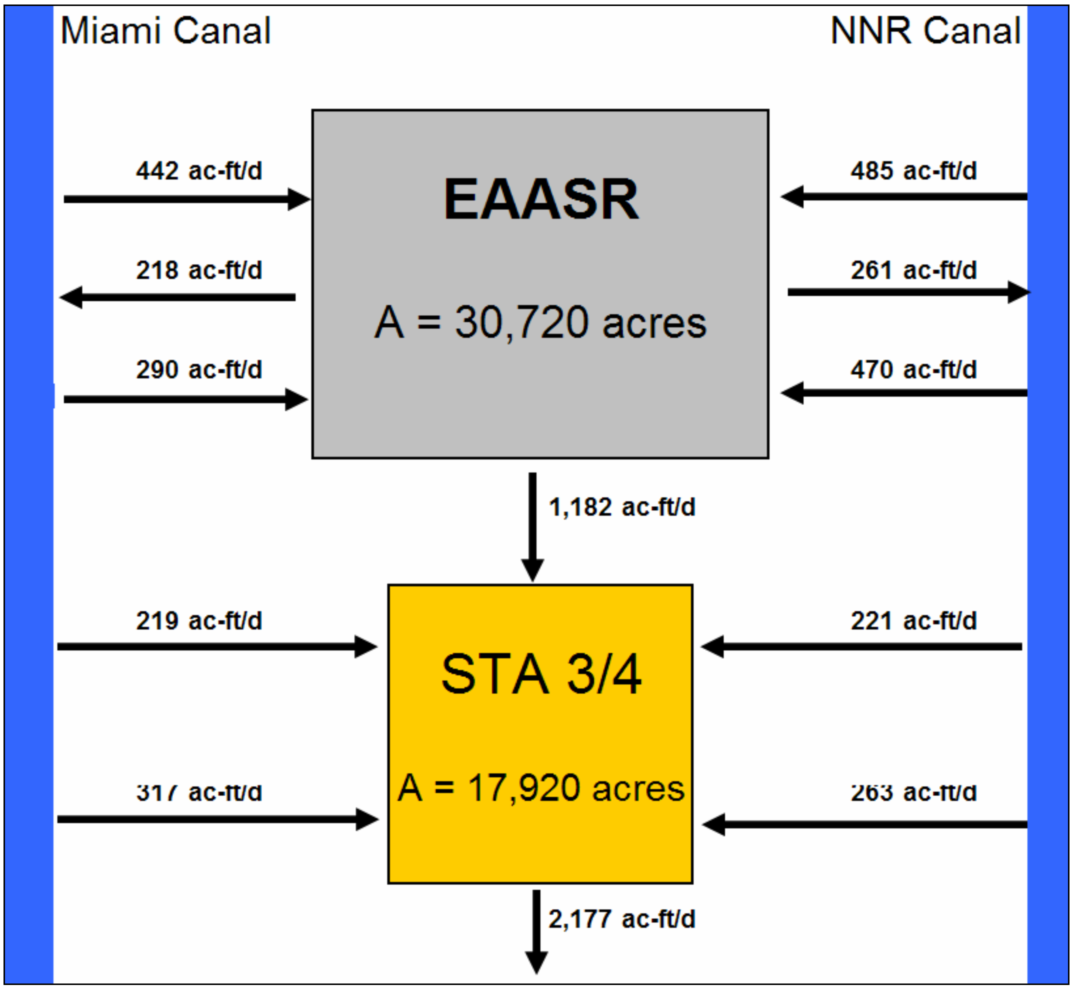

Figure 4-3. Single Compartment Base Scenario Flow Diagram

The SC base Scenario's long–term water balance for the 36 year average of the area, inflows, and outflows were calculated (Figure 4-3). The total average inflow to the EAASR was 1,686 ac-ft/day. Of this total, 1,182 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet. Thus, the mean hydraulic residence time was 107.5 days or about three and a half months. The long term HRT of 29 days was calculated for STA 3/4 from the arithmetic mean of the annual HRT presented in Table 4-15. This value is 33 percent higher than if directly calculated from the long term average flow and depth. An HRT of 29 days was used for all subsequent long-term STA 3/4 analysis.

The SC STA Scenario's long-term water balance for the 36-year average of the area, inflows, and outflows were calculated (Figure 4-4). The total average inflow to the EAASR was 2,705 ac-ft/day. Of this total, 2,201 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet. Thus, the mean HRT was 67.5 days, slightly more than two months. STA 3/4 results were equal to the single compartment base scenario.

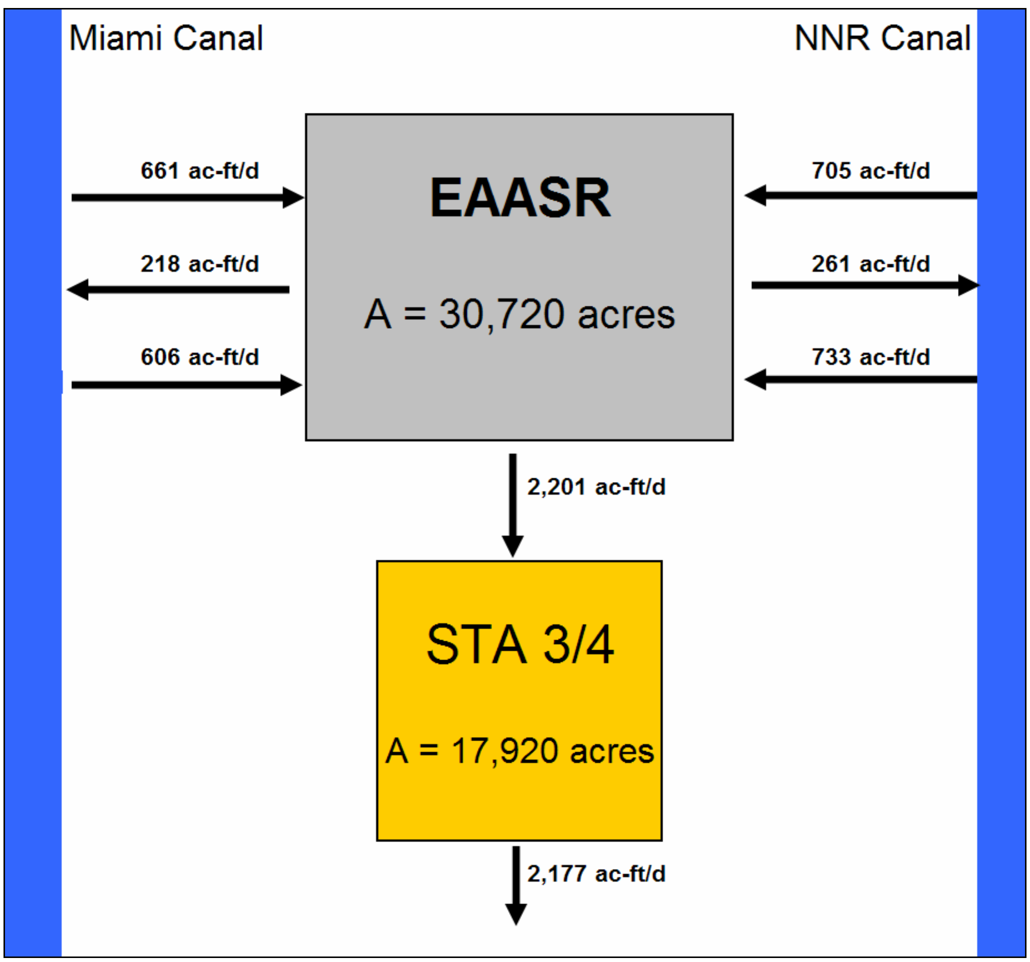

Figure 4-4. Single Compartment STA Scenario Flow Diagram

Two Compartment Reservoir Configuration Scenarios

The EAASR was portioned into two compartments (TC) for further analysis. The two compartment configuration is the most similar to the current design of the EAASR. The total external inflows and outflow for the EAASR are the same as in the single compartment case. The key difference is in how the water moves between the two compartments. Four scenarios were evaluated. The first scenario, which was considered to be the TSP scenario, was referred as the TC base scenario and is presented in Figure 4-5. The second scenario routed STA 3/4 inflows directly from the canals through the respective compartments before entering the STA. The second scenario is referred to as the TC STA scenario (Figure 4-6).

The TC base Scenario's long–term water balance for the 36 year average of the area, inflows, and outflow were calculated (Figure 4-5). The total average inflow to Compartment 1 was 2,011 ac-ft/day, including inter-reservoir transfers. The total average inflow to Compartment 2 was 1,284 ac-ft/day, including inter-reservoir transfers. Of this total, 1,717 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet in both compartments. Thus, the mean HRT for Compartment 1 was 45 days and 70 days for Compartment 2. STA 3/4 results were equal to the single compartment base scenario.

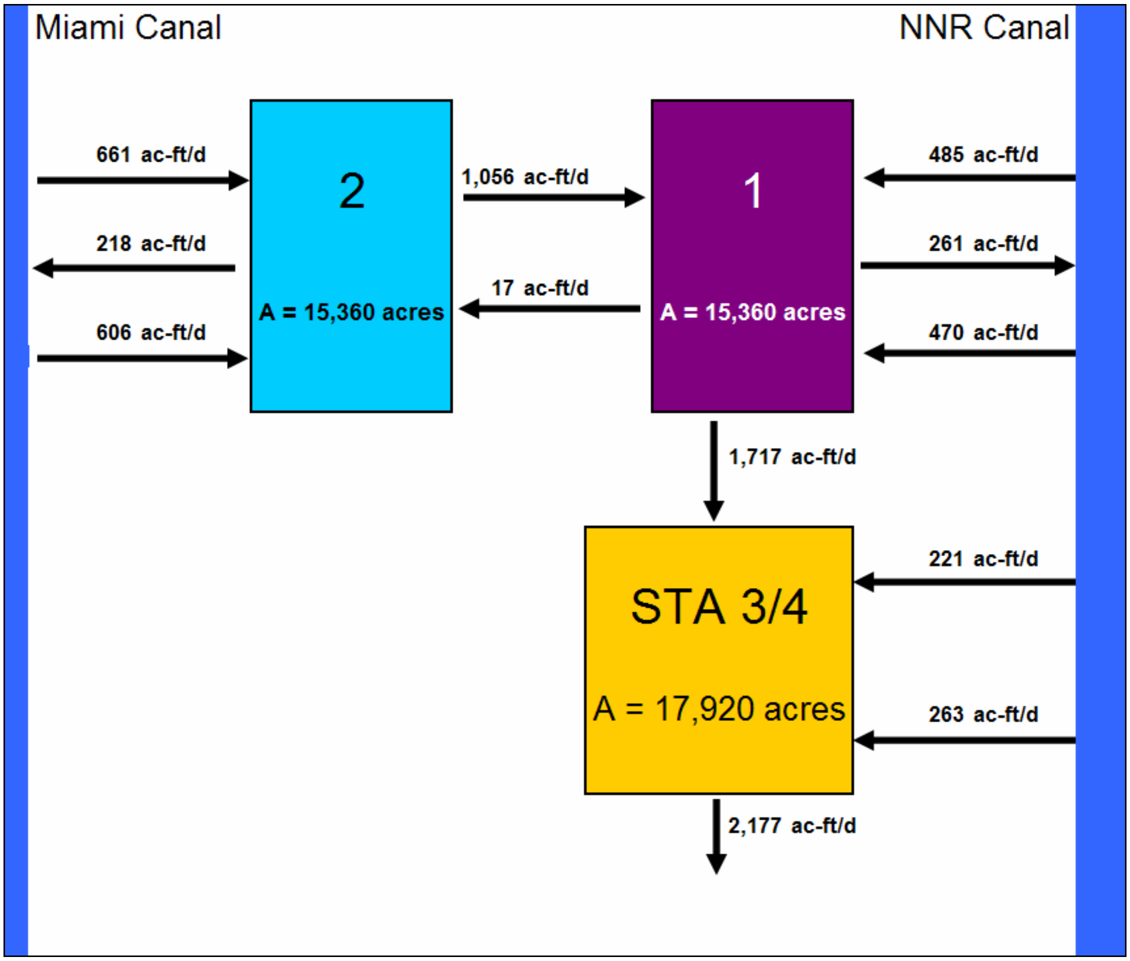

Figure 4-5. Two Compartment Base Scenario Flow Diagram

The TC STA Scenario's long–term water balance for the 36 year average of the area, inflows, and outflows were calculated (Figure 4-6). The total average inflow to Compartment 1 was 2,495 ac-ft/day, including inter-reservoir transfers. The total average inflow to Compartment 2 was 1,284 ac-ft/day, including inter-reservoir transfers. Of this total, 2,201 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet in both compartments. Thus, the mean HRT for Compartment 1 was 37 days and 70 days for Compartment 2. STA 3/4 results were equal to the single compartment base scenario.

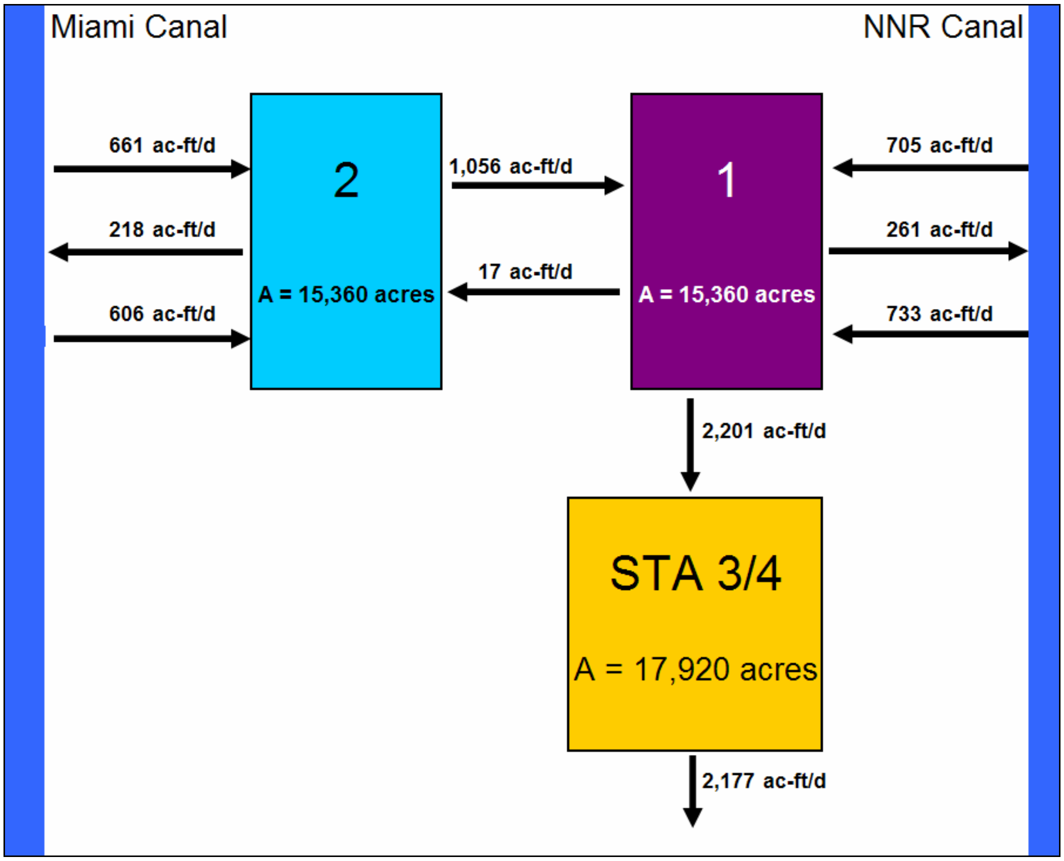

Figure 4-6. Two Compartment STA Scenario Flow Diagram

The HRT of Compartment 1 in both the TC base and TC STA scenarios was relatively low. Low removal rates were expected from this Compartment. It was hypothesized that an outflow from Compartment 2 to STA 3/4 would alleviate the heavy loading to Compartment 1 and improve treatment. Two scenarios for were generated to test the hypothesis, called TC Miami Scenario and TC Miami STA Scenario. The TC Miami Scenario's long–term water balance for the 36 year average of the area, inflows, and outflows were calculated (Figure 4-7). The total average inflow to Compartment 1 was 988 ac-ft/day, including inter-reservoir transfers. The total average inflow to Compartment 2 was 1,284 ac-ft/day, including inter-reservoir transfers. Of this total, 2,201 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet in both compartments. Thus, the mean hydraulic residence time for Compartment 1 was

92 days and 70 days for Compartment 2. STA 3/4 results were equal to the single compartment base scenario.

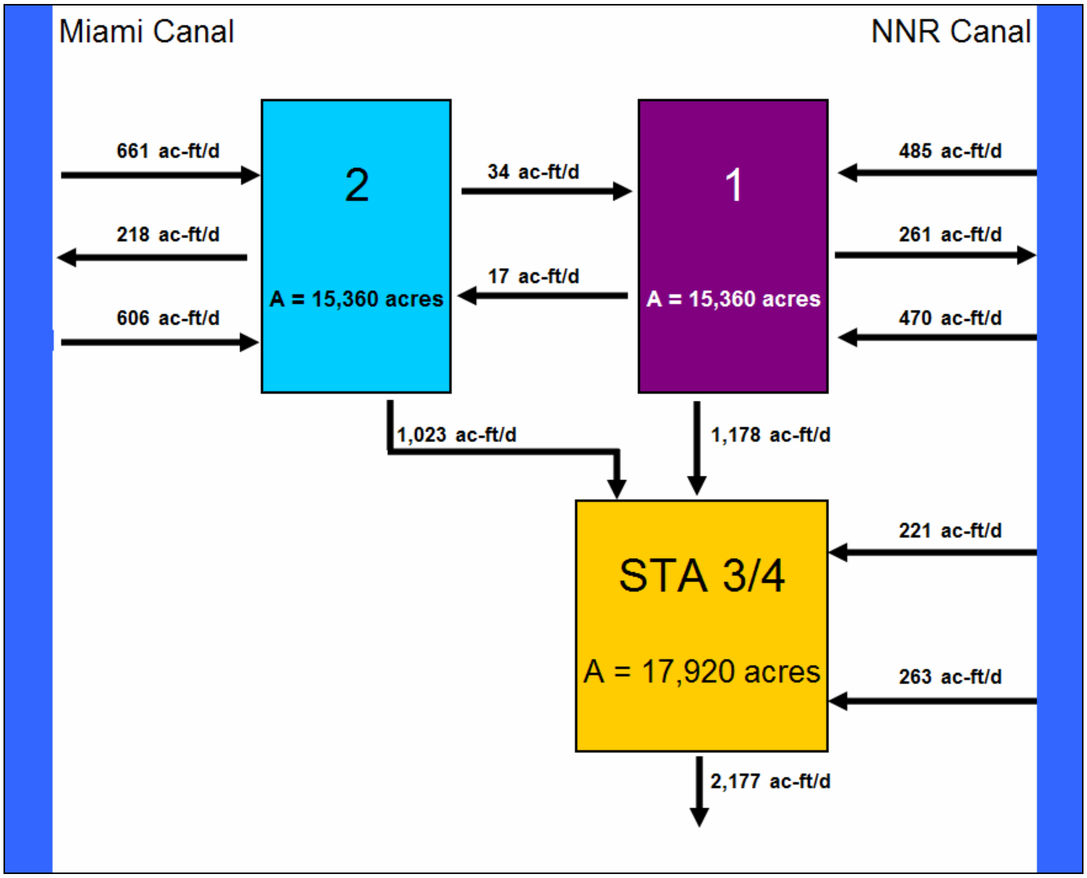

Figure 4-7. Two Compartment Miami Scenario Flow Diagram

The TC Miami STA Scenario's long–term water balance for the 36 year average of the area, inflows, and outflows were calculated (Figure 4-8). The total average inflow to Compartment 1 was 1,472 ac-ft/day, including inter-reservoir transfers. The total average inflow to Compartment 2 was 1,284 ac-ft/day, including inter-reservoir transfers. Of this total, 2,201 ac-ft/day was released to STA 3/4. The average depth of the EAASR was 5.9 feet in both compartments. Thus, the mean hydraulic residence time for Compartment 1 was 62 days and 70 days for Compartment 2. STA 3/4 results were equal to the single compartment base scenario.

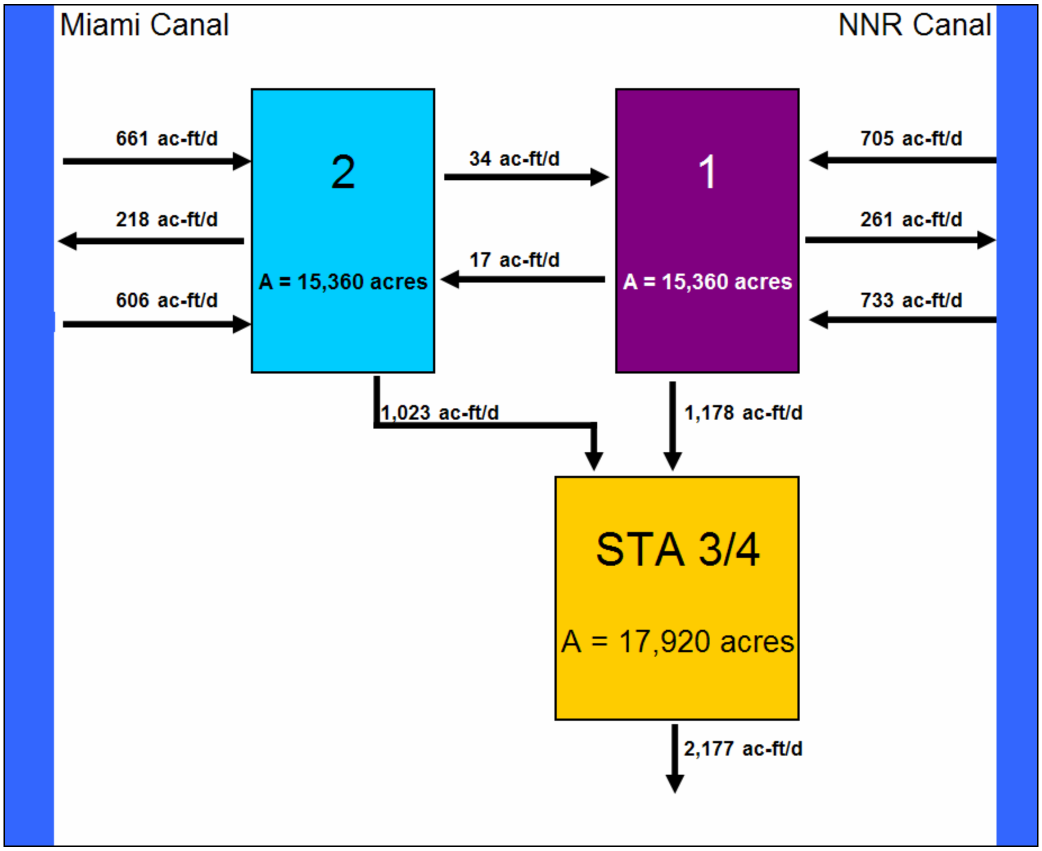

Figure 4-8. Two Compartment Miami STA Scenario Flow Diagram

Four Compartment Configuration Scenarios

Two scenarios were analyzed for the four compartment (FC) EAASR configuration. The total external inflows and outflow for the EAASR are the same as in the single compartment case. The key difference is in how the water moves among the four compartments. The first scenario, referred to as FC base scenario, was considered the MSP configuration (Figure 4-9). The direct flows to STA 3/4 were routed through Compartments B and D in the FC STA Scenario (Figure 4-10). The results for the scenarios for each compartment are presented in Tables 4-2 through 4-5. STA 3/4 results were equal to the single compartment base scenario.

Table 4-2. Compartment A Water Quantity for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (feet)	HRT (days)
FC base	5,120	589	8.3	72
FC STA	5,120	589	8.3	72

Table 4-3. Compartment B Water Quantity for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (feet)	HRT (days)
FC base	10,240	788	4.8	62
FC STA	10,240	1,272	4.8	39

Table 4-4. Compartment C Water Quantity for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (feet)	HRT (days)
FC base	5,120	525	8.5	83
FC STA	5,120	525	8.5	83

Table 4-5. Compartment D Water Quantity for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (feet)	HRT (days)
FC base	10,240	570	4.5	82
FC STA	10,240	1,105	4.5	42

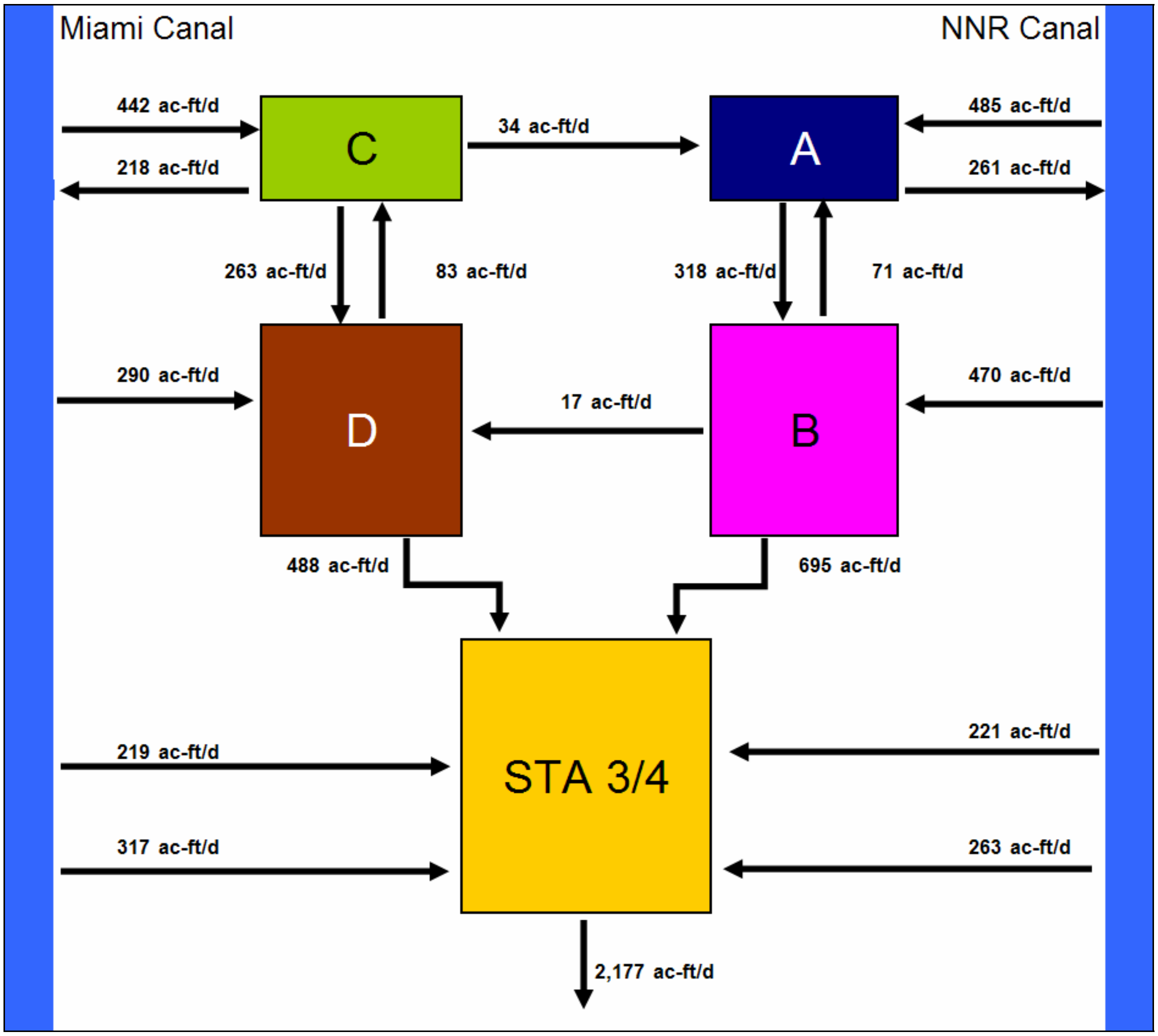

Figure 4-9. Four Compartment Base Scenario Flow Diagram

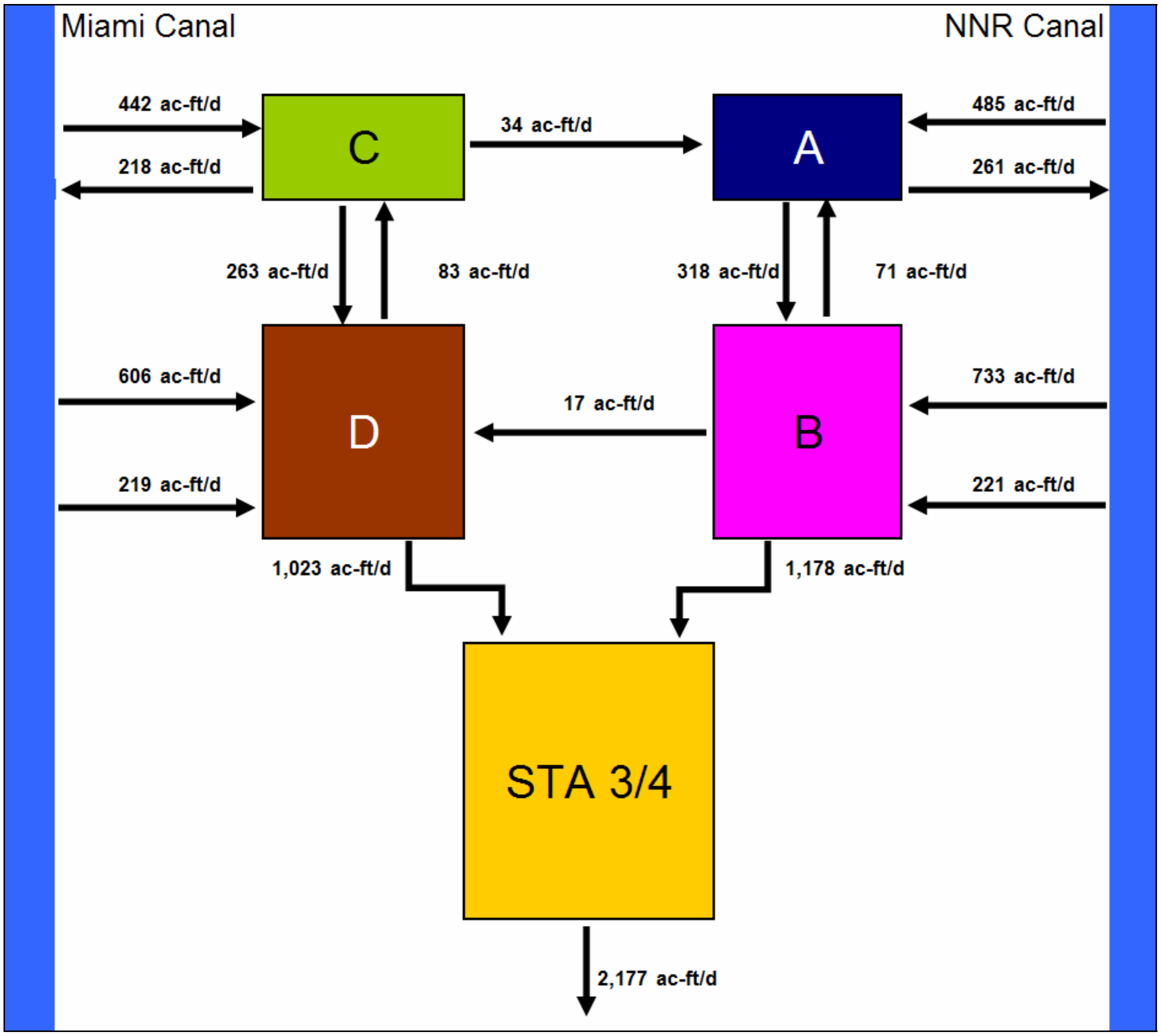

Figure 4-10. Four Compartment STA Scenario Flow Diagram

Flow Equalization

One of the usual purposes of storage upstream of a treatment system is to reduce the fluctuations in inflows to the treatment unit. The long-term average mean, standard deviation, and coefficient of variation (COV) for the inflow and outflow to the EAASR single compartment scenarios are shown in Table 4-6. The COV is ratio of the standard deviation and mean values. If equalization is being accomplished, then the COV of the output should be less than the COV of the input.

Table 4-6. Mean, Standard Deviation, and COV of Single Compartment Scenarios

	Inflow			Outflow		
Scenario	Mean (ac-ft/d)	Standard Deviation (ac-ft/d)	Coefficient of Variation	Mean (ac-ft/d)	Standard Deviation (ac-ft/d)	Coefficient of Variation
EAASR SC base	1,686	3,262	1.9	1,662	4,179	2.5
EAASR SC STA	2,705	3,904	1.4	2,681	4,591	1.7

The single compartment scenarios of the EAASR do not indicate the reservoir is used for flow equalization. In both cases, the COV is higher for the outflow than inflow. The STA scenario displays less variation, but it is not believed that this corresponds to more flow equalization. With residence times in the range of two months, the EAASR is able to completely dampen fluctuation from most rainfall events and should have a significant impact on the longer-term precipitation events during the wet season. The EAASR is to be a multi-purpose reservoir. Thus, the ability to use it to equalize inflows to STA 3/4 may be constrained by these other purposes.

Comparison of STAs and Lakes in Southern Florida

Quantity-related design parameters for STAs and lakes and reservoirs are shown in Table 4-7 (Walker and Kadlec 2005b). With the exception of the Iron Bridge wetland with an HRT of 66 days, the HRTs for wetlands and STAs are in the range of 7 to 21 days. Thus, the mean residence time of 29 days for STA 3/4 shows that STA 3/4 can potentially be used to a greater extent. The associated median operating depth for the comparables is about 1.7 feet. The mean operating depth of 2.3 feet for STA 3/4 is on the high side, but not exceptional. These STAs are designed as water quality control facilities; accordingly, there is relatively little variability in how they operate.

In stark contrast to the relatively homogeneous behavior of the 22 STAs, the 15 entries in the lake and reservoir database indicate a wide range of behavior. The four periods studied for Lake Okeechobee have HRTs in the range of 580 to 715 days. At the other extreme, four entries have reported HRTs of less than 10 days. Mean depths range from 4.1 to 11.2 feet. The estimated HRT range for the EAASR was 67 to 107 days with a mean depth of 5.9 feet. Thus, the possible Lake/Reservoir comparables in Table 4-6 can be reduced to George, Istokpoga, Harney, Jessup, Crescent, and Thonotosassa with regard to quantity characteristics. More detailed analysis of reservoir comparables will be presented in the next section on water quality.

Table 4-7. Comparative HLRs and HRTs for 37 Reactors in Southeast Florida (Data from Walker and Kadlec 2005b)

Number	Category	HLR in/day	HRT days	Mean Depth ft	Max Depth ft	% Full
	Emergent Wetlands					
1	ENRP_C1	1.1	17	1.6	2.2	74.3%
2	ENRP_C2	2.1	14	2.5	2.9	87.4%
3	ENRP_C3	1.1	13	1.1	1.5	75.4%
4	STA1W_C1	1.8	13	2.0	3.0	67.9%
5	STA1W_C2	2.9	11	2.6	3.5	74.8%
6	STA1W_C3	2.6	7	1.6	2.4	66.0%
7	STA5_C1AB	2.6	8	1.7	2.2	79.4%
8	STA5_C2AB	1.5	9	1.1	2.0	57.4%
9	BoneyMarsh	0.8	23	1.5	3.0	51.2%
10	IronBridge	0.4	66	2.3	2.3	99.6%
11	WCA2A	1.4	13	1.5	4.3	35.6%
	Median	1.5	13	1.6	2.4	74.3%
	Pre-existing Wetlands					
1	STA2_C1	1.2	22	2.1	2.7	79.7%
2	STA2_C2	1.9	14	2.2	3.3	64.4%
3	STA6_C3	2.7	7	1.6	2.5	66.0%
4	STA6_C5	1.3	15	1.6	2.3	70.1%
5	WCA2A	1.7	9	1.2	4.0	31.2%
6	WCA2A	1.8	8	1.2	4.0	31.0%
7	WCA2A	1.4	11	1.2	4.0	30.7%
	Median	1.7	11	1.6	3.3	64.4%
	Submerged Aquatic Vegetation Systems					
1	ENRP_C4	5.0	5	2.2	2.5	87.2%
2	STA1W_C4	3.7	7	2.0	2.8	72.0%
3	STA1W_C5AB	3.7	7	2.2	3.3	66.0%
4	STA2_C3	2.0	17	2.9	4.3	66.2%
	Median	3.7	7	2.2	3.1	69.1%
	Lakes or Reservoirs					
1	OKEE_7578	0.2	674	8.4	10.5	79.6%
2	OKEE_7986	0.2	704	8.8	11.0	80.4%
3	OKEE_8794	0.2	714	8.6	10.9	78.6%
4	OKEE_9599	0.2	578	9.4	11.3	83.7%
5	HELLNBLAZES	24.9	2	4.1	6.4	64.3%
6	SAWGRASS	20.7	3	4.4	6.7	65.2%
7	GEORGE	1.9	73	11.2	12.6	89.0%
8	ISTOKPOGA	0.4	170	5.2	6.8	77.1%
9	ISTOK_2	0.4	178	5.2	6.1	84.3%
10	POINSETT	4.3	8	3.0	6.1	48.2%
11	HARNEY	6.9	16	9.4	15.0	63.0%
12	HARNEY_2	8.7	9	6.7	11.1	60.4%
13	JESSUP	0.4	176	5.3	9.7	54.4%
14	CRESCENT	1.1	112	10.0	12.2	81.8%
15	THONOTO	1.1	54	5.0	7.7	64.6%
	Median	1.1	112	6.7	10.5	77.1%

Water Quality for the EAASR and STA 3/4

The water quality of the EAASR and STA 3/4 were separated into the inflow water quality and uptake parameters. The inflow water quality and each uptake rate parameter are detailed in this section.

Inflow Water Quality

Inflow to the EAASR and STA3 /4 occurred from four external sources. A mean concentration for each source was calculated from historical data. Pumping Stations S2 and S3 are used to control the water entering and leaving Lake Okeechobee through the NNR and Miami Canals. The water passing through pump stations S2 (NNR Canal) and S3 (Miami Canal) was divided into two types: to LOK from the EAA (back pumping), and from LOK to the EAA. These were designated as Basin and LOK_{Canal}, respectively and correspond to the external inflows in the water quantity section. The mean, coefficient of variation (standard deviation divided by mean), and count of data for each parameter are presented in Tables 4-8 through 4-11. The data included measurements from 1973 to 2004, which were taken at different frequencies depending on the parameter.

In both the NNR and Miami Canals, water quality exiting LOK was of higher quality than water entering LOK. The mean water quality coming to LOK from the EAA was higher quality in the Miami Canal than in the NNR Canal. The coefficients of variation for concentrations to LOK were similar, with the exception of iron, turbidity and dissolved oxygen. The reverse is true for flows from LOK to the EAA, where S2 had better water quality than S3, with the exception of iron and phosphorus, as TP. The coefficients of variation for the flows from LOK are similar with the exception of sodium.

Table 4-8. NNR Basin Mean, Coefficient of Variation, and Count of Water Quality Parameters

Parameter	NNR Basin Mean	NNR Basin Coefficient of Variation	NNR Basin Number of Records
TP (mg/L)	0.150	0.53	236
TKN (mg/L)	3.69	0.34	227
NOx-N (mg/L)	1.811	1.01	227
TN (mg/L)	5.505	0.46	227
DO (mg/L)	2.47	0.59	176
pH (su)	7.19	0.05	133
Specific Conductance (uS/cm)	1191	0.21	177
Turbidity (NTU)	10.7	1.34	160
TSS (mg/L)	18.1	1.45	138
Alkalinity as CaCO3 (mg/L)	317	0.27	186
Calcium (mg/L)	109.2	0.22	88
Chloride (mg/L)	137.1	0.28	205
Sulfate (mg/L)	101.9	0.41	67
Sodium (mg/L)	97.8	0.29	88
Total Iron (ug/L)	267	0.89	57
Total Mercury (ng/L)	2.82	0.50	11
Atrazine (ug/L)	0.670	0.97	16

Table 4-9. LOK_{NNR} Canal Mean, Coefficient of Variation, and Count of Water Quality Parameters

Parameter	LOK_{NNR} Mean	LOK_{NNR} Coefficient of Variation	LOK_{NNR} Number of Records
TP (mg/L)	0.077	0.46	76
TKN (mg/L)	1.79	0.35	72
NOx-N (mg/L)	0.206	2.01	72
TN (mg/L)	1.998	0.45	72
DO (mg/L)	6.57	0.26	70
pH (su)	7.78	0.04	99
Specific Conductance (uS/cm)	625	0.25	72
Turbidity (NTU)	71.0	0.87	103
TSS (mg/L)	12.9	0.96	67
Alkalinity as CaCO3 (mg/L)	138	0.33	75
Calcium (mg/L)	48.6	0.23	22
Chloride (mg/L)	82.0	0.25	74
Sulfate (mg/L)	49.4	0.27	29
Sodium (mg/L)	52.6	0.30	22
Total Iron (ug/L)	170	0.70	27
Total Mercury (ng/L)	NA	NA	0
Atrazine (ug/L)	0.280	0.54	26

Table 4-10. Miami Basin Mean, Coefficient of Variation, and Count of Water Quality Parameters

Parameter	Miami Basin Mean	Miami Basin Coefficient of Variation	Miami Basin Number of Records
TP (mg/L)	0.112	0.73	148
TKN (mg/L)	3.06	0.33	142
NOx-N (mg/L)	1.996	0.85	142
TN (mg/L)	5.053	0.46	142
DO (mg/L)	3.45	0.42	125
pH (su)	7.23	0.05	133
Specific Conductance (uS/cm)	962	0.27	124
Turbidity (NTU)	8.2	0.82	106
TSS (mg/L)	12.9	1.10	91
Alkalinity as CaCO3 (mg/L)	248	0.24	112
Calcium (mg/L)	106.7	0.29	55
Chloride (mg/L)	112.2	0.37	125
Sulfate (mg/L)	72.8	0.43	54
Sodium (mg/L)	70.4	0.30	55
Total Iron (ug/L)	192	0.49	44
Total Mercury (ng/L)	2.2	0.33	9
Atrazine (ug/L)	0.470	1.26	13

Table 4-11. LOK_{Miami} Mean, Coefficient of Variation, and Count of Water Quality Parameters

Parameter	LOK_{Miami} Mean	LOK_{Miami} Coefficient of Variation	LOK_{Miami} Number of Records
TP (mg/L)	0.060	0.50	105
TKN (mg/L)	1.85	0.41	97
NOx-N (mg/L)	0.297	1.74	97
TN (mg/L)	2.143	0.52	97
DO (mg/L)	6.35	0.30	98
pH (su)	7.8	0.06	99
Specific Conductance (uS/cm)	767	0.42	100
Turbidity (NTU)	6.9	0.84	103
TSS (mg/L)	8.2	0.70	78
Alkalinity as CaCO3 (mg/L)	164	0.44	104
Calcium (mg/L)	64.0	0.44	32
Chloride (mg/L)	101.0	0.45	104
Sulfate (mg/L)	69.5	0.74	37
Sodium (mg/L)	71.5	0.64	32
Total Iron (ug/L)	148	0.93	32
Total Mercury (ng/L)	NA	NA	0
Atrazine (ug/L)	0.280	2.01	26

As stated previously, TP is the major parameter of interest in the system. The overall flow-weighted average TP concentration for the EAASR and STA 3/4 system is 0.101 mg/L. TP concentrations range from a low of 0.060 mg/L for LOK releases via the Miami Canal to a high of 0.150 mg/L for NNR Basin.

The relationship between concentration and flow was investigated for all the water quality parameters. A linear regression was used to evaluate the relationship. For NNR Canal, flows for total iron to LOK showed a weak relationship with an R^2 of 0.36. All other parameters did not show a significant relationship. Thus, concentration will be assumed to be independent of flow for all constituents.

Background Concentration

The removal of TP was modeled using the KC* equation. The background concentration, *C**, is the lowest possible concentration the reactor can reach. An accurate value of *C** is important, because the concentration approaches *C** asymptotically. A Walker and Kadlec (undated) report calibrated values of C* ranging from 0.004 to 0.020 mg/L for STAs. Walker and Havens (2003) use 0.007 mg/L as the background concentration for precipitation. In this study, the background concentration will be determined using calibration data with the constraint that C* >= 0.007 mg/L, the estimated value for precipitation.

Reservoir TP Overall Reaction Rate

Several water quality models have been developed to simulate the TP kinetics in general CERP reservoirs including Walker and Kadlec (2005a) and USACE and SFWMD (2005). The general CERP reservoir models use large datasets of comparable systems to find the average overall TP kinetics. A more specific set of comparables was sought to develop a water quality model for the Everglades Agricultural Reservoir

(EAASR), a CERP reservoir. The selection of comparable systems is also documented in Reisinger et al (2006).

Long-term average evaluation of comparable systems

Walker and Kadlec (2005a) tabulated the long term averages of a comprehensive set of 18 comparable Florida lakes and a reservoir in the documentation of the DMSTA v.2 calibration (Figure 4-6). The long term average values were used to determine several closely comparable systems of the Single Compartment base EAASR Scenario. The SC base scenario was used, because it is the most general of the scenarios. The analysis was performed on both the water quantity and TP water quality of the comparable dataset, as they were inseparable for parameter estimation. The analysis of comparables was performed using three categories of decision variables: lake characterization, water quantity, and water quality. The decision variables and weighting factors were chosen to best represent the parameters in Equation 3-4. The selected decision variables for lake characterization are surface area and depth. Water quantity was represented by the HRT and HLR. Water quality was represented by the inflow TP concentration. A weighted decision matrix was used to evaluate the dataset of comparables. A rating of one to five was given for each decision variable for each lake, where five was the most comparable to the EAASR. A weighting factor was applied to each decision variable, where the sum of all weighting factors equals one. The percent of the total points (five) was used to rate each dataset. Equation 4-6 was used to calculate the rating of each lake or reservoir.

$$P_i = f_i * 100 = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} W_{i,j} R_{i,j}}{\sum_{j=1}^{m} W_j R_j} \qquad \text{Eqn. 4-6}$$

Where i = individual lake, j = decision variable, n = number of lakes, m = number of decision variables, P = percent of total points, f = ratio of points received, W = weighting factor, and R = rating from one to five.

The weighting factors, ratings, percent of total points, and overall rank for lakes ranked five and under are presented in Table 4-12. The Crescent Lake, Lake Istokpoga_2, Lake Jessup, Lake George, and Lake Poinsett datasets were developed by Burns and McDonnell (2004a). The Lake Istokpoga dataset was developed by Walker and Haven (2003). Crescent Lake and Lake Istokpoga were found to be clearly the most comparable overall to the EAASR. A sensitivity analysis was performed using a range the weighting factors and repeatedly found Crescent Lake and Lake Istokpoga to be the highest ranked systems. These lakes were determined to be the most comparable to EAASR and were reviewed in further detail.

Table 4-12. Decision Rankings for Comparable Systems Ranked Five and Better

Decision Variable	Surface Area	Depth	HLR	HRT	Inflow TP Conc.	Percent of Total Points	Rank
Weighting	0.1	0.1	0.1	0.35	0.35	NA	NA
Crescent Lake	4	3	4	5	5	92%	1
Lake Istokpoga	5	5	5	3	5	86%	2
Lake Istokpoga_2	5	5	5	3	5	86%	3
Lake George	3	2	2	4	4	70%	4
Lake Jessup	3	5	5	3	3	68%	5
Lake Poinsett	2	4	1	2	5	63%	3

More detailed analysis of selected comparables

Next, the salient attributes of Crescent Lake and Lake Istokpoga were analyzed in more detail by looking at time series data and the extent to which the terms in the water and TP budgets were measured. The analysis was again divided into lake characterization, water quantity and water quality.

Crescent Lake was found to have a large quantity and high frequency of TP samples. However, large uncertainty exists in the mass balance due to high proportion of ungaged flows and a large percentage of TP measurements associated with ungaged flows. Additionally, no direct stage-area or stage-volume relationship exists. The depth profile fluctuated regularly from 8.8 feet to 11.5 feet in depth. This more detailed analysis found that Crescent Lake was not a very reliable data source for parameter estimation.

Lake Istokpoga has a relatively complete water balance. TP measurements are infrequent, but have an average of two data points per average residence time. A recent bathymetric map provides a stage-area and stage-volume relationship for the lake (SFWMD 2005b). The depth profile fluctuated generally over a relatively small range from 4.9 feet to 5.6 feet. Three recent reports are available for Lake Istokpoga: Walker and Havens (2003), Burns and McDonnell (2004a), and South Florida Water Management District (2005). The conclusion from the more detailed analysis is that Lake Istokpoga is the best candidate for parameter estimation.

Selection of the appropriate period of record for the chosen comparable system

Lake Istokpoga is located northwest of Lake Okeechobee, near the center of Highland County. The inflow and outflow TP concentrations and the HRT were assumed to be key variables for parameter estimation when using Equation 4-3. The mass balance terms used to calculate the value of key variables were found from recent reports and weather station records. The period of record (POR) used for parameter estimation was selected by influent TP concentrations in the range of 0.100 mg/L and no significant trends over time.

The inflow mass balance terms include gaged and ungaged inflows and rainfall. A map of Lake Istokpoga and the location of major mass balance terms, except ET, are shown in Figure 4-11. Inflows to the lake were measured at Arbuckle Creek and Josephine Creek. TP was measured at each of the creeks. Ungaged inflows were estimated as 17% of the gaged flow and were assumed to be from seepage (Walker and Haven 2003). Rainfall was measured at the S-68 structure. The TP concentration in ungaged inflows was estimated as 0.050 mg/L and rainfall concentrations as 0.007 mg/L (Walker and Haven 2003). Outflows from the lake occur mainly from the measured S-68 structure and evapotranspiration (ET). Outflows can occur through the controlled Istokpoga Canal, although it is seldom used and is considered to be a negligible outflow (Walker and Haven 2003). Pan evaporation was measured approximately 30 miles northeast of the lake at the S-65 structure. A pan coefficient of 0.76 was used to convert the measurement to ET (Burns and McDonnell 2004a). The outflow concentration at S-68 was sampled and it was assumed that no TP was transported in the ET. The volume in the lake was calculated using the stage-volume relationship reported in SFWMD (2005b) and the measured headwater stage at the S-68 structure. The removed TP mass was calculated as the difference in inflow and outflow mass balance terms.

The POR was determined for the mass balance terms presented above. The beginning date of the POR was determined by the TP samples, which were first taken in February of 1988 (Burns and McDonnell 2004). Water quantity and quality data from calendar years 1988 to 2002 were downloaded from the SFWMD DBHYDRO database and used in the remainder of the analysis. This period reflects the longest continuous period where all inputs were measured. Missing data were interpolated as needed.

Figure 4-11. Lake Istokpoga and Mass Balance Locations

Quarterly and bimonthly TP sampling frequencies were found at each measured flow location during the 1988 to 2005 POR, with the exceptions of 2001 and 2002 that were sampled less frequently. Time series plots of the TP concentrations indicate an increasing trend in the latter part of the time series for S-68 (Figure 4-12) and Arbuckle Creek (Figure 4-13). The desired comparable TP concentration is 0.100 mg/L for the Arbuckle Creek inflow and with minimal trends for Arbuckle Creek and S-68. If the entire POR is used, then the TP concentration increases from approximately 0.060 to 0.190 mg/L for Arbuckle Creek and from approximately 0.025 mg/L to 0.085mg/L for S-68. A portion of the POR was selected to minimize the increasing trend and the optimal POR for S-68 was determined to be from 1988 through 1997. The outflow had a mean TP concentration of approximately 0.035 mg/L for this period (Figure 4-12). The portion of the total POR was reduced to yield an optimal POR for Arbuckle from 1988 through 1995 (Figure 4-13). The inflow concentration for this period was approximately 0.080 mg/L for this period.

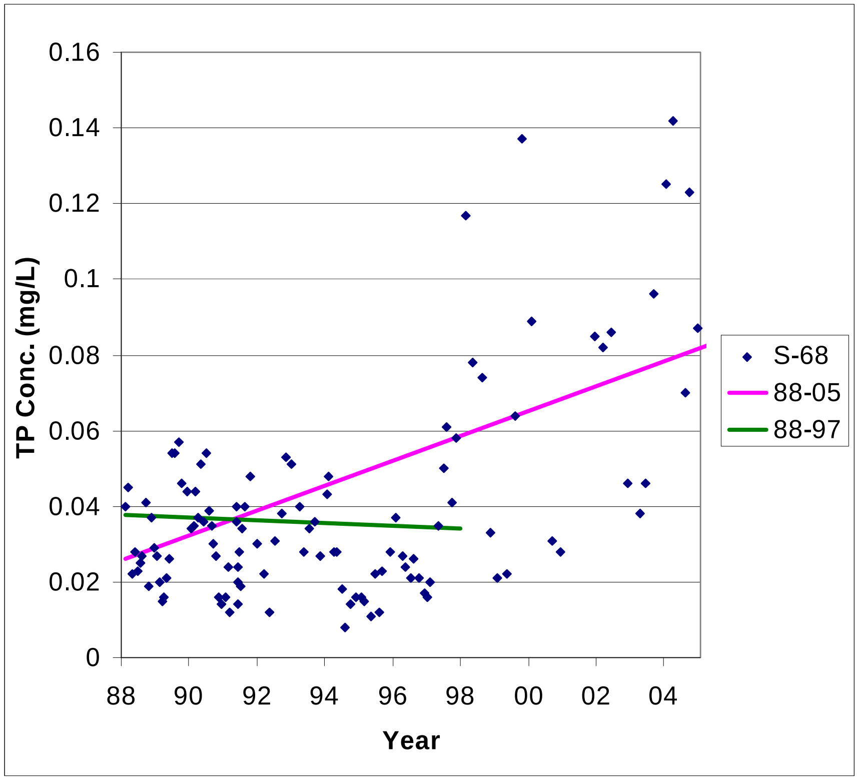

Figure 4-12. S-68 TP Data and Adjusted POR

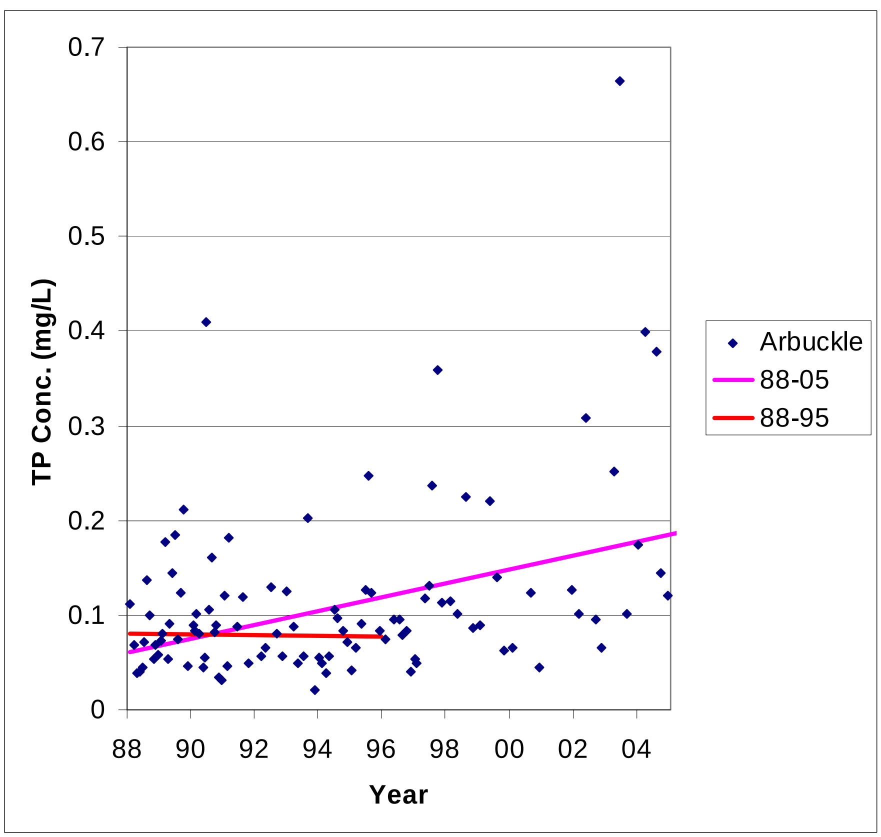

Figure 4-13. Arbuckle Creek TP Data and Adjusted POR

A compromise POR from 1988 through 1997 was chosen to produce the least temporal trends overall. This period provided the least trend in the S-68 dataset and a slight positive trend from 0.100 mg/L to 0.125 mg/L in Arbuckle Creek. Additionally, the selected POR was on average closer to the inflow concentration goal than the optimal Arbuckle period. This POR included 80 TP samples of Arbuckle Creek and Josephine Creek and 89 TP samples of S-68. The TP samples for each location were analyzed for trends as a function of the calendar month. Arbuckle and Josephine Creeks included four to eight samples for each calendar month and S-68 had six to 10 samples for each calendar month. No clear monthly trend was found.

A POR of January 1, 1988 to December 31, 1997 was determined for Lake Istokpoga from the constraints set by the TP temporal trends. A monthly averaging period for the mass balance of Lake Istokpoga was chosen. Preliminary estimates of the EAASR HRT were found to be between two and five months, which allow for a parameter estimate on a monthly scale. A monthly averaging period was found to be acceptable for Lake Istokpoga's water quantity and quality data. Excellent inflow and stage records allow the estimation of the several short periods of missing data with little additional error. Due to the bimonthly and quarterly TP sampling, uncertainty exists at any water quality averaging period. A number of averaging or regression methods could be reasonably used to estimate the missing monthly TP concentrations for the POR. Therefore, an averaging period equal to that of the water quantity was chosen.

Rate constant calibration

All TP measurement stations were used for the TP calibration of the overall rate constant. Data was generated for each station shown in Figure 4-14. It was assumed that no change in the quantity or quality of the influent occurred between sampling and the lake. The inflow measuring points, Arbuckle Creek and Josephine Creek, were therefore relocated to their respective lake inlets (Figure 4-14).

The median value of each sampling station in µg/L was determined (Figure 4-15). A well defined concentration gradient existed from the Arbuckle Creek inflow at the northern end of the lake to the outflow at the southeast corner of the lake. A probable flow path was developed for the Arbuckle and Josephine Creek flows. Due to the low concentration, the Josephine Creek flow path was not used.

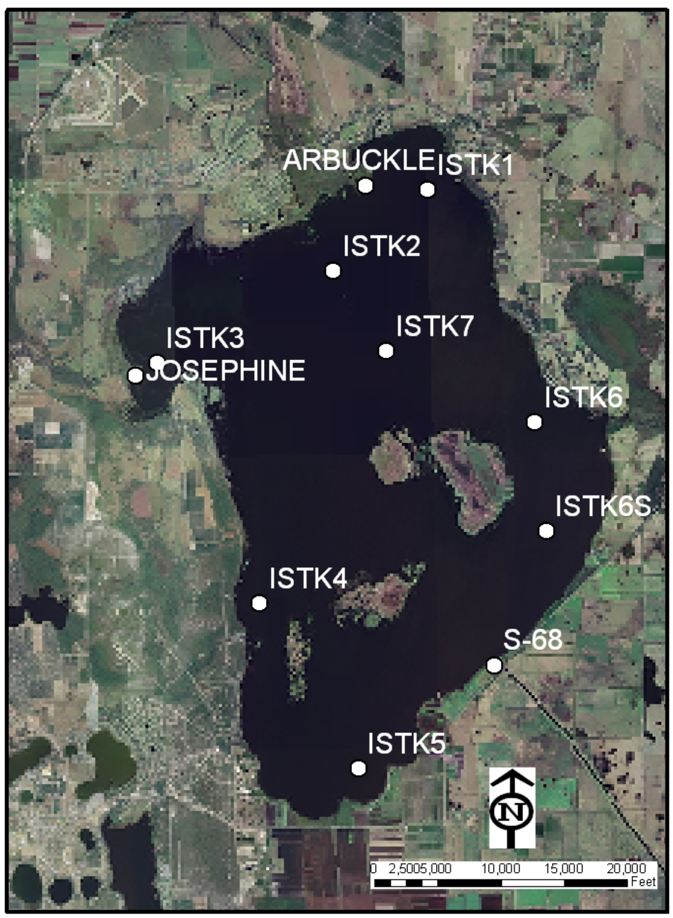

Figure 4-14. Water Quality Sampling Stations in Lake Istokpoga

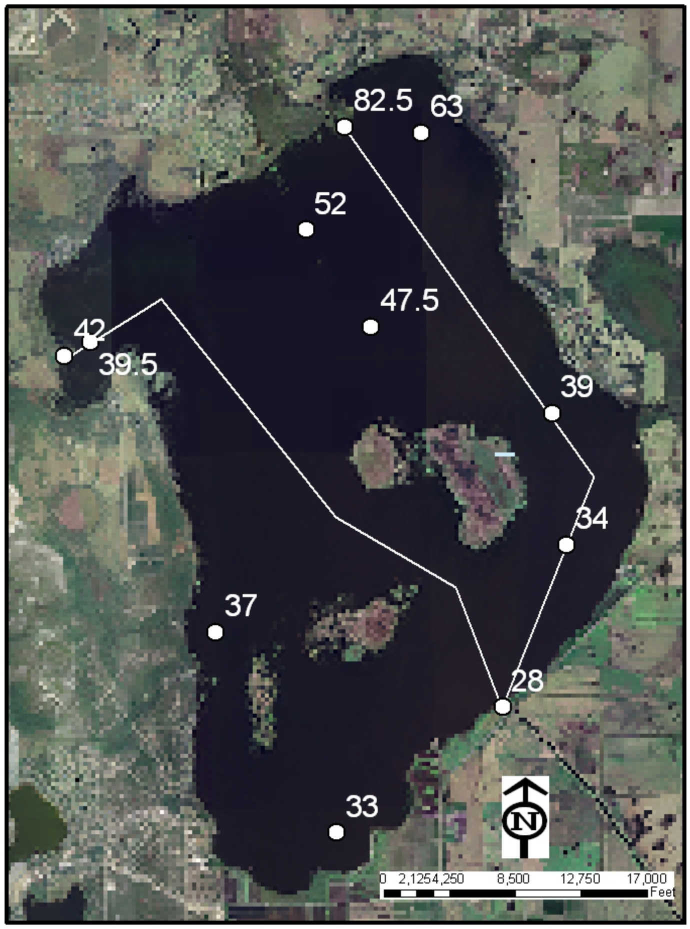

Figure 4-15. Median TP Values at Lake Istokpoga Sampling Stations

The average HRT of 197 days was developed for the lake using the mass balance terms described in the preceding section. Knowing the HRT for the lake, it is possible to develop a TP concentration vs. residence time curve based on the inlet, outlet, and in-lake measurements. The resulting curve is shown in Figure 4-16. Using the boundary conditions of the concentration at 0 days was equal to 0.082 mg/L, the concentration at 60 days was equal to 0.0475 mg/L, and the concentration is 0.028 mg/L at 197.5 days, then the overall rate constant, k_V, was calculated as 0.016 days^{-1} and the background concentration, C*, is 0.0254 mg/L.

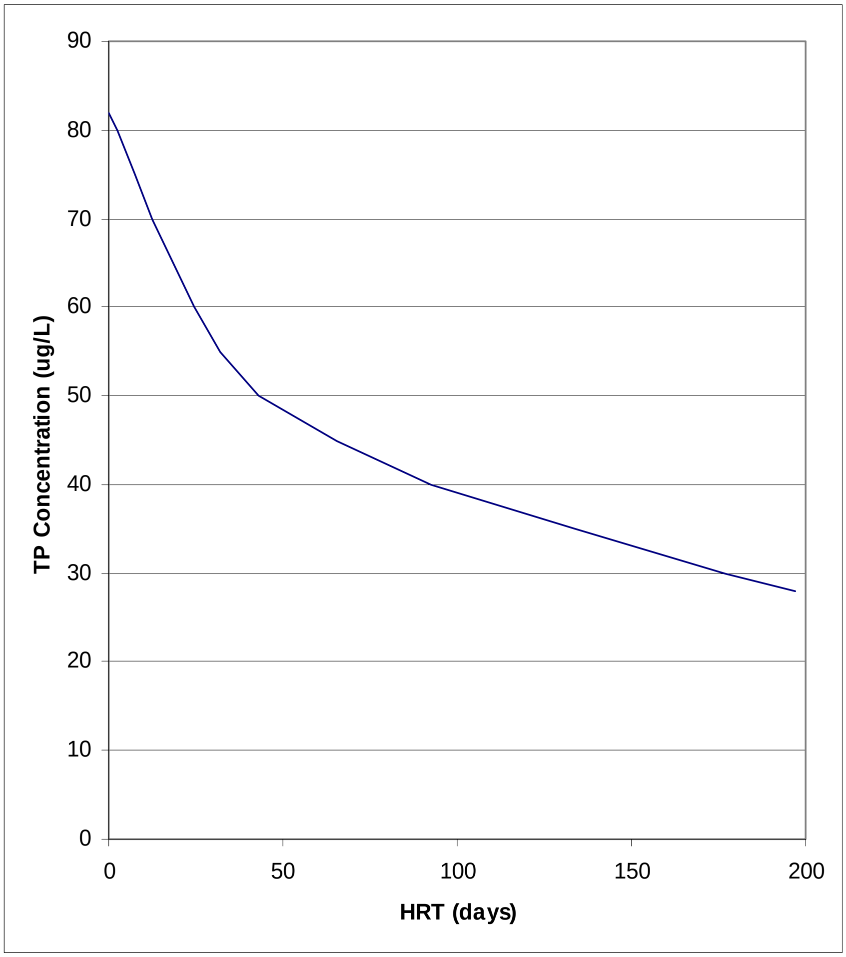

Figure 4-16. Lake Istokpoga TP Removal in Arbuckle Creek Flow Path

EAASR reaction rate sensitivity analysis

A sensitivity analysis was performed on the calibration of the EAASR TP removal rate constant. As a two parameter calibration was performed, both the reaction rate and background concentration were evaluated. The SC STA scenario was used for the sensitivity analysis, which is characterized by a 67.5 day HRT and 0.101 mg/L inflow TP concentration.

The combined effect of C* and the overall reaction rate was first analyzed. The EAASR outflow concentration for multiple background concentrations and reaction rates spanning two orders of magnitude were calculated (Figure 4-17). The results indicate, as expected, an increasing trend in outflow concentration for greater background concentrations and the greater the reaction rate the less variability in outflow occurred. For a k of 0.01 days^{-1}, which is similar to the calibrated value, the outflow concentration varied from about 0.055 mg/L at C* equal to 0.005 mg/L to 0.065 mg/L at C* equal to 0.030 mg/L. From this analysis, it was clear that the calibration of k and C* can significantly affect the results of the modeling.

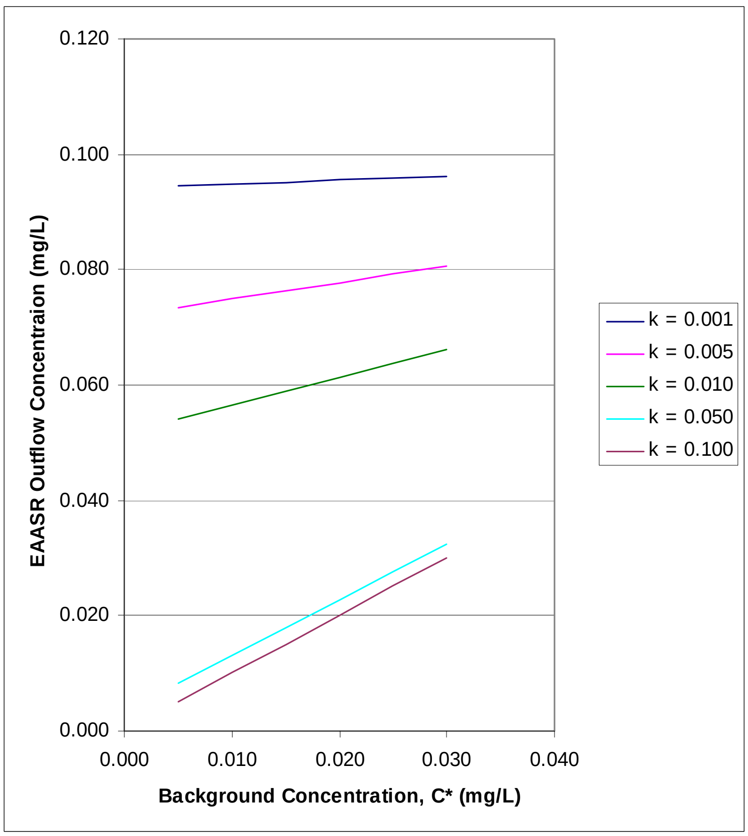

Figure 4-17. Sensitivity Analysis for EAASR Parameters k and C*

The effect of the overall reaction rate on both the EAASR and STA 3/4 was evaluated. The outflow concentrations for large ranges of EAASR k values were calculated for the EAASR and STA 3/4. This analysis used a fixed EAASR C* of 0.025 mg/L and the reported STA 3/4 parameters. A large effect on the outflow concentration of the EAASR was observed for reaction rates less than 0.05 days^{-1}. The STA 3/4 outflow concentration is relatively independent of the EAASR outflow concentration, which is the only inflow to the STA, and thus reaction rate. This independence was due to the relatively long HRT and high reaction rate. In fact, if the STA 3/4 received all inflow without first routing through the reservoir it would still achieve an outflow concentration of 0.021 mg/L. This result does not account for mass loading and its long term effect on the STA. Therefore, such an operating scheme is not suggested. Data from this analysis for selected reaction rates are presented in Table 4-13.

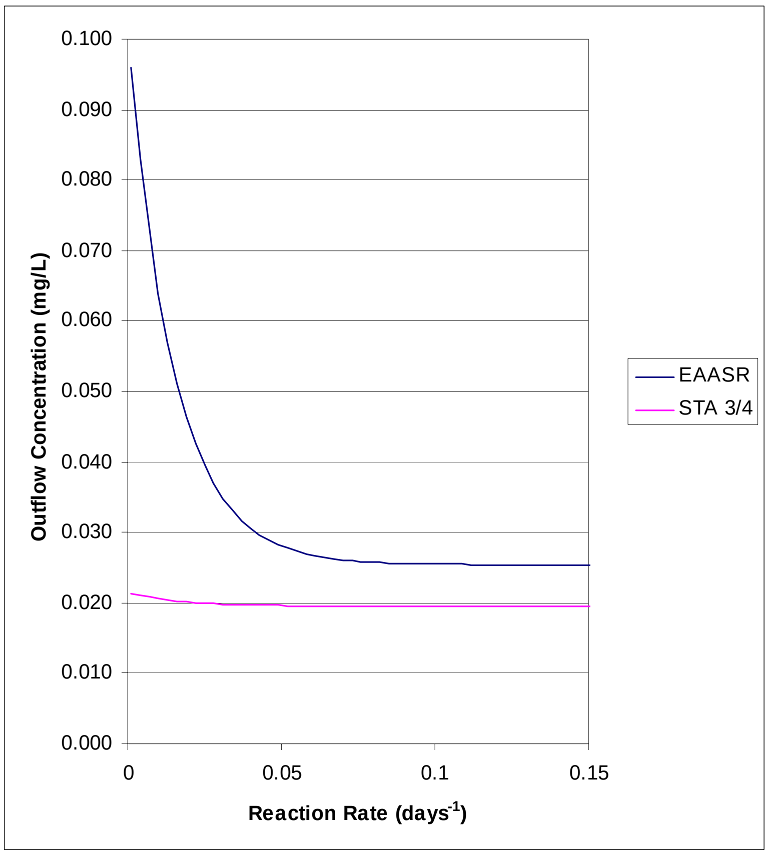

Figure 4-18. Outflow Concentration of the EAASR and STA 3/4 for Varying Reaction Rates

Table 4-13. Selected Results of the EAASR and STA 3/4 for Varying Reaction Rates

HRT (days)	EAASR Reaction Rate ($days^{-1}$)	C* (mg/L)	EAASR Cin (mg/L)	EAASR Cout (mg/L)	STA 3/4 Cout (mg/L)
67	0.001	0.025	0.101	0.096	0.021
67	0.005	0.025	0.101	0.079	0.021
67	0.010	0.025	0.101	0.064	0.021
67	0.050	0.025	0.101	0.028	0.020
67	0.100	0.025	0.101	0.025	0.020
67	0.150	0.025	0.101	0.025	0.020

The Basis of Design Report provides an alternative analysis of the EAASR TP uptake. The parameter estimates needed to produce these results will be evaluated to allow comparison between the simulations. The report models only compartment 1 of the TC configuration, which is referred to as Phase 1. Phase 1 consists of a 12 foot reservoir on 15,833 acres of Component A creating 190,551 acre-feet of possible storage (SFWMD 2006). The location and simulated water balance are shown in Figure 4-19. The water balance was simulated from the SFWMM Version 5.4.2 using the ECP 2010 and 2015 simulations, as compared to the 2050 Next Added Increment simulation used in the previous scenarios. An average daily inflow of 1,988 acre-feet per day was calculated from the water balance and an average depth over the POR of 4.5 feet was reported. An HRT of 35.8 days was calculated for Phase 1.

SFWMD (2006) reported an average TP concentration of 82 ppb entering the reservoir. DMSTA 2 was used to simulate Phase 1 and found an outflow of 68 ppb or a 17 percent removal. These results were generated using an areal reaction rate on a daily basis. To obtain these results using the UF WQDT with a background concentration of 00.0254 mg/L a reaction rate of 0.0033 $days^{-1}$ would be needed. The value is almost one order of magnitude lower than the Lake Istokpoga estimate. Due to the differences in configuration and reactions rates the two modeling efforts should not be directly compared.

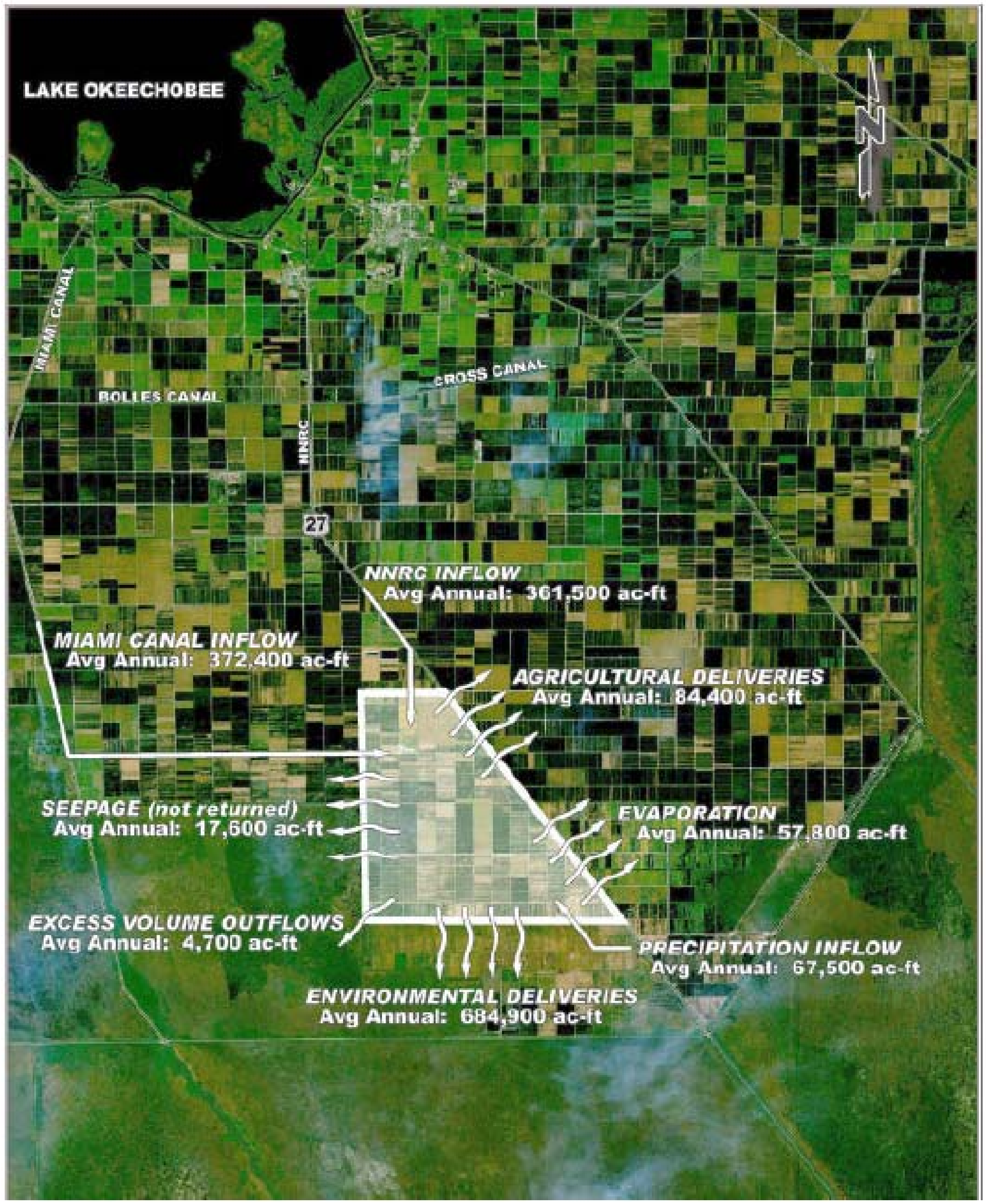

Figure 4-19. Water Balance and Location of the EAASR – Phase 1 (SFWMD 2006).

STA TP Reaction Rate

Key parameters for 16 STAs in southeast Florida are shown in Table 4-14. The average inflow TP concentration is 0.102 mg/L. The optimal values of C* and k can be determined by solving the following constrained optimization problem using the Excel Solver. The objective function is to minimize the sum of the squares of the errors between the calculated and measured outflow concentrations for the 16 STAs. C* is constrained to be >= 0.007 mg/L. Optimized values of two decision variables k and C* were calculated as 0.127 days^{-1} and 0.0194 mg/L, respectively for an assumed average inflow concentration of 0.102 mg/L.

Table 4-14. Characteristics of 16 STAs in Southeast Florida (Data from Walker and Kadlec 2005a)

STA	Mean Depth (ft)	HRT (days)	Inflow Conc. (mg/L)	Outflow Conc. (mg/L)	Percent Removal
ENRP_C1	1.6	17	0.089	0.039	56%
ENRP_C2	2.5	14	0.068	0.034	49%
ENRP_C3	1.1	13	0.039	0.019	50%
ENRP_C4	2.2	5	0.036	0.017	53%
STA1W_C1	2.0	13	0.140	0.05	64%
STA1W_C2	2.6	11	0.142	0.088	38%
STA1W_C3	1.6	7	0.058	0.033	43%
STA1W_C4	2.0	7	0.100	0.032	68%
STA1W_C5AB	2.2	7	0.153	0.055	64%
STA2_C1	2.1	22	0.100	0.012	88%
STA2_C2	2.2	14	0.110	0.021	81%
STA2_C3	2.9	17	0.128	0.015	89%
STA5_C1AB	1.7	8	0.121	0.071	42%
STA5_C2AB	1.1	9	0.203	0.125	39%
STA6_C3	1.6	7	0.071	0.019	73%
STA6_C5	1.6	15	0.079	0.016	79%
Average	2.0	11	0.104	0.042	60%

Predicted Performance of EAASR Removal of TP

The calculated outflow concentrations from the EAASR for various assumed values of initial concentration and residence time are shown in Figure 4-20. For a residence time of 50 days, the effect of the initial concentration at 50 days and the associated percent removal is shown in Table 4-15. The percent removal varies from a low of 19 % if the initial concentration is 0.025 mg/L to 42 % if the initial TP concentration is 0.150 mg/L.

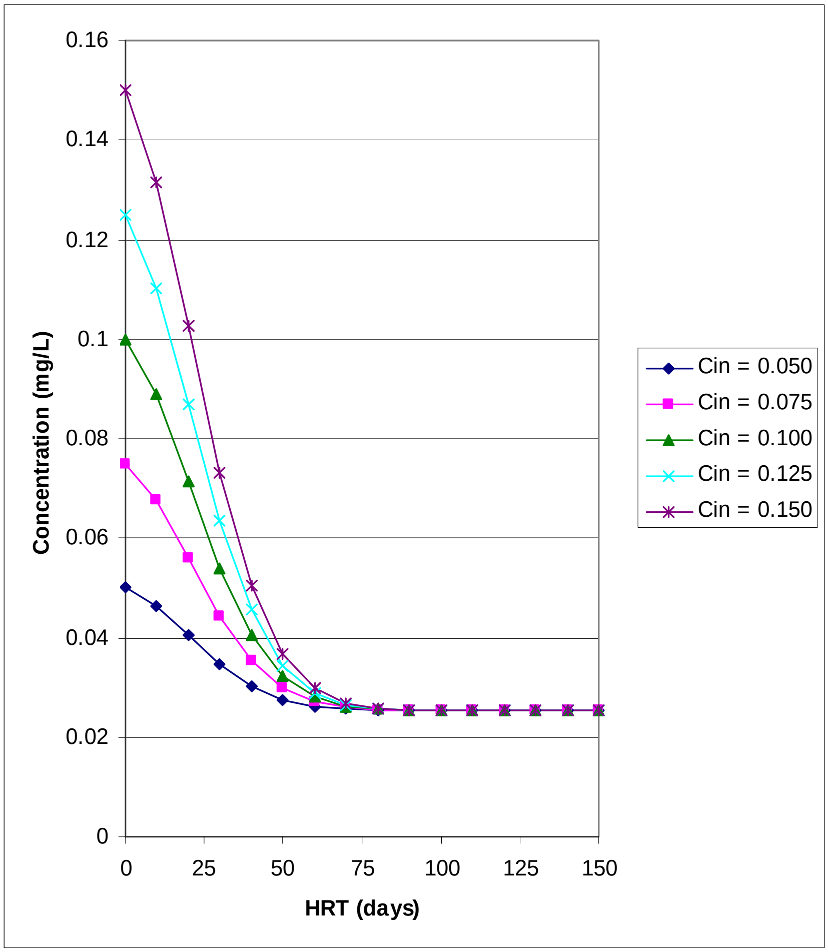

Figure 4-20. Effect of Initial Concentration and Residence Time on Outflow TP Concentration for the EAASR

Table 4-15. Effect of Initial TP Concentration on TP at 50 Days and Percent Control for the EAASR

Initial TP (mg/L)	TP (mg/L) at 50 days	% Control
0.050	0.04	19%
0.075	0.06	25%
0.100	0.07	28%
0.150	0.09	42%

Predicted Performance of STA 3/4 Removal of TP

The primary differences between the EAASR and STA 3/4 with regard to the removal Equation 4-3 is that the residence times in the STAs are typically in the range of

7 to 21 days whereas the rate constant is an order of magnitude higher at 0.127 day^{-1}. The effect of the much higher rate constant for the STAs is dramatic as shown by comparing Figure 4-20 for the EAASR and Figure 4-21 for the STAs. An assumed rate constant of k equals to 0.127 day^{-1} causes the concentration to reach the assumed background level in 50 days over the entire range of assumed inflow concentrations. Figure 4-22 shows the same information with the x axis rescaled to a maximum residence time of 50 days instead of 150 days.

The results shown in Figure 4-22 suggest that using residence times in the 7 to 21 day range provide a relatively good level of performance. For a residence time of 15 days, the associated outflow concentrations and % control are shown in Table 4-16. In this case, the percent control ranges from a low of 60% for an initial concentration of 0.025 mg/L to a high of 76% if the initial concentration is 0.150 mg/L, though all are approaching the background concentration.

These results indicate the following key points about the EAASR/STA system:

- The STAs are much more effective water quality controls than the EAASR in that they achieve significant removals in 7 to 21 days of residence time as dramatically illustrated by comparing Figures 4-25 and 4-27.
- The EAASR can provide significant water quality improvements if the residence times exceed 25 days and the initial concentrations are relatively high.
- For the same area, the residence times in the STAs can be expected to be significantly less than for the EAASR since they are operated at much shallower depths.
- The initial concentration has a significant effect on performance especially if performance is measured as percent pollutant removal.

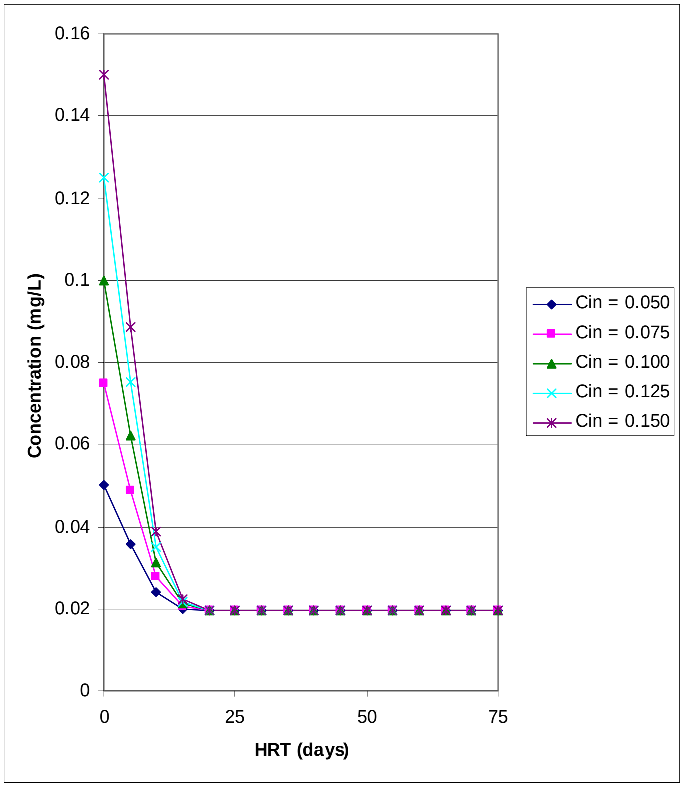

Figure 4-21. Effect of Initial Concentration and Residence Time on Outflow TP Concentration for the STAs

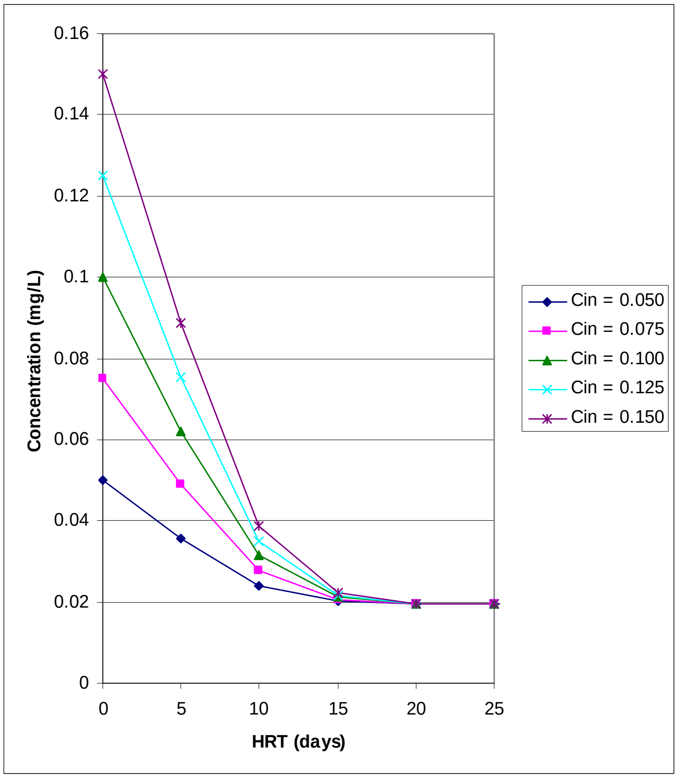

Figure 4-22. Figure 4-21 Rescaled to Residence Times Up to 50 Days

Table 4-16. Effect of Initial TP Concentration on TP at 15 Days and Percent Control for the STAs

Initial TP (mg/L)	TP (mg/L) at 50 days	% Control
0.050	0.020	60%
0.075	0.021	72%
0.100	0.021	79%
0.150	0.022	86%

Summary and Conclusions

The UF WQDT is a steady-state mass balance model utilizing the KC* kinetic model and was developed to determine the TP water quality of the EAASR and STA 3/4. The model uses a single aggregate inflow and concentration, depth, background concentration, and a volumetric reaction rate to simulate TP. The model calculates the HRT and HLR of each reactor, as well as the outflow concentration and percent removal. Long-term averages were determined to be the most appropriate level of sophistication needed in order to provide key insights for the dynamic EAASR design.

Water quantity and quality inputs to the model were calculated for the base and STA scenarios for each configuration. The HRT of the EAASR ranged from 39 to 107.5 days. The EAASR was not used for flow equalization. The HRT of STA 3/4 was calculated to be 29 days for all scenarios. Mean inflow concentrations of 17 parameters of interest for the four external inflow sources to the reservoir and STA 3/4 were reported. Parameter estimations were performed using closely comparable systems with high quality data. Lake Istokpoga was found to be the best comparable for the general single compartment scenario of the EAASR. Data from 16 STAs were used as comparables to STA 3/4. The following water quality parameters estimates for the EAASR and STA 3/4 were selected:

- C* = 0.0254 mg/L for the reservoir and 0.0194 mg/L for the STA
- k = 0.016 day^{-1} for the reservoir and 0.127 day^{-1} for the STA

A sensitivity analysis of the EAASR reaction rate and background concentration was performed for the SC STA scenario. The calibration of each parameter was found to significantly affect the results especially if the reaction rates are less than 0.05 $days^{-1}$ for a background concentration of 0.025 mg/L. To reproduce TP removal estimates provided in the BODR, a reaction rate of 0.0033 $days^{-1}$ for a C* of 0.025 is needed. Due to the differences in configurations and reaction rates the modeling efforts are not directly comparable.

An analysis of the predicted performance of the EAASR and STA 3/4 systems was performed. STAs were found to provide significantly greater water quality treatment than reservoirs. The STA systems will approach the background concentration asymptotically for retention times greater than 25 days. However, since the STA is operated at much lower depths than the reservoir, they will have much lower HRT for a given area and inflow. The initial concentration can affect the outcome of the EAASR or STA 3/4, especially if measured by the percent removal of TP.

The initial concentration of each scenario is calculated in Chapter 5, as the inflow of the TC and FC scenarios are a function of their removal. The resulting concentrations and the inputs from this chapter will be used to generate TP estimates for each scenario.

CHAPTER 5
ESTIMATED WATER QUALITY CHANGES IN THE EAASR AND STA 3/4 SYSTEMS

The results of the analysis of the SFWMM output and the water quality studies to estimate the outflow concentrations from the EAASR and STA 3/4 are provided in this chapter. Each scenario is evaluated on a steady-state long-term basis using the UF WQDT. Key insights are discussed for each scenario and summarized at the conclusion of the section. The annual variability in the SC STA scenario is evaluated to provide an indication of the variability in the 36 year data set. This analysis was performed using a variant of the UF WQDT that made annual steady-state evaluations. Key insights on the variability of water quality are discussed.

Analysis of Long-Term Averages

The EAASR and STA 3/4 were evaluated on a steady-state basis for the average behavior over the 36 years of SFWMM simulation. Results from the UF WQDT for each scenario are presented below for the one, two, and four compartment reservoir options.

Single Compartment Reservoir

The single compartment reservoir was the simplest configuration. Two scenarios were evaluated to provide a basis for further comparison with the two and four compartment scenarios; the SC base Scenario (Figure 4-3) and the SC STA scenario (Figure 4-4). The depth of each scenario was varied to 9 feet and 12 feet from 5.9 feet to illustrate the effects of depth on the overall performance of the reservoir and STA 3/4. STA 3/4 received water directly from the NNR and Miami Canals in the SC base scenario. In the SC STA scenario, STA 3/4 inflows were first routed through the single compartment reservoir (Figure 4-4), and therefore the inflow concentration is equal to the EAASR outflow concentration. The results of the above scenarios are presented for the EAASR and STA 3/4 in Tables 5-1 and 5-2, respectively.

Table 5-1. Single Compartment EAASR Results for Total Phosphorus with Variable Depths

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	Percent Removal
SC base	30,720	1,686	5.9	108	0.105	0.040	62%
SC base @ 9 ft.	30,720	1,686	9.0	164	0.105	0.031	70%
SC base @ 12 ft.	30,720	1,686	12.0	219	0.105	0.028	74%
SC STA	30,720	2,705	5.9	67	0.101	0.051	49%
SC STA @ 9 ft.	30,720	2,705	9.0	102	0.101	0.040	60%
SC STA @ 12 ft.	30,720	2,705	12.0	136	0.101	0.034	66%

Table 5-2. STA 3/4 Results for the Single Compartment EAASR for Total Phosphorus with Variable Depths

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	Percent Removal
SC base	17,920	2,201	2.4	29	0.066	0.021	69%
SC base @ 9 ft.	17,920	2,201	2.4	29	0.061	0.020	67%
SC base @ 12 ft.	17,920	2,201	2.4	29	0.060	0.020	66%
SC STA	17,920	2,201	2.4	29	0.051	0.020	61%
SC STA @ 9 ft.	17,920	2,201	2.4	29	0.040	0.020	50%
SC STA @ 12 ft.	17,920	2,201	2.4	29	0.034	0.020	42%

The results of varying the depth show that it may be possible to improve the quality of the EAASR outflow by increasing the mean depth beyond 5.9 feet. The EAASR has a maximum depth of 12 feet. If it could be kept full, then the HRT increases from 108 days to 219 days resulting in a significant improvement in water quality. However, it is unlikely that the EAASR could be operated full since this would conflict with other purposes such as flood control and water supply. An intermediate increase in depth to 9 feet also shows good improvement in water quality and would be more feasible to attain.

Routing all STA 3/4 inflows, the SC STA scenario, through the EAASR provides large gains in water quality when compared to the base scenario. Long-term STA 3/4 inflow concentrations were identical for the SC STA scenario and the SC base scenario at 12 feet of depth. Therefore, it may be possible to achieve similar gains to increasing the depth of the EAASR by routing all STA inflow through the EAASR first. The combination of increasing depth and routing STA flows achieves some additional gains in water quality. At the low concentrations of the STA, it is difficult to achieve large gains in water quality. Large gains are more easily made by altering the EAASR operations.

STA 3/4 alone could achieve nearly the same water quality as the EAASR/STA two reactor system because of the 29 day HRT. Recall from Figure 4-22, the outflow TP concentration at an HRT of 29 for STA 3/4 is approaching the background level. This suggests that the HRT may be under used and more inflow could be accommodated to reduce its HRTs to about 10-15 days, without a significant decrease in load reduction.

Two Compartment Reservoir

The two compartment reservoir differs from the single compartment case mainly due to the interaction between the two compartments and the elimination of direct flow from the Miami Canal. The base scenario was modeled as presented (Figure 4-5). In the TC STA Inflow scenario, the direct NNR canal flows to STA 3/4 were routed through the reservoir before being released to the STA (Figure 4-6). The results of the analyses are shown in Tables 5-3 through 5-5. The TC base scenario EAASR achieved good removal, though lower than the SC base scenario. However, the STA achieved identical outflow concentrations in the SC and TC base scenarios. The increased loading in the TC STA scenario decreased the EAASR performance, as expected. However, the STA inflow concentration was less than the TC base scenario due to mixing and treatment in the EAASR. The STA outflow concentration TC STA scenario was higher than the SC STA scenario, reinforcing the findings presented in the above section.

The higher concentrations in Compartment 1 as compared to the SC scenarios were mainly caused by reduced treatment due to the higher loading for Compartment 2. An outflow from C2 to STA 3/4 was included in the TC Miami and TC Miami STA (Figures 4-7 and 4-8), and the outcome of the resulting scenario analyses are presented in Tables 5-3 through 5-5. The resulting reduction in load increased the inflow concentration and treatment in Compartment 1, resulting in little gains. The outflow from C1 decreased the inflow concentration of STA 3/4 and therefore resulted in lower outflow concentrations. From these results, it is believed that the addition of an outflow from Compartment 2 to STA 3/4 may allow additional water quality benefits, due to operational flexibility and mixing.

The water quality gains were evaluated on a mass basis (Table 5-6). The total removal from the system was extremely similar between scenarios, with the exception of TC Miami. However, routing the STA inflows through the reservoir shifted the removal from the STA to the reservoir. These findings are consistent with those for the single compartment scenarios. The lower removal in the case of TC Miami is largely a factor of less mass to be removed in the STA.

Table 5-3. Compartment 1 Result for the Two Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	Percent Removal
TC base	15,360	2,011	5.9	45	0.078	0.051	35%
TC STA	15,360	2,495	5.9	37	0.084	0.058	31%
TC Miami	15,360	988	5.9	92	0.112	0.045	60%
TC Miami STA	15,360	1,472	5.9	62	0.111	0.057	49%

Table 5-4. Compartment 2 Result for the Two Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	Percent Removal
TC base	15,360	1,284	5.9	70	0.087	0.045	48%
TC STA	15,360	1,284	5.9	70	0.087	0.045	48%
TC Miami	15,360	1,284	5.9	70	0.087	0.045	48%
TC Miami STA	15,360	1,284	5.9	70	0.087	0.045	48%

Table 5-5. STA 3/4 Result for the Two Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	Percent Removal
TC base	17,920	2,201	2.4	19	0.064	0.020	76%
TC STA	17,920	2,201	2.4	19	0.058	0.020	77%
TC Miami	17,920	2,201	2.4	19	0.048	0.020	77%
TC Miami STA	17,920	2,201	2.4	19	0.052	0.020	77%

Table 5-6. TP Removal by Mass in Kilograms per Day

Scenario	C1	C2	EAASR Total	STA 3/4	System Total
TC base	67	67	134	119	253
TC STA	80	67	147	104	250
TC Miami	82	67	148	77	225
TC Miami STA	98	67	165	86	251

Four Compartment Reservoir

Two scenarios were analyzed for the four compartment (FC) EAASR configuration. The FC base scenario was modeled as presented in Figure 5.9. The FC STA scenario was modeled as presented in Figure 5-10. The results for each compartment are presented in Tables 5-7 through 5-11. Results from the analysis are similar to the two compartment configuration, therefore little water quality gains were realized from the increased compartmentalization.

Table 5-7. Compartment A Result for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	% Removal
FC base	5,120	589	8.3	72	0.131	0.059	55%
FC STA	5,120	589	8.3	72	0.133	0.060	55%

Table 5-8. Compartment B Result for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	% Removal
FC base	10,240	788	4.8	62	0.085	0.058	32%
FC STA	10,240	1,272	4.8	39	0.088	0.063	28%

Table 5-9. Compartment C Result for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	% Removal
FC base	5,120	525	8.5	83	0.102	0.046	46%
FC STA	5,120	525	8.5	83	0.102	0.050	43%

Table 5-10. Compartment D Result for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	% Removal
FC base	10,240	570	4.5	82	0.067	0.047	45%
FC STA	10,240	1,105	4.5	42	0.068	0.048	46%

Table 5-11. STA 3/4 Result for the Four Compartment EAASR Configuration

Scenario	Area (acres)	Inflow (ac-ft/d)	Depth (ft)	HRT (days)	C_{in} (mg/L)	C_{out} (mg/L)	% Removal
FC base	17,920	2,201	2.4	19	0.053	0.020	77%
FC STA	17,920	2,201	2.4	19	0.056	0.021	70%

The water quality gains were evaluated on a mass basis (Table 5-12). The total removal from the system was virtually identical between scenarios (Table 5-11). Routing the STA inflows through the reservoir shifted the majority of the removal from the STA to the reservoir.

Table 5-12. TP Removal by EAASR and STA 3/4 in Mass in Kilograms per Day

Scenario	A	B	C	D	EAASR Total	STA 3/4	System Total
FC base	52	26	36	14	129	90	281
FC STA	53	39	34	27	153	95	280

Annual Variability in Performance for the SC STA Scenario

As shown in long-term analysis, the overall performance does not vary greatly for the one, two, and four compartment cases. Also, it is desirable to direct inflows through the EAASR before sending them to STA 3/4. Thus, the SC STA scenario (Figure 4-4) will be used to estimate the annual variability in performance due to variability in inflow rates and operating depths.

The annual variability in the SC STA scenario for the EAASR and for STA 3/4 are reported in Table 5-13 and Table 5-14, respectively. On an annual basis, the reservoir varies over a large range of flows and depths. The annual average inflows varied from 695 to 5,662 acre feet/day. The mean annual depths ranged from 0.7 to 11.9 feet. The resulting calculated HRTs are between 23 and 113 days. The inflow concentration to the EAASR was relatively stable and varied from 0.084 to 0.135 mg/L. The calculated outflow concentrations reflected the HRT and C_{in} characterizations and varied from 0.042 to 0.092 mg/L. The associated percent removals varied from as low as 24% to a high of 69%.

On an annual basis, STA 3/4 received inflows ranging from 253 to 5,540 acre feet per day. Average depths ranged from 1.6 to 3.1 feet. The resulting calculated HRTs were between 10 and 116 days. The inflow concentration varied widely from 0.042 to 0.092 mg/L. The calculated outflow concentrations ranged from 0.019 to 0.029 mg/L.

Table 5-13. Annual EAASR Variability for the Single Compartment STA Scenario

Year	EAASR Qin (ac-ft/d)	EAASR HRT (days)	EAASR Depth (ft)	EAASR C_{in} (mg/L)	EAASR C_{out} (mg/L)	Percent Removal (%)
1965	2,104	56	3.83	0.113	0.061	46%
1966	3,898	73	9.32	0.097	0.048	51%
1967	1,641	70	3.74	0.118	0.056	53%
1968	3,471	62	6.97	0.104	0.055	47%
1969	4,236	70	9.64	0.096	0.049	50%
1970	4,942	70	11.18	0.088	0.046	48%
1971	1,616	91	4.79	0.126	0.049	61%
1972	1,294	118	4.96	0.134	0.042	69%
1973	1,074	97	3.41	0.127	0.047	63%
1974	1,789	50	2.92	0.117	0.066	43%
1975	1,755	73	4.15	0.124	0.056	55%
1976	1,220	105	4.17	0.126	0.044	65%
1977	1,564	112	5.69	0.128	0.043	67%
1978	2,608	92	7.80	0.107	0.044	59%
1979	5,111	41	6.85	0.089	0.058	34%
1980	1,749	67	3.81	0.108	0.054	50%
1981	992	46	1.50	0.135	0.077	43%
1982	3,354	63	6.93	0.107	0.055	49%
1983	5,290	57	9.75	0.088	0.051	42%
1984	3,643	62	7.39	0.088	0.048	45%
1985	1,505	62	3.04	0.122	0.061	50%
1986	1,701	113	6.27	0.124	0.041	66%
1987	1,671	66	3.57	0.114	0.056	51%
1988	1,757	44	2.53	0.099	0.061	38%
1989	937	23	0.69	0.122	0.092	24%
1990	695	54	1.22	0.135	0.072	47%
1991	3,670	53	6.35	0.095	0.055	42%
1992	3,420	59	6.60	0.097	0.053	45%
1993	3,548	68	7.87	0.093	0.048	48%
1994	3,618	63	7.45	0.105	0.054	48%
1995	3,914	93	11.91	0.090	0.040	56%
1996	4,118	75	10.09	0.086	0.044	49%
1997	2,556	78	6.45	0.100	0.047	53%
1998	5,662	38	7.09	0.084	0.057	32%
1999	3,214	66	6.95	0.093	0.049	48%
2000	2,057	84	5.60	0.101	0.045	55%
Average	2,705	67	5.90	0.101	0.051	49%
COV	0.51	0.33	0.47	0.16	0.21	NA

Table 5-14. Annual STA 3/4 Variability for the Single Compartment STA Scenario

Year	STA 3/4 Qin (ac-ft/d)	STA 3/4 HRT (days)	STA 3/4 Depth (ft)	STA 3/4 C_{in} (mg/L)	STA 3/4 C_{out} (mg/L)	Percent Removal (%)
1965	1,062	29	1.72	0.061	0.020	67%
1966	3,686	14	2.80	0.048	0.024	49%
1967	1,250	30	2.07	0.056	0.020	64%
1968	2,818	16	2.53	0.055	0.024	56%
1969	3,612	14	2.83	0.049	0.024	50%
1970	4,726	12	3.17	0.046	0.025	45%
1971	1,042	36	2.07	0.049	0.020	60%
1972	1,149	33	2.10	0.042	0.020	53%
1973	521	57	1.64	0.047	0.019	59%
1974	1,494	25	2.08	0.066	0.021	68%
1975	1,224	28	1.92	0.056	0.020	64%
1976	687	51	1.96	0.044	0.019	56%
1977	598	56	1.86	0.043	0.019	54%
1978	2,787	16	2.53	0.044	0.023	49%
1979	4,293	12	2.84	0.058	0.028	52%
1980	1,673	24	2.27	0.054	0.021	61%
1981	441	64	1.57	0.077	0.019	75%
1982	2,224	19	2.34	0.055	0.023	59%
1983	5,161	11	3.14	0.051	0.027	46%
1984	3,054	15	2.60	0.048	0.024	51%
1985	896	40	2.01	0.061	0.020	68%
1986	1,182	31	2.02	0.041	0.020	52%
1987	1,031	35	2.04	0.056	0.020	65%
1988	1,487	25	2.11	0.061	0.021	66%
1989	532	61	1.82	0.092	0.019	79%
1990	253	116	1.63	0.072	0.019	73%
1991	3,149	15	2.57	0.055	0.025	55%
1992	2,584	17	2.49	0.053	0.023	56%
1993	3,111	16	2.78	0.048	0.023	52%
1994	2,585	19	2.67	0.054	0.023	58%
1995	3,555	16	3.08	0.040	0.022	44%
1996	4,071	13	3.03	0.044	0.024	45%
1997	1,428	27	2.19	0.047	0.020	57%
1998	5,540	10	3.24	0.057	0.029	49%
1999	2,384	18	2.45	0.049	0.022	54%
2000	1,957	21	2.29	0.045	0.021	53%
Average	2,201	29	2.35	0.051	0.022	57%
COV	0.65	0.73	0.20	0.21	0.12	NA

Extensive operating information and guidelines have been developed for STAs in South Florida. For example, the draft operations plan for STA-1E indicates an operating depth range between 0.5 and 4.5 feet (Goforth 2006). Annual depth results (Table 5-14) indicate that the STA is operated in this range.

The annual summaries of the operation of the EAASR and STA 3/4 over the 36 year period are summarized in cumulative density functions (CDFs) (Figure 5-1) that indicate the % <= indicated value as a function of variables of interest. As shown in Figure 5-1, the mean annual inflows of the EAASR and STA 3/4 follow a similar pattern, which was expected as all STA inflows are first routed through the EAASR.

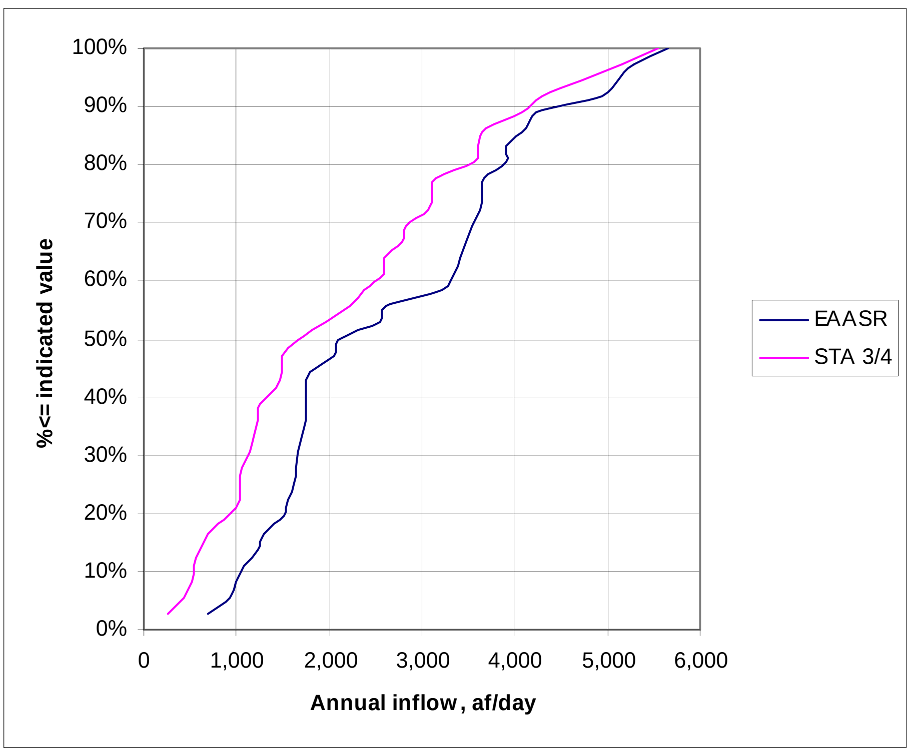

Figure 5-1. Mean Annual Inflows from SC STA Scenario

A clear difference in operating depths is shown in the CDF's for EAASR and STA 3/4 (Figure 5-2). The depth profile of the EAASR is nearly linear 2:1 slope throughout the entire range of the design depth. The STA operates over a relatively narrow range from 1.5 to 3.5 feet, as stated previously.

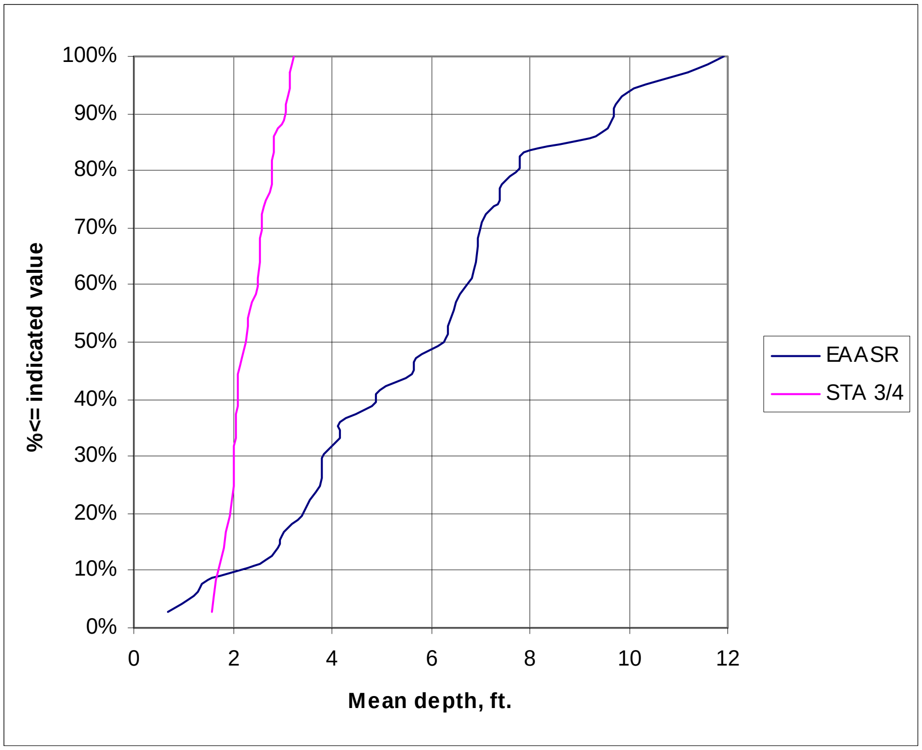

Figure 5-2. Mean Annual Depths from SC STA Scenario

The HRT profile reflects the difference in depth profiles (Figure 5-3). The EAASR operates under a large range of HRT's. The HRT distribution shows STA 3/4 operating in the within the normal range of STAs, 14 to 21 days, for approximately 19% of the years for <= 14 days and 50% of the years for <= 21 days. The remaining 50 percent of HRT are above this range, again indicating the STA may be able to receive more hydraulic loading.

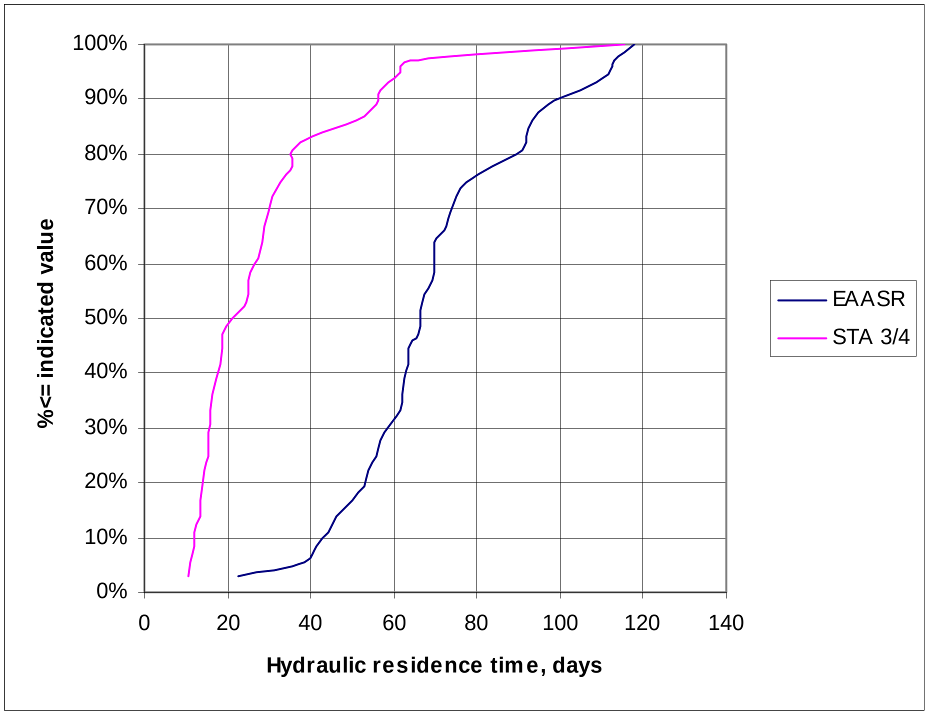

Figure 5-3. Mean Annual HRT from SC STA Scenario

The reductions of TP concentrations through the EAASR/STA 3/4 system were observed (Figure 5-4). Median (50%) inflow TP concentration to the EAASR is about 0.110 mg/L. This TP concentration is reduced to a median of about 0.050 mg/L as it leaves the EAASR and enters STA 3/4. It exits STA 3/4 at a TP concentration of about 0.020 mg/L. As the treatment progresses through the EAASR and STA, the variability in concentration decreases as shown by the increasingly vertical CDF curves. This is an indication of a functioning storage/treatment system.

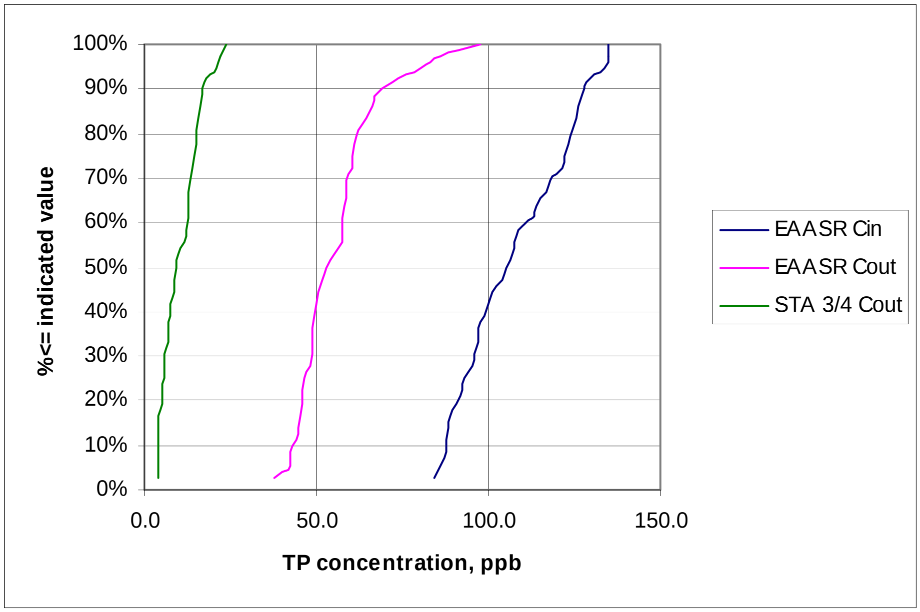

Figure 5-4. Mean Annual Inflow and Outflow Concentrations from SC STA Scenario

Summary and Conclusions

The overall results for the three configurations are shown in Table 5-15. The input TP concentrations vary from 0.067 to 0.133 mg/L depending on the number of compartments. Similarly, the output concentrations from the EAASR indicate a significant treatment effect with the concentrations reduced to 0.028 to 0.063 mg/L depending on the configuration. However, the variability in performance is greatly dampened in the STA 3/4 outflow with the outflow concentrations all very similar in the 0.020-0.021 mg/L range. The EAASR has a significant water quality impact because its hydraulic residence times exceed two months. The residence times in STA 3/4 are also high for an STA with a calculated mean of about 29 days. Thus, the combined system has ample time to store and treat the water. The EAASR can also provide a significant ability to manage the inflows to STA 3/4 in order to optimize its performance. From an operational point of view, it is desirable to maximize the amount of inflow that can be passed through the EAASR before entering STA 3/4.

Table 5-15. Summary Results for the One, Two, and Four Compartment Scenarios

Compartments	EAASR Cin (mg/L)	EAASR Cout (mg/L)	STA Cout (mg/L)
1	0.101-0.105	0.028-0.051	0.020-0.21
2	0.078-0.112	0.045-0.058	0.020
4	0.067-0.133	0.046-0.063	0.020-0.021

The analysis of annual variability of the SC STA scenario found a similar inflow pattern for the EAASR and STA 3/4. The depth profiles were clearly different, with the EAASR fluctuating through out the entire range of design depths and STA 3/4 remaining relatively constant. The variation in concentration decreased as the water was treated by the EAASR/STA 3/4 system. This indicated a functioning storage/treatment system. The multiple scenarios were compared and the following conclusions were drawn. The compartmentalization of the reservoir can provide additional operational flexibility to manage the mixing of influents and treatment times to achieve additional water quality improvements. An additional outflow structure from Compartment 2 to STA 3/4 can increase the operational flexibility of the EAASR and may increase water quality improvements. Operating the EAASR at greater depths may further increase the water quality treatment. The EAASR does not significantly improve the outflow water quality from STA 3/4 as compared to using STA 3/4 only because of the relatively long residence times in STA 3/4. This suggests that the current inflows to STA 3/4 could be increased to improve water quality even more in the EAASR/STA 3/4 storage/treatment train.

The actual performance of the EAASR/STA system could vary widely from the predictions presented in this thesis for several reasons including:

- Inflow quantities and water quality can be expected to vary over the next 50 years

- The SFWMM estimates of inflows and operations are not based on any kind of optimization for the EAASR/STA system but represent an estimate of their role in a regional water management scenario.

- The behavior and performance of the EAASR/STA can be expected to vary depending on how it is operated for flood control and water supply purposes as well as water quality enhancement.

CHAPTER 6
SUMMARY AND CONCLUSIONS

This effort aimed to create and use a model to estimate water quality in the EAASR and Stormwater Treatment Area (STA) 3/4. The model was designed to function in the dynamic and challenging EAASR design process. Key insights on the most current EAASR and STA 3/4 configurations were found.

Chapter 2 presented the background and previous work on CERP, the EAASR, systems engineering, and reservoir modeling. CERP is an ambitious project to "get the water right" in the South Florida Ecosystem and restore the Everglades. The project goal will be accomplished by all 63 projects operating together. The Acceler8 project streamlines the CERP planning, design, and construction process to provide benefits to the system more quickly and cost-efficiently. The EAASR, a CERP and Acceler8 project, will provide storage for water supply, flood control, and flow equalization for water quality treatment areas. Water supply and flood control design approaches are well developed, while water quality approaches are less developed. The streamlining of the planning and design of the EAASR has posed several challenges resulting in an iterative design process with multiple conceptual design alternative formulations and analyses. Due to differences in the simulation, uncertainty exists when these multiple formulations and analyses are compared.

The systems engineering approach to design provides a proven approach that can meet the challenges of the EAASR planning and design process. The approach incorporates disciplinary models that may produce a more optimal design than traditional approaches. A model in the water quality discipline was therefore sought to assess which of several alternatives are better. Simple empirical and mass balance models were found that can be used for the EAASR. Comparable lake and reservoir systems were found to provide parameter estimates for EAASR. Due to the wide range of possible operational conditions and planning and design challenges, a water quality model developed specifically for the EAASR was be necessary. The water quality model must therefore incorporate measures to meet the planning and design challenges of the EAASR project.

Chapter 3 presents several iterations of EAASR configurations that have been developed throughout the project. Early configurations used a combination of Components A, B, and C of Figure 2-2. Configurations were then formulated using only Component A. The sizing of the reservoir was evaluated first. Three configurations were developed to evaluate the volume of the reservoir. Four additional alternatives were developed to evaluate the depth of the reservoir. A 12 foot deep, 360,000 acre-foot reservoir was subsequently decided upon. Three configurations were then developed to assess the compartmentalization of the reservoir. The configurations were developed for a single compartment, two compartments, and four compartments. The location of the compartments affected the source of water received for both the EAASR and STA 3/4. Unlike early configurations, internal transfers between the compartments occurred from multiple compartments.

The review of the EAASR configurations was performed to provide the context in which the water quality model is developed. To use these configurations, a water quality model should include depth, area, and compartmentalization with varying area. Due to the inter-reservoir transfers, the model must be able to simulate reservoirs in series, with feedback loops. Additionally, the ability to include multiple inflows and outflows would be useful.

Chapter 4 details the water quality model, the UF WQDT, and water quantity and quality inputs. The UF WQDT is a steady-state mass balance model utilizing the KC* kinetic model and was developed to simulate the TP water quality of the EAASR and STA 3/4. The model uses a single aggregate inflow and concentration, depth, background concentration, and a volumetric reaction rate to simulate TP. The model calculates the HRT and HLR of each reactor, as well as the outflow concentration and percent removal. Long-term average simulations were determined to be the most appropriate level of sophistication needed in order to provide key insights for the dynamic EAASR design.

Water quantity and quality inputs to the model were calculated for the base and STA scenarios for each configuration. The HRT of the EAASR ranged from 39 to 107.5 days. The EAASR was not used for flow equalization. The HRT of STA 3/4 was calculated to be 29 days for all scenarios. Mean inflow concentrations of 17 parameters of interest for the four external inflow sources to the reservoir and STA 3/4 were reported. Parameter estimations were performed using closely comparable system with high quality data. Lake Istokpoga was found to be the best comparable for the general single compartment scenario of the EAASR. Data from 16 STAs were used as comparables to STA 3/4. The following water quality parameters estimates for the EAASR and STA 3/4 were selected:

- $C^* = 0.0254$ mg/L for the reservoir and 0.0194 mg/L for the STA
- $k = 0.016$ day^{-1} for the reservoir and 0.127 day^{-1} for the STA

A sensitivity analysis of the EAASR reaction rate and background concentration was performed for the SC STA scenario. The calibration of each parameter was found to significantly affect results of the analysis. Particularly reaction rates less than 0.05 $days^{-1}$ for a background concentration of 0.025 mg/L. To reproduce TP removal estimates provided in the BODR an reaction rate of 0.0033 $days^{-1}$ for a C* of 0.025 is needed. Due to the differences in configuration and reaction rate the modeling efforts are not directly comparable.

An analysis of the predicted performance of the EAASR and STA 3/4 systems was performed. STAs were found to provide significantly greater water quality treatment than reservoirs. The STA systems will approach the background concentration asymptotically for retention times greater than 25 days. However, since the STA is operated at much lower depths than the reservoir, they will have much lower HRT for a given area and inflow. The initial concentration can affect the outcome of the EAASR or STA 3/4, especially if measured by the percent removal of TP.

Chapter 5 presented the results and conclusions of the UF WQDT analysis of the scenarios described in Chapter 4. The overall results for the three configurations are shown in Table 5-15. The input TP concentrations vary from 0.067 to 0.133 mg/L depending on the number of compartments. Similarly, the output concentrations from the EAASR indicate a significant treatment effect with the concentrations reduced to 0.028 to 0.063 mg/L depending on the configuration. However, the variability in performance is greatly dampened in the STA 3/4 outflow with the outflow concentrations all very similar in the 0.020-0.021 mg/L range. The EAASR has a significant water quality impact because its hydraulic residence times exceed two months. The residence times in STA

3/4 are also high for an STA with a calculated mean of about 29 days. Thus, the combined system has ample time to store and treat the water. The EAASR can also provide a significant ability to manage the inflows to STA 3/4 in order to optimize its performance. From an operational point of view, it is desirable to maximize the amount of inflow that can be passed through the EAASR before entering STA 3/4.

The analysis of annual variability of the SC STA scenario found a similar inflow pattern for the EAASR and STA 3/4. The depth profiles were clearly different, with the EAASR fluctuating through out the entire range of design depths and STA 3/4 remaining relatively constant. The EAASR and STA 3/4 remove roughly equal portions of the median concentrations. The variation in concentration decreased as the water was treated by the EAASR/STA 3/4 system. This indicated a functioning storage/treatment system. The multiple scenarios were compared and the following conclusions were drawn. The compartmentalization of the reservoir can provide additional operational flexibility to manage the mixing of influents and treatment times to achieve additional water quality improvements. An additional outflow structure from Compartment 2 to STA 3/4 can increase the operational flexibility of the EAASR and may increase water quality improvements. Operating the EAASR at greater depths may further increase the water quality treatment. The EAASR does not significantly improve the outflow water quality from STA 3/4 as compared to using STA 3/4 only because of the relatively long residence times in STA 3/4. This suggests that the current inflows to STA 3/4 could be increased to improve water quality even more in the EAASR/STA 3/4 storage/treatment train.

The actual performance of the EAASR/STA system could vary widely from the predictions presented in this thesis for several reasons including:

- Inflow quantities and water quality can be expected to vary over the next 50 years
- The SFWMM estimates of inflows and operations are not based on any kind of optimization for the EAASR/STA system but represent an estimate of their role in a regional water management scenario.
- The behavior and performance of the EAASR/STA can be expected to vary depending on how it is operated for flood control and water supply purposes as well as water quality enhancement.

Steady state modeling of long-term average outflow concentrations was performed to provide key insights on the compartmentalization and general operations of the EAASR and STA 3/4. Further work is needed to assess the operations EAASR and STA 3/4 in more detail. The results of this study should be calibrated against daily time step simulations of the operation of the system. The daily simulation should be guided by an optimizer that directs the simulator towards optimal operating policies. This simulation/optimization strategy needs to incorporate a life cycle analysis and the existing as well as proposed constraints on multi-purpose operation that are embedded in the SFWMM. The life cycle evaluations of the performance of the EAASR/STA system should include explicit consideration of the need for periodic maintenance and removal of settled materials.

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BIOGRAPHICAL SKETCH

On January 23, 1982, I was born and named Daniel L. Reisinger in Southern Florida. I attended public schools throughout my childhood and graduated from Cooper City High School in the year 2000. I attended the University of Florida and was awarded a Bachelor in Science degree from the College of Engineering, Environmental Engineering and Sciences department. After obtaining my undergraduate degree, I remained at the University of Florida to obtain a Master of Engineering degree from the College of Engineering, Environmental Engineering and Sciences department.