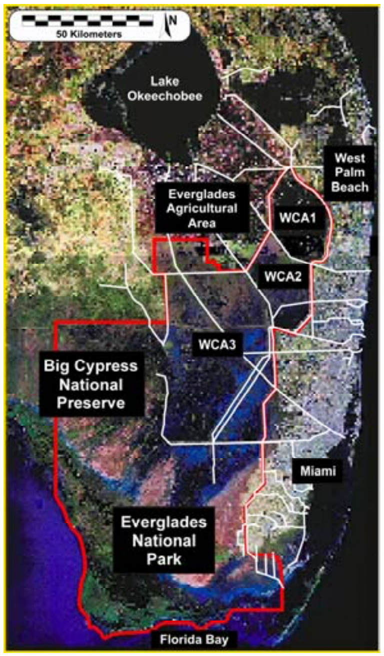
Documentation of the Everglades Landscape Model: ELM v2.5



http://my.sfwmd.gov/elm

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July 10, 2006

Table of Contents

Preface

Documentation purpose

This documentation report provides the information necessary to fully understand the *goals & objectives, supporting data, algorithms, performance, and uncertainties* of the Everglades Landscape Model (ELM). This document, the model source code & data, and further supporting information are maintained on the ELM web site:

http://my.sfwmd.gov/elm

Depending on the depth to which one probes, the documentation audience ranges from the lay public to expert scientists:

- The *lay-person* who is curious about the Everglades and modeling should be able to glean interesting “big picture” insights by reading the Executive Summary, Chapters 1 – 3, and the Overview sections of the remaining Chapters.
- The *resource manager* who desires a definitive overview of what the ELM can and cannot do will benefit most from the above summaries, along with reviewing sections of Chapters 6 – 8.
- The primary purpose of this documentation, however, is to provide *scientists and engineers* with hierarchical documentation that a) starts with general overviews which are b) linked to increasing levels of scientific and mathematical detail.

Document organization

Each Chapter of this document has its own Table of Contents.

- Chapter 1: ***Introduction*** to the Everglades and the model ***Goals & Objectives***.
- Chapter 2: General overview of ***Wetland Ecological Models***.
- Chapter 3: Graphical and verbal descriptions of the South Florida and General Ecosystem ***Conceptual Models*** on which the ELM is based.
- Chapter 4: Graphical, verbal, and statistical-summary descriptions all of the ***Data*** that are used in the model.
- Chapter 5: Graphical, verbal, and mathematical descriptions of the ***Model Structure*** and algorithms (including links to source code).
- Chapter 6: Analysis of ***Model Performance*** relative to the historical period of record (1981 - 2000).
- Chapter 7: Aspects of ***Uncertainty*** in the model and associated data, including sensitivity analysis, appropriate model expectations, and model complexity.
- Chapter 8: Descriptions of potential ***Model Applications*** for research and management.
- Chapter 9: Descriptions of past and planned ***Model Refinements***, including an overview of its current limitations.
- Chapter 10: A ***User’s Guide*** that provides the simple steps to installing and running this Open Source model.

Acknowledgments

The ELM is the result of long-term collaborative efforts by a diverse group of scientists that extend beyond the current developers. The work was initiated in the early 1990's by faculty (Robert Costanza, Principal Investigator) at the University of Maryland's Maryland Institute for Ecological Economics, under a contract initiated by Dewey Worth and Tom Fontaine of the South Florida Water Management District (SFWMD). Bob Costanza was the "driver" of the process of understanding the modeling need and how to best meet that need.

The model uses the excellent Spatial Modeling Environment (SME) software developed by the University of Maryland faculty, primarily Tom Maxwell. The University of Maryland's Alexey Voinov was instrumental in developing numerous vital components of the modeling project, from conceptual models to algorithms and code. Tim Waring and Charles Cornwell made significant contributions while employed at the SFWMD, as did Naiming Wang and Jason Godin. Ken Rutchey aided model development through contributions of vegetation maps and supervision of the ELM team. Also at the SFWMD, Fred Sklar was alternately a Project Manager and a Supervisor during different time periods, and served as a crucial expert in guiding this landscape modeling project.

Beyond anonymous comments received during the publication process of peer reviewed manuscripts, numerous scientists and engineers in south Florida have provided helpful comments on the model and its documentation. Most recently, those reviewers at the SFWMD included Tim Bechtel, Lisa Cannon, Eric Flaig, Tom James, Zaki Moustafa, Garth Redfield, Fred Sklar, Todd Tisdale, Paul Trimble, Dewey Worth, and Joyce Zhang. Comments received during a 2002 Interagency Review of the ELM were likewise useful in improving the model.

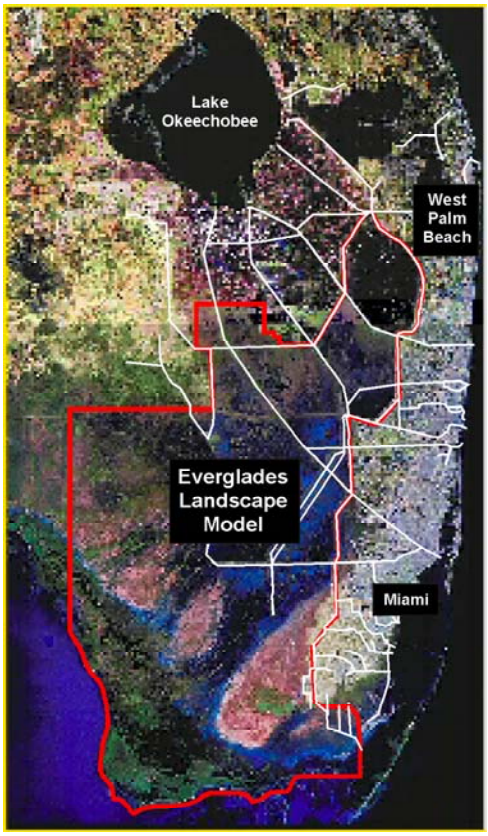
Tom Fontaine, Bill Nuttle, Dean Powell, and Patricia Strayer were the senior managers in the SFWMD who supported the ELM project during its primary development phases within the Everglades Systems Research Division. Jayantha Obeysekera, Ken Tarboton, Luis Cadavid, and Ken Konyha managed the project during the recent enhancements to its documentation, leading to the (2006) independent, external peer review of the model and its application.

Primary funding for this modeling project came from the state of Florida through the SFWMD. Funding for the (2006) external peer review of the model came from State and Federal contributions to the Comprehensive Everglades Restoration Plan, and Florida's Long Term Plan for Achieving Everglades Water Quality Goals.

Executive Summary

Today's Everglades are significantly different from the landscape that existed a century ago. Humans compartmentalized a once-continuous watershed, altering the distribution and timing of water flows, and increasing the quantity of nutrients that move into the Everglades. The result is a degraded mosaic of ecosystems in a region that is highly controlled by water management infrastructure. However, plans are being developed and implemented to restore parts of this system towards their earlier state.

In planning for this project, computer simulation models are being used to predict the relative benefits of one alternative plan over another. One such tool under consideration is the Everglades Landscape Model (ELM). The ELM is a regional scale simulation model designed to improve understanding of the ecology of the greater Everglades landscape. This model integrates, or dynamically combines, the hydrology, water quality, and biology of the mosaic of habitats in the Everglades landscape. It is a state-of-the-art *model that is capable of evaluating long-term, regional benefits of alternative project plans with respect to water quality* and other ecological Performance Measures.



Prior to using the results of the ELM in such applications, planners for the Comprehensive Everglades Restoration Plan (CERP) have requested that the model be thoroughly reviewed by an independent panel of experts. In order to facilitate this peer review, we refined aspects of the model and its documentation, resulting in this documentation report. This comprehensive report includes the information necessary for scientists and planners to understand *a) the ELM objectives, b) how it works, c) how well it works, and d) how to interpret its results*.

Goals

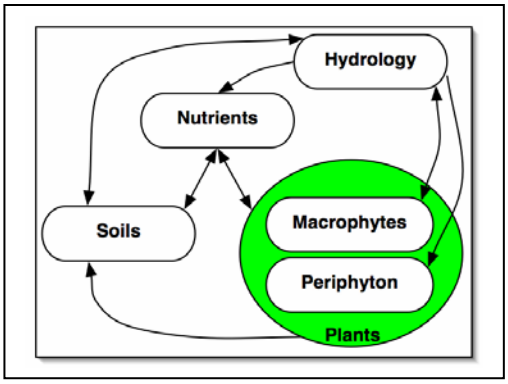
- Develop a simulation modeling tool for integrated ecological assessment of water management scenarios for Everglades restoration
  - Integrate hydrology, biology, and nutrient cycling in spatially explicit, dynamic simulations
  - Synthesize these interacting hydro-ecological processes at scales appropriate for regional assessments,
  - **Understand and predict the relative responses of the landscape to different water and nutrient management scenarios**
  - Provide a conceptual and quantitative framework for collaborative field research and other modeling efforts

Application

- Specific **model objectives** (Performance Measures)
  - ELM v2.5: Relative predictions of phosphorus 1) concentrations and 2) net load along spatial gradients in the greater Everglades, over decadal time scales
  - Other ecological Performance Measures proposed, pending model/data updates
- Appropriate applications
  - Relative comparisons of the above Performance Measures under scenarios of alternative water management plans
- Project requests for ELM application
  - CERP: Initial CERP Update, Decompartmentalization of Water Conservation Area-3, C-111 Spreader Canal, Florida Bay Feasibility Study
  - Modified Water Deliveries to Everglades National Park (now “CSOP”)
  - Long Term Plan for Achieving Water Quality Goals: Recovery of Impacted Areas

Design

- Encompass the greater Everglades region at fine resolution (10x finer than South Florida Water Management Model, or SFWMM)
- Multi-decadal simulation period
- Combine physics, chemistry, biology – *interactions*
  - *Hydrology*: overland, groundwater, canal flows
  - *Nutrients*: phosphorus cycling and transport
  - *Periphyton*: response to nutrients and water
  - *Macrophytes*: response to nutrients and water
  - *Soils*: response to nutrients and water
- Combine ecological research with modeling
  - research advances led to model refinements
  - model output aided research designs



Reliability

- Excellent performance (1981 – 2000 history-matching)
  - *Regional water quality*: the offset (median bias) of predicted and observed values of phosphorus in the marsh and canals is 2 ppb (parts per billion), and the phosphorus accumulation rate (net load) matches observed gradient patterns.

  - *Regional hydro-ecology*: the ELM hydrologic output is comparable to the SFWMM, and ecological variables such as peat accretion are consistent with available information

- Tested computer code
  - evaluated model response to wide range of conditions (sensitivity analyses)
  - years of experience in testing and refining code
  - applied at different scales for regional and sub-regional evaluations

- Uses best available data
  - comprehensive, unique summary of Everglades ecology
  - thorough QA/QC of input data
  - continuous interactions with other Everglades scientists and engineers

Review

- Open Source
  - All ELM data and computer source code freely available on web site
  - Requires only Open Source (free) supporting software

- Publications
  - 1996-2006: Peer-reviewed scientific journals and book chapters
  - 1993-2006: Technical reports published by South FL Water Management District

- CERP Model Refinement Team
  - 2002: Inter-agency review of ELM
  - 2002: Comments ranged from highly positive to highly negative
  - 2003: Recommended independent peer review

- Independent Panel of Experts
  - 2006: July 10, 2006 - Initiated independent peer review of ELM

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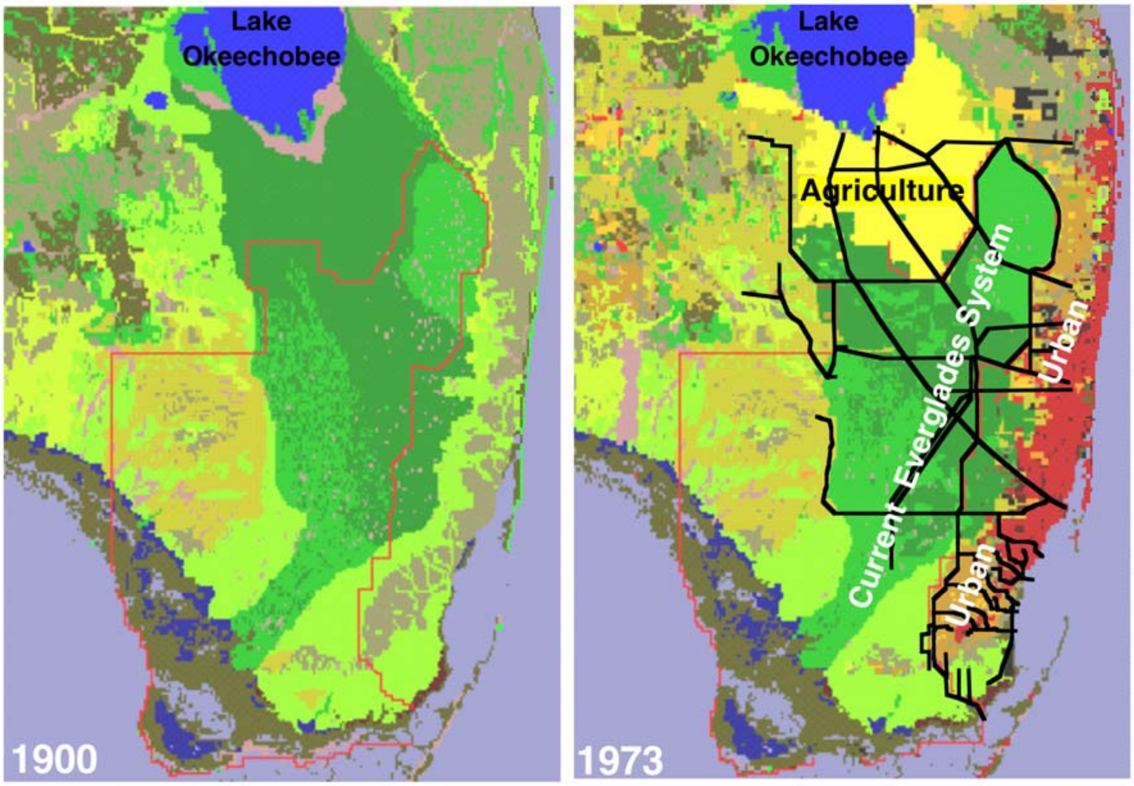
Chapter 1: Introduction, Goals & Objectives



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Chapter 1: Introduction, Goals & Objectives

1.1 Overview

This Chapter provides the background for the Everglades Landscape Model (ELM) documentation, We review how and why the Everglades region has changed, and how the ELM is intended to be applied towards understanding and better managing the system. The Everglades landscape is “inside” a highly engineered system of inter-connected water basins, with altered water flows and nutrient additions that have caused ecological impacts during multiple decades of management. A variety of projects are underway that will attempt to restore as much of the existing Everglades as possible. While field observations and expert judgments are integral to this goal, computer modeling tools such as the ELM are part of the process of better understanding the landscape, and refining plans for its restoration. This Chapter introduces the ELM as a model that is designed to evaluate the long-term, regional benefits of alternative project plans with respect to water quality and other ecological Performance Measures.

1.2 Introduction

The Everglades region of south Florida, USA, is currently a vast system of neo-tropical estuaries, wetlands, and uplands interspersed among agricultural and urban land uses. Starting in the early part of the 20'th century, long stretches of canals were dug in attempts to drain the relatively pristine Everglades for agriculture. However, after severe flooding in 1947, the Central and South Florida (C&SF) Project was initiated. In this massive engineering feat, the U.S. Army Corps of Engineers developed an elaborate network of canals, levees, and water control structures to improve regional flood control and water supply (Light and Dineen 1994). It was ultimately very effective in managing water for those purposes, enhancing the development of urban and agricultural sectors of the region. As shown in Figure 1.1 below, dramatic increases in such land uses occurred during the 20'th century, significantly reducing the spatial extent of the "natural" Everglades system by the mid 1970's. Agricultural and urban development has generally continued through the present day, particularly along the corridors east and north of the Everglades. While the C&SF Project led to a reduction in spatial extent of the Everglades, it also fragmented the once-continuous Everglades wetlands into a series of large impoundments.

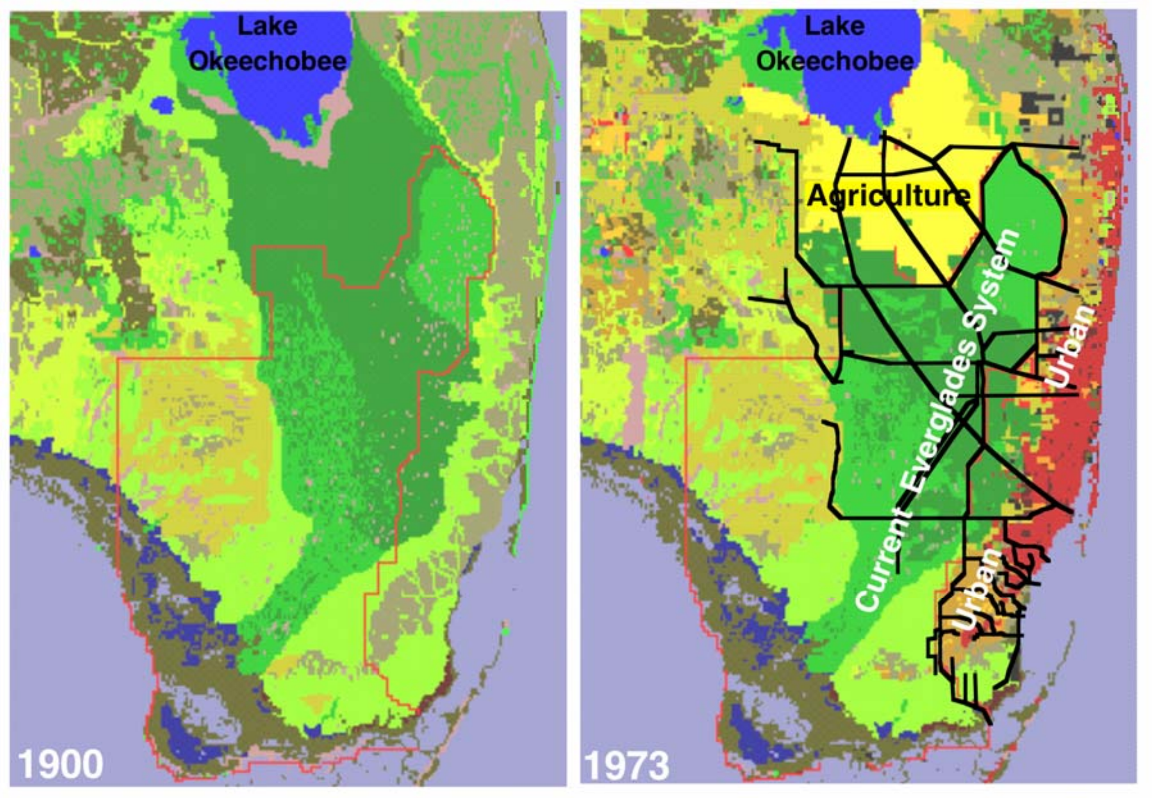

Figure 1.1. Agricultural (yellow) and urban (orange/red) land use expanded dramatically in south Florida during the 20'th century. Black lines denote some of the major canals & levees that were constructed as part of the C&SF Project. The red polygon is the domain of the Everglades Landscape Model. Land use data from Costanza (1975).

Water historically flowed from the northern parts of the region into and through the Everglades largely as overland sheet flow. This flow regime changed to point releases at the pumps and weirs of water control structures. Operational criteria for these managed flows dictated the timing and magnitude of water distribution into and within the Everglades, further modifying its hydrology. Many of these inflows also carried higher loads of nutrients into the historically oligotrophic Everglades, as a result of agricultural and urban development. The altered distribution and timing of flows in a fragmented watershed, combined with increased nutrient loads into the Everglades, changed this mosaic of habitats. Increasingly, the public and scientific communities were concerned that ecological structure and function would continue to decline within this nationally and internationally protected landscape. In the late 20th century, it became apparent that revisions in the infrastructure and operations of the C&SF Project were necessary in order to halt further ecological degradation, and a plan to restore the Everglades was developed by federal and state agencies (USACE and SFWMD 1999). After years of effort, the Comprehensive Everglades Restoration Plan (CERP) was developed, and has been implemented as a thirty year project to address the future of south Florida’s ecology – while also enhancing urban and agricultural water supply for what is anticipated to be a doubling of the regional population by 2050.

In the Everglades, the existing management infrastructure bisects the area into a series of impoundments, or Water Conservation Areas (WCAs). Everglades National Park is south of these WCAs, while Big Cypress National Preserve is to the west (Figure 1.2). Agricultural land uses dominate the area just north of the Everglades, while extensive urban land uses predominate along the eastern boundary of the Everglades. Lake Okeechobee, historically bounding the northern Everglades marshes, is now connected to those marshes via canal routing.

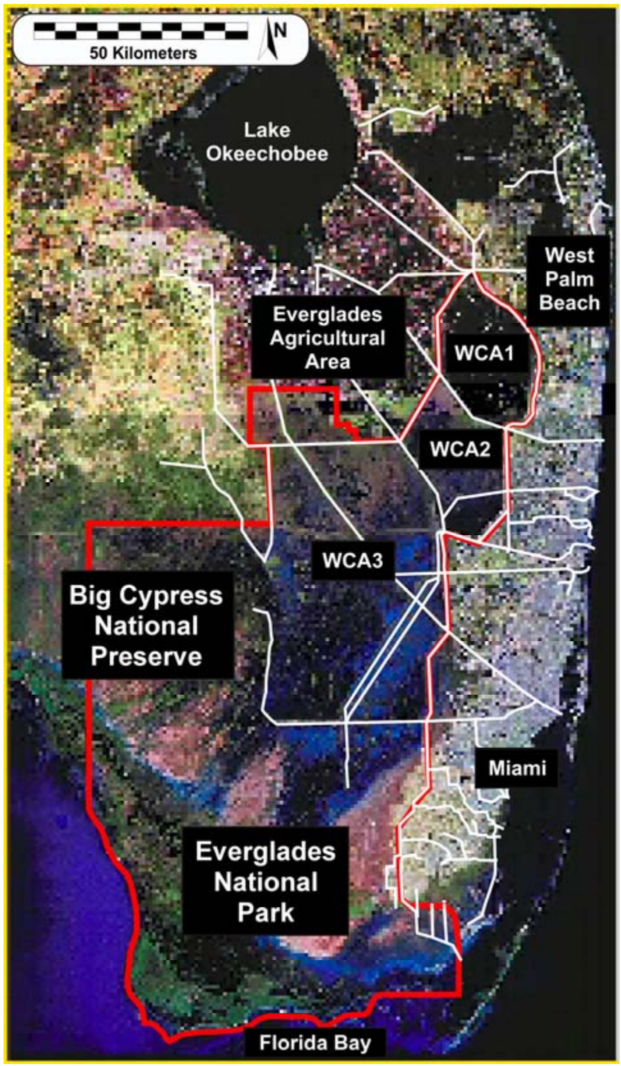

Figure 1.2. A mid-1990's satellite image of south Florida, showing the locations of major subregions in and around the greater Everglades. The red polygon is the domain of the Everglades Landscape Model.

Anthropogenic nutrient enrichment was introduced into the Everglades from management of agricultural, and to a lesser extent, urban runoff. Because of the significant, negative, impacts of this nutrient loading on the naturally oligotrophic system, a series of wetlands is being created along the northern periphery of the Everglades. These Stormwater Treatment Areas (STAs) are intended to serve as natural nutrient filters to remove nutrients (primarily phosphorus) from waters flowing into the Everglades. The first constructed wetlands to be in operation were effective in reducing phosphorus concentrations well below the interim target of 50 $ug{\cdot}L^{-1}$ (Chimney et al. 2000, Nungesser et al. 2001), and will be supplemented with other phosphorus removal mechanisms and on-farm best management practices to reduce Everglades inflow concentrations to the threshold target of 10 $ug{\cdot}L^{-1}$ (FDEP 2000).

The managed system enables a variety of flow distributions. Operation of the entire system for flood control, water supply, and the environment is governed by a complex set of rules adopted and modified over time by the South Florida Water Management District and the U.S. Army Corps of Engineers. Control over this system is managed by operating a large number of pumps, weirs, and culverts to pass water into the canals and wetlands, distributing it as needed in various parts of the regional system. Thus, different regions of the Everglades experienced different hydrologic regimes, often to the detriment of the wetland ecosystems. Under the CERP, there will be significant decompartmentalization of the levees impounding parts of the Everglades, increased storage above and below ground, and modified flows throughout the south Florida landscape (USACE and SFWMD 1999).

Changes to the hydrologic and nutrient management under the CERP is anticipated to provide some level of restoration of the Everglades system. However, there is significant uncertainty in the potential ecological response. In order to better understand and plan the restoration process, 1) predictive simulation models are being used to refine the plan, and 2) an extensive monitoring and adaptive assessment procedure (CERP_Team 2001b) is being implemented. The primary simulation tool used to date is the South Florida Water Management Model (SFWMM), a model with rule-based management of water flows and resultant water levels in the entire south Florida region, from Lake Okeechobee to the southern Everglades (HSM 1999). Most of the Everglades restoration targets were derived from the Natural System Model. This hydrologic companion to the SFWMM is basically the SFWMM with the water management infrastructure removed, adjusting various data to attempt to simulate the regional hydrology prior to any drainage efforts (SFWMD 1998). The Everglades Landscape Model (ELM) is a regional scale, process-oriented simulation tool designed to develop an understanding of the ecological interactions in the greater Everglades landscape. The ELM integrates modules describing the hydrology, biogeochemistry, and biology of ecosystems in a heterogeneous mosaic of habitats that comprise the Everglades.

1.3 Purpose of models

Simulation models are explicit abstractions of reality, and at best are tools that should provide insights into a better understanding of a problem. The Everglades hydrologic simulation models referenced above have provided very useful insight. However, they do not, and were not intended to, provide by themselves a full understanding of the long term ecosystem dynamics in the Everglades. “Restoring” the Everglades ecology involves “getting the water right” (CERP_Team 2001a). However, even if a “perfectly” accurate model of water depths and flows were available, there still would exist significant uncertainties in how much water is needed at which times, over what spatial and temporal scales. Importantly, the nutrients associated with that water are fundamental components of the ecosystem function in the landscape.

To better understand the long term ecological effects of changing hydrologic regimes, it is important to assess the *cumulative* influence of the magnitude and timing of the changes. Interacting with these hydrologic dynamics are the nutrient transformations and transport. As the physical and chemical dynamics interact with the biological communities, the system dynamics cumulatively define the transient ecosystem states under different conditions. While the basics are well-understood, and many of the details known, there remain uncertainties in predicting all potential changes in the Everglades.

We do, however, have a very good understanding of the interactions among general ecosystem processes, and of the nature of changes at the landscape scale.

Interactions are the essence of ecosystem science. Ecology has been classically defined as the interactions of organisms (including plants) and their environment (Odum 1971). For the Everglades region as an entity, a relatively simple model is desired that can capture the cumulative, interactive nature of the ecosystem dynamics, synthesizing the state of our understanding of the general ecosystem processes. The level (or scale) of computational complexity can be relatively coarse, which is dependent upon our current scientific knowledge-base. Fundamentally, there is a need for a model - or models - that can quantify the relative potential (or probability) of long-term cumulative ecosystem responses to altered hydrologic and nutrient inputs across the greater Everglades landscape. The challenge is to synthesize Everglades habitat change, with habitats being an integrated combination of hydrologic, water quality, soils, and periphyton/plant variables that are simulated with a reasonable degree of relative certainty. With such a model, the trends in relative habitat change could be evaluated under different scenarios of hydrologic/nutrient management.

1.4 ELM goals and objectives

The ELM is a regional-scale, integrated ecological assessment tool designed to understand and predict the relative response of the landscape to different water management scenarios in south Florida, USA. In simulating changes to habitat distributions, the ELM dynamically integrates hydrology, water quality, soils, periphyton, and vegetation in the Everglades region. The model has been used as a research tool to better understand the dynamics of the Everglades, enabling hypothesis formulation and testing. This is a critical, ongoing application of the model. However, one of the primary objectives of this simulation project is to evaluate the relative ecological performance of alternative management scenarios.

> ***Goals**: Develop a simulation modeling tool for integrated ecological assessment of water management scenarios for Everglades restoration*

- Integrate hydrology, biology, and nutrient cycling in spatially explicit, dynamic simulations
- Synthesize these interacting hydro-ecological processes at scales appropriate for regional assessments
- **Understand and predict the relative responses of the landscape to different water and nutrient management scenarios**
- Provide a conceptual and quantitative framework for collaborative field research and other modeling efforts

1.4.1 Objectives, current model version

The ELM simulates an integrated set of dynamic ecosystem interactions, but has initially focused on the “water quality” component of those dynamics for regional applications. The first regional application of ELM was released in the spring of 2000. That version (ELM v2.1) was intended to address several Performance Measures that relate to the water quality of the greater Everglades region. The current ELM v2.5 continues to focus on those water quality objectives, with enhancements to the model capabilities and documentation. The following are Performance Measures were initially approved by the CERP RECOVER (REstoration COordination and VERification) Water Quality Team and Regional Evaluation Team (RECOVER-RET 2004) for use in Everglades restoration planning. The Performance Measures are undergoing (June 2006) further review by other RECOVER teams. The ELM v2.5 is available to address the following Performance Measures:

> ***Specific objectives:*** *compare alternative management scenarios, predicting relative differences in ecological (water quality) variables from a long-term, regional perspective*

- Concentration of Total Phosphorus (TP) in surface water (GE-4[1])
- Net loading (accumulation) of TP in the ecosystem (GE-5)

These Performance Measures are specified in detail in the Model Application Chapter of this documentation. The spatial and temporal scales associated with these Performance Measures are relative to RECOVER's goal to understand and predict system response over long time scales across the regional system (>10,000 km^2). Although the spatio-temporal grain associated with these Performance Measures has not been explicitly defined by RECOVER for all Performance Measures, a seasonal to annual temporal grain, and gradients with a 1-km spatial grain, are consistent with our ability to discriminate ecologically significant spatial patterns and temporal trends across the greater Everglades.

1.4.2 Objectives, future model version

Consistent with its research goals, the ELM will continue to be a work in progress, in parallel with advances in research and knowledge of the Everglades system. We collaborate with researchers across a variety of disciplines, both within the South Florida Water Management District and from other agencies and academic institutions. As a result of this ongoing work, we anticipate that the next major update, to ELM v3.0, will provide a useful degree of confidence in applying the ELM to the following Performance Measures (as proposed to CERP RECOVER):

> ***Specific objectives****: (for future version), compare alternative management scenarios, predicting relative differences in ecological variables from a long-term, regional perspective*

- "Water quality" Performance Measures listed above
- Periphyton biomass & community type
- Macrophyte biomass & community type
- Soil accretion & soil phosphorus concentration

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[1] GE-4 and GE-5 are the current Performance Measure labels used by RECOVER. These Performance Measures are described in the Model Application Chapter of the ELM documentation; further background information and descriptions of other Performance Measures are provided in the Programs – RECOVER links at www.evergladesplan.org

In an early subregional application of ELM (version 1.0), sufficient data were available for us to demonstrate (Fitz and Sklar 1999) that the model could effectively match historical observations of surface and pore water phosphorus, soil accretion, macrophyte biomass, and sawgrass-cattail succession. As an example of the reliability of results in this landscape modeling project, Figure 1.3 shows the good matches between observed vs. simulated porewater nutrients and cattail succession (from a 17-year simulation). The Model Performance Chapter of this ELM v2.5 documentation summarizes other ecological performance characteristics of the updated model.

We anticipate that completion of upcoming ELM v3.0 data and model analyses will further demonstrate the model utility in evaluating changes to habitats associated with these integrated ecological variables across most of the greater Everglades region.

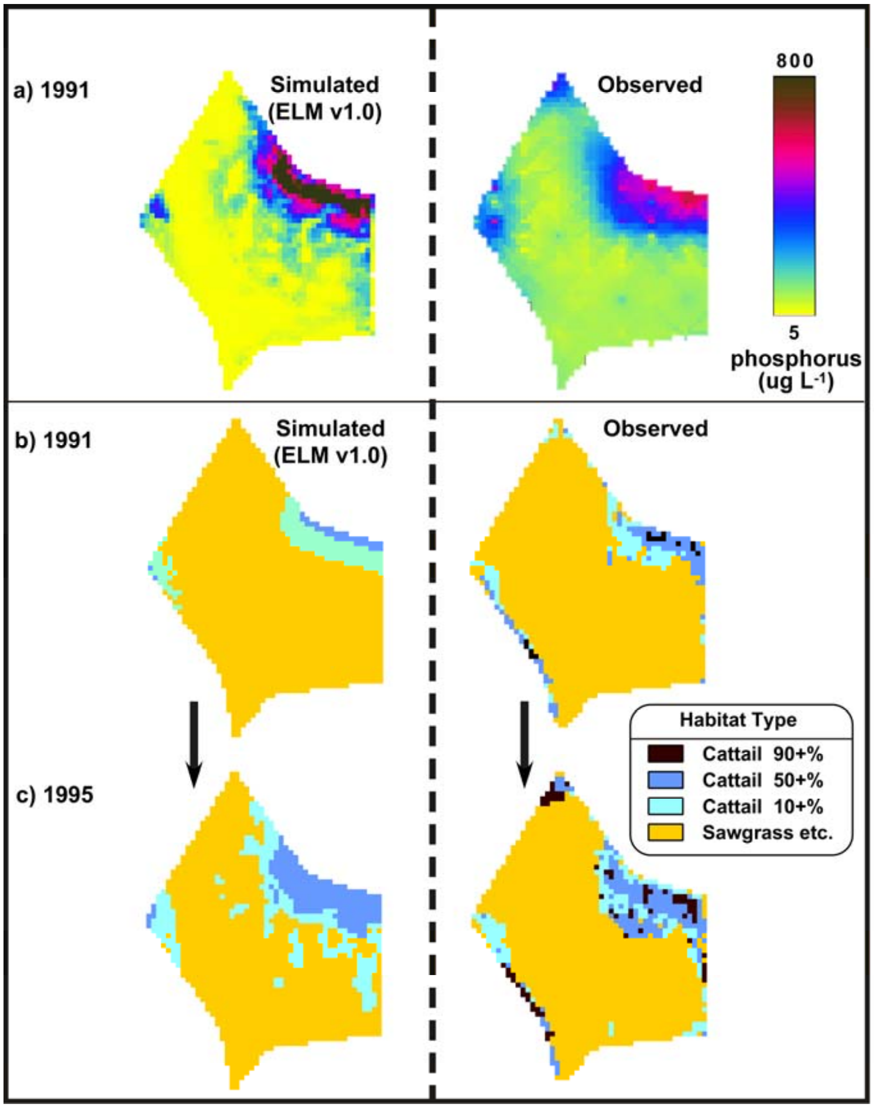

Figure 1.3. Early ELM v1.0 results in Water Conservation Area 2A (WCA-2A), showing observed and simulated a) porewater phosphorus increases in 1991, and cattail encroachment in b) 1991 and c) 1995. The model was driven by historical inflows and nutrient loads in a simulation from 1980 – 1996. See Fitz and Sklar (1999) for details.

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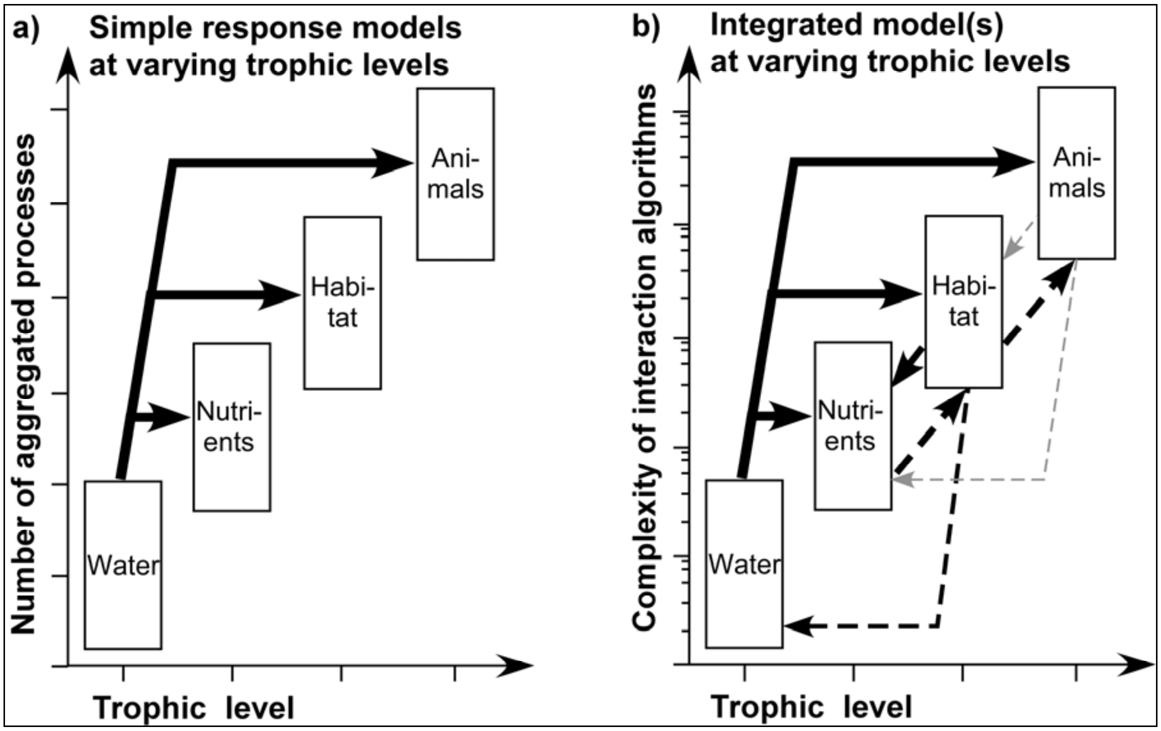
Chapter 2: Ecological Models: Wetlands



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Chapter 2: Ecological Models: Wetlands

2.1 Overview

This Chapter provides a generalized overview of the objectives and design of ecological models of wetland systems. The intent is to broadly introduce the reader to the important wetland characteristics that are typically the focus of ecological models, without delving into any specifics of the Everglades or of the Everglades Landscape Model. A draft of this text was submitted for publication in Elsevier B.V. publishers' "Encyclopedia of Ecology[1]".

While wetlands have a wide range of characteristics, ecological models of these systems share at least one general goal: to understand the ecological responses to varying magnitudes and frequencies of flooding. Regardless of the specific objectives and the level of model complexity, a principal driver of wetland models is flooding and associated surficial sediment saturation. These wetland physics influence the selection of the implicit or explicit ecological processes to be considered in model development. The hydrology is thus an important consideration in the spatial and temporal scales of the model. Horizontal and vertical transport processes establish the basis for biogeochemical transformations of nutrients in shallow surface waters and the upper sediment layers. Sediment accumulation and loss combine with vegetative and algal dynamics to lead to varying trajectories of habitat type in space and time. Animal trophic dynamics respond to these physical and biological processes as wetlands evolve over time. Integrated models across this spectrum of ecological process complexity are usually limited by our state of knowledge, particularly over long time scales. In combination with directed research and monitoring, the diversity of ecological modeling in wetlands is leading to improved understanding of wetland dynamics. In an era of increased management of wetlands, judicious application of this model-based knowledge should aid in more informed decisions regarding the fate of wetlands.

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[1] Draft of invited article, under review for publication *in*: S.E. Jøergensen, Editor in Chief. Encyclopedia of Ecology. Elsevier BV, Amsterdam, Netherlands.

2.2 Introduction

Wetlands encompass a variety of ecological characteristics, distributed across a wide range of climates. Ecological models of wetlands are likewise a diverse assemblage of tools for better understanding each particular ecosystem. However, these models generally share a common characteristic: a method to consider the responses of some part of the ecosystem to varying magnitudes and frequencies of flooding. For some purposes, this may be as simple as an assessment of the suitability of specific ranges of water levels for different biological communities. More complex ecological modeling tools may investigate biogeochemical dynamics under varying interactions between surface and ground water flows. A model of further ecosystem integration couples these hydrologic and biogeochemical processes to those of plants and higher trophic levels within a wetland.

Regardless of the objectives and the level of model complexity, a principal driver of wetland models involves the hydrology of flooding and associated surficial soil/sediment saturation. These wetland physics influence the selection of the implicit or explicit ecological processes to be considered in model development. Important modeling topics such as algorithm formulation (e.g., biogeochemical process equations) and model analysis (e.g., uncertainty) are specified in other articles. Moreover, other articles consider ecological models of a separate class of wetlands that are engineered or “constructed” for mitigation of anthropogenic disturbances. This article emphasizes the selection of appropriate model processes relative to the defining characteristics of “natural” wetland ecology.

2.3 Model Objectives

Defining the objectives is an important first step in modeling. Often the (real or perceived) failure of models is a disconnect between two model “niche” spaces: a) the expectations of the users for model application; and b) the original intent of the model design. The utility of a model lies in the intersection of expectations and design intent – a basic point that is sometimes lost in practice as a result of inadequate communication. For example, a model that is designed to explore alternative hypotheses of the effects of climatic disturbances on vegetative succession can enhance understanding of potential responses to infrequent events. Particularly if supporting data for the model are sparse, such a model may not necessarily be the most appropriate tool to use in predicting the 10-20 year ecosystem responses to managed water flows into a relict wetland. Conceptual models serve an important role in this process. The simple conceptual models of wetland ecology that are summarized here can serve to organize information on scientific knowns and unknowns for a particular (set of) objective(s), and thus be useful ecological models as such. However, the primary intent of their presentation is to highlight the important wetland dynamics that are implemented as mathematical simulation models at various scales of space, time, and process- complexity.

For the conceptualization step, it is convenient to separately consider hydrology, biogeochemistry, and the biology of plant and of animal components – or modules in a simulation model. The interaction of these organisms and their environment (i.e., ecology) can be considered either implicitly within any of these modules, or explicitly within an integrated model framework of interacting modules. Conceptually, many different ecological models of wetlands can be summarized as different trophic level responses to a hydrologic “driver” (Figure 2.1a). The water levels or flows drive the response of the ecological component of interest, with no feedbacks from those dynamics that affect the hydrology. For example, some wetland nutrient models are as simple as employing a first order equation that describes nutrient loss from surface water when it is present. Alligators have specific hydrologic requirements for nesting and other activities in order to maintain a viable population. A simple alligator model driven by changing surface water depths can investigate the long term population sustainability under different scenarios of hydrologic perturbations. Both of these examples focus on the influence of water levels on ecosystem properties, but do not consider how those properties may in turn affect water levels (i.e., through changes in vegetative resistance to flow, or altered microtopography). Such simple modeling frameworks can extrapolate spatial and/or temporal trends, aiding the understanding of wetland component of interest.

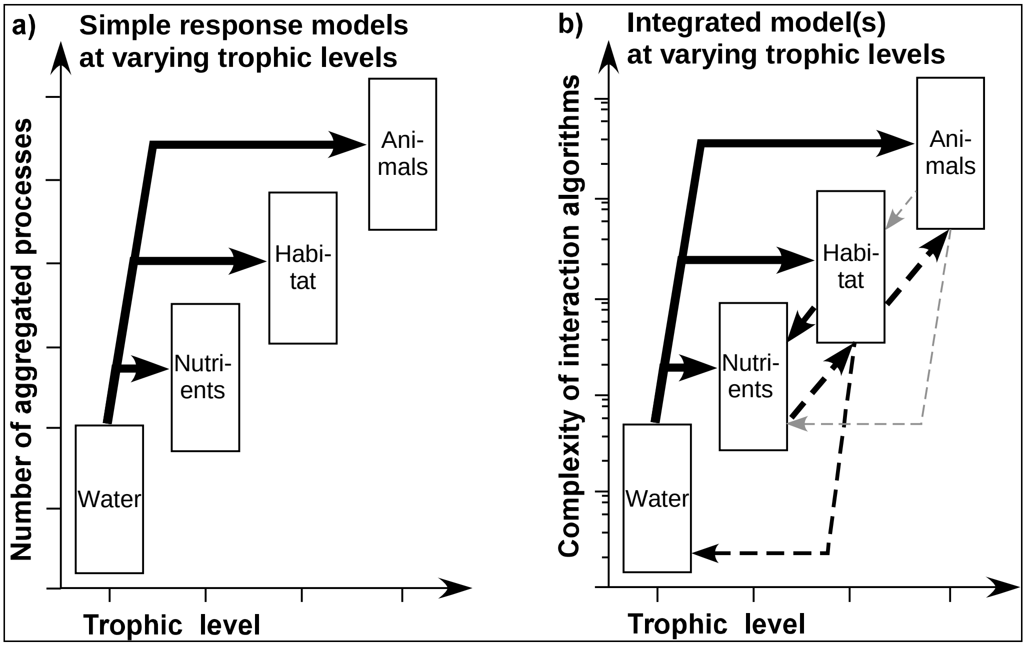

Figure 2.1. Trophic level and aggregation of different models. a) As simple (Nutrient, or Habitat, or Animal) models of ecological responses to hydrology incorporate higher trophic levels, the number of (implicit) aggregated processes increases. b) With increased explicit integration among trophic levels, the complexity of interacting equations may increase geometrically.

There are varying degrees of aggregation in such models of trophic level responses to hydrology, with an increasing total number of aggregated processes with increasing trophic level. (Network or energy analyses of ecosystems point to this increased complexity with trophic level). A simple model of habitat responses to decreased water levels may assume that limiting nutrients do not increase with soil oxidation over time. Similarly, a model abstraction of a herbivore population response to changing wetland hydrology may make the basic assumption that the freshwater marsh habitat does not change to an upland during the simulation. Each of these broad assumptions actually implies a suite of more detailed assumptions regarding the actual interactions that occur in the actual wetland system. The broad assumptions make use of observed correlations between an altered input (water flow) and an altered ecosystem property, but generally mask the underlying causal processes behind the resulting ecosystem change(s). While simplifying the mathematical equations of model structure, simple assumptions still must be verified for the conditions being considered. Nevertheless, such broad assumptions can be very reasonable in the correct context of model application, and they provide the framework for simple, successful simulation to better understand a part of the wetland ecosystem. A point to keep in mind is that simple ecological models tend to make complex assumptions in aggregating complex system dynamics.

While simpler models of a wetland habitat may aggregate the affects of processes such as nutrient cycling and plant herbivory, more complex integrated approaches include some explicit level of those lower and higher trophic level interactions (Figure 2.1b). The algorithms rapidly become more complex with those interactions, with the intent of the design presumably to increase the realism as constraining assumptions are lifted. In the simple models of trophic response to hydrology, the developer has a few large opportunities to misrepresent the actual wetland dynamics. Alternatively, as the numbers of interactions are increased in an attempt at greater “realism”, the developer increases the number of ways to produce a simulation that fails to characterize the targeted components of a wetland system. A cornerstone of model conceptual and mathematical development is assessing the most effective tradeoff between two factors: model complexity and predictability. At some point, an increase in model “reality” of simulating complex interactions is (usually) associated with a decrease in accurately tracking all of the observed behaviors of the system (i.e., model predictability) – largely due to incomplete scientific understanding. Ecosystems are notoriously complex systems, with significant data requirements in order to parameterize an “entire” suite of interactions for a given ecosystem. To meet the objectives of a modeling exercise, a fundamental step is to determine the ecological processes that are important to the wetland dynamics of interest – and what processes are supported with sufficient observational rigor relative to the overall modeling goals. The important or unique processes of wetlands that are considered in ecological models are summarized in a hierarchy of trophic levels below.

2.4 Model Design

2.4.1 Water

“Getting the water right” is a primary consideration in understanding the dynamics of wetlands, and the phrase is a driving principal behind an ambitious restoration effort in the remnants of the vast Everglades wetlands of North America. The hydrologic “engine” of ecological models of wetlands is the foundation of the spatial and temporal scales of the other ecological components of the model. The science of hydrologic modeling is extensive, and here we simply touch upon some of the important considerations for supporting ecological models of wetlands.

At the simplest level, the hydrologic driver of a wetland model may consider surface water alone as a single unit (Figure 2.2a). While this concept may be useful in modeling a component such as fish survival in a homogenous area, it can be extended to consider spatial variation in topography and water depths, employing a 2D surface water model.

Alternatively, the more important physical driver of an ecological component (e.g., for a rooted macrophyte community) may be temporal transitions among ponded, saturated, and unsaturated sediments within a unit area, in which case the spatial discretization lies in the vertical zonation among surface and ground water storages. In one of the more comprehensive spatial frameworks (Figure 2.2d), both horizontal spatial heterogeneity and changes among vertical storages are important to the objectives, leading to a layered 2D or fully 3D dynamic model. While the physics of any of these implementations are well understood, the most complex discretizations require increasingly extensive data and computing resources to implement. Additionally, because of the special expertise that may be needed, it is common for ecological models of wetlands to employ some degree of indirect or direct linkage to existing hydrologic models of the system being considered.

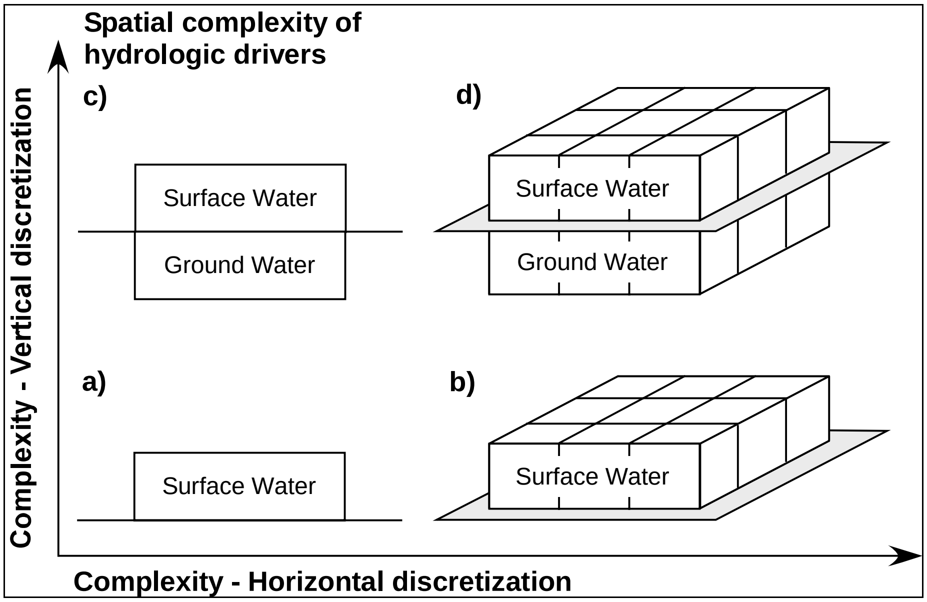

Figure 2.2. Spatial discretization of the hydrologic component of wetland models largely determines the questions that can be addressed. a) Simplest case, with ponded surface water depths of a single unit area; b) Horizontal extension of surface water across multiple spatial units; c) Vertical stratification of surface and ground water storages; d) Complex case of both vertical and horizontal spatial discretization.

Concomitant with the spatial considerations are those of the hydrologic processes (Figure 2.3) that are important to the ecological dynamics – hydrologic drivers that operate at time scales of minutes to days. When the water table (or stage) height is below ground surface, the distance from ground surface to the saturated water table is a zone of potential unsaturated storage within the pore spaces of the sediment. Ponded surface water generally denotes an underlying saturated ground water storage, with the water table above ground surface. Spatially distributed differences among water table heights present hydraulic head gradients. Resultant surface and ground water flows are modeled using a variety of computational methods. These horizontal flow calculations are dependent on the sediment and vegetation resistance associated with surface waters, and the hydraulic conductivity of the subsurface aquifer, respectively. Such overland and groundwater flow computations establish the basis for much of the other physical characteristics of a wetland model.

Other important design considerations for any wetland hydrologic model are the atmospheric exchanges. An elementary model of an isolated wetland may be primarily driven by estimates of net rainfall, which is the difference between vertical inflows of precipitation and losses to the atmosphere by evapotranspiration. Precipitation is most often a forcing function that is input to ecological models, as are a variety of other meteorological observations that are used to determine potential and actual evaporation and transpiration (combined into evapotranspiration, or ET). While the mechanistic detail is relatively complex, potential ET is a function of the net energy gradient between the wetland and atmospheric storages of water. Actual ET is largely determined by the available water storages in the wetland, and is influenced by emergent vegetation. In the absence of ponded surface water, actual ET rates are largely driven by plant transpiration and the depth of the unsaturated zone of storage in the soil relative to root depth. This biological effect is often simply determined through the use of static model parameters relating to land use or habitat type. These ET losses are withdrawn from surface and subsurface water storages, and are a principal component of the hydrologic budget. In particular, depth variations in ponded surface and unsaturated zones have significant repercussions in modeling ecological responses of wetlands.

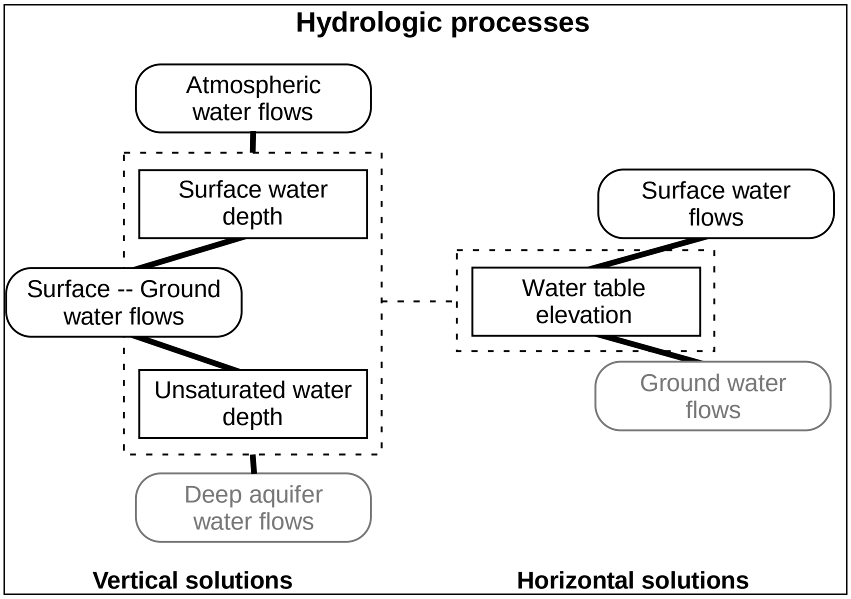

Figure 2.3. Hydrologic processes that influence ecological dynamics. Exchanges between surface waters and the surficial zone of the subsurface groundwater storages become particularly important in wetlands, with highly dynamic water tables relative to land surface. Rectangles denote attributes such as storage or height of water; flow processes are shown in rounded rectangles. Flow algorithms are distinguished here between their vertical vs. horizontal components. Flows that often are assumed to be of relatively minor importance in direct ecological responses are in lighter font.

Hydrologic linkages among the subsurface and surface storages are a defining characteristic of wetlands. They also can present relatively complex modeling problems, particularly in the presence of spatially distributed hydraulic gradients. In the presence of an unsaturated zone of water storage, surface water (from rainfall or local runoff) infiltrates into the pore spaces of the subsurface sediments. In fully saturated media overlain by ponded surface water, transpiration by rooted macrophytes withdraws water from subsurface storage, advecting water from surface to subsurface storages. Differences in the heights of the water table induce hydraulic gradients across space, leading to horizontal flows in the groundwater and the surface water. Depending on the changes in local storage capacities, these flow dynamics can result in vertical upflows or downflows among the surface and subsurface storages. Integrated hydrologic modeling of such surface and groundwater dynamics has been accomplished at a variety of levels of mechanistic detail. Ultimately, the importance of the detail in modeling these changes in surface – ground water storages and flows depends on the objectives of the modeling effort.

One of the more common design constraints for wetland ecological models is that of matching spatio-temporal scales of the hydrologic and biological processes. Water flows are usually considered at scales of minutes to days, whereas upper trophic level responses of plant and animal communities operate at time scales that are orders of magnitude greater. With models specific to hydrology often tending to emphasize fine temporal response algorithms, the computational requirements for hydrologic flows tend to reduce the model time domain, and tend to use spatial resolutions that are coarser than optimal for understanding spatial heterogeneity of ecological dynamics over annual to decadal time scales. Thus, the selection of the hydrologic characteristics to drive wetland ecological models can become a crucial factor in the endeavor’s scope and objectives.

2.4.2 Nutrients

Wetland modeling of nutrients not only involves a strong degree of coupling to hydrologic flows for nutrient transport, but is highly dependent on biological transformations. This dependence, however, again is directly related to the hydrology via intermittent flooding or saturation of the wetland soil and sediments, which largely determines the relative degree to which aerobic or anaerobic rates and processes are operative. Rarely is surface water very deep, if present at all in a generalized wetland. This results in a high surface area of (soil/sediment and vegetative) biological interaction relative to water volume. In parallel with water levels, nutrient availability to macrophytic, algal, and microbial communities becomes an important driver in the development of plant communities and organic soil accretion. Chemical sorption and precipitation mechanisms exert an influence in the wetland biogeochemistry that varies among systems, often dependent on the mineral content of underlying sediments. Modeling wetland nutrients involves determining the most useful combination of the physical hydrologic drivers and the biological mediation of nutrient transformations.

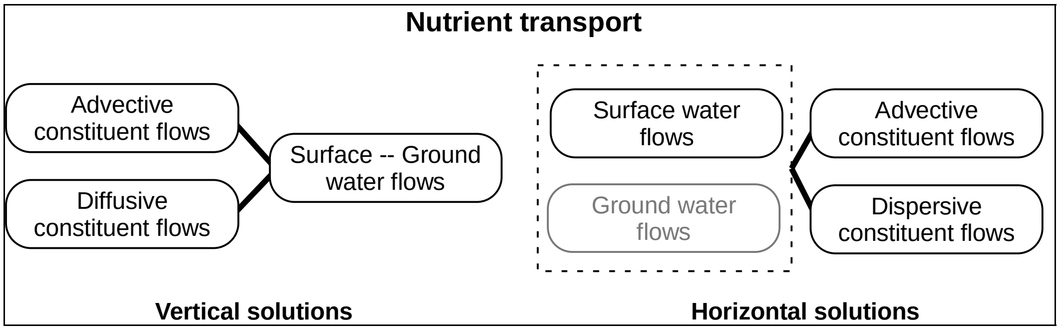

Figure 2.4. Transport processes of nutrients and other water-borne constituents. Beyond transport shown here, the fate of nutrients is highly dependent on biological activity in

shallow surface waters and the upper sediment zone. Flows that often are assumed to be of relatively minor importance in direct ecological responses are in lighter font.

Transport of nutrients and other constituents (e.g., salts) in the vertical and horizontal dimensions (Figure 2.4) is directly linked to hydrology. In most spatially distributed models, calculations of water advection in the horizontal dimension are coupled in some direct fashion to transport of nutrients that are dissolved and/or in suspended particulate forms. In addition to this transport mechanism, dispersive flux (i.e., a case of diffusion in turbulent flow regimes) further propagates constituents across space. This becomes important primarily in surface flows, rather than in the slower subsurface flows through a sediment zone. Because of the spatial and temporal variability in topography and vegetative resistance in these very shallow flow regimes, the relative contribution of dispersion to total nutrient transport remains difficult to accurately quantify. Instantaneous water velocity measurements at different locations in the water column, in combination with dispersion of dye tracers, provide some of the more useful, if still uncertain understanding of this transport process across a wetland region.

As noted in the hydrologic discussion, water flows involving the subsurface groundwater storages can lead to vertical gradients of flow between subsurface and surface waters. Mass balance dictates that dissolved nutrient constituents are advected with those vertical flows, including surface to subsurface flows induced by withdrawal of subsurface water by rooted macrophyte transpiration. Particularly in regions where transpiration is a major component of the hydrologic budget, this plant “pump” has the potential to mix water and nutrients among the surface and subsurface storages, albeit over a short distance approximating the root zone depth. Dissolved constituents also move across diffusion gradients between the surface and subsurface storages, though rates across very short diffusion lengths are usually low relative to other potential biological and physical flux mechanisms. The surficial sediments associated with the root zone are often modeled as the most “active zone” for biogeochemical dynamics of uptake and mineralization. As emphasized in a later section, dynamic water tables in this sediment zone establish a range of potential trajectories in nutrient and habitat status.

Phosphorus and nitrogen are the primary nutrients that are usually considered in wetland models, as one or the other are typically understood to be a limiting factor of wetland productivity. Nitrogen cycling is conceptually (and mathematically) more complex than that of phosphorus, principally because of the presence of atmospheric exchanges (nitrification and denitrification), and the more involved suite of oxidation-reduction reactions that transform nitrogen into inorganic forms of different bio-availability. Beyond nutrients that potentially limit biological reactions, modeling salinity in relation to hydrologic flows is a major component of coastal wetland models.

Boundary condition inflows of these nutrients from the atmosphere and from overland or groundwater sources are often a significant source of uncertainty in biogeochemical components of an ecological model. Wet and dry atmospheric deposition of nutrients such as nitrogen and phosphorus are difficult to measure in the field, and usually are assumed to represent minimal contributions to any external load to a wetland. Nevertheless, these atmospheric inputs may be the only external load to some systems. Most other wetlands have the added complexity of horizontal inflows. Even in the cases where overland and groundwater flows are measured or inferred with relative accuracy, nutrient concentrations associated with those flows are seldom monitored or understood at the relatively short time scales associated with the sometimes rapid changes in water flows.

Because of the potential assimilative capacity of wetlands for nutrients, “water quality” modeling in these systems has been of interest in a variety of nutrient management contexts. The efficiency of engineered, or constructed, wetlands in assimilating anthropogenically derived nutrients in surface waters has been investigated using a range of modeling techniques. Some of these efforts are based on first order equations of highly-aggregated nutrient losses from surface water storages, taking advantage of the simplifications possible through constructed wetland design and relatively predictable, managed water levels and flows. Physical entrainment and settling of suspended particulate matter, with associated nutrients, is combined with all other water column nutrient losses into parameters that aggregate the net nutrient assimilation by the biological and physical components of the wetland. The residence time of a water parcel as it flows through the wetland parcel becomes a primary consideration in determining nutrient assimilation of the wetland.

Ecological models associated with biogeochemical transformations in natural wetlands may start with a similar, simple suite of assumptions of relatively controlled physics and biology. The objectives of ecological modeling projects typically extend these modeling concepts to incorporate an increasingly broad suite of biogeochemical interactions. Because of the potential prevalence of microbial- and plant- based uptake and release of nutrients in wetlands, an important step in wetland nutrient modeling is an estimation of these biological contributions to total wetland nutrient budgets. Understanding these contributions becomes complex in wetland models due to the frequency with which the system is alternately wetter and drier, with resulting changes in primary nutrient controls.

The regular (often diel) fluctuations in flooding of tidal wetlands greatly contrast with isolated peat bogs that are dominated by seasonal or interannual cycles of net precipitation. These physical drivers are a major influence on the ecosystem type and landscape pattern that develops over long time scales, and thus the resulting biological processes that influence nutrient chemistry. For example, algae or periphyton (a composite of algal and microbial communities) are of relatively low importance in carbon production and nutrient uptake in an isolated wetland with infrequent flooding, while they can be the major nutrient uptake mechanism in a model of a freshwater wetland with extended hydroperiods (i.e., flooding duration). The methods for simulating nutrient processes associated with algal, gramminoid, and forested plant communities take on a wide range of process complexity, and are generally not unique to wetland models. As in other ecosystems, a primary consideration in modeling these biological effects in wetlands is understanding the spatial and temporal variations in biomass, productivity, and mortality of these biotic variables, including their relative nutrient uptake affinities.

Production and mortality of plants (and, to a much lesser extent, animals) establishes the source of organic material that may accumulate as part of the sediments of a wetland. Much of the complexity of wetland nutrient modeling stems from the variations of a water table level relative to land surface, affecting the extent to which the sediments are sources or sinks for nutrients. At a simple conceptual level, prolonged flooding or saturation of sediments tends to lead to anaerobic conditions in the sediments, with resulting lowered rates of organic decomposition compared to unflooded, more oxygenated zones.

Microbially- driven mineralization of organic detrital storages of phosphorus and nitrogen makes them available for plant uptake, or to be precipitated or sorbed back into the sediment/detrital storage complex. Laboratory isolation of specific flux paths such as sorption and desorption provides baseline rates of nutrient dynamics. However, the presence of interactions among biotic, chemical, and physical potential fluxes leads to a significantly more complex modeling problem. With fluctuating water tables around the sediment and surface water interface, and varying biological activity, discerning the (importance of) rates of the alternative pathways of nutrient flux is an ongoing topic of research. Model hypotheses can explore the repercussions of varying the magnitudes of such alternative paths, providing insight that may guide research goals.

2.4.3 Habitat

Habitats of wetlands have various operational definitions, and wetland habitat delineation is the subject of significant scientific and regulatory efforts. For the purposes of this modeling overview, habitats are simply considered to be combinations of soil/sediment and plant community characteristics. Principal characteristics of a generalized wetland habitat are the function of sediment accretion, and the related structure of the macrophyte and/or algal communities. Some of the more important applications of ecological models in wetlands involve understanding the processes that lead to alternative trajectories of habitat types – which support animal populations of interest. This leads to significant modeling challenges: understanding and quantifying the rates of sediment accretion and plant succession, under baseline and altered conditions, and generally across a long time domain.

Water and nutrients are two primary drivers of the development of wetland habitats. Modeling those dynamics over short time scales of months to years provides a snapshot of insight into the ecological interactions within given habitat types. However, the development and maintenance of habitats involve cumulative interactions over much longer time scales. A myriad of biological, chemical, and physical interactions can lead to changes in habitats. The succession of macrophyte communities, and accretion of sediments, become observable at multi-year or decadal time periods, with infrequent disturbances being a third major driver of the long term habitat trajectories. The frequency and magnitude of events such as prolonged drought or severe storms has the potential to significantly modify ecological processes, and thus the status of habitat types in a modeled wetland. Major disturbances including fire and hurricanes are specific to particular wetlands, and can directly modify the habitat structure and underlying ecological processes, as seen in examples of coastal and freshwater wetlands of southeastern North America.

Rather than consider all of the potential ecological interactions, models of habitat changes usually simplify the objectives to focus on more specific processes that are understood to be most important to the system of interest. While periphyton community dynamics may be modeled as an important habitat characteristic in the Everglades wetlands, sediments and macrophytes are typically the focus of models of wetland habitat change.

Some of the simplest such models involve dimensionless habitat suitability (0 – 1) indices, reflecting assumptions of the suitability of particular environmental conditions to maintain or establish some desirable habitat type. Hydrologic data and best professional judgments are typically the primary drivers of the suitability index. Models of this type serve to organize available (usually limited) information on the ecosystem requirements into a framework for discerning the relative benefits of alternative scenarios of wetland management.

With more advanced knowledge of the environmental drivers and biological responses, more of the causal factors for habitat change can be incorporated into an ecological model. Plant communities are a conspicuous component of wetland habitat structure, and processes associated with their population dynamics comprise an important part of wetland function. Ecological modeling of plant production and mortality has a long and diverse history. Terrestrial, marine, and lake literature provides a rich background for understanding the methods available for macrophyte and algal simulations, for a range of scales and objectives. Associated with the wetland hydrology, coastal wetland models often incorporate flow-induced salinity stressors on production or respiration/mortality. The extent to which nutrient biogeochemical processes interact to limit plant growth varies widely among model objectives. One of the more characteristic components of wetland plant models involve the need to develop response mechanisms for hydrology that may range from flooded to very dry, multiple times within a plant generation.

Dynamics of plant populations comprise an important component of wetland habitat modeling. Extending this, models of wetland vegetative succession provide insight into long term habitat trajectories. The most appropriate time scales range across multiple decades (to perhaps centuries), particularly for long-lived trees in mangrove, cypress, or riparian bottomland forests. Depending on the objectives, these models vary along a continuum of spatial and ecological-process complexity. Implied or explicit equations of competition for space and/or resources are commonly employed. However, compared to the number of models involving ecological processes at shorter time scales, there are relatively few succession-oriented wetland models.

Succession models of canopy gap dynamics in mangrove or other forested wetlands tend to synthesize physical and biogeochemical processes that influence individual trees and their canopy interactions. Simulation of the succession of species or specific community types is generally targeted to local plots that are sized on the order of tens of meters. Those dynamics can potentially be scaled up to apply across multiple plots within a larger regional landscape model. However, in the case of large spatial domains where water and constituent (nutrient and/or salt) flows are considered important, century-long simulations can become constrained by the data and computational complexity of the combination of spatially distributed gap dynamics plus hydrologic and constituent drivers.

Models of the pattern of long term vegetation succession dynamics in gramminoid wetlands tend to encompass a slightly shorter, but still multi-decadal, time scale that is associated with higher turnover rates of these plants compared to trees. While forest models may consider vertical spatial gradients within the understory and canopy, reduced-statured gramminoid succession has less of a vertical spatial dimension. Models of transition probabilities among habitats have provided the basis for understanding the principal variables associated with habitat changes, and such efforts tend to drive further research into causal factors underlying the change. Beyond the wetland hydrologic processes, gradients of stressors such as salinity or subsidies such as nutrient loads can be used to drive the relative success (or switching) of plant communities.

Whether via direct simulation of population processes, or indirectly via suitability indices, habitat change in wetlands is strongly affected by the cumulative effects of water depth and duration – which is directly coupled to changes in land surface elevation. With such interactions among biological and physical processes, which is of primary importance: the sediments or the vegetation component of habitat? That sometimes depends on whether the modeler is a soil or a plant ecologist! More precisely, it depends on how the physical hydrology interacts with the biological and chemical dynamics of the wetland over long time scales.

Land elevation patterns are modified by water velocity and associated erosion or deposition (Figure 2.5). These sedimentary processes shape creek geomorphology in tidal marshes that are largely high in mineral content. The organic soils of the Everglades have directional patterns that are clearly modified by water flows; the degree to which erosion and deposition of very fine flocculent detritus particles shape these patterns is a priority research topic in that wetland restoration effort. Hydrodynamic algorithms that use first principals of conservation of both mass and energetic momentum are frequently used in engineering applications to understand sheer stresses on sediment particles. With such physical dynamics operating at very short time scales, further challenges remain in effectively aggregating their effects within models that consider multi-decadal sedimentation dynamics.

A significant component of elevation changes in wetlands is due to positive feedbacks from accumulation of above and below- ground plant detritus. Root growth and mortality accumulate organic matter in the soils, and above ground plant dynamics add to that elevation potential. Countering this potential rise is the oxidation of the soil organic matter. Rates of this microbially-mediated decomposition are dependent on the quality of carbon (e.g., the refractory carbon content), available nutrients, and the degree of oxygenation of the soil matrix. Flooded sediments typically are characterized by anaerobic pathways of microbial metabolism, though different wetland macrophyte species have varying capabilities of maintaining increased oxygen in their root zone. Lowered water tables expose the sediment to increased oxygen availability and increased oxidation rates. The mineral content and the soil bulk density impact the relative magnitude of soil height that is lost with the decomposition. Due largely to the long time scales required for accurate measurement, supporting models of change in land surface elevation is difficult. However, research that better defines decomposition under varying environmental conditions is providing a useful basis for modeling a principal wetland process, and permanent sampling devices (such as Sedimentation-Erosion Tables) can monitor long term changes in sediment heights.

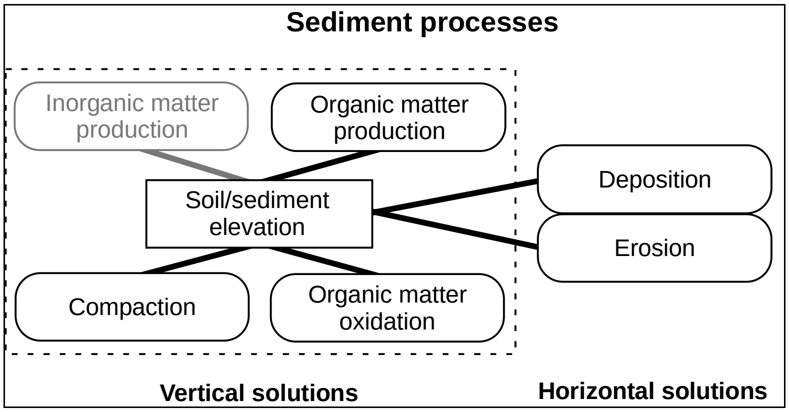

Figure 2.5. Processes that affect the sediments of a habitat. Patterns of land surface elevation are developed and maintained by the interactions among a variety of hydrologic and biological processes. Flows that often are assumed to be of relatively minor importance in direct ecological responses are in lighter font.

With direct effects of water levels, water flows (erosion and deposition), and plant dynamics (growth and mortality), sediments are integrated indicators of the relative "health" of wetlands: modeling these sediment/soil dynamics is a valuable approach to understanding long term, integrated wetland function. Perhaps because of the complexity of these multiple interacting processes, and long observational time scales, such all-encompassing simulations of wetlands are relatively uncommon.

2.4.4 Animals

Nutrient and habitat modules typically involve at least an aggregated level of direct linkages with horizontal flows and vertical surface-water to sediment interactions. Most wetland ecological models that focus on upper trophic level dynamics tend to be less directly coupled to those wetland physical interactions. Rather, the simulated animal dynamics typically respond to the resulting resource availability within habitats. Some wetland animals (e.g., fish) are restricted to habitats with ponded water levels. In turn, avian predators respond to potential concentration of prey in the small scale pools of a marsh. Thus, beyond their effect on habitat and resource structure itself, water level fluctuations are a fundamental determinant of the temporal and spatial availability of habitat. The periodicity of this availability ranges from daily flooding of intertidal wetlands, to annual recession of water levels in flooded wetlands with the onset of a dry season. Particularly in wetlands, the challenge of modeling animal trophic dynamics becomes one of representing the interactions within- and among- populations, in the context of habitats that may be dynamically varying with hydrology.

Much of early ecological science focused on animal population and community dynamics, with a rich literature on the associated modeling theory and practice. Trophic dynamic modeling becomes highly specific to the system of interest, relative to the particular scientific or management objectives. At a minimum, it may be generalized that many wetlands have detrital-based food webs. Those lower trophic level resources become the base for more complex predator-prey interactions. Simple equations of such interaction have been explored at many levels of modeling, along with associated energetics of foraging and resource assimilation. In understanding and modeling animal dynamics in wetlands, it appears that an ongoing challenge is that of sampling motile populations in a fluctuating environment.

Animal dispersal is complex in both time and space. For example, fish and invertebrates moving onto and off of intertidal marsh habitats are difficult to sample in a quantitative fashion. The density of emergent wetland vegetation, which serves as refugia for prey, also hinders estimates of motile animal densities needed for modeling. Nevertheless, data from innovative sampling devices and mark-recapture methods have been used to parameterize some models. Simulations of resource limitations and animal movements provides a context for generating hypotheses of the key regulators of animal interactions in a dynamic environment.

A modeling approach that is increasingly being used for such purposes is that of Individual Based Models (IBMs). As with simulations of forest succession due to interactions among individual trees, IBMs of animals incorporate individual variation in the quest for understanding dynamics of larger populations (or interacting populations). Relaxing some of the broader assumptions of population homogeneity, these modeling approaches explicitly incorporate some aspect of how individuals respond to dynamics of biological and/or physical changes in their environment. In such a model framework, multiple avian predators can be “rewarded” energetically by finding assemblages of fish prey individuals, which have responded to dry season recessions of wetland water levels and become concentrated in isolated pools of surface water. In understanding such potential interactions through the collective response of individuals, potential emergent properties of the population(s) can be explored in a highly dynamic wetland environment.

2.4.5 Integrated ecosystem

An integrated simulation model can take on a range of definitions. Largely dependent on the specific objectives, this may involve the interplay among physical, chemical, biological, and socioeconomic sciences. As apparent in the discussion of each trophic module above, a comprehensive understanding of wetland structure and function involves a rather complex suite of ecosystem properties. Integral with these “natural” properties are the effects of anthropogenic drivers – human degradation or restoration of wetland systems. Moreover, specific land use requirements may frame the possible trajectories of wetland change, all within the context of the human values ascribed to the function of the system. In planning for projects involving wetland modifications, there typically are limited data available on the specific system of interest. Comprehensive understanding of long term, fully integrated wetland dynamics is elusive.

Relatively simple modeling tools may be the best available to forecast the scenarios of wetland change. Statistically-oriented models based on past wetland behavior may serve to guide initial plans for such wetland management. However, such relatively simple models tend to make complex assumptions regarding long term wetland landscape trajectories. Outside of the envelope of past observations, uncertainty of such models becomes problematic, and the models tend to lack explanatory power. Given a general framework of socioeconomic drivers, it is desirable to determine the minimum set of ecosystem properties that will interact to lead to long term trajectories of wetland structure and function. Understanding the fundamental physical, chemical, and biological interactions – at some minimal level – becomes a goal for ecological simulations of wetland dynamics in this context.

Integrating the full ecosystem dynamics across a heterogeneous wetland landscape is a daunting goal. Given the current depth and breadth of our ecological understanding of any specific wetland, that goal would likely not result in analyses with significant forecasting utility. However, such model integration serves to highlight the missing information, and thus is a useful heuristic tool for advancing the state of knowledge. Moreover, there are varying degrees of scientific integration. Integrated ecosystem models, at some scales, can provide enhanced understanding of the potential trajectories of wetlands.

Such an incompletely integrated model is necessarily specific to the wetland and objectives of the particular project. Certain environmental or biological drivers may be assumed constant; others may be fundamental to understand potential scenarios of change. While there are innovative attempts to integrate terrestrial ecological models with long term meteorological models, the effects of global sea level rise on coastal marshes can assume a suite of increasing water heights to understand habitat trajectories – without necessarily incorporating feedbacks from changing vegetation on local climate. On the other hand, major shifts in habitat may have important repercussions to surface water hydrology, through feedbacks of vegetative resistance to flow, local evapotranspiration demands, or organic sediment accumulation and topographic patterns.

There is a core suite of variables and processes whose integration may provide insight into understanding long term wetland dynamics. The preceding overviews of the modeling at varying trophic levels outline the basic nature of some desirable levels of integration. The emergent characteristics of this potential integration reflect the unique character of wetland dynamics: understanding the physical drivers of intermittent flooding, and the biogeochemical and biological responses of the habitats to those dynamics. While not comprehensive, such integration within a simulation model is still difficult to parameterize for most wetlands, particularly over large spatio-temporal scales. Few wetlands in the world are studied adequately to implement such a complex model with significant certainty for forecasting. One of the most comprehensively studied wetland in the world is the Everglades of North America. A range of hydrologic, statistical, and ecological models are in use, or are under development, in order to better understand how to manage and restore the Everglades landscape. Considering more than 10,000 km^2 of coastal mangroves, freshwater marshes, and upland ecosystems, some of the ecological models attempt to integrate components of the ecosystems throughout the region. None of these modeling tools provides sufficient understanding to be confident of projected results even a mere 50 years from now. Hand in hand with simulation tools that make relative assessments of future scenarios, comprehensive monitoring is being implemented - to adaptively assess and modify plans as the landscape responds along unforeseen trajectories. As scientific understanding evolves, so do the models that assimilate that knowledge. Uncertainties in how major disturbances will affect these dynamics over long time scales become some of the interesting topics that can be explored with ecological models.

2.5 Further Reading

Costanza, R., and A. A. Voinov, editors. (2004) Landscape Simulation Modeling: A Spatially Explicit, Dynamic Approach. Springer Verlag, New York, New York. 330 pp.

DeAngelis, D. L., and W. M. Mooij. (2005) Individual-based modeling of ecological and evolutionary processes. Annual Review of Ecology, Evolution, and Systematics 36:147-168.

Mitsch, W. J., and J. G. Gosselink. (2000) Wetlands: Third Edition. John Wiley & Sons, New York, NY. 920 pp.

Reddy, K. R., R. G. Wetzel, and R. Kadlec. (2005) Biogeochemistry of phosphorus in wetlands. Pages 263-316 *in* J. T. Sims and A. N. Sharpley, editors. Phosphorus: Agriculture and the Environment. Soil Science Society of America, Madison, WI.

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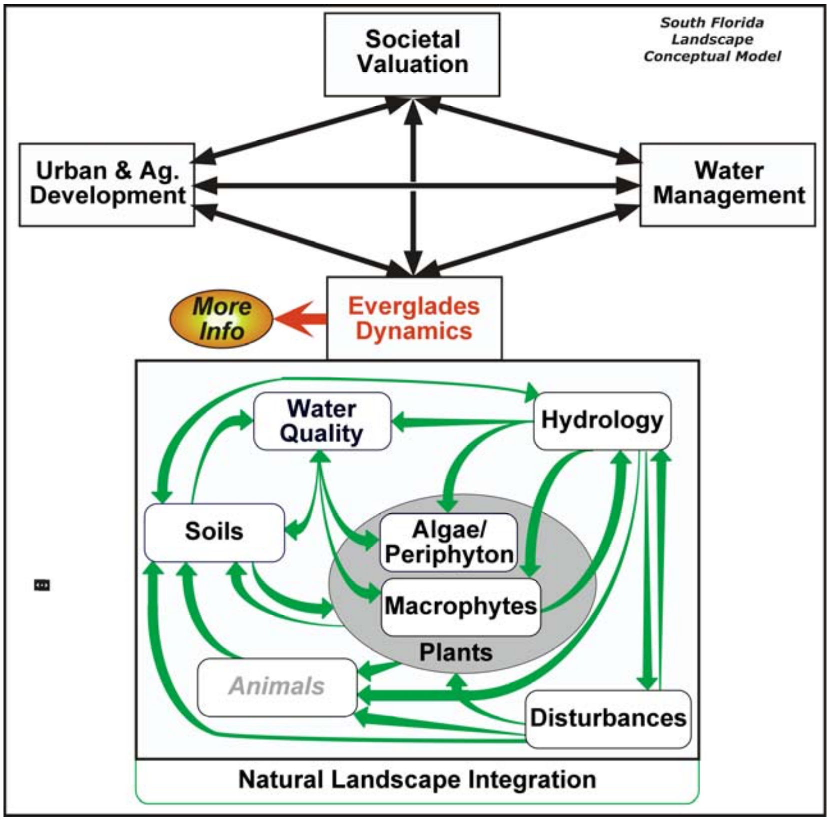
Documentation of the
Everglades Landscape Model:
ELM v2.5

Chapter 3: Conceptual Model



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July 10, 2006

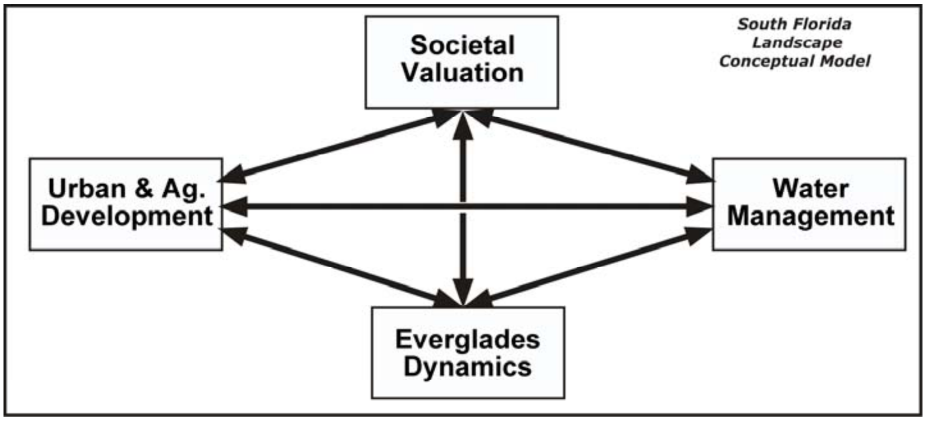
Chapter 3: Conceptual Model

3.1 Overview

The fundamental linkages among the natural and human-based environments are described in this chapter, using the South Florida Conceptual Model. This establishes the context of the "natural" Everglades landscape as it is integrated into the issues of the south Florida region. The General Ecosystem Conceptual Model for the "natural" area is then described, summarizing the ecological interactions among the primary physical, chemical, and biological processes that drive the ecosystem(s). Natural systems integrate these processes in a dynamic landscape. This is the basis of the concepts that were used in designing the Everglades Landscape Model, which is summarized in a subsequent Chapter on the Model Structure.

We recommend viewing this Conceptual Model via the hyper-linked version on the ELM web site (Home: Landscape tab at http://my.sfwmd.gov/elm).

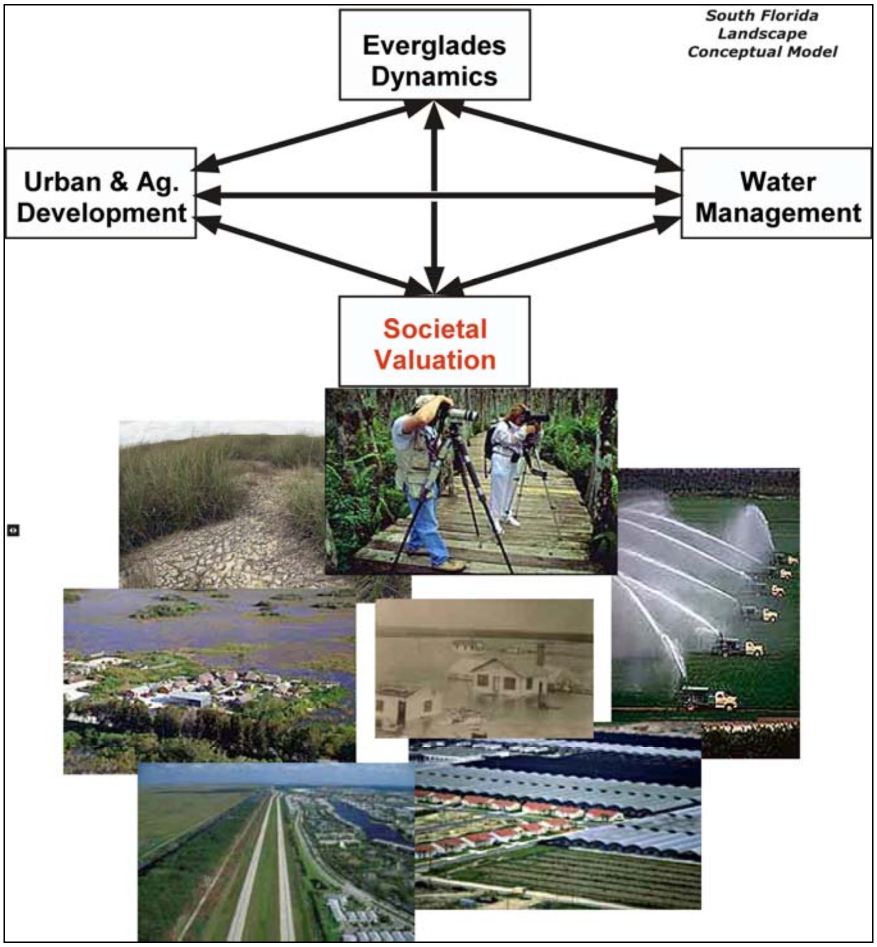
3.2 South Florida Conceptual Model



The ecology of the Everglades should be considered in the broader context of the South Florida landscape. A simple conceptual model of the relationships among the natural system and the different components of south Florida is briefly demonstrated in our South Florida Landscape Conceptual Model.

Water managers in south Florida are responsible for balancing the various demands placed on our public water resources in order to achieve a sustainable and productive environment for humans and the natural system on which we all depend. Field/lab research and modeling can aid in understanding the dynamics of the Everglades system in response to current and future water management practices. The interactions among the four Conceptual Model components shown here drives the ecological and economic system of south Florida. Water management attempts to integrate our societal values with the resource demands of urban, agricultural, and natural components of the regional landscape.

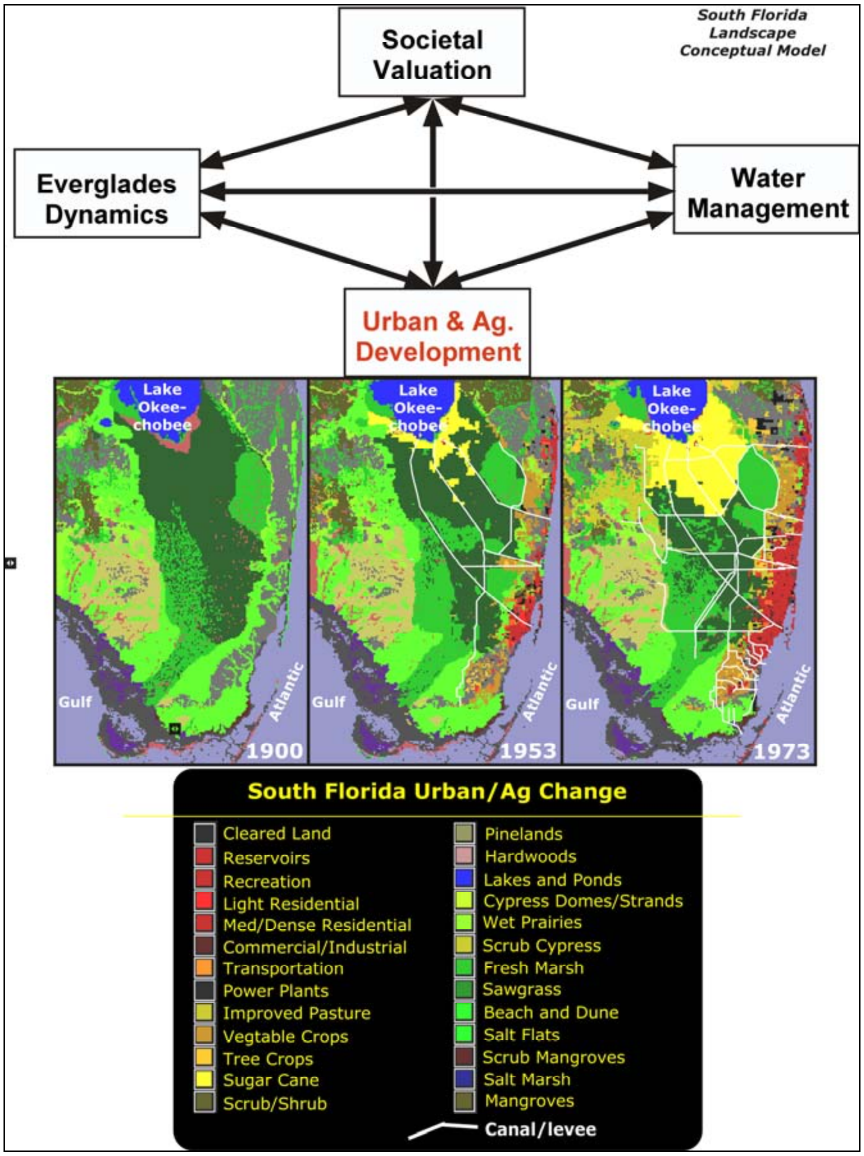
3.2.1 Societal valuation



Water Managers are responsible for balancing the various demands placed on our water resources in order to achieve a sustainable and productive environment for humans and the natural system on which we depend.

The economy of south Florida depends not only on tourism: agriculture contributes significantly to its productivity. The water resource needs of this sector are a significant consideration in water management planning. Water supply for residential demands is another important component of the regional water budget, while flood control for land used for agriculture and housing poses a different type of demand on water management. With human populations increasing dramatically since the mid 20th century in south Florida, water management has disrupted the natural timing and distribution of water in the Everglades, with concomitant deterioration in water quality. These changes have led to significant deterioration of this internationally recognized wetland. Demands for restoration of this unique landscape have come from the national and local levels, with citizens demanding that the natural system have a much greater consideration than in the past. Thus, a variety of publicly funded projects, including the ca. $9 billion Comprehensive Everglades Restoration Plan (CERP), have been initiated to restore this valued natural system. In this process, management alternatives are being tested to optimize the balance between the natural and human demands on water resources - with the primary objective involving the restoration the Everglades.

3.2.2 Urban and agricultural development

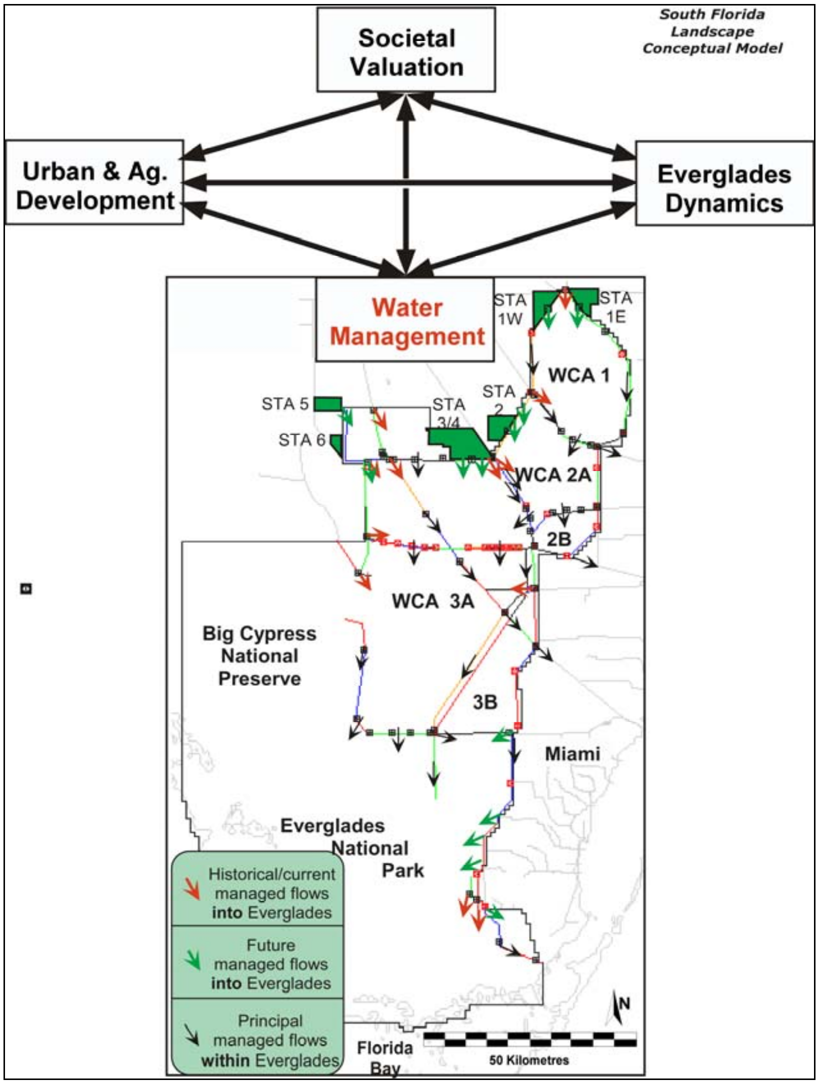


As canals and levees were built during the 19th and 20th centuries, agriculture and urban land uses dramatically increased, significantly reducing the spatial extent of the "natural" Everglades system by the mid 1970's.

Starting in the late 1800's and the early 1900's, long stretches of canals were dug in attempts to drain the relatively pristine Everglades for agriculture. Problems such as devastating floods led to Federal authorization (1948) of the Central and South Florida (C&SF) Project, creating an elaborate network of canals, levees, and water control structures to improve regional flood control and water supply. It was ultimately very effective in managing water for those purposes, accelerating the development of urban and agricultural sectors of the region. Agricultural and urban development has generally continued through the present day, particularly along the corridors east and north of the Everglades. The C&SF Project led to a reduction in spatial extent of the Everglades, and also fragmented the once-continuous Everglades wetlands into a series of large impoundments.

In the current-day Everglades, the existing management infrastructure bisects the area into a series of impoundments, or Water Conservation Areas (WCAs). Everglades National Park is south of these WCAs, while Big Cypress National Preserve is to the west. Agricultural land uses dominate the area just north of the Everglades, while extensive (primarily) urban land uses predominate along the eastern boundary of the Everglades. Lake Okeechobee, historically bounding the northern Everglades marshes, is now connected to those marshes via canals.

3.2.3 Water Management



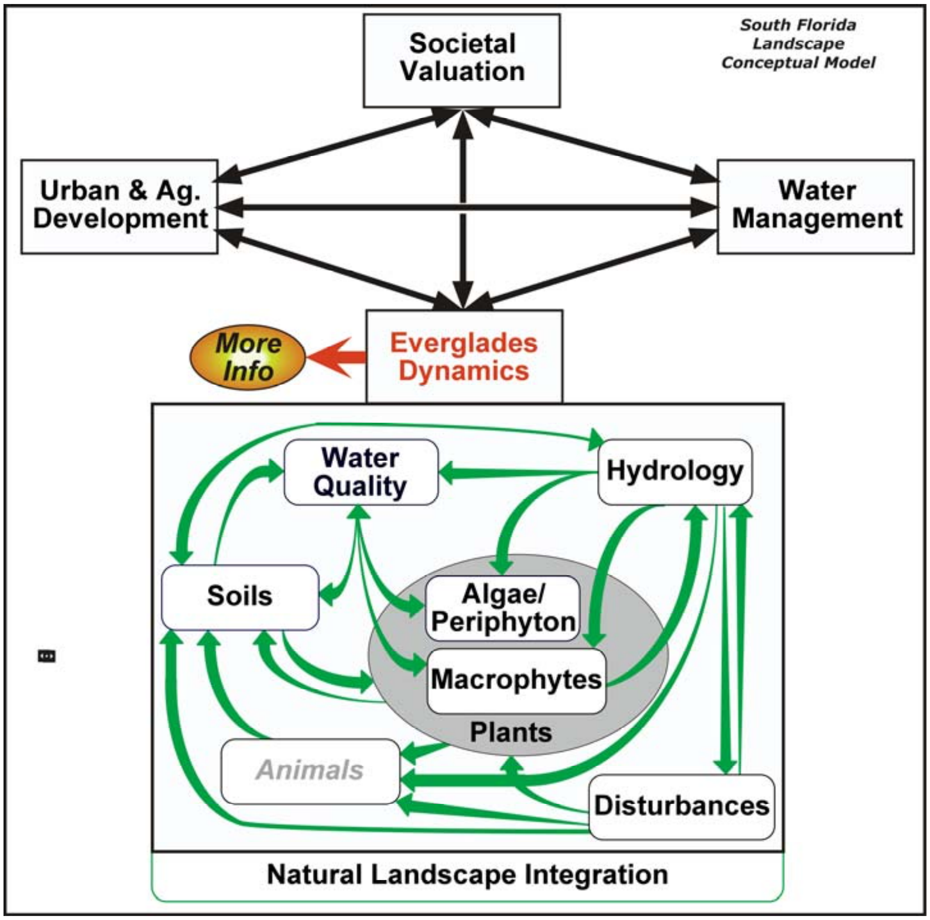
The managed flows of water into, and within, the Everglades are being evaluated by scientists and engineers in attempts to optimize the management network for the needs of this dynamic landscape.

The south Florida region, and much of the greater Everglades region, is driven by a complex engineering infrastructure that is operated to distribute water for environmental, water supply, and flood control needs. This network of canals, levees, and water control structures was designed many decades ago with the primary goal of improving water supply and flood control for the urban and agricultural sectors of the regional economy.

While successful in those respects, this hydrologic management - in conjunction with deteriorating water quality - had significant negative impacts on the Everglades ecology. The Everglades had been fragmented into separate, impounded basins (Water Conservation Areas) with dramatically altered flows and hydropatterns. Water historically flowed from the northern parts of the region into and through the Everglades largely as overland sheet flow. This flow regime changed to point releases at the pumps and weirs of water control structures. Operational criteria for these managed flows dictated the timing and magnitude of water distribution into and within the Everglades, further modifying its hydrology. With agricultural and urban runoff, many of these inflows also carried higher loads of nutrients into the historically oligotrophic (low-nutrient) Everglades. The altered distribution and timing of flows in a fragmented watershed, combined with increased nutrient loads, changed the mosaic of Everglades habitats - for the worse.

Details on the location, magnitude, and timing of these managed flows are vital components of understanding the Everglades dynamic response, from the scale of an individual tree island to that of the broader landscape of a Water Conservation Area or Everglades National Park. A variety of projects are underway to restore the Everglades by optimizing management of hydrology and water quality, two fundamental "drivers" of Everglades ecology. Multiple research groups are providing critical scientific insights into the benefits and risks associated with these endeavors, integrating quantitative ecological science into decisions on modifying Everglades water management.

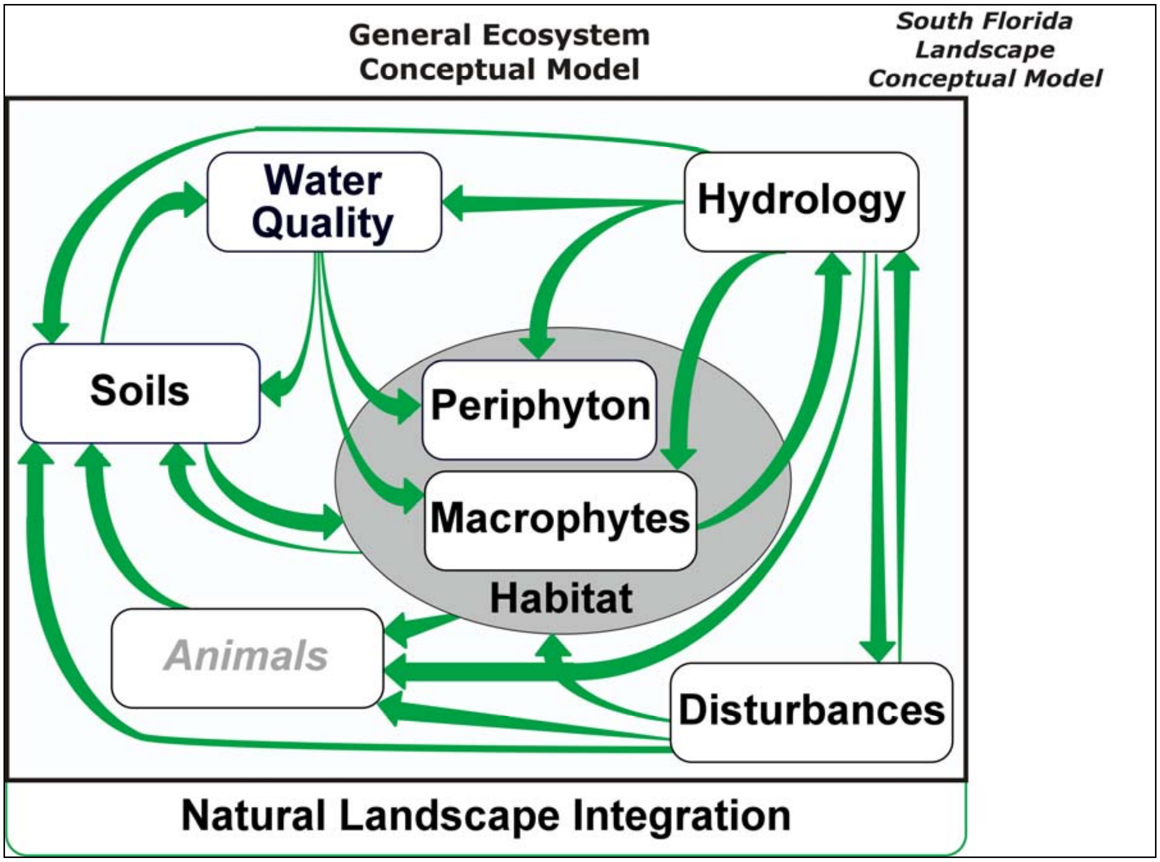
3.2.4 Everglades dynamics



As E.P. Odum (one of the "fathers" of ecology) put it, an ecosystem is more than the sum of its parts. The ecosystem feedbacks, or interactions, among the physical, chemical, and biological components of the Everglades landscape are fundamental to the dynamics of this complex system. Using a simple framework, we believe that insights into the basic interactive processes aid in better understanding the system behavior as a whole.

The Everglades landscape is a mosaic of different habitats that have evolved under a highly dynamic set of environmental conditions. As with any complex system, interactions among its different components are a fundamental aspect of its operation, and play an important role in sustaining the Everglades. [The human body is a complex system that is highly dependent on the proper interactions amongst it's physics (e.g., skeleton, blood flow), chemistry (e.g., nutrients, oxygen), and biology (e.g., organs, growth)]. The physical hydrology, biogeochemical nutrient cycling, and biology of plant & animal communities are determinants of the emergent ecosystem properties that comprise the landscape. Field/lab research and models involve methods to help understand these different "processes" that "drive" the system, providing us with insight into how to best attempt to restore and maintain this dynamic landscape.

3.3 General Ecosystem Conceptual Model

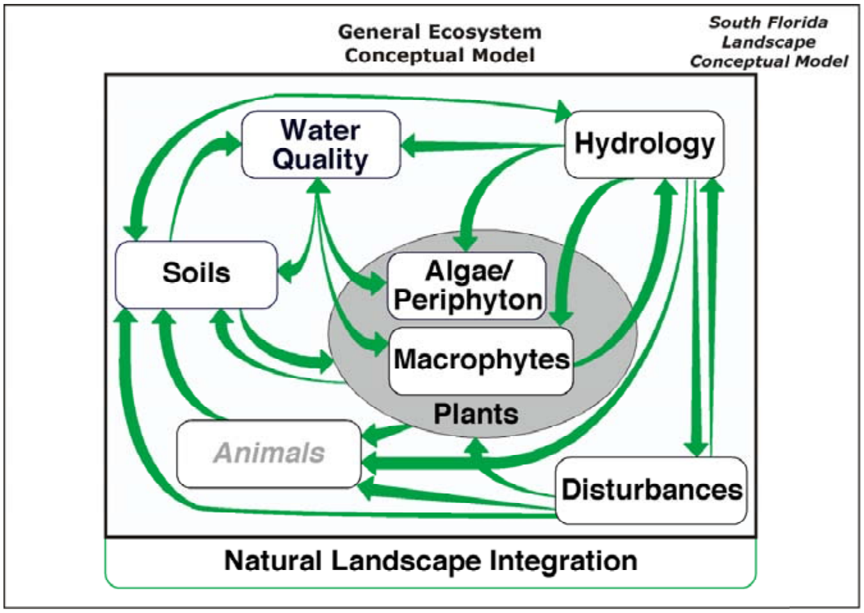


To assess the status of the natural system, it is critical to understand the interactions among the physical, chemical, and biological components of the Everglades landscape. ***The key is to simplify these interactions down to their most fundamental components, especially where supporting data are sparse.***

This **General Ecosystem Conceptual Model** summarizes the basics of these interactions among multiple variables in the landscape. *This conceptual model is at the heart of the dynamic equations that comprise the Everglades Landscape Model*, and has been part of a framework of research hypotheses. We have devoted a very large part of ELM efforts on developing the simplest set of fundamental, interacting equations that we believe effectively capture the essence of the important ecosystem dynamics.

Note: because the Everglades is such a tightly integrated functional system (as seen in the relationships in this Conceptual Model), it can be somewhat misleading to attempt to "measure" the performance of the system through one or two attributes such as water depth or water column nutrient concentration. The multiple Performance Measures that are being used for CERP and other restoration projects can best be understood and interpreted from a well-integrated, systems ecology perspective.

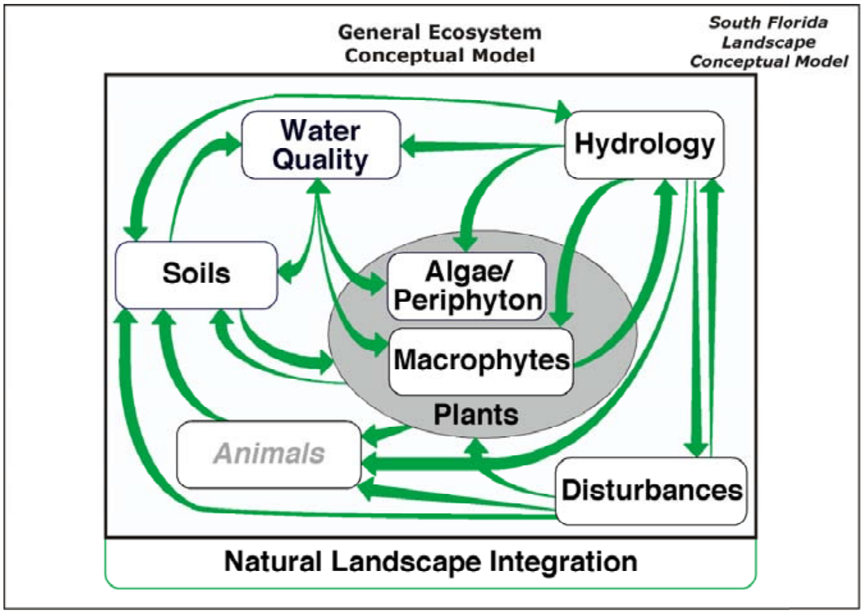
3.3.1 Hydrology



***Hydrology** is a critical "driver" of the landscape, in that we need to understand and get the water "right" in order to sustain a healthy Everglades.*

Hydrology is one of the "fast" processes that can change significantly on time scales on the order of hours, but climate change can produce decadal shifts in dynamics of the regional hydrologic cycle. While rainfall in south Florida is seasonal, it is variable both within seasons and among years. Intense rainfall events are often heterogeneously distributed at local scales; tropical disturbances can deluge the entire region. The pattern of water distribution (hydropattern) across the landscape is driven not only by rainfall inputs and (atmospheric- and macrophyte- mediated) evapotranspiration losses, but is intensively managed via the operations of the water management infrastructure (canals, levees, water control structures). Changes to water depths and flows can alter the habitat because different macrophyte species and algal/periphyton assemblages have distinct hydrologic adaptations. Likewise, changing water depths can alter the soils through increased accretion rates when wet for prolonged periods (i.e., long hydroperiods). On the other hand, soil losses increase with the oxidation (and fires) occurring under short hydroperiods. This increased soil oxidation increases the nutrient availability surface/soil waters. Soil nutrient chemistry is also affected by water exchanges between surface and soil/sediment water storages, a vertical advective process driven by groundwater losses due to plant transpiration and/or horizontal groundwater flows. Surface water flows are an important transport mechanism for nutrients and suspended organic matter in the landscape, while canal fluxes are faster across long distances. Surface water flows also play a role in suspension and deposition of soils & sediments, potentially altering the physical pattern of creeks and sloughs. While most of the horizontal flows in the Everglades are induced by head (elevation) gradients, wind and tide-driven circulation is predominant in Florida Bay. These surface flows are highly dependent upon the resistance to flow by macrophytes, and groundwater flows and seepage through levees vary significantly across the region depending on aquifer (or levee) transmissivity.

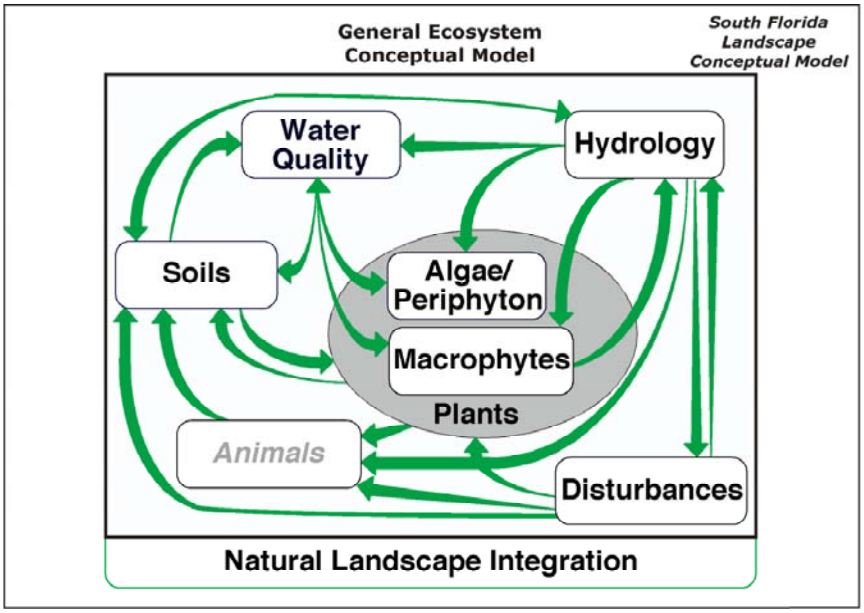
3.3.2 Water Quality



***Water quality** has been responsible for shifts in primary productivity and species composition of macrophyte and periphyton communities, and is another primary "driver" of the landscape at fast (weekly to annual) time scales.*

Because the predominant "native" Everglades macrophyte and periphyton communities have adapted to oligotrophic (low nutrient) waters, increases in phosphorus and nitrogen (i.e., eutrophication) can be detrimental to the structure and the function of those communities. Phosphorus is generally the more limiting nutrient in the freshwater Everglades, while nitrogen tends to govern plant productivity rates in the southern Everglades/Florida bay where estuarine gradients occur. Typically, anthropogenic (man-made) loading of otherwise-limiting nutrients causes ecological imbalance, shifting the structure and function of the ecosystem. Management of flows through water control structures and canals has significantly modified the distribution of these nutrient loads and concentrations across the landscape. Different macrophyte and periphyton communities can uptake phosphorus and nitrogen at varying rates, changing the ambient water quality (and changing the plant tissues and growth). As water exchanges among surface and soil/sediment pore waters, the associated nutrient fluxes can alter the microbially-mediated rates of soil/sediment decomposition, releasing nutrients in inorganic forms that are more available for biotic uptake. Along with nutrient availability, salinity gradients in the southern Everglades/Florida Bay have the potential to modify communities that have adapted to particular environmental conditions.

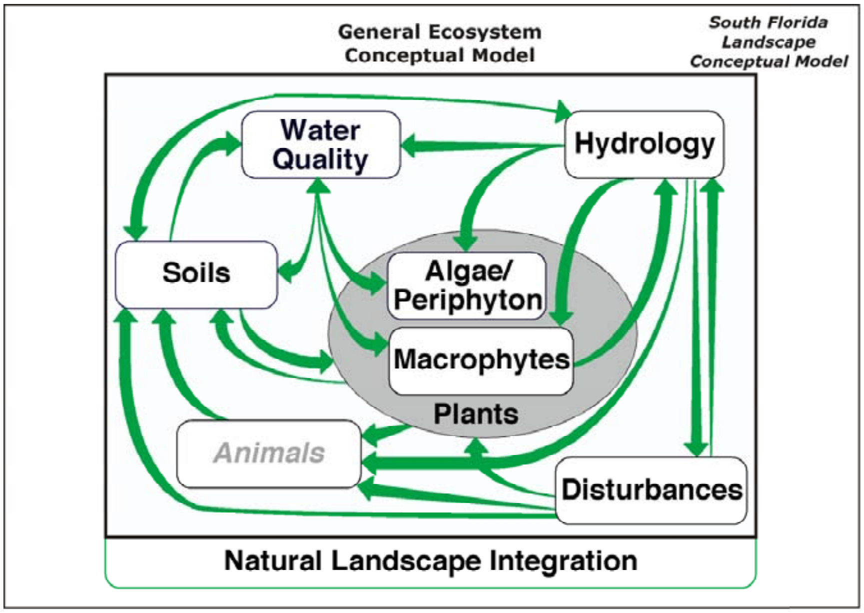
3.3.3 Algae/periphyton



***Periphyton** (assemblages of **algae** and microbes) are sentinel indicators of the quality of many habitats of the Everglades.*

Periphyton are found attached to macrophyte stems, floating as mats in the water column, and as a benthic layer on top of the soil . Long considered an integral part of the animal food web, periphyton respond rapidly to changes in water quality and hydroperiod. Like macrophytes, "native" periphyton are adapted to oligotrophic (low nutrient) conditions, while a variety of other periphyton are common in eutrophic (high nutrient) waters. Another important control on periphyton and algae is light availability: at intermediate and high plant densities (such as in high nutrient areas), emergent marsh macrophytes shade periphyton, and (to some extent) prevent healthy communities from developing. Capable of senescing during dry periods and coming back to high growth levels upon rehydration, there are a variety of different types of periphyton species & communities, depending on the subregion of the Everglades and its local environmental conditions.

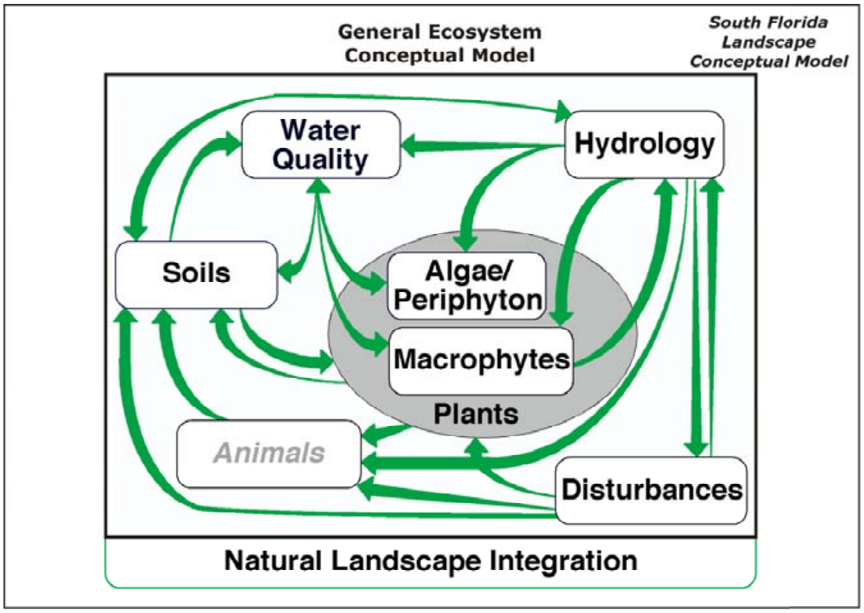
3.3.4 Macrophytes



***Macrophytes** are a primary determinant of the habitat quality in the Everglades landscape, which is largely defined by its heterogeneous mosaic of macrophytic vegetation that is dynamic over both annual and decadal time scales.*

There is a high diversity of plants in this region, ranging from emergent marsh plants such as the ubiquitous sawgrass, to hardwood trees of tree islands and mangrove forests. These, and many other common species, form a wide variety of plant communities with very different nutrient requirements, distinct hydrologic needs, and dynamic effects on the hydrologic cycle itself. Different adaptations by these plants create the habitat mosaic in response to a changing environment. For example, cattail is a "nuisance" species that grows rapidly in response to elevated nutrient availability, has morphological characteristics that allow it to thrive in flooded conditions, and easily colonizes areas that have been disturbed by man-made or natural events. Sawgrass, on the other hand, is a very dominant species in much of the Everglades where there are oligotrophic (low nutrient) conditions and "natural" fluctuations of water levels and disturbances. With mortality or dieback of leaves and roots of these plants comes the accumulation of organic matter in the form of peat soils. Tree islands have "died" in recent years due not only to excessive water depths covering tree roots for prolonged periods, but also due to fires in regions that have been overdrained and made more susceptible to catastrophic disturbance. Where regions of the Everglades have undergone successional shifts in plant communities, animal communities invariably are affected. Many animals are adapted to, and rely upon, high quality habitats that are often characterized by the heterogeneous, alternating distributions of dense and sparse vegetation of different species.

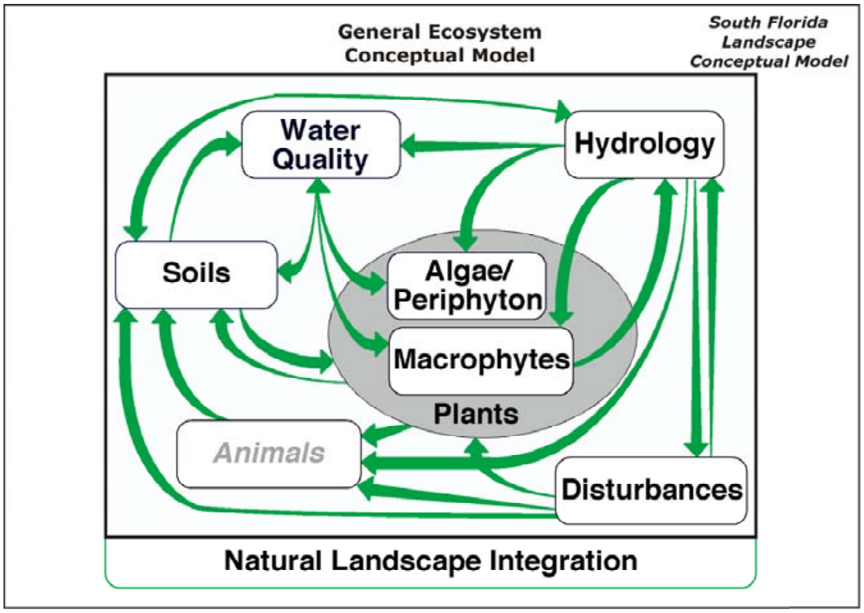
3.3.5 Soils



Soils (and sediments) *are in a long term, ca. decadal, balance between processes of accumulation and oxidation (and sometimes erosion), and are closely integrated with the development of different habitats.*

In regions of long hydroperiods where water ponds for much of the year, peat soils tend to accrete organic material that come from plant mortality and litterfall. Under shorter hydroperiods when those soils are exposed more frequently to the air (and thus more aerobic conditions), oxidation of the organic matter tends to reduce the depth of peat. This process is governed by microbial dynamics, and can be accelerated with higher nutrient availability. The oxidation of soil releases nutrients from tightly bound organic forms into inorganic chemical forms that are more readily available to plants and microbes. Disturbances such as droughts and "muck" fires can have significant impacts on peat soils, rapidly oxidizing the organic carbon, but leaving behind much of the nutrients to which the ecosystem may respond. Throughout much of the Everglades is a upper-soil layer of flocculent (fluffy) organic material that is partly live periphyton, but is principally the organic material from dead periphyton and macrophytes. This "floc" appears to play a critical role in nutrient cycling and transport of organic material among habitats - and potentially forms part of a detrital food web for animals. Thus, soils are closely integrated with water quality and plant or periphyton growth, and respond strongly to changes in hydrology. Inorganic constituents of soils vary in importance through the Everglades system, with calcitic periphyton sequestering calcium and phosphorus into an inorganic component that forms marl soils.

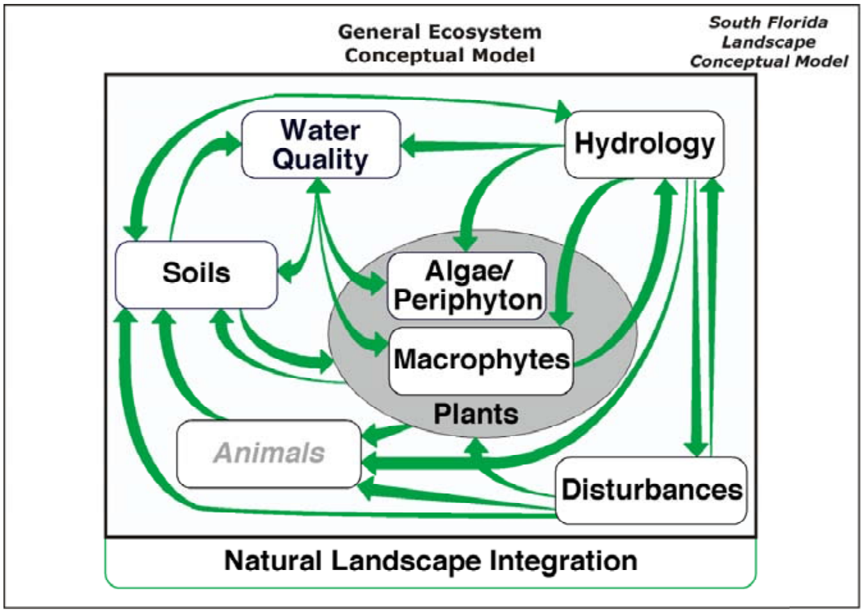
3.3.6 Disturbances



***Disturbances** such as fires, hurricanes, and severe drought or flooding can alter the ecological characteristics of the landscape over short and long time scales. There exists an important interaction between response to disturbances and the pre-existing structure and function of these dynamic ecosystems.*

The primary disturbances considered in the current version of the Everglades Landscape Model are drought and flood conditions. The Everglades landscape has adapted to "expect" natural variability in climate and related disturbances. While droughts and fire may appear to decimate the landscape, most of the vegetation and animal communities of the region can respond in positive ways: fire occurring in relatively local "patches" at infrequent intervals can enhance the system by opening up new space or clearing away brush species amongst cypress or hardwood communities; hurricanes may flush accumulated organic debris from the shallows of Florida Bay. However, there is potential danger in management regimes that exacerbate the natural response to disturbances. If the seasonality and frequency of disturbances are significantly altered, areas that remain overly dry during unusual periods can experience severe "muck" fires that burn deeply into the peat and eliminate more soil and vegetation than "surface" fires. Such fires can burn away the carbon in the soil, leaving elevated levels of phosphorus. Some macrophyte species such as nuisance cattail rapidly colonize and thrive in such a highly disturbed environment. Regions that have accumulated stresses such as long term nutrient loading can be "primed" for dramatic, potentially catastrophic shifts in the ecological balance.

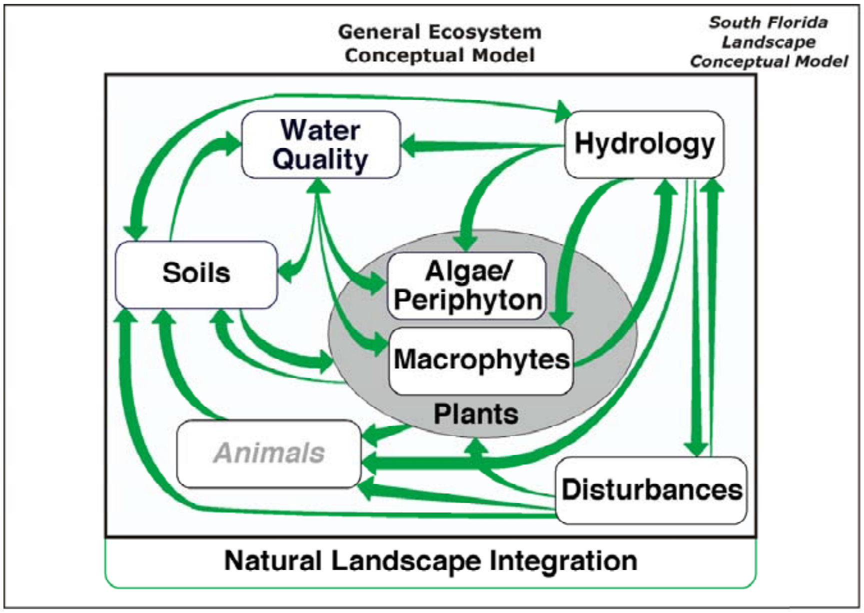
3.3.7 Animals



Animal *communities tend to integrate and respond to many of the factors that change the habitat mosaic of the landscape. Different populations of animal species have distinct reproductive and migratory habits that result in complex seasonal, annual, and decadal shifts in their population viability as the landscape evolves.*

The current Everglades Landscape Model does not consider animal dynamics, simulating only their habitat landscape. The ELM assumes that the higher trophic levels respond to changes in habitat, without the animal communities affecting the regional landscape changes over long time periods. Although most animals do not appear to significantly affect ecosystem processes or landscape patterns, some modify local habitats at small spatial scales, such as the development of ponds excavated by alligators for nesting, or local nutrient enrichment from colonies of birds. Wading birds are one of the conspicuous animals that thrive in the various hydrologic and habitat gradients of the Everglades. They respond to changing water levels and availability of (fish and other) prey, and can select for subregions throughout south Florida as conditions change among seasons and years. While fish are capable of migrating within regions of suitable hydrology and habitat, they obviously become limited in range, (and potentially more available as prey), as a region dries out. Many Everglades fish are omnivorous, feeding on a variety of detrital and invertebrate food sources. The nature of the interactions among animal populations, and among animals and their habitats, is one (very dynamic) indicator of the "health" of the landscape.

3.3.8 Integrated landscape

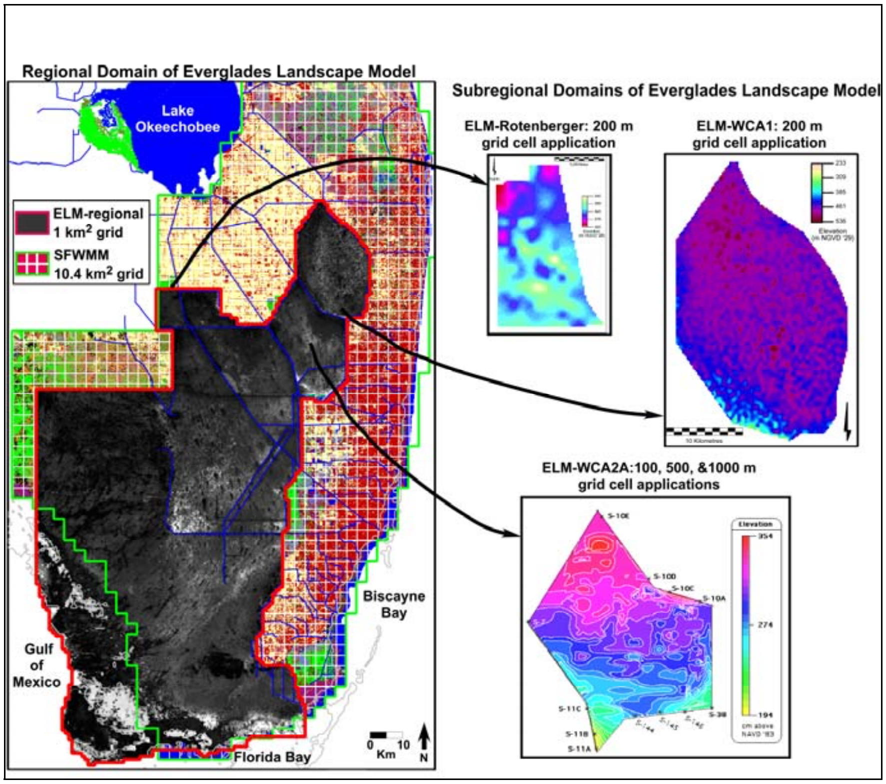


*An **integrated landscape** perspective allows us to synthesize the principal aspects of this dynamic system. The interactions among the ecological processes modifies the landscape pattern, while there is a critical effect of this pattern on the nature of these ecosystem processes themselves.*

Many research projects are conducted at relatively small scales in the laboratory or the "field". By formally aggregating and extrapolating some of these data, simulation modeling and other landscape-level analyses (such as those associated with the Everglades Landscape Model project) facilitate our understanding of the spatial and temporal interactions of this complex system. As part of this procedure, mapping the vegetation and soils gives a spatial perspective on the landscape pattern. To understand temporal interactions, many research projects provide insights on the mechanisms underlying the rates of change in soils, habitats, animals, and landscape drivers such disturbances, hydrology, and water quality. Simulation models allow us to further develop hypotheses on the landscape dynamics over long time scales, and can be used to make relative predictions of landscape responses at the appropriate temporal and spatial scales of interest.

Documentation of the
Everglades Landscape Model:
ELM v2.5

Chapter 4: Data



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July 10, 2006

Chapter 4: Data

4.1 Overview

There are three primary types of data used in modeling projects: observed input data, observed “target” data, and simulated (output) data. The principal focus of this Chapter is on documenting the observed data that were used in the project, fully describing the input data that affect the model dynamics. Additionally, at the end of this Chapter are summaries of the observed “target” data that were used to assess model performance.

The simulated data that are output by the model are described in the User’s Guide Chapter, in which output selection and interpretation are covered. The Chapter on Model Performance Assessment compares simulated data to observed data, while the Chapter on Uncertainty describes some of the important uncertainties associated with both simulated and observed data. *The Uncertainty Chapter is an essential component of understanding the model, data, and concomitant performance expectations of the ELM.*

Domain & static attributes

The spatial domain (grain and extent) of ELM is defined by an input map, and the vectors and points (grid cells) of the water management infrastructure are superimposed on this raster map via inputs from two databases. Two other databases contain the model parameters: one documents the parameters that are global across the domain, while the other contains parameters that are specific to the habitats distributed across the domain.

Initial conditions

These habitats (defined by macrophyte communities) are initialized by an input map, as are other dynamic spatial variables that involve water depths, soil nutrients, land surface elevation, and macrophyte biomass. In the current version, variables such as periphyton biomass and nutrient content are initialized by calculations involving global and/or habitat-specific parameters (i.e., without specific input maps).

Boundary conditions

The dynamic drivers of the model include spatially explicit, historical time series of rainfall, potential evapotranspiration, stage along the periphery of the domain, water flows through all managed water control structures, and nutrient concentrations associated with inflows into the model domain.

Data usage

The model was designed to provide the flexibility of modifying the scenario(s) of simulation entirely through Open Source database files, without need to modify the source code of the model. While we necessarily provide details on the derivation of some of the data in this documentation Chapter, the metadata associated with all data sources should impart a sufficient degree of understanding for their usage. An overview of the input methods for these data is provided in the Model Structure Chapter of this documentation, while the User’s Guide Chapter describes the relatively simple steps necessary to run model applications.

4.1.1 Metadata

All of the input data files used in the model have metadata directly associated with them in the project data directories. Those metadata provide the information necessary to use and interpret the input data files in model applications, while this documentation Chapter serves to expand on the metadata by further detailing the sources and derivation of the data themselves. The following table lists all of the files that are input to the ELM and described in this Chapter[1].

Type	Input filename	Description
Model domains		
	ModArea	Define spatial domain
	gridmapping.txt	Link coarse-fine grids
Initial condition maps		
	icSfWt	Initial surface water
	icUnsat	Initial unsaturated water
	Elevation	Initial land elevation
	Bathymetry	Initial (and constant) creek bathymetry
	soilBD	Initial (and constant) soil bulk density
	soil_orgBD	Initial (and constant) soil organic bulk density
	soilTP	Initial soil phosphorus
	HAB	Initial habitat type
	icMacBio	Initial total macrophyte biomass
Boundary conditions		
	BoundCond	Grid cells allowing boundary flows
	BoundCond_stage.BIN	Boundary stage/depth time series
	rain.BIN	Rainfall time series
	ETp.BIN	Potential ET time series
	CanalData.struct_wat	Structure: water flow time series
	CanalData.struct_TP	Structure: phosphorus conc. time series
	CanalData.struct_TS	Structure: salt (chloride) conc. time series
	CanalData.graph	Recurring annual time series of tide height
Static attributes		
	CanalData.chan	Canal/levee parameters/locations
	CanalData.struct	Water control structure attributes
	basins	Basin/Indicator Region locations
	basinIR	Basin/Indicator Region hierarchy
	GlobalParms_NOM	Parameters: global
	HabParms_NOM	Parameters: habitat-specific
	HydrCond	Parameters: hydraulic conductivity

---

[1] Two other files, outside of the Project's "Data" directory in the "RunTime" directory, are input to the model and serve to configure the model at runtime. See the User Guide Chapter for information on the "Driver.parm" and "Model.outList" configuration files.

4.2 Model domains

4.2.1 Spatial domain

The ELM can be applied at a variety of grid scale resolutions and extents without changing any source code. For an application at a particular spatial grain and/or extent, the following data files are used to define the model at the desired scale: 1) the appropriate grid resolution/extent of each of the map input files; 2) the grid resolution and geographic (upper left) origin in the two databases that define the canal/levee locations and water control structure attributes; and 3) the linked-list text file that maps coarser-grid data to the selected model application. The User Manual Chapter explains these steps needed to develop an application at a new spatial resolution/extent.

All spatial data are referenced to zone 17 of the Universal Transverse Mercator (UTM) geographic coordinate system, relative to the 1927 North American Datum (NAD).

4.2.1.1 Regional domain (infile = "ModArea")

The focus of this review is on the regional application of ELM to the greater Everglades region, from the northern Everglades marshes along the Everglades Agricultural Area to the mangroves along Florida Bay and the Gulf of Mexico. This region is generally restricted to the "natural" areas of the greater Everglades, including all of the Water Conservation Areas, Holey Land, Rotenberger Tract, most of Everglades National Park, and most of Big Cypress National Preserve (Figure 4.1). This regional application uses 1 km^2 square grid cells that encompass an area of 10,394 km^2 (4,013 mi^2). All of the maps of the regional application are bounded by the following rectangle of UTM coordinates in zone 17 (NAD 1927):

northing:	2,953,489 m
southing:	2,769,489 m
easting:	580,711 m
westing:	472,711 m

4.2.1.2 Subregional domains (infile = "ModArea")

The domains of existing sub-regional applications of the ELM are displayed in Figure 4.1. The grain of these subregional applications in the Rotenberger Tract and WCA-2A includes square grid dimensions of 100 m, 200 m, 500 m, and 1 km.

4.2.1.3 Multi-scale grid-mapping (input = "gridmapping.txt")

A variety of dynamic boundary condition data may be input from coarser model grids. The ELM v2.5 uses some dynamic boundary condition data (described in later sections) that are at the scale of the 2x2 mile (10.4 km^2) grid of the SFWMM. For regional or subregional applications of ELM, a "linked list" is generated to map boundary condition data from a coarse grid (usually that from the SFWMM) to the ELM grid. These data are generated from the pre-processor GridMap tool, and input to the ELM via the "gridmapping.txt" file.

4.2.1.4 Basins & Indicator Regions (input = "basins", "basinIR")

The map of the Basins and Indicator Regions (Figure 4.2) defines the spatial distribution of hydrologic Basins and Indicator Regions (BIR). These BIR spatial distinctions do not affect any model dynamics, but are used in summarizing nutrient & water budgets and selected ecological Performance Measures. Budgets and preset Performance Measure variables are output at the different spatial scales defined by the BIR. The Indicator Regions are particularly useful for summarizing model dynamics along ecological gradients.

The largest spatial unit is Basin 0, the “basin” of the entire domain. Hydrologic basins within the domain are regions with either complete restrictions on overland flows (such as Water Conservation Area 1 surrounded by levees) or partial restrictions of overland flows (i.e., Water Conservation Area 3A is bounded by levees except along part of its western boundary). Hydrologic basins are “parent” regions that (may) contain “child” Indicator Regions. Indicator Regions are drawn within a hydrologic basin boundary (but an Indicator Region may not belong to two parent basins). In reporting BIR output data, parent basins’ data include (e.g., sum) the data on all child Indicator Regions contained within them. When re-drawing the BIR (“basins”) map, the user must edit the “basinIR” text file that defines the inheritance characteristics and allowable surface flows of the BIRs (such as the flow allowed to/from Water Conservation Area 3A through the gap mentioned above).

4.2.2 Temporal domain

The ELM can be applied at a variety of time scales, depending on the objective and the availability of boundary condition data. The temporal extent of the historical period used in evaluating model performance (calibration/validation) is 1981 – 2000. The temporal extent of the available meteorological record (used in other CERP modeling efforts) is 1965 – 2000. As detailed later in this Chapter for each boundary condition data file, the temporal grain of these input data is 1-day. As described in the Model Structure chapter, the time step (dt) of the vertical solutions is 1-day, while the time step for horizontal solutions varies with the model grid resolution.

4.3 Initial condition maps

There are a number of map data files that are necessary to implement this spatially explicit landscape model. Those that are used in defining the initial conditions of the simulation were developed using the methods described below for each specific data set. Note that the initial conditions for some variables do not have individual input map files (see the descriptions of the Global and the Habitat-specific parameter databases).

4.3.1 Water depths

4.3.1.1 Surface water depth (input = “icSfWt”)

Output from the ELMv2.1 calibrated hydrology (initialized Jan 1, 1979) provided a snapshot of Jan 1, 1981 for initial ponded surface water depth input to ELMv2.5 (Figure 4.3).

4.3.1.2 Unsaturated water depth (input = “icUnsat”)

Output from the ELMv2.1 calibrated hydrology (initialized Jan 1, 1979) provided a snapshot of Jan 1, 1981 for initial unsaturated storage water depth input to ELMv2.5 (Figure 4.4).

4.3.2 Land surface elevation

We compiled a comprehensive topographic database that included the most up-to-date topographic point data from surveys distributed throughout the greater Everglades. The most extensive surveys, covering most of the greater Everglades, were conducted by the US Geological Survey (USGS) as part of their High Accuracy Elevation Data (HAED) Collection project (Desmond 2004). We used CORPSCON for Windows (v5.11.08) for conversion of horizontal and vertical datums where necessary. For each survey/basin, the ArcGIS (v8.3) TOPOGRID function (without drainage enforcement) was used to generate a Digital Elevation Model (DEM) at a 30 meter grid resolution. For the regional application of ELM, the individual DEMs for each basin were aggregated and mosaiced into a regional coverage (described below).

4.3.2.1 WCA1

Elevations data points were collected in 2004 under the USGS HAED project at 400-meter spacing using a variety of GPS-related techniques. Data were reported using the vertical datum NAVD88 and horizontal datum NAD83. Stated vertical accuracy of the original data was 15 cm overall. Figure 4.5 shows the 30 m DEM for the region.

4.3.2.2 WCA2A

From Oct 1992 to Feb 1993 fifteen iron pipe benchmarks were established throughout WCA2A for vertical and horizontal control by Keith and Schnars Surveyors. Hydrographic survey soundings were taken from the closest surveyed benchmark at 1/2 minute latitude/longitude grid locations. Vertical heights were based on sounding pole measurements ground referenced to water surface. The water surface elevation was determined based on the closest above-mentioned benchmark. Both peat and hard rock ground elevation were calculated. Data were reported using the NAVD88/NAD83 datums. Figure 4.6 shows the 30 m DEM for the region.

4.3.2.3 WCA2B

Because no updated fine-scale data were available, the elevation data used in the South Florida Water Management Model (SFWMM v5.4, 10.4 km^2 grids) were interpolated into 1 km^2 grids.

4.3.2.4 WCA3 North of I-75

LIDAR data was collected in 2000 by Earthdata Aviation Corporation under a USGS contract associated with their HAED project. During the time frame the area was experiencing drought conditions and had recently completely burned, which provided optimum conditions for collecting this type of data. Data was collected over a 5-meter grid system. Initial quality assurance checks using 153 data verification points resulted in an root mean square error of 0.19 m. Data were reported using the NAVD88/NAD83 datums. We removed artifacts in the proximity of roads/levees. Figure 4.7 shows the 30 m DEM for the region.

Recently (December 2005), the LIDAR data have been confirmed to have a bias, the magnitude of which may influence hydrologic modeling. The USGS anticipates that funding will become available during the summer of 2006 to acquire an improved elevation data set for this region using HAED methods.

4.3.2.5 Big Cypress National Preserve

This dataset was assembled by South Florida Water Management District staff for the Southwest Florida Feasibility Study project, using an existing District coverage and available toposheets. Data were reported using the NGVD29/NAD83 datums. Figure 4.8 shows the 30 m DEM for the region.

These elevation data are different from those used in the SFWMM v5.4, and this difference may be reflected in different model performance characteristics in the region. During the summer of 2006, the USGS may be funded to acquire HAED elevation data in parts of this region.

4.3.2.6 WCA3 South of I-75 and Everglades National Park

Elevations data points were collected from 2001 – 2003 as part of the USGS HAED project, with 400-meter sample point spacing using a variety of GPS-related techniques. Data were reported using the vertical datum NAVD88 and horizontal datum NAD83. Stated vertical accuracy of the original data was 15 cm overall. We removed artifacts in the proximity of roads/levees. Figure 4.8 shows the 30 m DEM for the region.

4.3.2.7 Holey Land

Water depth measurements were taken by the Florida Game and Fish Commission during a flat pool stage in 1992. Water depths were measured on a 0.5 minute latitude/longitude grid. Vertical distances were based on sounding pole measurements ground referenced to water surface. A total of 196 measurements were taken. Data were reported using the NGVD29/NAD27 datums. Figure 4.9 shows the 30 m DEM for the region.

4.3.2.8 Rotenberger Tract

Water depth measurements were taken by the Florida Game and Fish Commission during a flat pool stage in 1992. Water depths were measured on a 0.5 minute latitude/longitude grid. Vertical distances were based on sounding pole measurements ground referenced to water surface. A total of 136 measurements were taken. Data were reported in the NGVD29/NAD27 datums. Figure 4.10 shows the 30 m DEM for the region.

4.3.2.9 Regional map (input = "Elevation", "Bathymetry")

To generate the land surface elevation map for input to the regional ELM application, the fine-scale DEM in each basin was converted to a 1 km^2 grid resolution. In each basin, the 30 meter resolution DEM was filtered by averaging elevations in neighboring cells in a moving window of 1 km radius from the 30 meter cell. The filtered DEM was then aggregated into 1 km^2 ELM grid cells for the regional map (Figure 4.11). Because the ELM is set up to read positive values of input maps, negative values of elevation (i.e., approximately below sea level in NGVD 1929) were converted to positive values of creek/estuarine bathymetry as a separate map product.

4.3.3 Soils

Spatial maps of soil initial conditions were generated using standard Kriging, with a Spherical model, to interpolate spatial point observations on local variability within eight subregions. These subregions/basins were generally defined by levees: WCA-1, WCA-2, WCA-2B, WCA-3, WCA-3B, Rotenberger Tract, Holey Land, and the combined regions of Everglades National Park (ENP) and Big Cypress National Preserve (BCNP). Figure 4.12.shows locations of the spatial data points used to develop the maps of the soil variables. The following are the sources of the original data:

- WCA-1, 1991 survey, 94 points. (Reddy et al. 1993) (Newman et al. 1997)
- WCA-2A, 1990 survey, 74 points. (Reddy et al. 1991) (DeBusk et al. 1994)
- WCA-3A & WCA-3B, 1992 survey, 115 & 28 points, respectively. (Reddy et al. 1994a)
- Holey Land, 1993 survey, 36 points. (Reddy et al. 1994b, Newman et al. 1998)
- Rotenberger Tract, 1994 survey, 28 points. (Newman et al. 1998)
- Big Cypress National Preserve, Everglades National Park, and WCA-2B, 1995-1996 survey, 201 points. (Stober et al. 1998)

The initial condition of soils used in the model was within a homogenous zone from the soil/water interface down to 30 cm depth, or to the maximum depth of the peat layer. Interpolations were done by basin according to the following treatments:

- Aggregate 0 – 10 cm, 10-20 cm, and 20 – 30 cm layers of soil by arithmetic averaging
    - Vertical profile constraint: None
    - Basin: WCA-2
- Aggregate 0 – 10 cm with 10 – 20 cm layers of soil by double-weighting the 10-20 cm layer's mass, and arithmetic averaging
    - Vertical profile constraint: absence of 20 – 30 cm layer observations
    - Basins: WCA-1, WCA-3, WCA-3B, and Holey Land.
- Aggregate 0 – 10 cm layer of soil with estimated background levels for deeper layers, using 40 – 80 ug TP • cm^{-3} for layers down to a 30 cm depth, or to the greatest depth of the peat soil.
    - Vertical profile constraint: absence of 10 – 20 cm and 20 – 30 cm layer observations
    - Basins: WCA-2B, Rotenberger Tract, and Big Cypress/Everglades National Park.

4.3.3.1 Bulk density (input = "soilBD")

Soil bulk density was assumed constant for the simulation. Figure 4.13 shows the resulting map of the interpolated soil layer, with the following table containing the parameters in the kriging model.

Region	Number of Samples	Range	Nugget	Partial Sill	Sill
WCA1	85	14232	0.000260	0.000247	0.000506
WCA2A	74	17720	0.000277	0.000825	0.001102
WCA2B	11	9925	0.000245	0.004645	0.004891
ROTEN	31	2100	0.003905	0.005208	0.009113
HOLEY	36	11853	0.024584	0.022585	0.047169
WCA3	155	27893	0.012846	0.029237	0.042083
WCA3B	28	17720	0.000785	0.001280	0.002065
ENP/BCY	204	27893	0.024848	0.028166	0.053014

4.3.3.2 Organic bulk density (input = "soil_orgBD")

The organic bulk density is the bulk density of only the organic (ash-free) mass of the soil layer[2]. Figure 4.14 shows the resulting map of the interpolated soil layer, with the following table containing the parameters in the kriging model.

Region	Number of Samples	Range	Nugget	Partial Sill	Sill
WCA1	85	20590	0.000123	0.000111	0.000234
WCA2A	74	23707	0.000041	0.000111	0.000152
WCA2B	11	11359	0.000765	0.000495	0.001260
ROTEN	31	2091	0.000872	0.001875	0.002746
HOLEY	36	4962	0.000000	0.000200	0.000200
WCA3	155	39925	0.000158	0.000588	0.000745
WCA3B	28	9251	0.000288	0.000211	0.000500
ENP/BCY	204	17546	0.000603	0.000248	0.000852

4.3.3.3 Total phosphorus concentration (input = "soilTP")

The initial concentration of soil total phosphorus was estimated from observations of Davis (1989) in WCA-2A from the late 1970's[3], and data on the current concentration in deep soil layers (that are relatively un-impacted by recent anthropogenic inputs). Figure 4.15 shows the resulting map of the interpolated soil layer, with the following table containing the parameters in the kriging model.

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[2] (1-(percent_ash/100))*soilBD, where percent_ash is the percent of ash weight relative to entire core weight

[3] Maximum in northern WCA-2A was approximately 300 mg TP kg^{-1}

Region	Number of Samples	Range	Nugget	Partial Sill	Sill
WCA1	85	19849	24196	8508	32704
WCA2A	74	9917	19385	52156	71541
WCA2B	10	9925	1114	1902	3015
ROTEN	31	5431	1001	1725	2726
HOLEY	36	3910	18676	7462	26138
WCA3	155	11849	9420	2720	12140
WCA3B	28	23707	5224	3822	9045
ENP/BCY	204	14508	14802	7374	22176

4.3.4 Vegetation

4.3.4.1 Habitat type (input = “HAB”)

To create a regional habitat map, data from six major vegetation classification efforts were used (Figure 4.16):

- WCA-1, 1987 satellite interpretation. (Richardson et al. 1990)
- WCA-2A, 1995 photo interpretation. (Rutchey and Vilchek 1999)
- WCA-3, 1995 photo interpretation. (Rutchey et al. *in review*)
- Everglades National Park & Big Cypress National Preserve (ENP & BCNP), 1995 photo interpretation. (Welch et al. 1999)
- Rotenberger Tract, 1992 photo interpretation. SFWMD, unpublished data.
- Other subregions, 1995 FLUCCS photo interpretation. Unpublished update of FLUCCS (1985)

These photo-interpreted vegetation classes were aligned (“cross-walked”) among the projects, and mosaiced into a fine scaled regional map. In this process, the more detailed vegetation classes from these studies were aggregated into more general classes. The map was then spatially aggregated to a 1 km^2 grid scale using majority-rules, producing a regional habitat map of 28 classes for the ELM domain (Figure 4.17).

Moreover, several map features were developed beyond those in the original observations. The distinct Ridge and Slough (RS) habitat in Shark River Slough of Everglades National Park was delineated by satellite-based habitat classes from the Florida Gap Analysis Project (GAP[4]). The landscape characteristics of the finer-scale RS heterogeneity in some of the more pristine RS habitats was captured at the 1-km^2 model scale by spatial pattern analyses. A moving window scanned across fine-scale (100 m) habitat data, and calculated an index of relative heterogeneity. This index was used to define the degraded vs. more pristine RS habitats. In the current ELM v2.5[5], the habitat succession module is not executed, and thus the habitat types remain constant during the simulation.

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[4] **http://www.wec.ufl.edu/coop/GAP/lcmapping.htm**

[5] See Fitz and Sklar (1999) for ELM v1.0 habitat succession dynamics in WCA-2A.

4.3.4.2 Macrophyte biomass (input = “icMacBio”)

The initial total carbon biomass (of photosynthetic and non-photosynthetic components) of macrophytes was estimated at approximately 25-35% of the habitat-specific maximum biomass (parameter in HabParms database), with the within-habitat variation based on the estimated soil nutrient gradient in 1981 (described above for soils). This coarse adjustment was made by running the model for one year (1981) under all of the other imposed initial and boundary conditions described above, and then using the resulting biomass for subsequent initial biomass conditions (Figure 4.18). An refined spatial map of initial biomass may be produced for future model versions, using an approach based on NDVI (Normalized Difference Vegetation Index) from available remote sensing products.

4.4 Static attributes

4.4.1 Water management infrastructure

4.4.1.1 Canal and levee network (input = “CanalData.chan”)

The canals and associated levees are defined in a text data file (CanalData.chan) that is input to the model. This data file provides attributes of precise geographic canal-reach vector locations and the multiple attributes of these canal reaches. The file is created/maintained using a vector-capable GIS (GRASS). Scripts are used to input the data into the GRASS GIS for any desired pre-processing, including visualization.

All geographic coordinates use (the metric units of) UTM zone 17, North American Datum of 1927. In ELMv2.5, there are over 90 individual canal reaches, each identified by a numeric ID. Figure 4.19 displays the canal reach topology for the entire domain of the regional implementation. In the southern Everglades, tidal creeks (and open water tidal boundaries) are represented with these vector hydrologic attributes (with tidal inputs described in a later section). Increased detail in Water Conservation Areas 1 and 2 is shown in Figure 4.20, and Figure 4.21 shows the increased detail needed in northern Water Conservation Area 3A.

The format of the file is detailed in its associated metadata file, “CanalData.chan.info”. A canal reach is defined as a continuous vector object, usually (but not necessarily) associated with an upstream and a downstream water control structure. A reach is comprised of one or more line segments using geographic (UTM) coordinates for each beginning and ending point of a segment. Thus, a canal reach may be as simple as a straight line, or have the complexity of rounded curves or angular bends. The attributes defined for each canal reach are assumed to be homogenous along its entire length.

- Levee location: proceeding from first coordinate in the reach coordinate list to the last in the list, the levee location attributes are integers as follows:
    - 1 = levee is to left of canal
    - 0 = levee is not present (no levee)
    - -1 = levee is to right of canal
    - 2 = levees are on both sides of canal
- Depth (m) of the canal reach, from canal bottom to rim of canal

- Width (m) of the canal reach (square cross-sections only); a NEGATIVE width indicates that the canal reach is inoperative (ignored)
- Seepage coefficient, or hydraulic conductivity of levee (m/d)
- Initial salt/tracer concentration (g/L)
- Initial total phosphorus (TP) concentration (mg/L)
- Initial water depth (m)
- Surface roughness associated with any lip/berm along a reach (d/(m^(1/3)))
- Identifier of the hydrologic basin with which the reach has overland flow interactions (does not effect flux calculations, used only in budget summaries)
- Comments on the canal reach, including brief description of location and usage

4.4.1.2 Water control structures (input = "CanalData.struct")

The attributes of all water control structures are maintained in a relational database using "FilemakerPro" software. This FilemakerPro database, "Structs_attr_v2.5.fmp", is found in the ./SME/Projects/Dbases directory. The database allows the user to select the scenario/alternative that is to be simulated, such as a historical calibration run or an Alternative to be evaluated for projects such as CERP. The functionality of the database greatly simplifies the development of new water management alternatives for Project evaluations, and includes capabilities such as the calculation of grid cell locations for any model scale (grain and extent) using geographic coordinates.

After making the simple query to select the water control structures for the desired simulation, the data are exported into a plain text file for input to the model. Figure 4.22 displays a database snapshot of the attributes for all of the water control structures used in the historical (calibration/validation) runs of ELM v2.5.

The text input file, CanalData.struct, provides attributes of all water control structures used in the model. This text input file is created/maintained using the relational database. Significantly more details on the attributes are found in the relational database; the text metadata CanalData.struct.info file provides basic descriptions of the data fields for each water control structure (record) that is input to the model.

The following are field descriptors for this input file:

- *Driver*: integer attribute indicating how model uses the structure:
    - -1 = structure is inoperative, ignored in the model
    - 0 = structure is a calculated virtual structure (rule-based, not driven by input data time series)
    - 1 = structure is driven by a time series of data, either observed data or data from another model
    - >1 = structure is an aggregated (total, summed) flow generally for a group of structures (e.g., S11=sum of S11A, S11B, S11C), and that flow is disaggregated into equal partitions: integer 2-9 (e.g., "2" for S11 total flow) denotes a structure holding the aggregated flow, while 10x that single-digit integer (e.g., "20" for each of S11A, S11B, S11C) denotes one of multiple structures that will have equal-partitions of the total flow (e.g., S11A, S11B, S11C flow will each be 1/3 of the total S11 flow, and applied in the correct spatial location)

- *aaName*: name of structure as used in model
- *TP*: Total Phosphorus concentration (ug/L) associated with water flows at this structure; a number denotes the constant concentration to apply to all flows, while the string "tser" denotes that the structure is expected to have time-series data (in "CanalData.struct_TP") for each daily flow value
- *TN*: Total Nitrogen concentration (ignored/unused)
- *TS*: Total Salt/tracer concentration (g/L) associated with water flows at this structure; a number denotes the constant concentration to apply to all flows, while the string "tser" denotes that the structure is expected to have time-series data (in "CanalData.struct_TS") for each daily flow value
- *St_N*: Structure location, the Northing (row) grid cell number (used only to obtain land surface elevation for virtual structure calculations)
- *St_E*: structure location, the Easting (column) grid cell number (used only to obtain land surface elevation for virtual structure calculations)
- *C-fr*: Canal from (i.e., source) which water flows through this structure (or blank)
- *C-to*: Canal to (i.e., destination) which water flows through this structure (or blank)
- *ClNfr*: Northing grid Cell number (row) from (i.e., source) which water flows through this structure (or blank)
- *ClEfr*: Easting grid Cell number (column) from (i.e., source) which water flows through this structure (or blank)
- *ClNto*: Northing grid Cell number (row) to (i.e., destination) which water flows through this structure (or blank)
- *ClEto*: Easting grid Cell number (column) to (i.e., destination) which water flows through this structure (or blank)
- *HW*: HeadWater (source) stage (numeric values unused/obsolete); only use is in tide-based virtual structures, containing text string which identifies the CanalData.graph headwater time series of stage
- *TW*: TailWater (destination) stage (numeric values unused/obsolete); only use is in tide-based virtual structures, containing text string which identifies the CanalData.graph headwater time series of stage
- *ClHWN*: Unused
- *ClHWE*: Unused
- *ClTWN*: Northing grid cell row number to check for tailwater depth in boundary condition virtual structures
- *ClTWE*: Easting grid cell column number to check for tailwater depth in boundary condition virtual structures
- *Flow_c*: Flow coefficient (m^3/d), used only in virtual structure flow calculations; originally a weir-flow calculation, value is currently just a large number to accommodate nearly-instantaneous flow of the volumetric flow potential

4.4.2 Model parameters

Because the ELM is a spatially distributed model of the fundamental properties of ecosystems, it necessarily uses a relatively large number of parameters to define rates, initial conditions, and various other system attributes. The parameters are not "hard-coded" into the model source code, but organized within user-friendly databases. To accurately communicate the data requirements of the model, the parameters should first be classified according to their spatial distributions, their importance in influencing model results, and according to the degree to which they can be supported by available research.

Their spatial distribution, if any, is a fundamental component of these data. There are no more than approximately 40 individual parameters that are important to model results and that impose data acquisition needs. Some of these parameters are distributed in some spatial context. The spatial distributions range from those that are spatially-constant, those that are distributed among habitat types across the landscape, and parameters that are distributed among individual grid cells across the landscape. A previous section (describing the water management network) documented the parameter attributes of the water control structures and canal/levee vectors. The remaining ecological parameters in the three spatial classes are documented in the following sections.

While there are decades of monitoring and research activities in the greater Everglades, the past 5-10 years has dramatically increased our knowledge of system properties. Many of the parameters in use in the current ELM v2.5 have not been updated from ELM v2.1, and we anticipate that the next version of ELM will significantly advance our synthesis of this base of knowledge of the Everglades.

4.4.2.1 Global parameters (input = "GlobalParms_NOM")

Global parameters are those that apply uniformly throughout the spatial domain of the model. These parameters are documented and maintained within the OpenOffice (= MS Excel) database/workbook "GlobalParms_v2.5.xls". This parameter database contains the following fields for each parameter:

- *Rank*: a ranking of the relative importance (sensitivity) of each parameter
- *Parameter name*: the name of the parameter as used in model code
- *Nominal Value:* the value of the parameter that was selected by the user
- *Units:* the units used in the numeric value of the parameter
- *Default Value*: the default value used in calibrating/validating the current ELM
- *diff?:* A warning flag to denote the selected value of differs from the default value
- *Brief documentation:* brief description of the parameter definition
- *Extended documentation:* extended description of the parameter, including applicable literature sources.

Figure 4.23 shows a snapshot of the primary worksheet used in this database, including all of the global parameters. The GlobalParms_v2.5.xls database also contains worksheets (not displayed here) that automate the selection of high and low values of the parameters that are used in the automated sensitivity analysis (whose results are described in the Uncertainty Chapter, with instructions on user-implementation in the User's Guide Chapter). Of the 70 global parameters, 30 are unused or not intended to be modified except in model sensitivity experiments. A total of 23 of the 70 global parameters have the potential to affect, to at least a very small but observable extent, the hydrologic and water quality Performance Measures being considered[6] (see Uncertainty Chapter). Six of those 23 potentially- important parameters have significant effects on multiple Performance Measures.

4.4.2.2 Habitat-specific parameters (input = "HabParms_NOM")

Habitat-specific parameters are those that apply only to the specified habitat type within spatial domain of the model. These parameters are documented and maintained within the OpenOffice (= MS Excel) database/workbook "HabParms_v2.5.xls". This database is somewhat more complex than that of the GlobalParms, with multiple parameters per record (a record with multiple parameter fields for each habitat) compared to one parameter per record in the former. This parameter database contains the following fields for each parameter:

- *Rank*: a ranking of the relative importance (sensitivity) of each parameter
- *Parameter name*: the name of the parameter as used in model code
- *Nominal Value:* the value of the parameter that was selected by the user
- *Units:* the units used in the numeric value of the parameter
- *Documentation:* description of the parameter, including applicable literature sources.

Figure 4.24 shows a snapshot of the primary documentation (definitions) worksheet used in this database, with all of the parameters listed. The OpenOffice/Excel (HabParms_v2.5.xls) database can be used to view the parameter values and their associated documentation. The database also contains worksheets that automate the selection of high and low values of the parameters, used in the automated sensitivity analysis (whose results are described in the Uncertainty Chapter, with instructions on user-implementation in the User's Guide Chapter). Of the 40 habitat-specific parameters, 5 are unused in this version of the model. A total of 13 of the 40 habitat-specific parameters have the potential to affect, to at least a very small but observable extent, the hydrologic and water quality Performance Measures being considered[7]. Of those 13 "important" parameters, one (1) has significant effects on multiple Performance Measures.

While each of the 40 habitat-specific parameters may have unique values for each of 28 habitats considered in the model (i.e., 1120 potentially unique values), such unique-by-each-habitat distributions do not exist for any of the parameters. The actual number of unique parameter values in the entire matrix is less than 140 (calculated in HabParms_v2.5.xls), with the most complex distribution of a single parameter across habitats having unique values for less than half of the habitats. When considering only the 13 "important" parameters, the actual number of unique values is 64, across all 28 habitats. Finally, only half (14) of the total number of habitats comprise >90% of the region of the ELM domain. Thus, in general, *there is, in total, on the order of several dozen unique-by-habitat values that may be important to quantify for model application*.

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[6] Those performance measures are water depth, and TP concentration in surface and in pore water. For details on the analyses, see the Sensitivity Analysis section of the Uncertainty chapter of this documentation.

[7] Ibid.

Of those parameters that we do assign unique values, basic field observations are used to support the parameter values. Generally, habitat-distributions of parameters are limited to differences among broadly defined ecosystem types involving *sedge, forest, savannah, and scrub* type habitats. Within an ecosystem type, any (usually limited) variation employs simple field-supported modifications of parameters according to the following: 1) slight modifications of maximum macrophyte biomass and related parameters along a gradient (e.g., the 3 cattail habitats of high, medium, and low density), 2) replication of data from one habitat type to values for a similar habitat, differing in one or two primary attributes (e.g., from a simplistic perspective, *Juncus* and *Cladium* could differ primarily in salt tolerance, with some limited structural parameter differences), and 3) specific field research and monitoring data that supports the use of distinctions among the attributes of different habitats.

Instead of supporting a parameter database that includes such a large number (28) of habitat types for 40 parameters (in a 2D array of parameters), we could obtain the same or similar model results in the current water-quality oriented version by simply not including all of the fundamental habitat types. This is attractive in terms of reducing the apparent complexity of the ELM via a smaller 2D array of parameters, but would do little to decrease the actual complexity in terms of the data that currently populates the 2D array of parameters. As discussed, the large majority of parameter values are the same for multiple habitat types, and thus the numerical complexity of such a large array is never realized. Moreover, a reduction of the number of habitat types would require increased maintenance of spatial and parameter databases, as future model updates include increased levels of differentiation among ecological dynamics of soils, periphyton, macrophytes, and habitat succession. Whereas we can currently simply improve the parameter values as data become available, the alternative is to incrementally modify both the habitat type map and the number of records supported in the database. The bottom line: from a model development and refinement perspective, it is attractive to maintain the two-dozen habitat types currently defined as the minimum (that only begins) to represent the regional heterogeneity across the greater Everglades.

We have taken a *simple approach that generally assumes a high degree of similarity among most habitats, while providing a database mechanism to recognize differences in attributes where they are important,* either currently or in the future. Regardless of the database implementation of habitat-specific parameters, that assumption of broadly-based habitat-similarity will remain until increased knowledge supports more refined distinctions in the heterogeneity of the greater Everglades.

4.4.2.3 Aquifer hydraulic conductivity (input = “HydrCond”)

The map of hydraulic conductivity (Figure 4.25) used in the groundwater flux calculations is a static, spatially distributed parameter (i.e., can potentially have unique values for each of 10,394 grid cells). The hydraulic conductivity (permeability) and aquifer depth data are the same input data used in the (10.4 km^2 grid of) SFWMM v5.4, interpolated to the 1 km^2 ELM grid. Because the base datum (below 0 m NGVD 1929 sea level) used in ELM is chosen to be 6.0 meters (changeable in the GlobalParms database), the hydraulic conductivity was modified to account for the extent to which surficial aquifer depth exceeds the ELM base datum depth: the hydraulic conductivity was multiplied by the ratio of the aquifer depth to the ELM base datum depth.

4.5 Boundary conditions

4.5.1 Meteorological

4.5.1.1 Rain (input = "rain.BIN")

Rainfall input to the model is the spatial time series data developed by SFWMD staff for use in regional models such as the South Florida Water Management Model (SFWMM) and Regional Simulation Model. The data file used in ELM v2.5 was "rain_v2.0_nsm_wmm.bin", identical to the data used in the SFWMM v5.4 (but renamed for ELM input). The 2 dimensional grid data has a ~10.4 km2 grid cell resolution (2 miles by 2 miles). The spatial extent encompasses most of the ELM domain; in the southwest Everglades (mangrove region), missing data were filled in with the nearest grid cell to the easterly direction that contained data. The temporal resolution is daily summed rainfall. The temporal extent spans the period 1965-2000 (inclusive). A variety of techniques were used to accommodate missing data and to spatially interpolate (using a Triangular Irregular Network method) observations at point rainfall monitoring locations. Details on methods used to generate the data are available in the SFWMM v.5.4 documentation.

4.5.1.2 Evapotranspiration (input = "ETp.BIN")

Potential evapotranspiration (ETp) input to the model is the spatial time series data developed by SFWMD staff for use in regional models such as the South Florida Water Management Model (SFWMM) and Regional Simulation Model. The "grid_io" format data file used in ELM v2.5 was "ETp_recomputed_tin_wmmgrid.bin", identical to the data used in the SFWMM v5.4 (but renamed for ELM input). The 2 dimensional grid data has a ~10.4 km2 grid cell resolution (2 miles by 2 miles). The spatial extent encompasses most of the ELM domain; in the southwest Everglades (mangrove region), missing data were filled in with the nearest grid cell to the easterly direction that contained data. The temporal resolution is daily summed potential evapotranspiration. The temporal extent spans the period 1965-2000 (inclusive). A variety of techniques were used to accommodate missing data and to spatially interpolate (using a Triangular Irregular Network method) observations at point ETp monitoring locations. Details on methods used to generate the data are available in the SFWMM v.5.4 documentation.

4.5.2 Hydrologic

4.5.2.1 Flow constraints (input ="BoundCond")

Figure 4.26 shows the input map that defines the type of boundary flow calculations (groundwater and/or surface water) that were allowed along the ELM domain border.

4.5.2.2 Stage/depth (input = "BoundCond_stage.BIN")

Using output from the SFWMM v5.4 calibration and verification runs (1981-2000), we obtained daily water depths from SFWMM grid cells that were adjacent to the ELM boundary grid cells. The positive (above land surface) or negative (below land surface) water depths were used (Model Structure Chapter) in head-based flow calculations along this domain boundary. These calculated cell-to-cell flows are in addition to the (imposed) flows through managed water control structures that are described in a subsequent section of this Chapter.

4.5.2.3 Tidal height (input = "CanalData.graph")

In the southern and southwestern region bordering Florida Bay and the Gulf of Mexico Figure 4.26, boundary flows were mediated by tidal exchanges with major rivers/creeks and estuaries. For ELM v2.5, the tide (stage) heights were simply annually-repeating, monthly mean tide heights (using the same concept as input data to the SFWMM v5.4). We used a development version (April 2006) of the data used in the South Florida Regional Simulation Model (SFRSM) development. Daily (NOAA predictions of) tidal amplitudes were summarized into monthly mean values at three locations: Everglades City (northern mangrove region), Flamingo (central/western Florida Bay), and Manatee Bay (extreme-eastern Florida Bay[8]). The tidal fluctuations were input to "virtual structures" (see Model Structure Chapter) to impose tide heights onto the boundary vectors. (Monthly data points were interpolated to daily values within the model). The model boundary vectors along the Florida Bay and Gulf of Mexico exchanged flows with interior river/creek vectors via inter-reach virtual structures.

The spatial distribution of tide observations may be input to any discretizaton of the vectors and virtual structures, and longer periods of observation may also be incorporated. However, the freshwater stage gages that we current target for evaluating model performance were at significant distances from tidal sources (see Performance Assessment Chapter), and the model results at the currently targeted gage locations were relatively insensitive to increases or decreases in tidal amplitude. As indicated in the Chapter on Model Refinements, we anticipate extending the formal evaluation of the model into the mangrove-dominated regions, acquiring enhanced data sets to drive the tidal dynamics.

4.5.2.4 Managed flows (input = "CanalData.struct_wat")

All water flows through managed water control structures within the model domain were "imposed" as data-derived, daily forgings. Historical flows through managed water control structures for the 1981 – 2000 period of record were obtained from the SFWMD "DBHYDRO" database (SFWMD 2005). As described elsewhere (Akpoji et al. 2003) (Damisse and Raymond 2000), these flows were derived from either direct flow estimates through pump structures, or calibrated flow estimates based on head and tail waters at structures such as weirs. With the exceptions noted below, all data were extracted[9] using a database field identifier ("dbkey") that denoted data that had undergone extensive quality assurance/control for use in regional modeling, and especially for the SFWMM.

There were two types of exceptions to the direct use of historical data found in that regional modeling dbkey of DBHYDRO: 1) cases where (flows through) multiple water control structures were aggregated into a single "structure" flow for regional modeling; and 2) cases where observed data were either unavailable in the database or known to be unreliable/inaccurate.

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[8] this station is east of US Highway 1, and its direct application to ELM boundary conditions in Florida Bay may need further refinement.

[9] all data with database revision date on or before 09/05/2003

There were two cases in which it was necessary to disaggregate a single combined flow into multiple flows through separate structures. This was considered important because the actual structures were separated by distances on the order of 5-10 km, and the nutrient flows associated with individual (disaggregated) structures had concomitant spatial distinctions that were important to ecological dynamics. One such combined flow was that of the S10 structures (S10A + S10C + S10D), and the other combined flow was that of the S11 structures (S11A + S11B + S11C). We partitioned the S10 total flow into separate S10A, S10C, and S10D flows according to the daily flow ratios found in another database field identifier ("preferred" dbkey) for each individual structure. Similar calculations were done for the S11 combined flow, partitioning that into separate S11A, S11B, and S11C flows. Thus, the sum of the disaggregated flows for each set of structures remained consistent with the flow data that was quality-assured for regional modeling purposes, while maintaining the actual relative differences among individual structures.

The other type of exception to use of historical flows from the DBHYDRO database involved structures with either extensive missing data, or data that was found to be inaccurate after extensive checking by data users and/or other regional modeling efforts (Santee *pers. comm.*). For the ELM v2.5 historical simulation, we used water control structure flows from the SFWMM v5.4 in a number of cases. In some cases such as S-339 and S-340 (in WCA-3A), the data are known to have extensive missing data and/or erroneous flow estimate calculations (likely due, for example, to difficulties in site access). For ELM v2.5, any water control structure flow that was available as output from the SFWMM v5.4 was used in place of the data from DBHYDRO.

Table 4.1 provides the names of all of the managed water control structure flows that were used in ELM v2.5 simulations, and denotes whether the data source was that of DBHYDRO or SFWMM calculations (including the "dbkey").

4.5.3 Nutrient/constituent inflows

4.5.3.1 Atmospheric nutrient deposition

To estimate atmospheric deposition of total phosphorus (TP) into the model domain, we applied a spatially- and temporally- constant concentration of total phosphorus to all rainfall events. With the rainfall distributed heterogeneously across time and space, the concentration was selected[10] that resulted in a long-term mean deposition rate of approximately 25 mg-TP m^{-2} yr^{-1}. This rate is consistent with that used by Walker (1993), and is intermediate between low values (ca. 10-15 mg-TP m^{-2} yr^{-1}) reported in the interior of the Everglades (Ahn and James 2001) (Walker 1999), and higher values (ca. 30-50 mg-TP m^{-2} yr^{-1}) reported outside of the periphery of the Everglades (Ahn and James 2001).

For use in versions subsequent to ELM v2.5, we further analyzed the Everglades data (Walker 1999) (Ahn and James 2001) to develop a spatially distributed model of the long-term daily mean total (wet plus dry) deposition. This deposition rate will be applied

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[10] GlobalParms database parameter "TP_IN_RAIN" = 0.20 mg/L

as a single map of the daily deposition rate that is distributed relative to the apparent local sources.

4.5.3.2 Phosphorus in structure inflows (input = "CanalData.struct_TP")

The concentration of nutrients and other constituents (i.e., chloride) must be known for the water volumes associated with all flows through water control structures. Total phosphorus (TP) concentration in the source water is always known (via internal model calculations) for all structure flows whose source waters are within the active domain of the model. For flows whose source water was external to the model domain, the concentration associated with each daily flow volume was imposed through input time series data.

For these inflow structures, we obtained estimates of the TP concentrations for all daily inflow volumes. A major constraint on developing this ~continuous time series of concentration was the (generally) very low frequency of water quality sampling relative to the much more continuous characteristic of water flow. Some sites in this region were monitored for water quality strictly through the use of "grab" samples that were intended to be made at the regular intervals of bi-weekly, monthly, or even longer periods. Very frequently, however, the sampling intervals varied widely among the years and among monitoring sites. Some of the more "important" sites also had automatic composite (over multiple days) sampling devices for water quality, but these autosamplers also had discontinuous records. Thus, regardless of the sampling methods, there were significant temporal gaps in the data records during the historical period of record. These gaps in the time series of concentrations were filled in using the best available method, as described below.

The SFWMD "Load Program" (Mo et al. 2003) was used (Germain pers. comm.) to develop a daily concentration time series for each inflow structure. In deriving daily concentration estimates for any given monitoring site, the "Load Program" 1) preferentially used the daily automated composite samples, if available; and 2) when temporal gaps were encountered in the targeted daily time series, linear interpolations of concentration were made between the two nearest points of autosampler data or grab sample data, depending on availability. In the (relatively limited number of) cases where no concentration estimate was available for an earlier date, the long-term mean concentration was applied uniformly across the initial time gap. In one instance (at the structure G155_W), there was no water quality monitoring associated directly with the flow monitoring site. In this case, the concentration from the upstream L3 (1/1/1981–10/29/1984) and L3BRS (10/30/1984 – 12/31/2000) sites were used in the "Load Program" to estimate the concentration associated with G155_W flows.

The time series of daily concentrations that were obtained with these methods were the best available for this modeling effort, or for any other project that requires estimates of ~continuous nutrient loading to the Everglades. However, *it is critical that users understand the significant uncertainties that these data impart to models or other projects*, particularly at time scales shorter than seasonal or annual. In the Uncertainty Chapter of this documentation, we analyze and discuss how to best understand and make use of these data.

4.5.3.3 Chloride in structure inflows (input = "CanalData.struct_TS")

Another water quality constituent in the ELM is chloride, which is used as a conservative tracer that is input to the model domain solely via water control structures. The concentration of chloride must be known for the water volumes associated with all flows through water control structures. Chloride (CL) concentration in the source water is always known (via internal model calculations) for all structure flows whose source waters are within the active domain of the model. For flows whose source water was external to the model domain, the concentration associated with each daily flow volume was imposed through input time series data.

For these inflow structures, we obtained estimates of the CL concentrations for all daily inflow volumes. A major constraint on developing this ~continuous time series of concentration was the (generally) very low frequency of water quality sampling relative to the much more continuous characteristic of water flow. To obtain daily estimates of CL concentrations, we used the same interpolation methods described above for the phosphorus inputs.

The time series of daily concentrations that were obtained with these methods were the best available for this modeling effort, or for any other project that requires estimates of ~continuous constituent loading to the Everglades. However, *it is critical that users understand the significant uncertainties that these data impart to models or other projects*, particularly at time scales shorter than seasonal or annual. In the Uncertainty Chapter of this documentation, we analyze and discuss how to best understand and make use of these data.

4.6 Performance assessment targets

4.6.1 Hydrologic

4.6.1.1 Stage

Daily observations of stage height (water surface elevation) in marsh monitoring sites were retrieved from the SFWMD DBHYDRO database (SFWMD 2005). These target stage data are the same as those used in assessing the performance of the SFWMM v5.4. The locations of these stage monitoring sites are shown in the Model Performance Chapter, in which we compare model predictions to the observed data.

4.6.2 Water quality

4.6.2.1 Surface water quality constituents

Observations of the water quality constituent concentrations in the water column at water control structure, marsh, and canal monitoring sites were retrieved for total phosphorus (TP) (Hill pers. comm.) and chloride (CL) from the water quality database associated with the SFWMD DBHYDRO database (SFWMD 2005). A summary of these phosphorus data is in Table 4.6.2.1. The locations of these water quality monitoring sites are shown in the Model Performance Chapter, in which we compare model predictions to the observed data.

4.6.3 Ecological

4.6.3.1 Other ecological targets

A variety of other ecological data were acquired from the SFWMD Everglades Division ERDP database. For ELM v2.5, these primarily included additional water column constituent concentration data at the research transects in Water Conservation Area 2A. As noted in the Model Performance Chapter, other specific ecological attributes were summarized from published literature sources.

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4.8 Tables

Three tables (4.1 – 4.3) follow.

Table 4.1. Water control structure names as used in the ELM/SFWMM, with the name & database code used in the DBHYDRO database. The source of daily flow data used in ELM v2.2 - v2.5 simulations is indicated in the last column: “SFWMMv5” indicates use of simulated flows output from the SFWMM v5.4, while “ELMv2.2” indicates the use of the observed data.

Flows updated in the database				Flows used in ELM v2.4 Model Run	
Name	**Sources**			ELMv2.4	sources
ELM dataset	DBKeys	DBHYDRO	Note		
ACME1	PI317	ACME1		ACME12	SFWMMv5
ACME2	PI318	ACME2			
ACMWS	PI321	ACME12WS		ACMWS	SFWMMv5
G155	P1039	G155_W		G155	ELMv22
G204	P1042	G204		G204	SFWMMv5
G205	P1043	G205		G205	SFWMMv5
G206	P1044	G206		G206	SFWMMv5
G250_P	P1046	G250_P		G250_P	ELMv22
G251	P1047	G251_P		G251	ELMv22
G310	M2901	G310		G310	ELMv22
HLYQIN	P1040	G200A_P		HLYQIN	ELMv22
L28WQ	P0974	S190		L28WQ	SFWMMv5
LWDD	P1064	LWDDSUMQ		LWDD	ELMv22
				NSIMP2	SFWMMv5
				NSIMP3	SFWMMv5
				RTECV1	SFWMMv5
				RTECV2	SFWMMv5
S10A	P0795_15261	S10	S10 total(P0795) were distributed according to the ratios of S10 ACD (DBKeys15261,15262,15263)	S10A	ELMv22
S10C	P0795_15262	S10		S10C	ELMv22
S10D	P0795_15263	S10		S10D	ELMv22
S10E	P1066	S10E		S10E	ELMv22
S11A	P1067_15258_JJ856	S11_T	S11 total(P1067) were distributed according to the ratios of S11ABC (DBKeys 1558, 15259, 15260)	S11A	ELMv22
S11B	P1067_15259	S11_T		S11B	ELMv22
S11C	P1067_15260	S11_T		S11C	ELMv22
S-12A	P0796	S12A		S-12A	ELMv22
S-12B	P0950	S12B		S-12B	ELMv22
S-12C	P0951	S12C		S-12C	ELMv22
S-12D	P0952	S12D_S		S-12D	ELMv22
S140A	P0956	S140		S140A	SFWMMv5
				S142E	SFWMMv5
				S142W	SFWMMv5
S143	P0957	S143		S143	ELMv22
S144	P0958	S144_C		S144	ELMv22
S145	P0959	S145_C		S145	ELMv22
S146	P0960	S146		S146	ELMv22
S150	P0961	S150		S150	ELMv22
S151	P0962	S151		S151	ELMv22
S175	P0969	S175		S175	SFWMMv5
S18C	P0973	S18C		S18C	SFWMMv5
S197	P0978	S197_C		S197	SFWMMv5
S31	P0991	S31		S31	SFWMMv5
S332	P0994	S332		S332	SFWMMv5
S333	P0997	S333		S333	ELMv22
S334	P0998	S334		S334	ELMv22
S337	P1001	S337_C		S337	SFWMMv5
	P1003	S339_S		S339	SFWMMv5
S34	P1004	S34	DBHYDRO rev .2003/09	S34	ELMv22
	P1005	S340_S		S340	SFWMMv5
S343	P1006	S343_T		S343	SFWMMv5
S344	P1007	S344		S344	SFWMMv5
S38	P1011	S38		S38	SFWMMv5
S39	P1012	S39		S39	ELMv22
S5A2NO	P1016	S5A+S5AS_T	Negtive (S5A+S5AS_T)	S5A2NO	SFWMMv5
S5A2SO	P1016	S5A+S5AS_T	Positive (S5A+S5AS_T)	S5A2SO	SFWMMv5
S6in	P1019	S6	Positive S6	S6in	ELMv22

Table 4.2. Summary of total phosphorus concentration data at boundary inflow sites.

Station	Sample Date		Number of Days Sampled	Mean Sample Frequency (Day)	TP (ug/l)				
	Start	End			Mean	Median	Min	Max	Std Dev
ACME1DS	2/5/1997	12/18/2000	48	29	87	71	35	348	52
ENR012	12/16/1993	12/28/2000	393	7	26	21	8.5	630	32
G200	7/26/1989	12/27/2000	285	15	62	49	5	423	47
G310	6/1/2000	12/28/2000	30	7	32	26	14	84.5	18
G94D	2/5/1997	12/18/2000	54	26	105	98	21	263	54
L28I	1/3/1979	10/16/2000	277	29	61	45	12	666	58
L3BRS	10/30/1984	12/27/2000	217	27	119	94	20	514	85
S140	1/3/1979	12/28/2000	431	19	62	43	4	688	68
S150	1/2/1979	12/26/2000	359	22	57	49	8	679	47
S175	5/2/1995	12/20/2000	150	14	7	6	4	18	3
S18C	10/5/1983	12/20/2000	368	17	8	7	1	59	6
S332	10/5/1983	12/20/2000	454	14	9	7	4	57	7
S332D	6/16/1999	12/28/2000	94	6	7	6	2	33	4
S5A	1/2/1979	12/28/2000	682	12	155	141	4	550.5	83
S6	1/2/1979	12/28/2000	729	11	89	72	12	872	78
S7	1/2/1979	12/26/2000	674	12	75	61	10	1030	63
S8	1/2/1979	12/27/2000	782	10	95	69	4	1286	94
S9	1/3/1979	12/26/2000	518	15	17	14	3	172	14

Table 4.3. Summary of observed data on total phosphorus concentrations

Station	Sample Date		Number of Days Sampled	Mean Sample Frequency (Day)	TP (ug/l)				
	Start	End			Mean	Median	Min	Max	Std Dev
217	1/10/1979	8/27/1986	47	59	11	8	2	52	9
B-2	1/10/1979	5/14/1991	35	129	197	134	17	719	181
B-5	1/10/1979	8/26/1986	43	65	41	20	5	232	46
C123SR84	1/27/1988	12/12/2000	159	30	47	38	7	262	34
CA210	3/28/1979	2/21/1984	30	60	12	10	2	48	11
CA211	3/28/1979	2/21/1984	31	58	23	14	2	138	28
CA212	3/28/1979	2/21/1984	31	58	74	34	5	989	173
CA213	3/28/1979	2/21/1984	30	60	13	10	5	40	8
CA214	3/28/1979	2/21/1984	30	60	20	8	4	199	41
CA215	8/9/1994	12/19/2000	125	19	6	6	1	48	4
CA216	3/28/1979	11/30/1983	25	68	23	12	2	144	34
CA217	3/28/1979	2/21/1984	28	64	13	10	3	92	17
CA218	3/28/1979	2/21/1984	30	60	11	8	2	43	10
CA219	3/28/1979	2/21/1984	30	60	19	6	2	307	55
CA220	3/28/1979	2/21/1984	31	58	14	9	2	122	21
CA221	3/28/1979	2/21/1984	32	56	13	7	3	100	18
CA23	3/28/1979	2/21/1984	30	60	103	89	46	216	47
CA24	3/28/1979	2/21/1984	29	62	169	133	40	771	152
CA25	3/28/1979	2/21/1984	26	69	166	130	23	646	144
CA26	3/28/1979	11/30/1983	26	66	17	11	5	73	15
CA27	6/28/1994	11/20/2000	121	19	11	9	4	83	9
CA28	6/28/1994	10/23/2000	103	22	105	79	22	509	81
CA29	8/9/1994	11/20/2000	122	19	8	7	2	90	8
CA311	6/16/1994	12/19/2000	140	17	6	5	1	36	4
CA315	6/16/1994	12/19/2000	147	16	6	6	1	17	3
CA32	6/29/1994	12/4/2000	110	21	9	8	4	94	9
CA33	5/20/1994	12/19/2000	105	23	13	10	5	62	8
CA34	6/16/1994	11/21/2000	118	20	10	9	3	70	8
CA35	6/29/1994	11/8/2000	81	29	12	10	3	55	8
CA36	6/16/1994	9/14/2000	111	21	31	24	9	192	25
CA38	6/16/1994	12/5/2000	120	20	8	7	1	103	11
COOPERTN	5/9/1991	12/19/2000	228	15	11	11	4	41	5
ENR002	12/16/1993	12/28/2000	378	7	100	93	8	677	64
EP	10/27/1986	12/19/2000	121	43	6	4	2	34	5
G123	12/14/1982	12/27/2000	115	57	18	15	4	80	11
G204	7/26/1989	10/16/2000	93	44	56	38	9	325	55
G205	7/26/1989	10/16/2000	94	44	52	34	10	394	63
G206	7/26/1989	10/16/2000	94	44	24	16	4	199	30
L3	1/2/1979	6/29/2000	335	23	114	83	12	860	103
L40-1	1/2/1979	1/4/1999	164	45	65	50	17	410	53
L40-2	1/2/1979	1/4/1999	164	45	86	78	9	383	53
L7	1/2/1979	3/29/1993	77	68	105	65	6	1415	175

4.9 Figure legends

Figure 4.1 The spatial domains of the regional application and subregional applications of ELM.

Figure 4.2 Hydrologic Basins and Indicator Regions for the regional implementation of ELM.

Figure 4.3 Initial depth of ponded surface water, January 1, 1981.

Figure 4.4 Initial depth of water in unsaturated storage, January 1, 1981.

Figure 4.5 Initial land surface elevation for WCA-1.

Figure 4.6 Initial land surface elevation for WCA-2A.

Figure 4.7 Initial land surface elevation for WCA-3A north of Alligator Alley (I-75).

Figure 4.8 Initial land surface elevation for central and southern Everglades and Big Cypress National Preserve.

Figure 4.9 Initial land surface elevation for Holey Land.

Figure 4.10 Initial land surface elevation for Rotenberger Tract.

Figure 4.11 Initial land surface elevation for the regional ELM domain, January 1, 1981.

Figure 4.12 Locations of soil core samples from different surveys.

Figure 4.13 Initial (and constant) bulk density of soil.

Figure 4.14 Initial (and constant) bulk density of only the organic fraction of soil, January 1, 1981.

Figure 4.15 Initial total phosphorus concentration of soil, January 1, 1981.

Figure 4.16 Vegetation classification efforts that were used in developing the habitat map for the model.

Figure 4.17 Habitat types, ca. 1995; cattail were replaced with adjacent habitat types (usually sawgrass) for initial habitat types, January 1, 1981.

Figure 4.18 Initial total biomass of macrophytes, January 1, 1981.

Figure 4.19 Canal reach identities, water control structure locations, and generalized flow diagram for the regional implementation of ELM, displayed for entire domain.

Figure 4.20 Canal reach identities and water control structure locations in the regional implementation of ELM, displayed for WCA-1 and WCA-2.

Figure 4.21 Canal reach identities and water control structure locations in the regional implementation of ELM, displayed for northern WCA-3A.

Figure 4.22 Water control structure attributes for all of the structures operating in the ELM v2.5 historical simulation (continued through 18 pages).

Figure 4.23 The GlobalParms database, documenting the parameters that are global to the model domain (continued through 3 pages).

Figure 4.24 The HabParms data base, documenting the parameters that are specific to each habitat defined in the model domain (continued through 2 pages).

Figure 4.25 Hydraulic conductivity of the surficial aquifer simulated in ELM.

Figure 4.26 The stage-based grid-cell and vector allowable-flow conditions along the borders of the regional ELM domain.

4.10 Figures

Twenty six figures follow this page (46 pages).

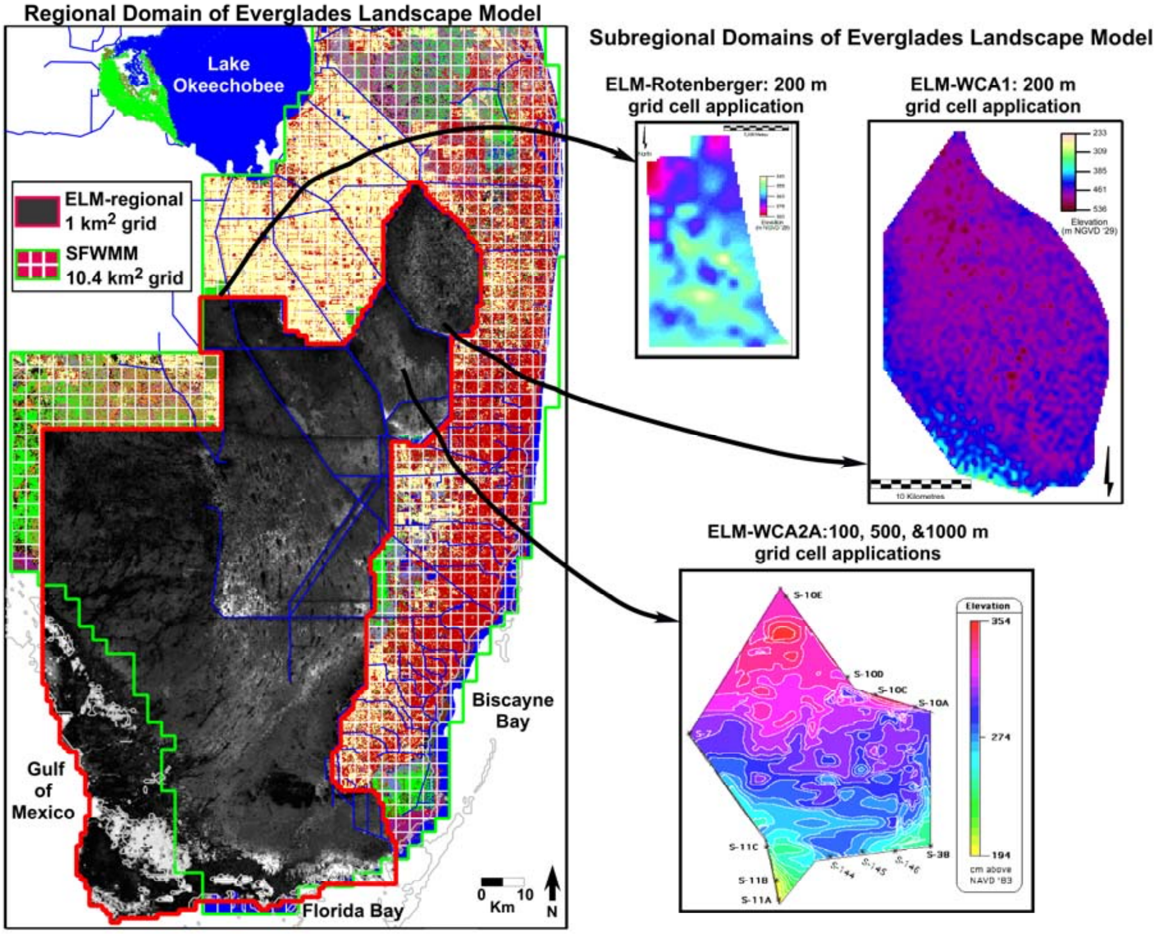

Regional Domain of Everglades Landscape Model
Lake Okeechobee
ELM-regional 1 km² grid
SFWMM 10.4 km² grid
Gulf of Mexico
Biscayne Bay
Florida Bay
0 10 Km
N
Subregional Domains of Everglades Landscape Model
ELM-Rotenberger: 200 m grid cell application
North
Elevation (m NGVD '29)
ELM-WCA1: 200 m grid cell application
233
309
385
461
536
Elevation (m NGVD '29)
10 Kilometres
ELM-WCA2A:100, 500, &1000 m grid cell applications
S-10E
S-10D
S-10C
S-10A
S-7
S-11C
S-11B
S-11A
S-144
S-145
S-146
S-38
Elevation
354
274
194
cm above NAVD '83

Figure 4.1.

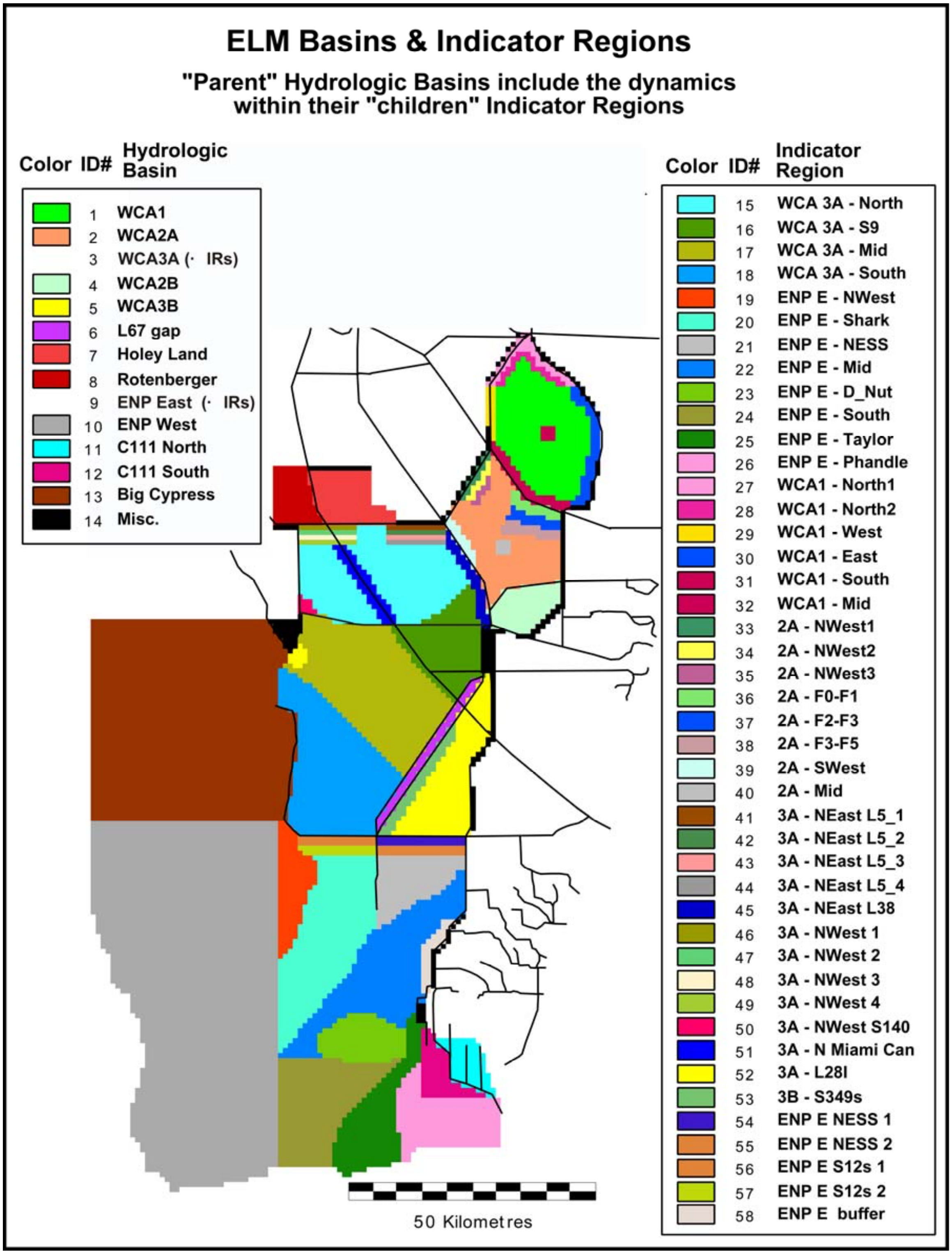

ELM Basins & Indicator Regions
"Parent" Hydrologic Basins include the dynamics
within their "children" Indicator Regions
Color ID# Hydrologic Basin
1 WCA1
2 WCA2A
3 WCA3A (· IRs)
4 WCA2B
5 WCA3B
6 L67 gap
7 Holey Land
8 Rotenberger
9 ENP East (· IRs)
10 ENP West
11 C111 North
12 C111 South
13 Big Cypress
14 Misc.
Color ID# Indicator Region
15 WCA 3A - North
16 WCA 3A - S9
17 WCA 3A - Mid
18 WCA 3A - South
19 ENP E - NWest
20 ENP E - Shark
21 ENP E - NESS
22 ENP E - Mid
23 ENP E - D_Nut
24 ENP E - South
25 ENP E - Taylor
26 ENP E - Phandle
27 WCA1 - North1
28 WCA1 - North2
29 WCA1 - West
30 WCA1 - East
31 WCA1 - South
32 WCA1 - Mid
33 2A - NWest1
34 2A - NWest2
35 2A - NWest3
36 2A - F0-F1
37 2A - F2-F3
38 2A - F3-F5
39 2A - SWest
40 2A - Mid
41 3A - NEast L5_1
42 3A - NEast L5_2
43 3A - NEast L5_3
44 3A - NEast L5_4
45 3A - NEast L38
46 3A - NWest 1
47 3A - NWest 2
48 3A - NWest 3
49 3A - NWest 4
50 3A - NWest S140
51 3A - N Miami Can
52 3A - L28I
53 3B - S349s
54 ENP E NESS 1
55 ENP E NESS 2
56 ENP E S12s 1
57 ENP E S12s 2
58 ENP E buffer
50 Kilometres

Figure 4.2.

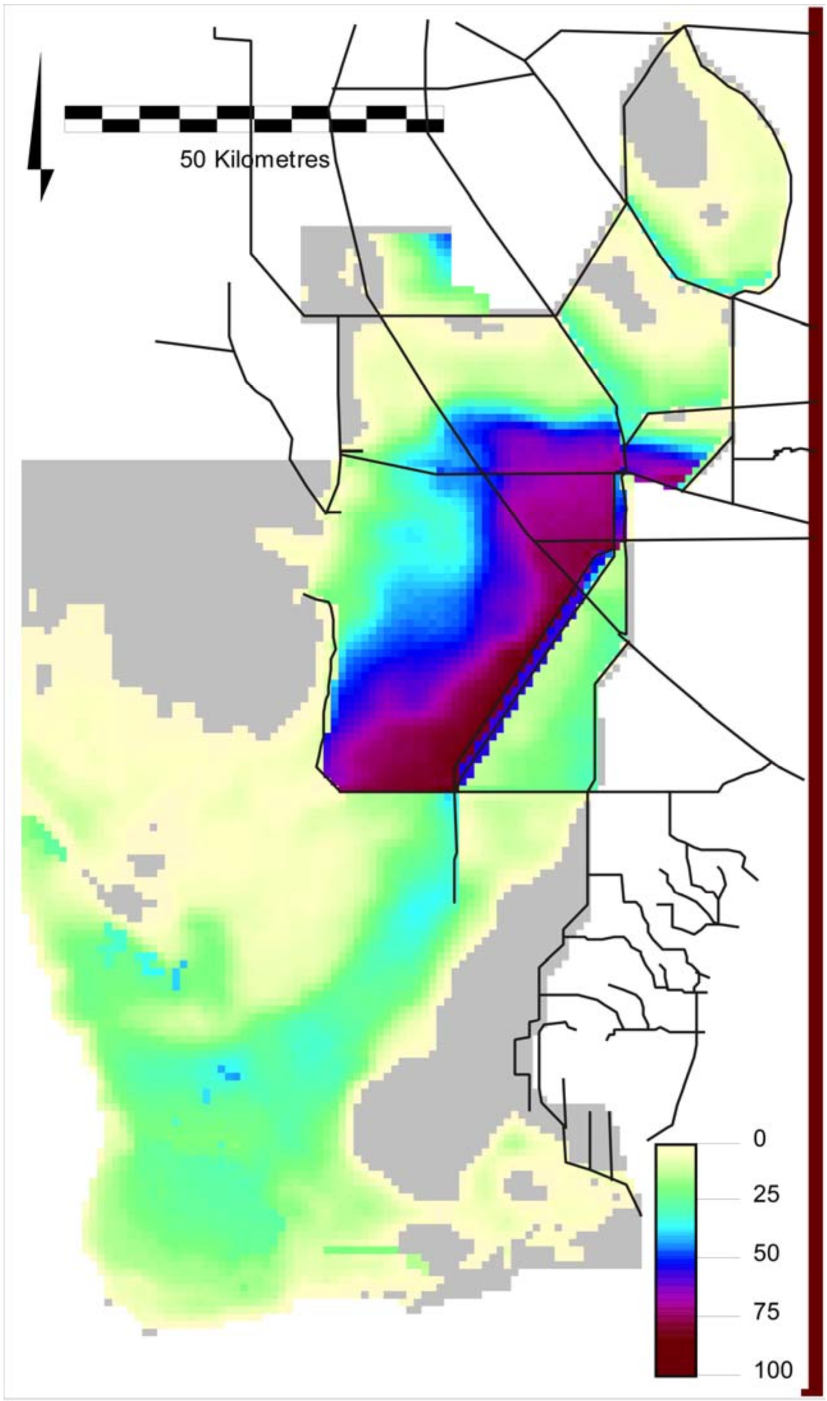


Figure 4.3.

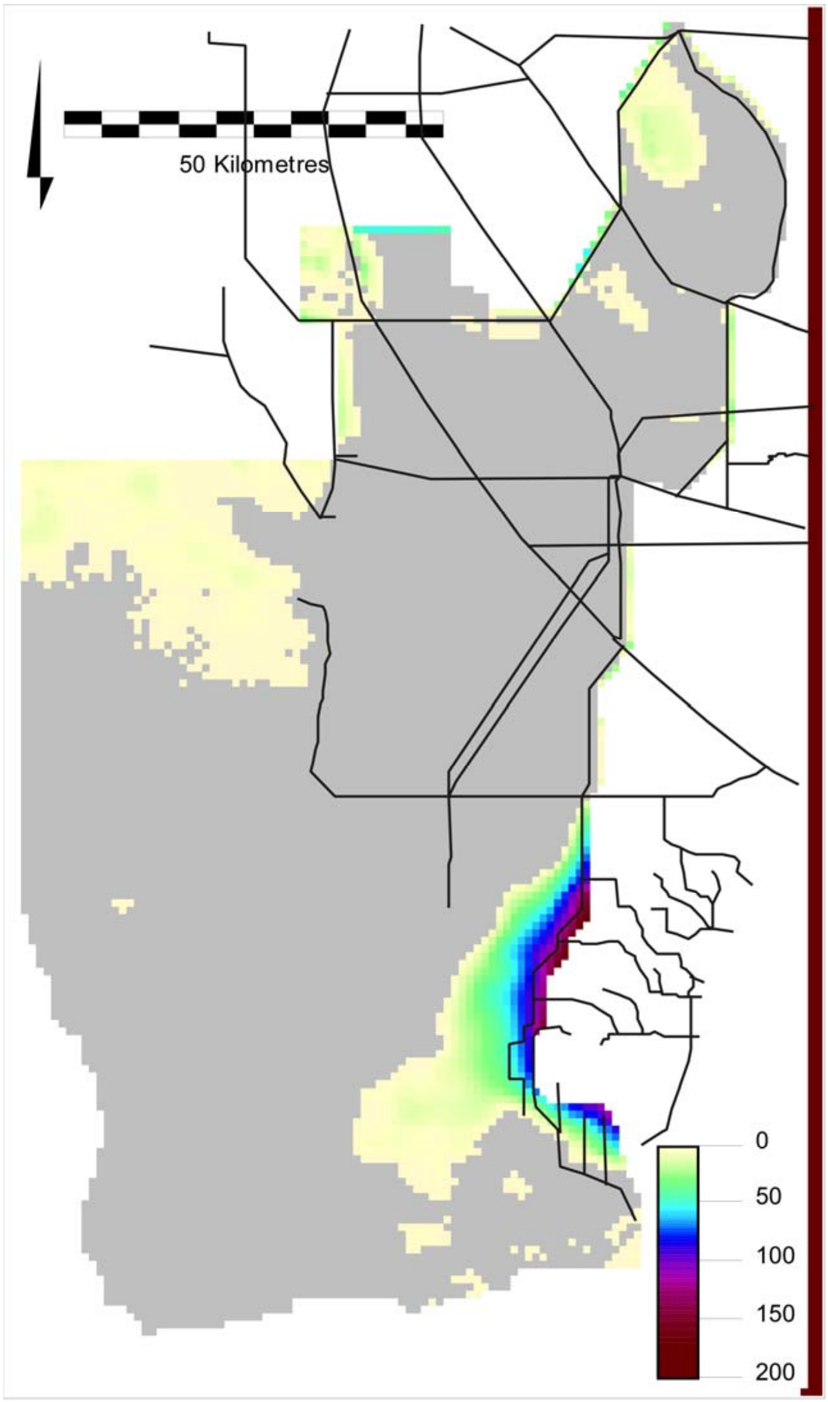


Figure 4.4.

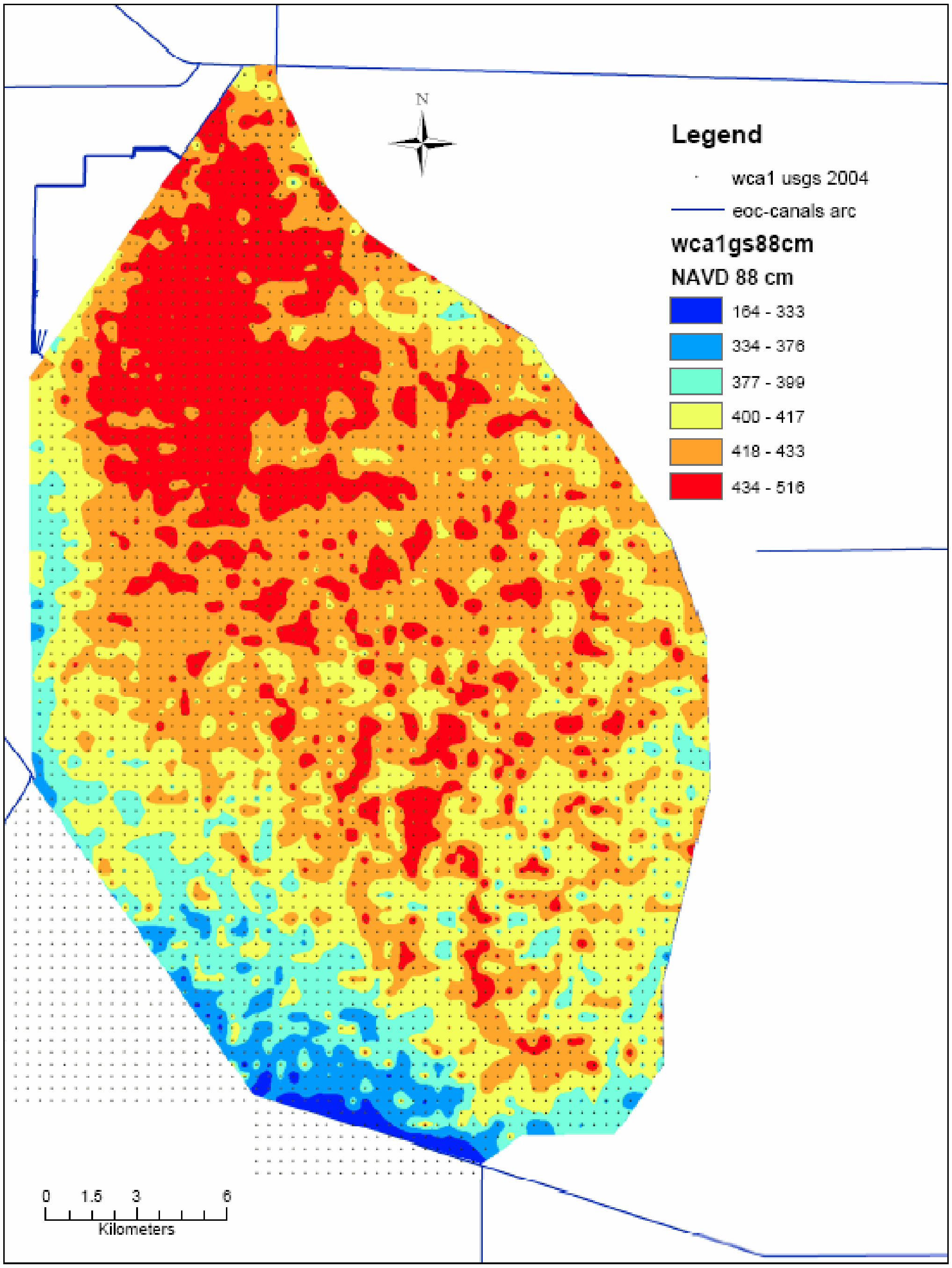

N
Legend
wca1 usgs 2004
eoc-canals arc
wca1gs88cm
NAVD 88 cm
164 - 333
334 - 376
377 - 399
400 - 417
418 - 433
434 - 516
0
1.5
3
6
Kilometers

Figure 4.5.

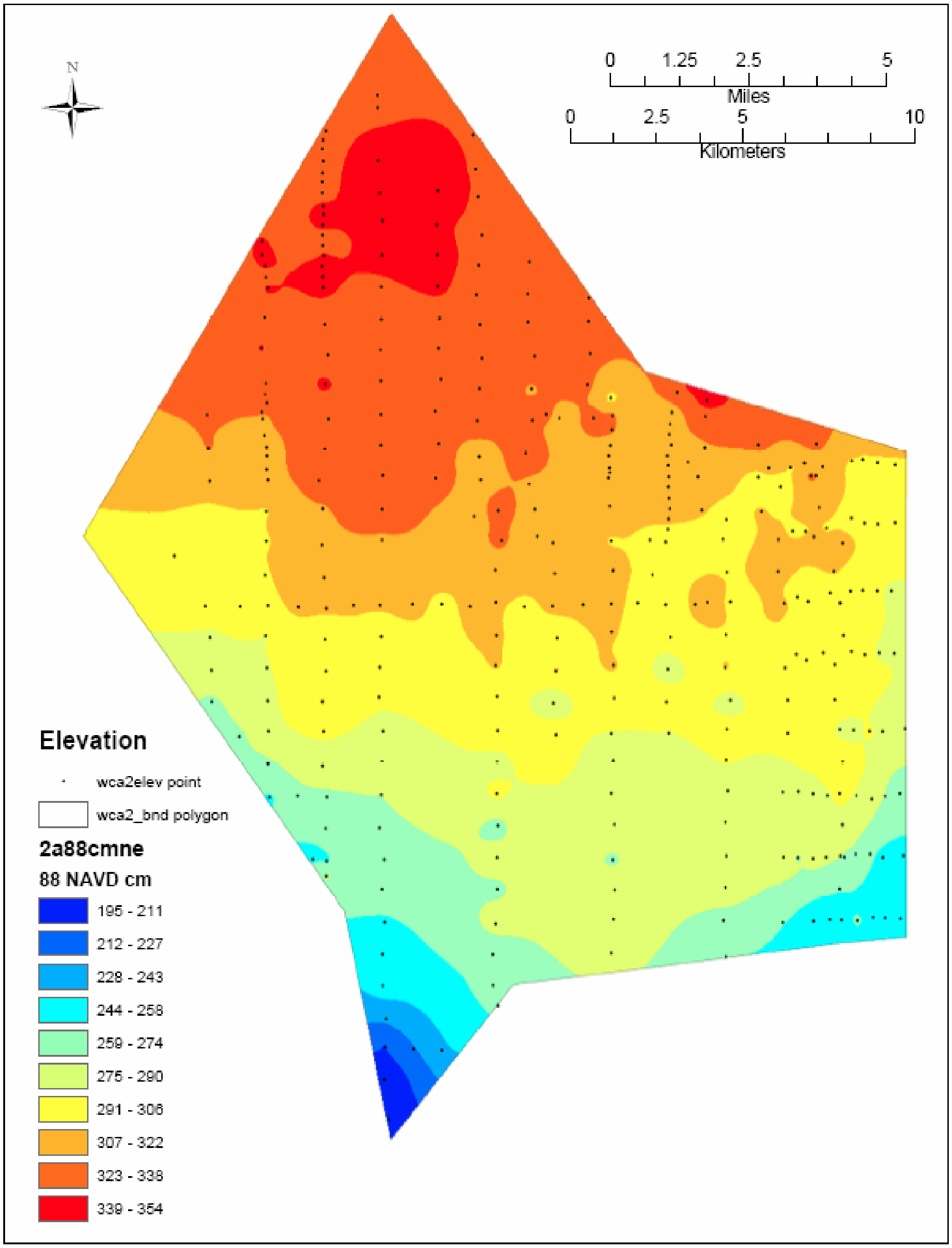

N
0
1.25
2.5
5
Miles
0
2.5
5
10
Kilometers
Elevation
wca2elev point
wca2_bnd polygon
2a88cmne
88 NAVD cm
195 - 211
212 - 227
228 - 243
244 - 258
259 - 274
275 - 290
291 - 306
307 - 322
323 - 338
339 - 354

Figure 4.6.

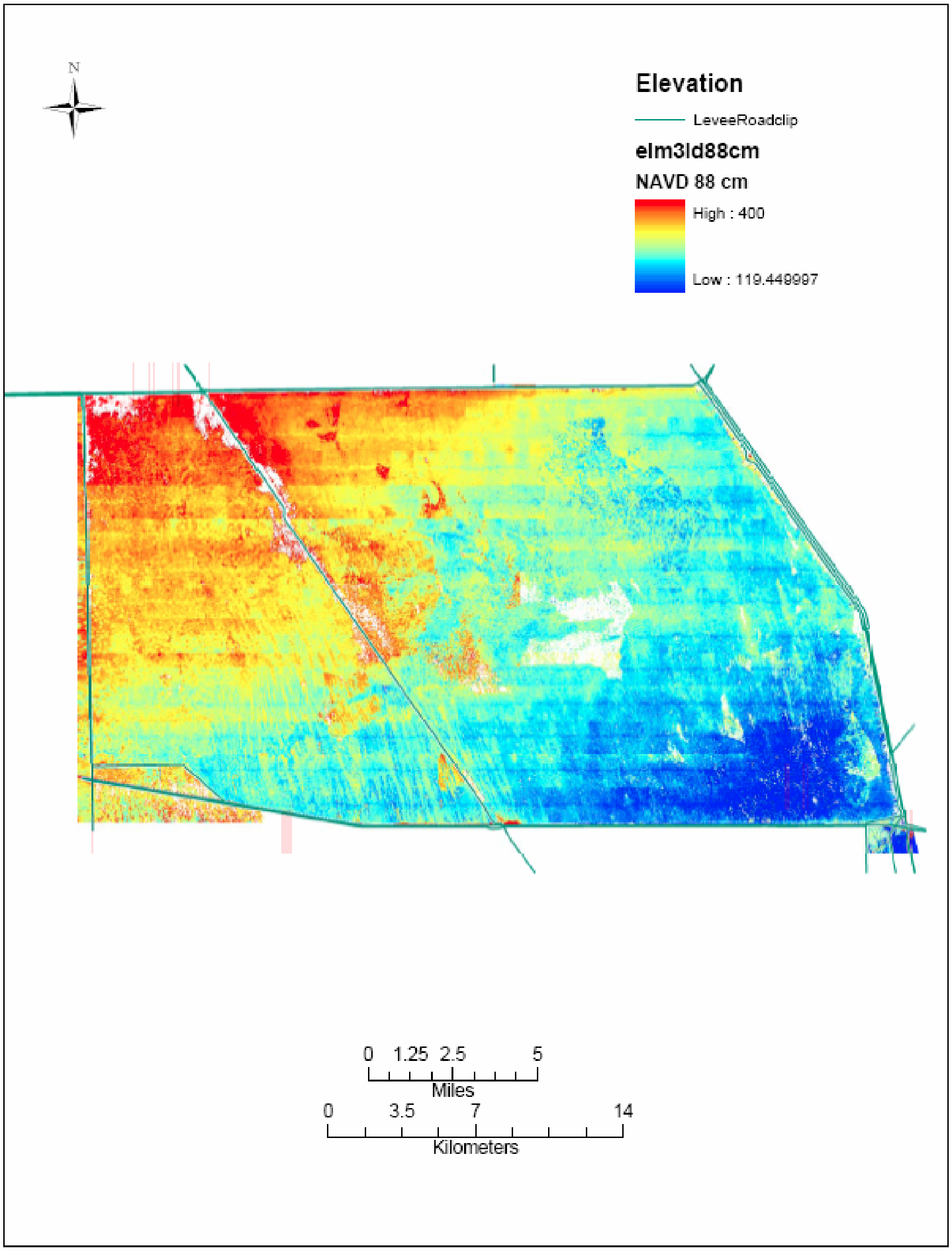

N
Elevation
LeveeRoadclip
elm3ld88cm
NAVD 88 cm
High : 400
Low : 119.449997
0
1.25
2.5
5
Miles
0
3.5
7
14
Kilometers

Figure 4.7.

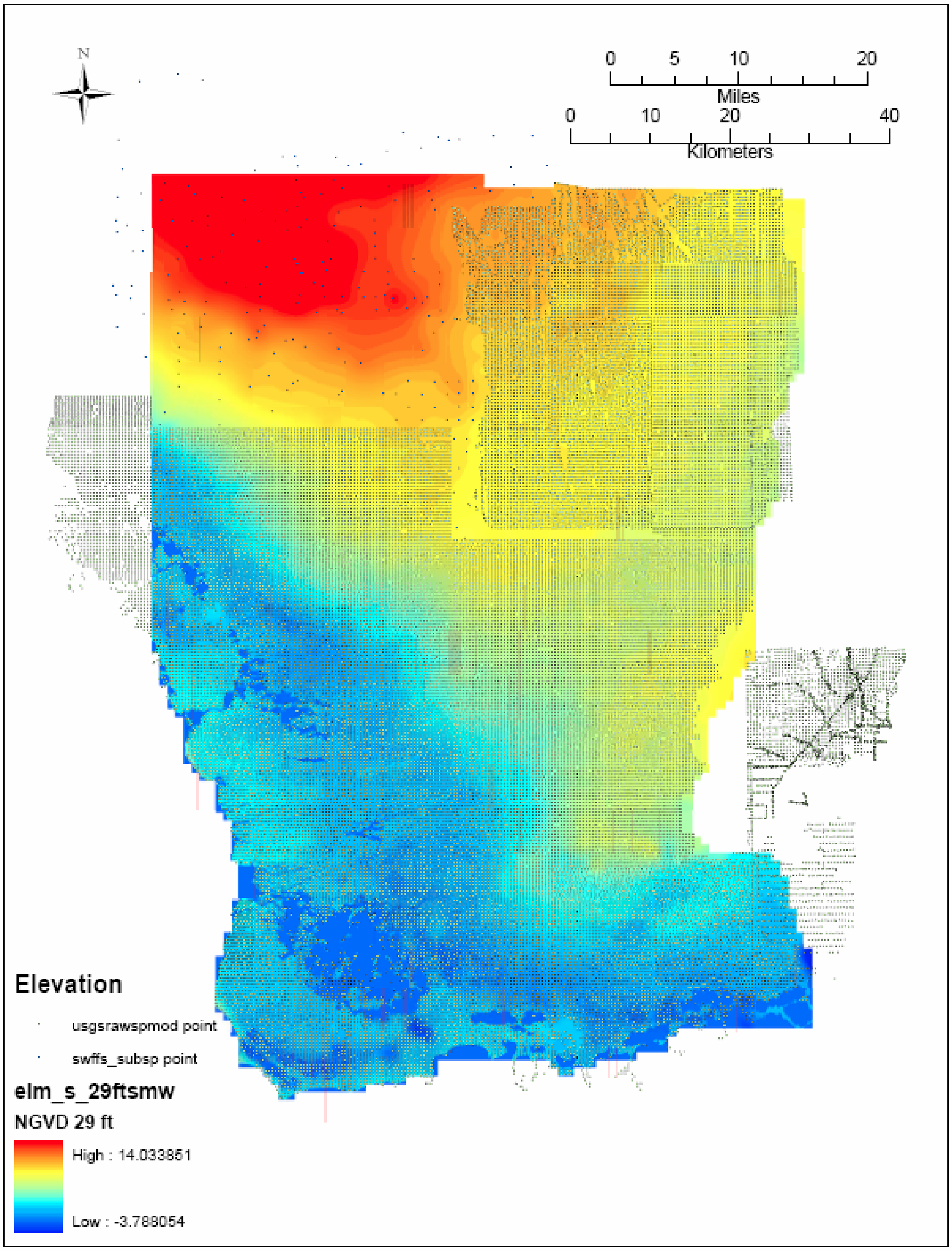

N
0
5
10
20
Miles
0
10
20
40
Kilometers
Elevation
usgsrawspmod point
swffs_subsp point
elm_s_29ftsmw
NGVD 29 ft
High : 14.033851
Low : -3.788054

Figure 4.8.

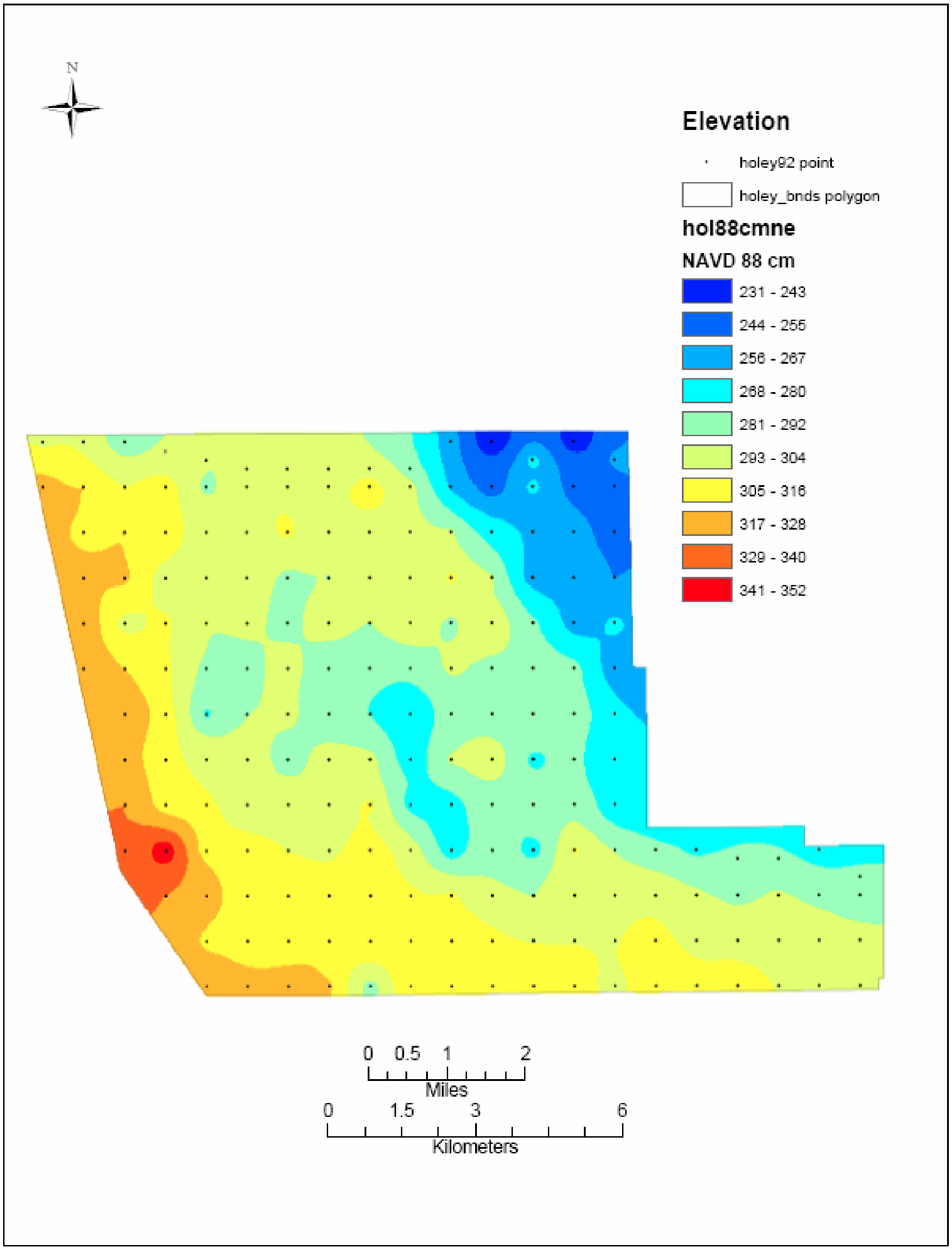

N
Elevation
holey92 point
holey_bnds polygon
hol88cmne
NAVD 88 cm
231 - 243
244 - 255
256 - 267
268 - 280
281 - 292
293 - 304
305 - 316
317 - 328
329 - 340
341 - 352
0 0.5 1 2
Miles
0 1.5 3 6
Kilometers

Figure 4.9.

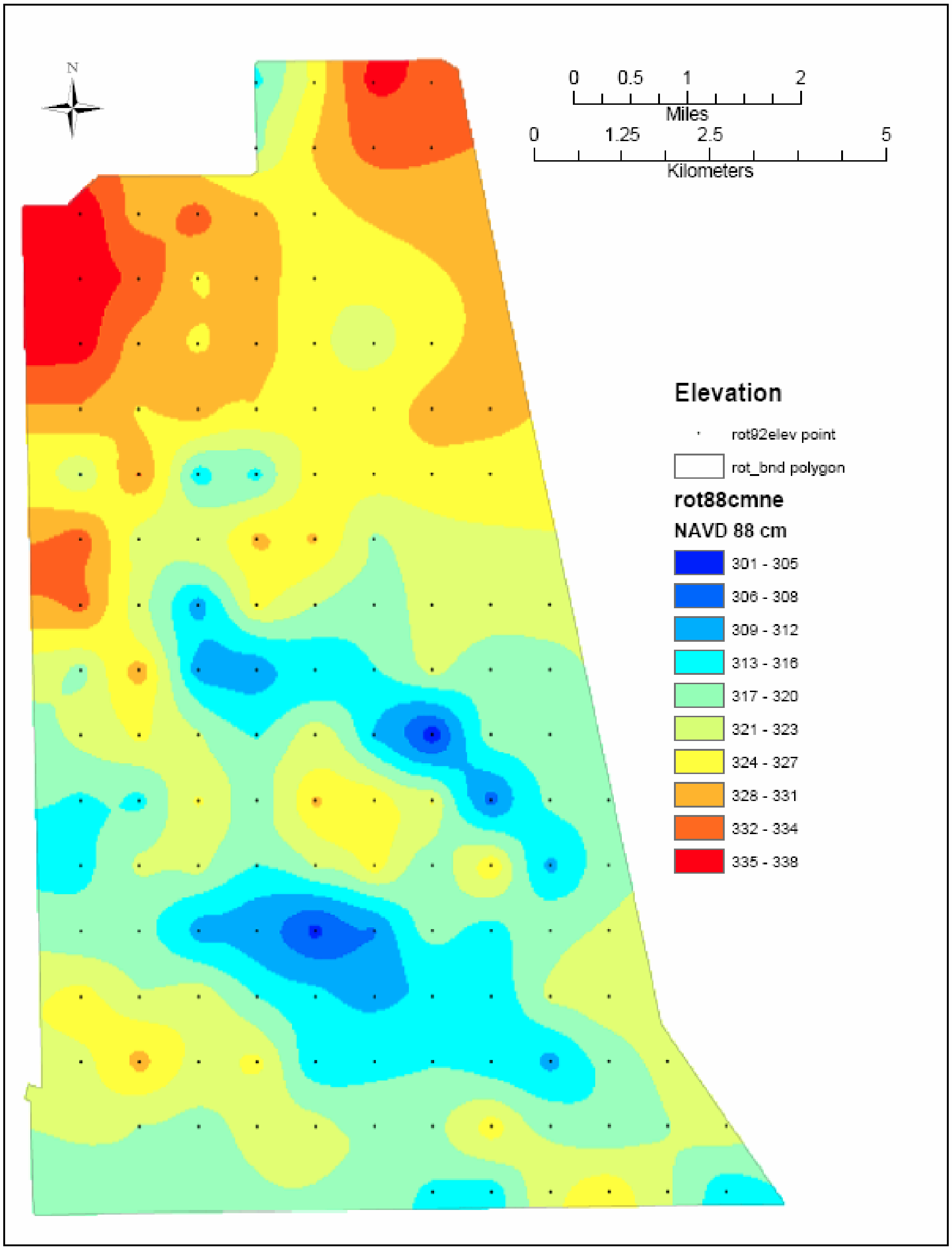

N
0
0.5
1
2
Miles
0
1.25
2.5
5
Kilometers
Elevation
rot92elev point
rot_bnd polygon
rot88cmne
NAVD 88 cm
301 - 305
306 - 308
309 - 312
313 - 316
317 - 320
321 - 323
324 - 327
328 - 331
332 - 334
335 - 338

Figure 4.10.

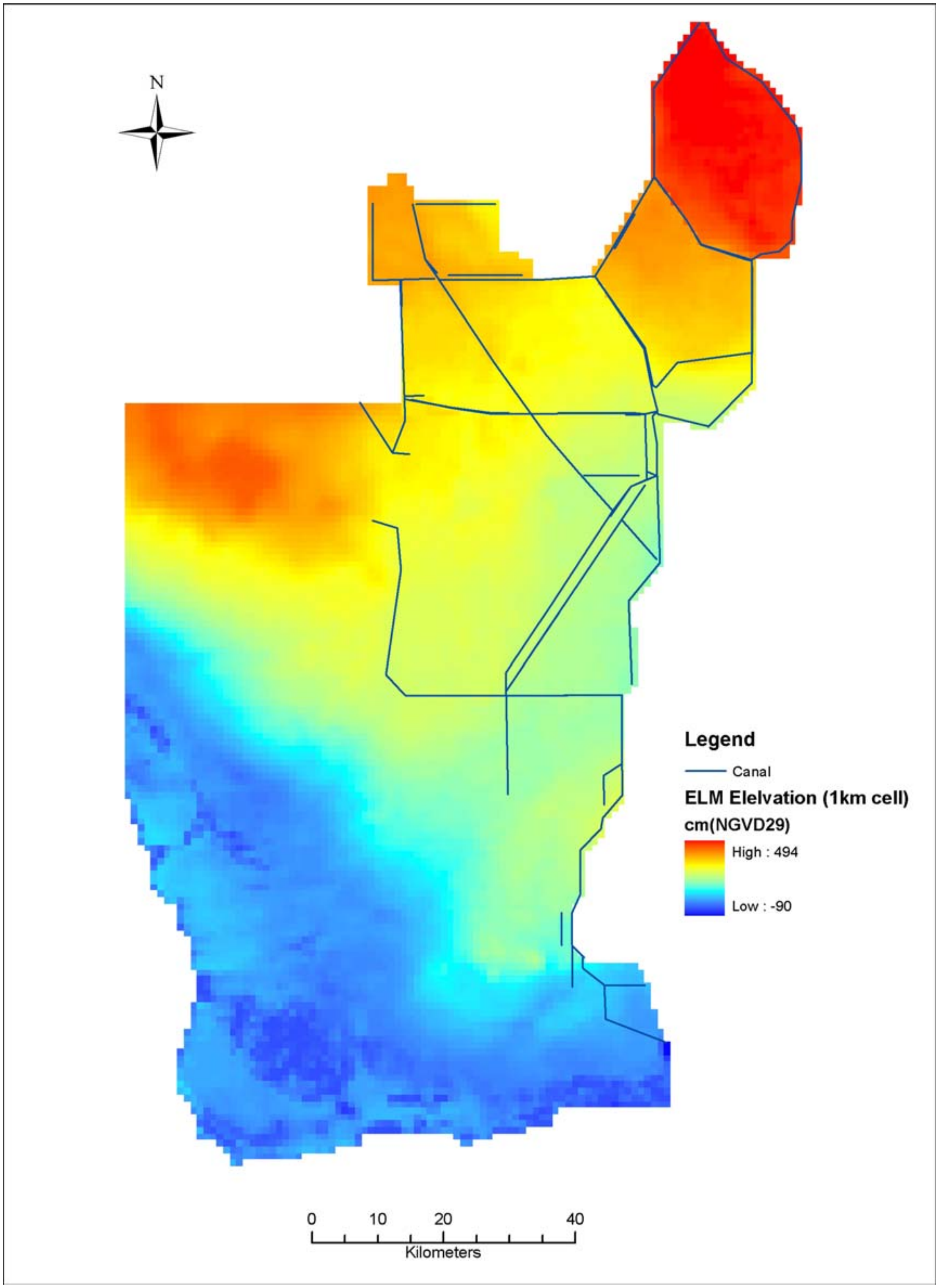

N
Legend
Canal
ELM Elelvation (1km cell)
cm(NGVD29)
High : 494
Low : -90
0
10
20
40
Kilometers

Figure 4.11.

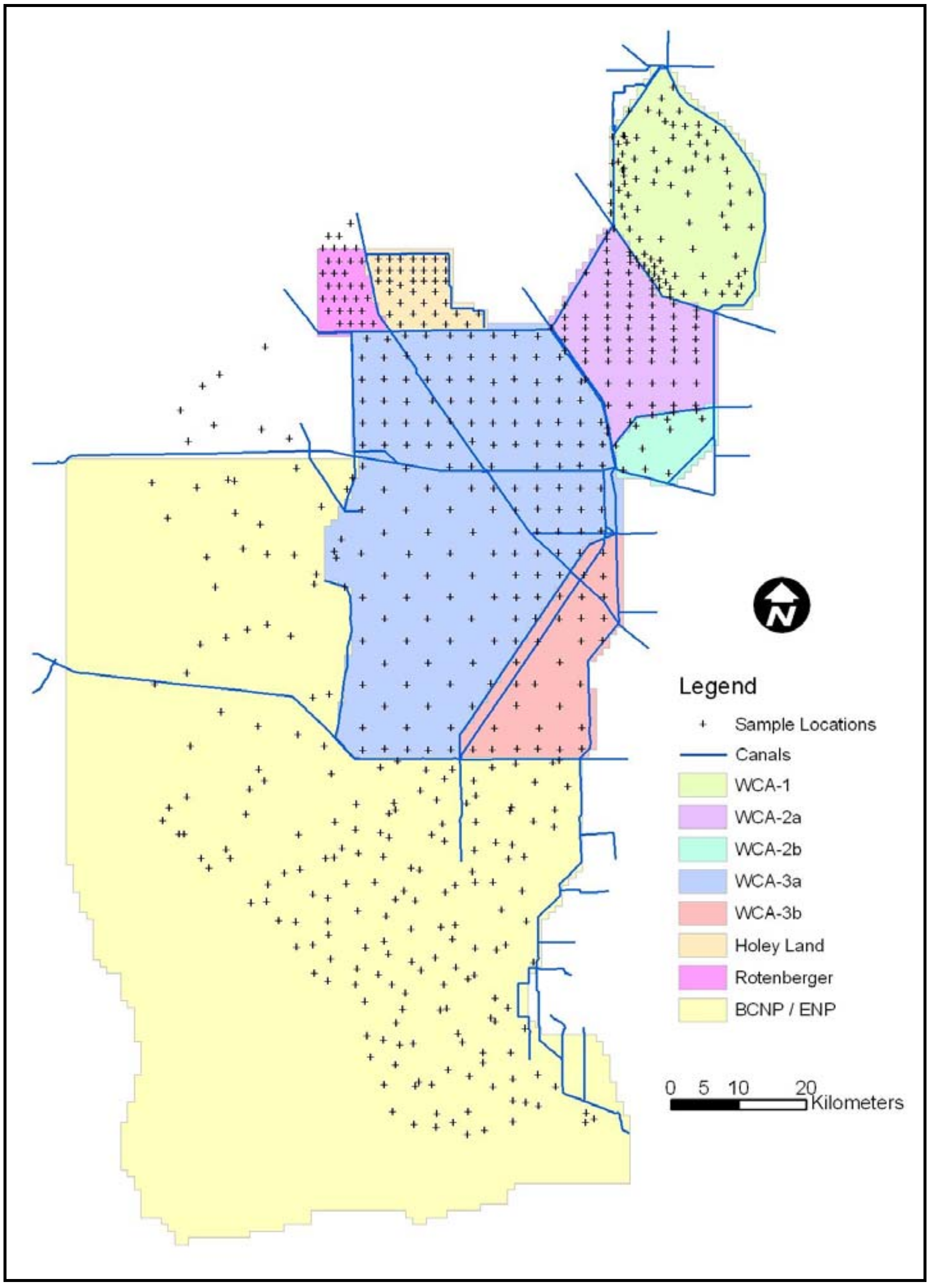

Legend
Sample Locations
Canals
WCA-1
WCA-2a
WCA-2b
WCA-3a
WCA-3b
Holey Land
Rotenberger
BCNP / ENP
0 5 10 20 Kilometers
N

Figure 4.12.

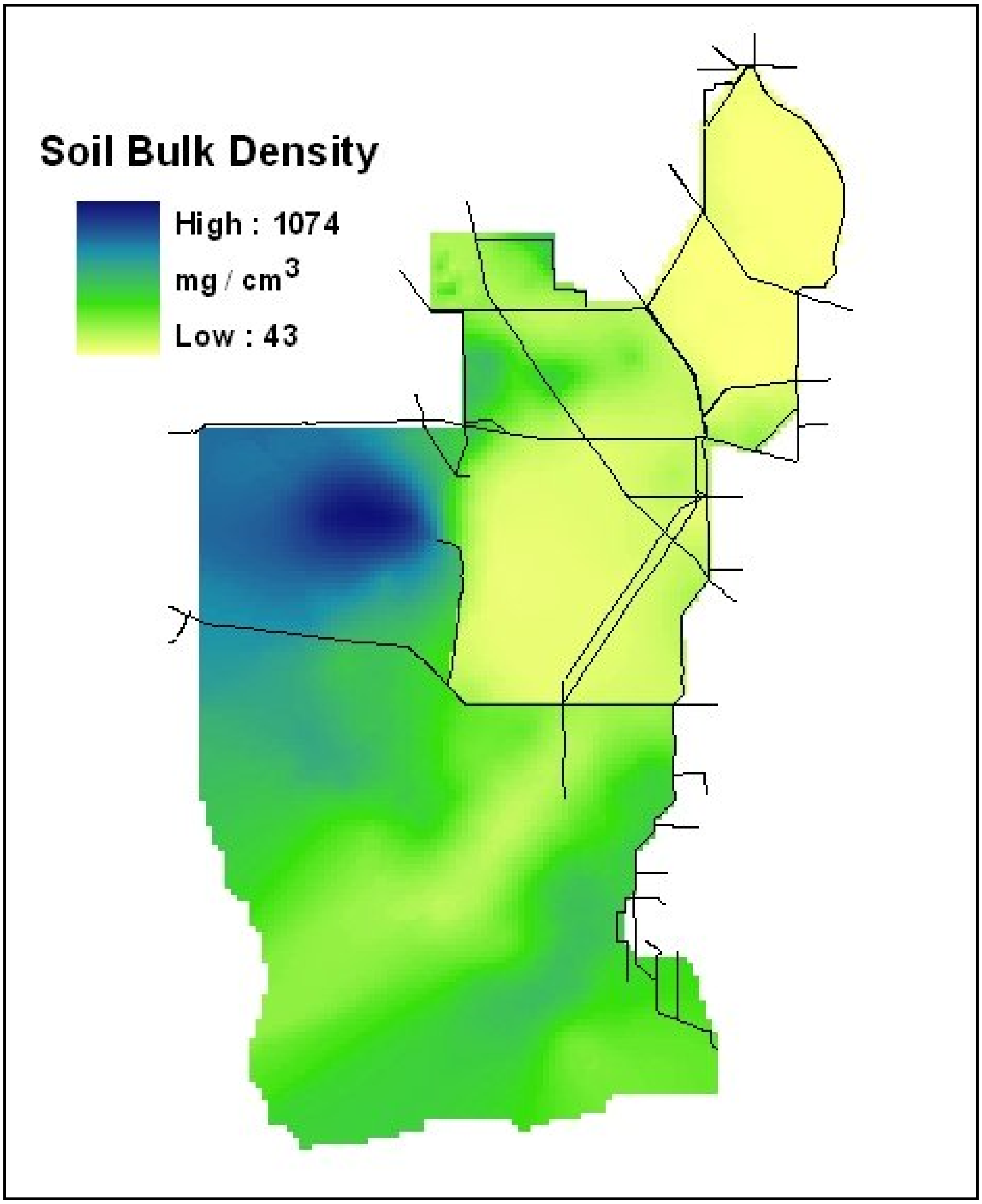


Figure 4.13.

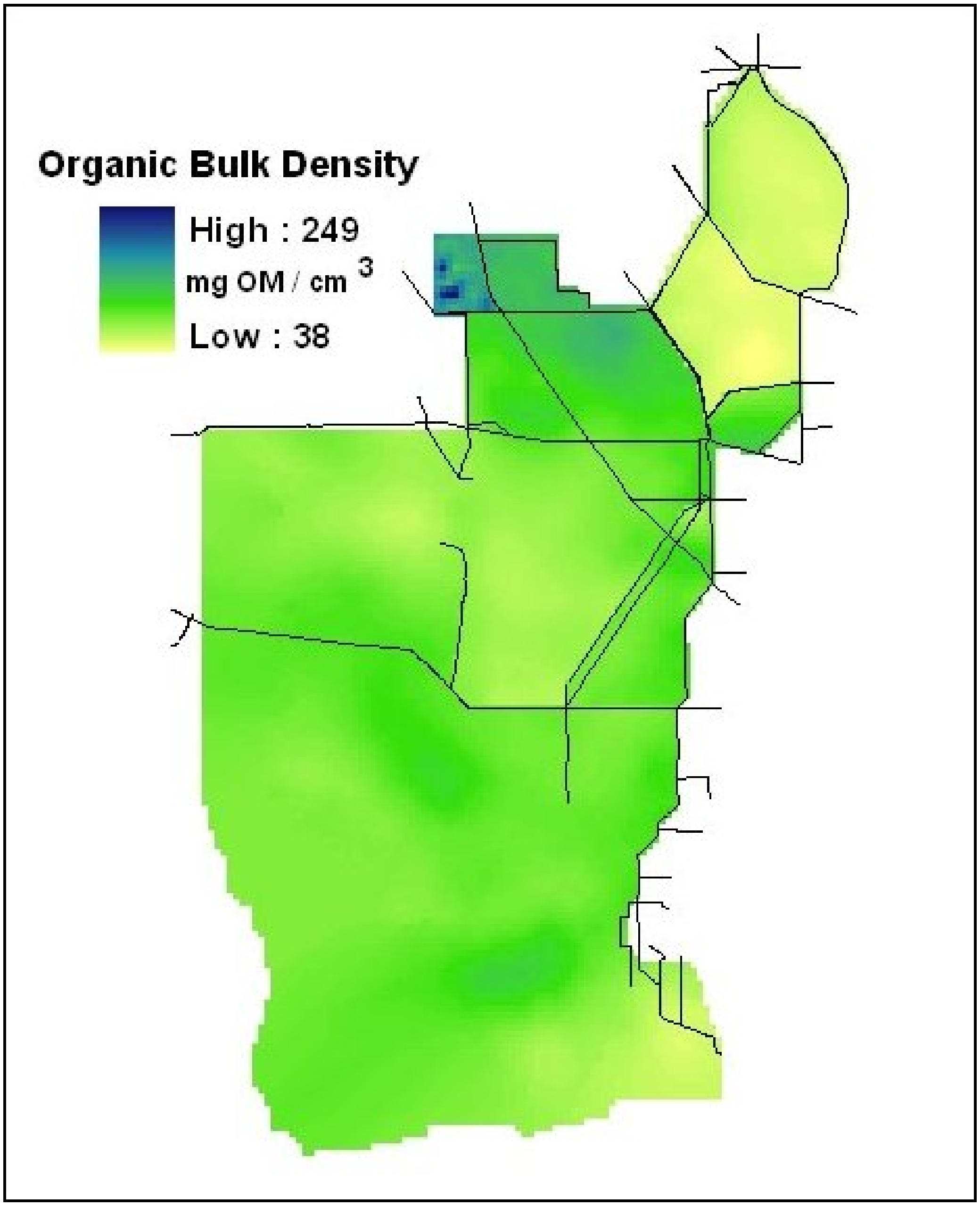


Figure 4.14.

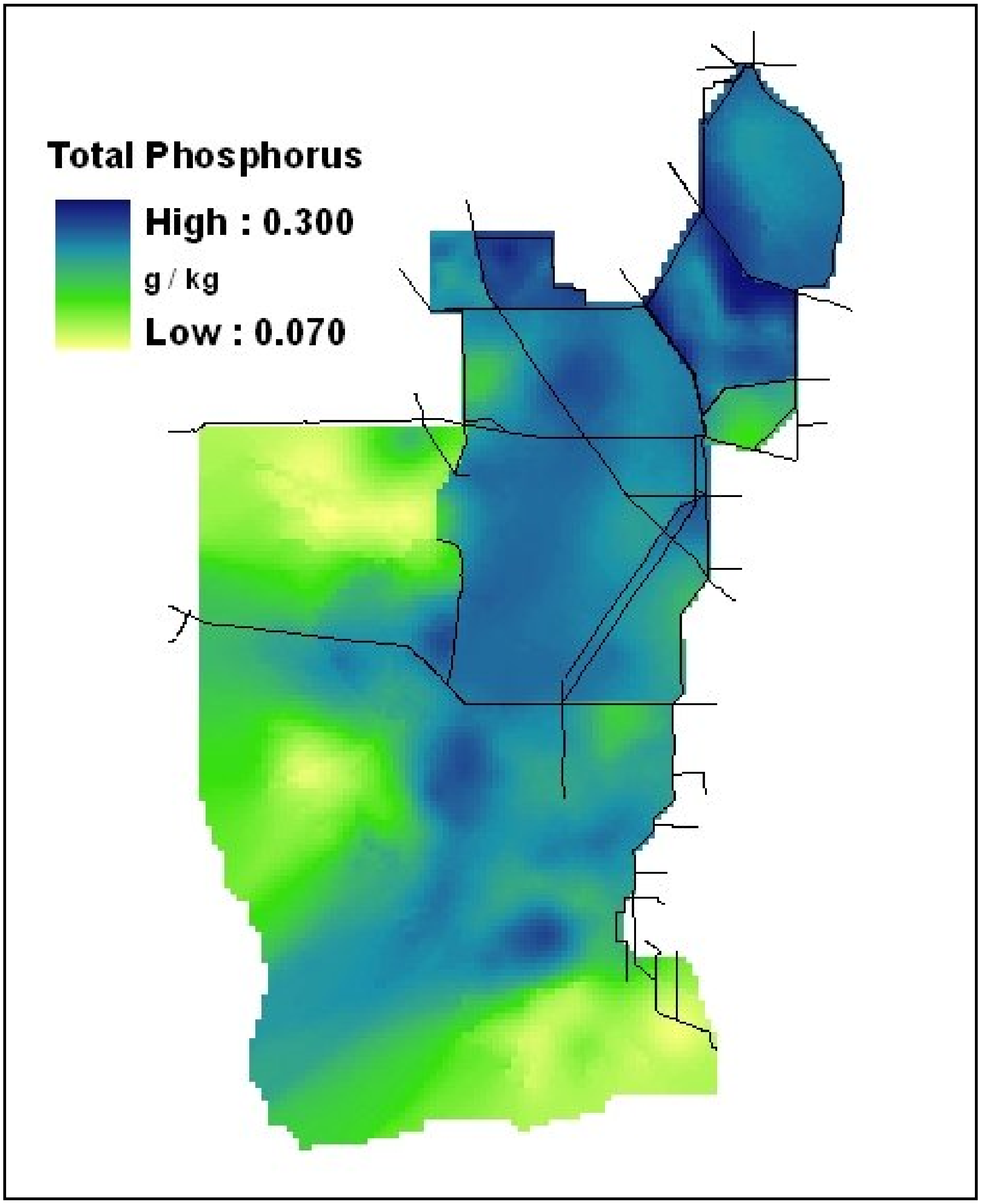


Figure 4.15.

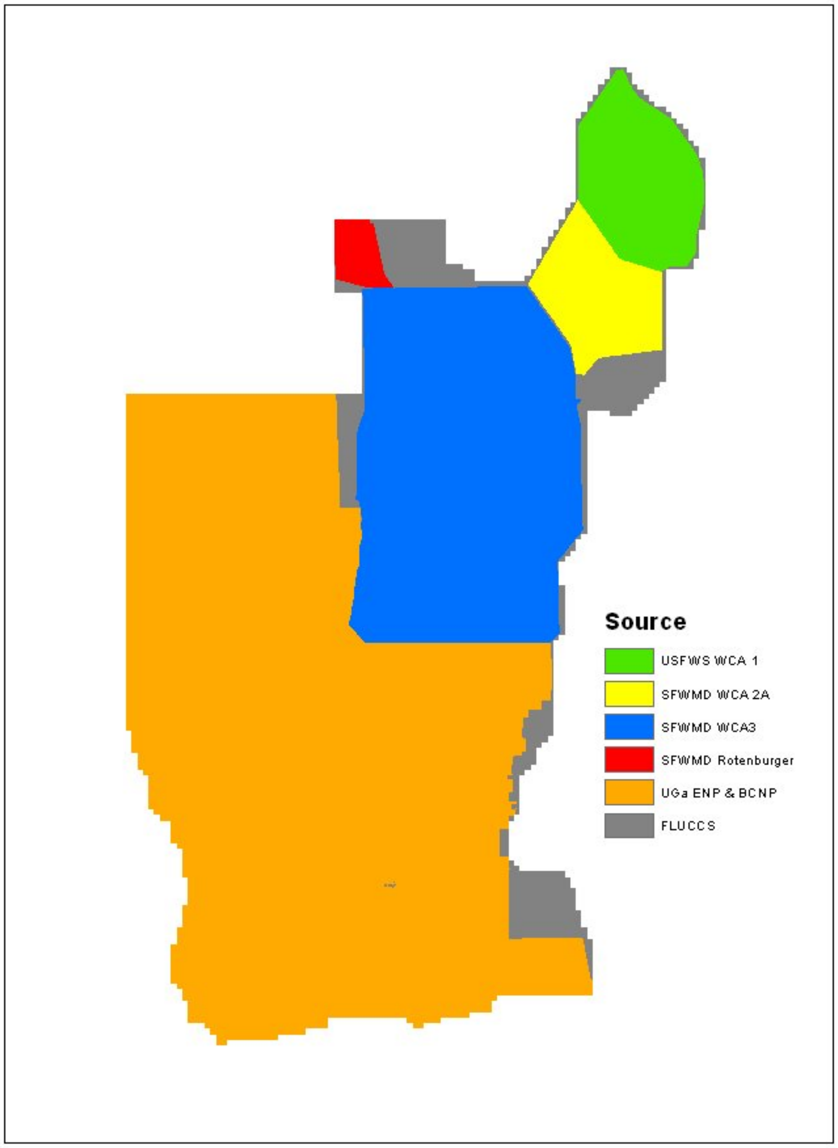
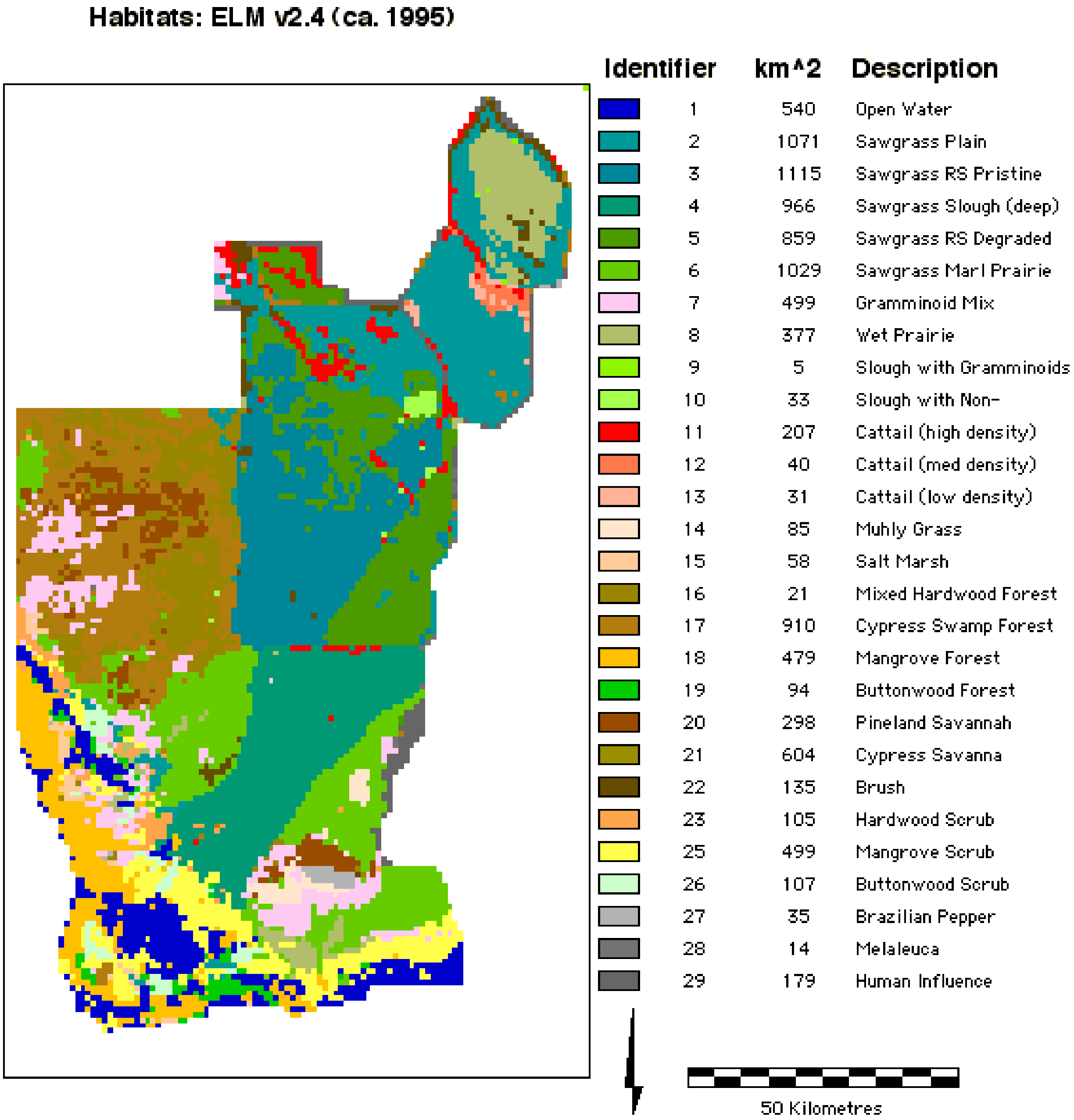

Source
USFWS WCA 1
SFWMD WCA 2A
SFWMD WCA3
SFWMD Rotenburger
UGa ENP & BCNP
FLUCCS

Figure 4.16.



	Identifier	km^2	Description
🟦	1	540	Open Water
🟦	2	1071	Sawgrass Plain
🟦	3	1115	Sawgrass RS Pristine
🟩	4	966	Sawgrass Slough (deep)
🟩	5	859	Sawgrass RS Degraded
🟩	6	1029	Sawgrass Marl Prairie
🟪	7	499	Gramminoid Mix
🟩	8	377	Wet Prairie
🟩	9	5	Slough with Gramminoids
🟩	10	33	Slough with Non-
🟥	11	207	Cattail (high density)
🟧	12	40	Cattail (med density)
🟧	13	31	Cattail (low density)
⬜	14	85	Muhly Grass
🟧	15	58	Salt Marsh
🟫	16	21	Mixed Hardwood Forest
🟫	17	910	Cypress Swamp Forest
🟨	18	479	Mangrove Forest
🟩	19	94	Buttonwood Forest
🟫	20	298	Pineland Savannah
🟫	21	604	Cypress Savanna
🟫	22	135	Brush
🟧	23	105	Hardwood Scrub
🟨	25	499	Mangrove Scrub
🟩	26	107	Buttonwood Scrub
⬜	27	35	Brazilian Pepper
⬛	28	14	Melaleuca
⬛	29	179	Human Influence

Figure 4.17. Note: Habitats initialized in 1981 without any cattail habitat types.

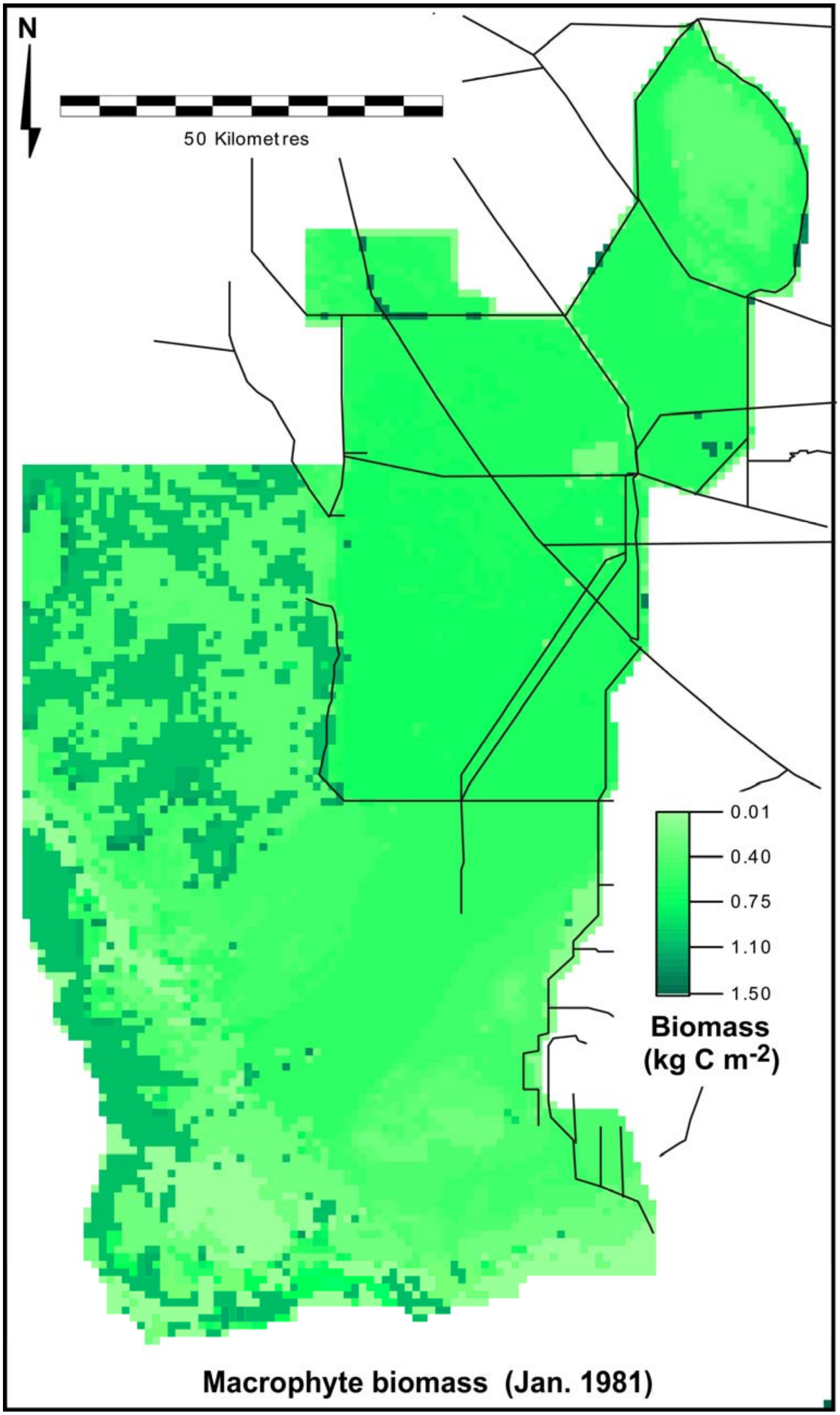

N
50 Kilometres
0.01
0.40
0.75
1.10
1.50
Biomass
(kg C m-2)
Macrophyte biomass (Jan. 1981)

Figure 4.18.

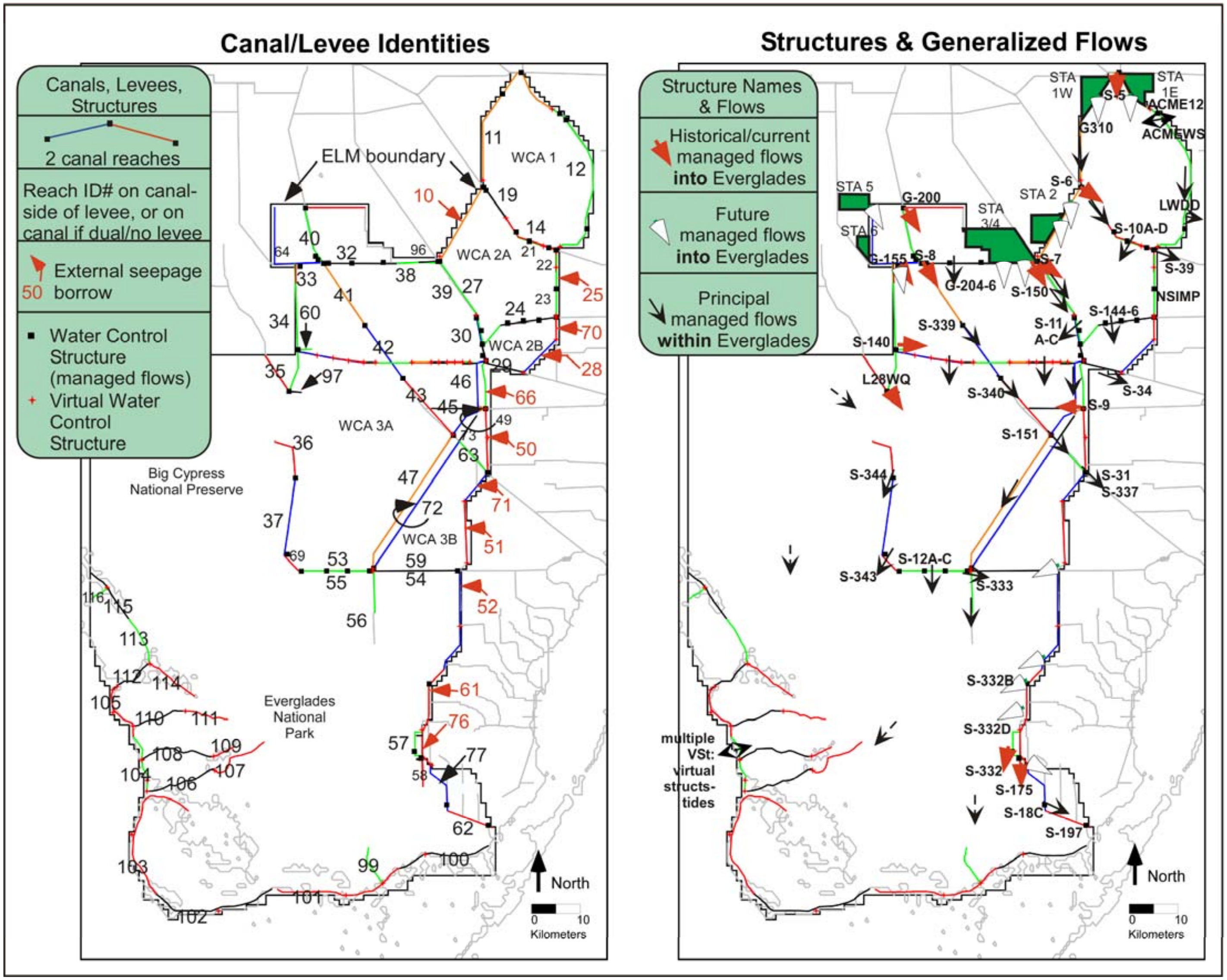

Canal/Levee Identities
Canals, Levees, Structures
2 canal reaches
Reach ID# on canal-side of levee, or on canal if dual/no levee
External seepage borrow
50
Water Control Structure (managed flows)
Virtual Water Control Structure
ELM boundary
WCA 1
WCA 2A
WCA 2B
WCA 3A
WCA 3B
Big Cypress National Preserve
Everglades National Park
10
11
12
14
19
21
22
23
24
25
27
28
29
30
32
33
34
35
36
37
38
39
40
41
42
43
45
46
47
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
66
69
70
71
72
73
76
77
96
97
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
North
0
10
Kilometers
Structures & Generalized Flows
Structure Names & Flows
Historical/current managed flows into Everglades
Future managed flows into Everglades
Principal managed flows within Everglades
STA 1W
STA 1E
STA 2
STA 3/4
STA 5
STA 6
S-5
ACME12
ACMEWS
G310
S-6
LWDD
S-10A-D
S-39
G-200
G-155
S-8
G-204-6
S-7
S-150
NSIMP
S-144-6
S-339
S-11 A-C
S-140
L28WQ
S-340
S-34
S-9
S-151
S-344
S-31
S-337
S-343
S-12A-C
S-333
S-332B
S-332D
S-332
S-175
S-18C
S-197
multiple VSt: virtual structs-tides
North
0
10
Kilometers

Figure 4.19

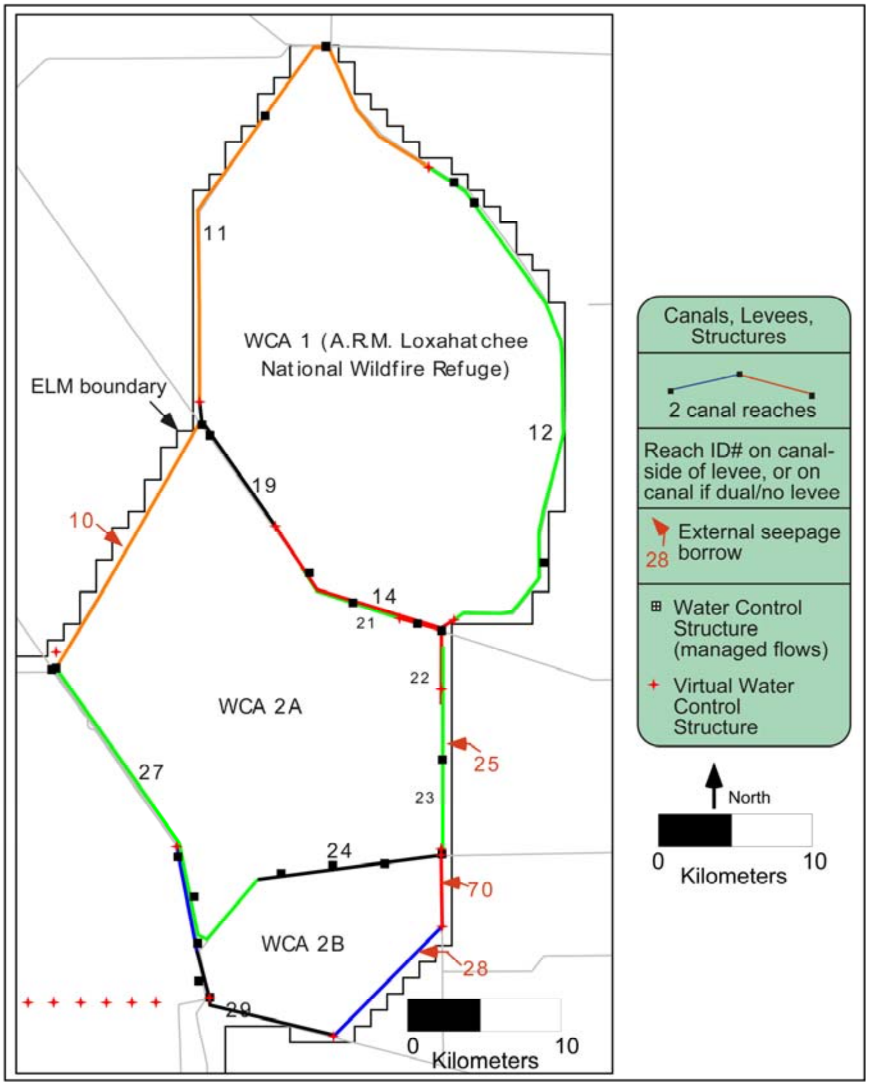

WCA 1 (A.R.M. Loxahatchee National Wildfire Refuge)
ELM boundary
11
12
19
14
21
22
23
24
25
27
28
29
70
10
WCA 2A
WCA 2B
0
10
Kilometers
Canals, Levees, Structures
2 canal reaches
Reach ID# on canal-side of levee, or on canal if dual/no levee
External seepage borrow
28
Water Control Structure (managed flows)
Virtual Water Control Structure
North
0
10
Kilometers

Figure 4.20.

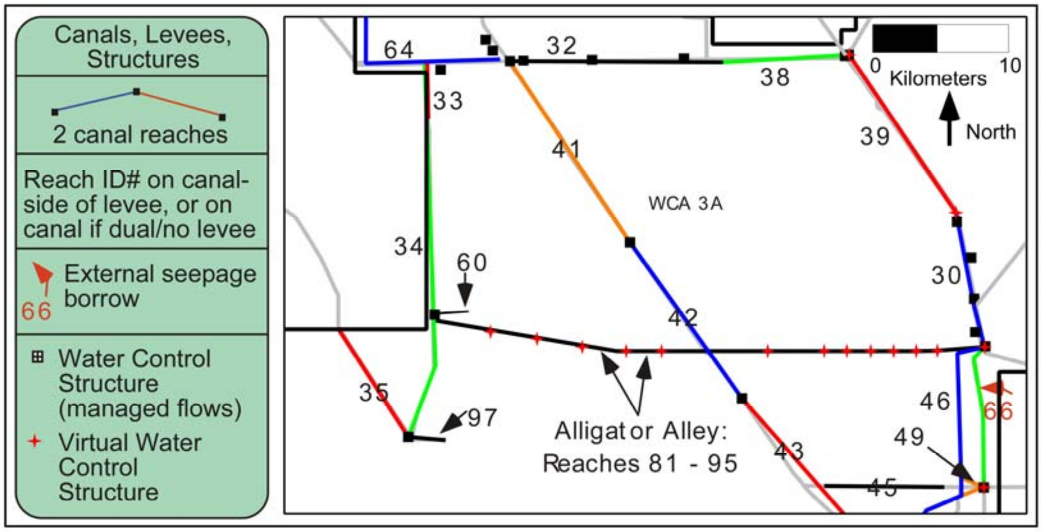

Canals, Levees, Structures
2 canal reaches
Reach ID# on canal-side of levee, or on canal if dual/no levee
External seepage borrow
66
Water Control Structure (managed flows)
Virtual Water Control Structure
64
32
38
33
41
39
WCA 3A
34
60
30
42
35
97
Alligator Alley: Reaches 81 - 95
43
46
66
49
45
0
10
Kilometers
North

Figure 4.21.

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	ACME12	ACME1, ACME2,	tser	tser	LEC	WCA1	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Runoff from ACME basin into L-40 canal in eastern WCA-1 via ACME Pump#1 (ACME1DS) plus Pump#2 (G-94D) (SFWMM names can be: ACME1=ACME1DS=ACME12=ACMERO=ACMERF). (ACMERF,
ELM	ACME12						To:			11										
WMM	ACMEWS	ACME12WS,			WCA1	LEC	Fr:			12	☐	☒	☐	☐	☐	☐	☐	☐	☐	Water supply releases from L-40 canal in eastern WCA-1 to ACME basinPump#2 (G-94D), (plus Pump#1?). SFWMM names: ACME12WS=ACME2=ACMEWS (ACMEWS for ALTs). Near L40-2 WQ
ELM	ACMEWS						To:	1	1											
WMM	G155	G-155	tser	tser	EAA	WCA3A	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-3 canal split at Confusion Corner, input into cell of NW WCA-3A
ELM	G155						To:	45	42											
WMM	G200	G-200, HLYQIN	tser	tser	LOK	Holey L	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	From Miami Canal into NW tip of Holey Land. Assume water from LOK in ALTS? (always 0 flow in Restudy ALT3) ELMv2.1name = HLYQIN (HLYQIN ZERO IN V5.4 SFWMM calib)
ELM	G200						To:	47	30											
WMM	G204	G-204			Holey L	WCA3A	Fr:			32	☒	☒	☒	☐	☐	☐	☐	☐	☐	One of 3 outflows from southern Holey Land into north WCA-3A (G-204, G-205, G-206). Historical flows are bad-use SFWMM v5.4 simulated flows in calibration.
ELM	G204						To:	50	41											
WMM	G205	G-205			Holey L	WCA3A	Fr:			32	☒	☒	☒	☐	☐	☐	☐	☐	☐	One of 3 outflows from southern Holey Land into north WCA-3A (G-204, G-205, G-206) Historical flows bad-use SFWMM v5.4 simulated flows in calibration.
ELM	G205						To:	55	41											
WMM	G206	G-206			Holey L	WCA3A	Fr:			32	☒	☒	☒	☐	☐	☐	☐	☐	☐	One of 3 outflows from southern Holey Land into north WCA-3A (G-204, G-205, G-206) Historical flows are bad-use SFWMM v5.4 simulated flows in calibration.
ELM	G206						To:	61	41											
WMM	G251	G-251, ENR012	tser	tser	STA	WCA1	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	Originally the outflow from Everglades Nutrient Removal (ENR) Project into L-7 in NW WCA-1; now outflow from STA1-W into WCA-1 (G-251 also known as ENR012). G251 not in SFWMMv5.0 glossary. SFWMMv5.4
ELM	G251						To:			11										

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To		Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	G310	**G-310**	tser	tser	STA	WCA1	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Outflow from STA-1W into L-7 canal in NW WCA-1. DEVELOP (location just same as G251 here) G310 not in SFWMMv5.0 glossary
ELM	G310						To:			11										
WMM	L28WQ	**L28-Int**	tser	tser	BC	WCA3A	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Flow from L28Interceptor canal into western WCA-3A. Removed from Restudy ALTD+, with flows coming from S-190, no levee along SW L-28I. SFWMM name is L28WQ (ELMv2.1 name=L28WQ)
ELM	L28WQ						To:			97										
WMM	LWDD	**LWDD, G-94A,**			WCA1	LEC	Fr:			12	☒	☒	☒	☒	☒	☒	☒	☐	☒	Water supply releases from L-40 canal in eastern WCA-1 into Lake Worth Drainage District (LWDD) via G-94A plus G-94B, which are well-separated (but usually in same ELM reach). SFWMMv5.0HistFlow
ELM	LWDD						To:	1	1											
WMM	NSIMP2	**S-38B**	38	0.05	LEC	WCA2A	Fr:	1	1		☐	☒	☐	☒	☐	☐	☐	☐	☐	One of two pump flows from North Springs Improvement District (NSIMP) into east WCA-2A. Other NSIMP pumps, but ELM only models these 2 inflows. ALSO a gated culvert in L-36 borrow, acts as divide between
ELM	NSIMP2						To:	96	46											
WMM	NSIMP3	**S-38B**	38	0.05	LEC	WCA2A	Fr:	1	1		☐	☒	☐	☒	☐	☐	☐	☐	☐	One of two pump flows from North Springs Improvement District (NSIMP) into east WCA-2A. Other NSIMP pumps, but ELM only models these 2 inflows. ALSO a gated culvert in L-36 borrow, acts as divide between
ELM	NSIMP3						To:	96	46											
WMM	RTECV1	**S-8**			Rot	WCA3A	Fr:			64	☒	☒	☐	☐	☐	☐	☐	☐	☐	One of 2 unregulated flows thru existing culverts into Miami canal above S8, considered to go out of system because S8 flow is from out of system (95base this is part of S8 flow). Historical flows bad-use
ELM	RTECV1						To:	1	1											
WMM	RTECV2	**S-8**			Rot	WCA3A	Fr:			64	☒	☒	☐	☐	☐	☐	☐	☐	☐	One of 2 unregulated flows thru existing culverts into Miami canal above S8, considered to go out of system because S8 inflow is from out of system (95base this is part of S8 flow). Historical flows bad-use
ELM	RTECV2						To:	1	1											
WMM	S10A	**S-10A**			WCA1	WCA2A	Fr:			14	☐	☒	☐	☐	☐	☐	☐	☐	☐	From Hillsboro Canal in WCA-1 to NE region of WCA-2A. S10-A,C,D similar. SFWWM aggregates A,C,&D into 1 flow. For ALTS, ELM partitions the SFWMM flow among structs. ELM calib uses indiv. flows.
ELM	S10A						To:			22										

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To		Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2R	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	S10C	**S-10C**	—	—	WCA1	WCA2A	Fr:			14	☐	☒	☐	☐	☐	☐	☐	☐	☐	From Hillsboro Canal in WCA-1 to NE region of WCA-2A. S10-A,C,D similar. SFWWM aggregates A,C,&D into 1 flow. For ALTS, ELM partitions the SFWMM flow among structs. ELM calib uses indiv. flows.
ELM	S10C						To:			21										
WMM	S10D	**S-10D**	—	—	WCA1	WCA2A	Fr:			14	☐	☒	☐	☐	☐	☐	☐	☐	☐	From Hillsboro Canal in WCA-1 to NE region of WCA-2A. S10-A,C,D similar. SFWWM aggregates A,C,&D into 1 flow. For ALTS, ELM partitions the SFWMM flow among structs. ELM calib uses indiv. flows.
ELM	S10D						To:			21										
WMM	S10E	**S-10E**	—	—	WCA1	WCA2A	Fr:			19	☒	☒	☒	☒	☒	☒	☒	☒	☒	From Hillsboro Canal in WCA-1 to northern tip of WCA-2A. Much smaller structure than other S-10s (A,C,D).
ELM	S10E						To:	82	26											
WMM		**S11**	—	—	WCA2A	WCA3A	Fr:			27	☐	☒	☐	☐	☐	☐	☐	☐	☐	From North New River Canal in SW WCA-2A into L-38W canal in NE WCA-3A. S-11-A,B,C similar. SFWWM aggregates A,B,&C into 1 flow. For ALTS, ELM partitions the flow among structs. ELM calib uses indiv.
ELM	S11						To:			30										
WMM	S11A	**S-11A**	—	—	WCA2A	WCA3A	Fr:			27	☐	☒	☐	☐	☐	☐	☐	☐	☐	From North New River Canal in SW WCA-2A into L-38W canal in NE WCA-3A. S-11-A,B,C similar. SFWWM aggregates A,B,&C into 1 flow. For ALTS, ELM partitions the flow among structs. ELM calib uses indiv.
ELM	S11A						To:			30										
WMM	S11B	**S-11B**	—	—	WCA2A	WCA3A	Fr:			27	☐	☒	☐	☐	☐	☐	☐	☐	☐	From North New River Canal in SW WCA-2A into L-38W canal in NE WCA-3A. S-11-A,B,C similar. SFWWM aggregates A,B,&C into 1 flow. For ALTS, ELM partitions the flow among structs. ELM calib uses indiv.
ELM	S11B						To:			30										
WMM	S11C	**S-11C**	—	—	WCA2A	WCA3A	Fr:			27	☐	☒	☐	☐	☐	☐	☐	☐	☐	From North New River Canal in SW WCA-2A into L-38W canal in NE WCA-3A. S-11-A,B,C similar. SFWWM aggregates A,B,&C into 1 flow. For ALTS, ELM partitions the flow among structs. ELM calib uses indiv.
ELM	S11C						To:			30										
WMM	S12A	**S-12A**	—	—	WCA3A	ENP	Fr:			53	☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-29 borrow in southern WCA-3A into northern Everglades National Park (ENP). S-12 A,B,C,D similar.
ELM	S12A						To:	45	104											

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	Description
WMM	S12B	S-12B	—	—	WCA3A	ENP	Fr:			53	x	x	☐	☐	☐	☐	☐	☐	☐	From L-29 borrow in southern WCA-3A into northern Everglades National Park (ENP). S-12 A,B,C,D similar.
ELM	S12B						To:	50	104											
WMM	S12C	S-12C	—	—	WCA3A	ENP	Fr:			53	x	x	☐	☐	☐	☐	☐	☐	☐	From L-29 borrow in southern WCA-3A into northern Everglades National Park (ENP). S-12 A,B,C,D similar.
ELM	S12C						To:	54	104											
WMM	S12D	S-12D	—	—	WCA3A	ENP	Fr:			53	x	x	☐	☐	☐	☐	☐	☐	☐	SFrom L-29 borrow in southern WCA-3A into northern Everglades National Park (ENP). S-12 A,B,C,D similar.
ELM	S12D						To:	58	104											
WMM		S140in	tser	tser	BC	WCA3A	Fr:	1	1		☐	x	☐	☐	☐	☐	☐	☐	☐	From L-28 canal into short C-60 canal in NW WCA-3A (v2.1=S140A) In ALTS, S140A = (ROTOL4+HLYL4+ST3TL4+ST6TL4+S140FC). In many ALTS, partitioned into other structs, thus this not always used.
ELM	S140in						To:			60										
WMM		S140out	—	—	WCA3A	BC	Fr:			60	☐	x	☐	☐	☐	☐	☐	☐	☐	From short C-60 canal in NW WCA-3A to L-28 canal.
ELM	S140out						To:	1	1											
WMM	S142E	S-142E S-34	—	—	WCA3A	WCA2B	Fr:			30	☐	x	X	x	X	X	☐	☐	x	From WCA-3A into NNRiver canal reach between S143 & S34; sources of this NNR reach are G-123 (south NNR), S-141 (2B), S-142E (3A), and S-143 (2A); outflows are S-34 (to south) and S-142W (to WCA-3A).
ELM	S142E						To:			29										
WMM	S142W	S-142W G-123	—	—	WCA2B	WCA3A	Fr:			29	☐	x	X	x	X	X	☐	☐	x	From NNRiver canal reach between S143 & S34, into WCA-3A; sources of this NNR reach are G-123 (south NNR), S-141 (2B), S-142E (3A), and S-143 (2A); outflows are S-34 (to south) and S-142W (to WCA-3A).
ELM	S142W						To:			30										
WMM	S143	S-143	—	—	WCA2A	WCA2B	Fr:			27	x	x	X	x	X	X	x	x	x	From south WCA-2A into NNRiver canal reach above S-34 (which controls further down-canal flows); G-123 pumps north across S-34; S-141 is release from 2B above S-34); S-142 is in/out of 3A above S-34.
ELM	S143						To:			29										

Figure 4.22 (18 pages)

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	S144neg	**S144neg**	—	—	WCA2B	WCA2A	Fr:	87	54		☐	☒	☐	☐	☐	☐	☐	☐	☐	From WCA2B into L35B borrow in south WCA-2A (three identical structs, 144,145,146)
							To:			24										
WMM ELM	S144pos	**S144pos**	—	—	WCA2A	WCA2B	Fr:			24	☐	☒	☐	☐	☐	☐	☐	☐	☐	From L35B borrow in south WCA-2A into WCA2B (three identical structs, 144,145,146)
							To:	87	54											
WMM ELM	S145neg	**S145neg**	—	—	WCA2B	WCA2A	Fr:	90	53		☐	☒	☐	☐	☐	☐	☐	☐	☐	From WCA2B into L35B borrow in south WCA-2A (three identical structs, 144,145,146)
							To:			24										
WMM ELM	S145pos	**S145pos**	—	—	WCA2A	WCA2B	Fr:			24	☐	☒	☐	☐	☐	☐	☐	☐	☐	From L35B borrow in south WCA-2A into WCA2B (three identical structs, 144,145,146)
							To:	90	53											
WMM ELM	S146neg	**S146neg**	—	—	WCA2B	WCA2A	Fr:	93	53		☐	☒	☐	☐	☐	☐	☐	☐	☐	From WCA2B into L35B borrow in south WCA-2A (three identical structs, 144,145,146)
							To:			24										
WMM ELM	S146pos	**S146pos**	—	—	WCA2A	WCA2B	Fr:			24	☐	☒	☐	☐	☐	☐	☐	☐	☐	From L35B borrow in south WCA-2A into WCA2B (three identical structs, 144,145,146)
							To:	93	53											
WMM ELM	S150in	**S150in**	tser	tser	LOK	WCA3A	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	From EAA (NNRiver/Hillsb basin) to L-38W canal in NE WCA-3A. 95Base = discharge from EAA NNR/HLSB basin to conveyance canal in NE WCA-3A; in 50Base onward, is water supply from LOK's S-351
							To:			39										
WMM ELM	S150out	**S150out**	—	—	WCA3A	LOK	Fr:			39	☐	☒	☐	☐	☐	☐	☐	☐	☐	From EAA (NNRiver/Hillsb basin) to L-38W canal in NE WCA-3A. 95Base = discharge from EAA NNR/HLSB basin to conveyance canal in NE WCA-3A; in 50Base onward, is water supply from LOK's S-351
							To:	1	1											

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	S151	**S-151**			WCA3A	WCA3B	Fr:			47	☒	☒	☐	☐	☐	☐	☐	☐	☐	From Miami Canal in WCA-3A (at juncture of L-67A), into Miami Canal (C304) in WCA-3B. S-151 is not split into two flows (WS and Reg.) for calibration
ELM	S151						To:			63										
WMM	S175	**S-175**	tser	tser	LEC	ENP	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-31W south of Frog Pond into continuation of L-31W (S175D canal) and into marsh region just upstream of Everglades National Park east panhandle. Check calib SFWMM v5.4 vs observed data flows
ELM	S175						To:			58										
WMM	S18C	**S-18C**	tser	tser	LEC	ENP	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From northern C-111E canal into lower C-111 canal (upstream of culverts/newly-degraded levee). S-197 downstream of the latter area historically controlled how much of this water flowed south into marsh
ELM	S18C						To:			62										
WMM	S197	**S-197**			ENP	LEC	Fr:			62	☒	☒	☒	☒	☒	☒	☐	☐	☒	From C-111 canal (reach containing culverts/newly-degraded levee, downstream of S-18C) to Barnes Sound.
ELM	S197						To:	1	1											
WMM	S31	**S-31**			WCA3B	LEC	Fr:			63	☒	☒	☒	☒	☒	☒	☐	☐	☒	From C304 (Miami Canal) in WCA-3B to C-6 (Miami Canal) in urban LEC. For ALTS, S-31 split into 3 structs, plus S-337
ELM	S31						To:	1	1											
WMM	S332	**S-332**	tser	tser	LEC	ENP	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-31W into marshes of Taylor Slough (in Everglades National Park).
ELM	S332						To:	67	141											
WMM	S332B	**S-332B**	7	0.04	LEC	ENP	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	From L-31N (between S-176 & S-331) into detention areas north of Taylor Slough, intended to recycle seepage from the Park. A plan had set of S-332A,B,C,D of similar config. (LOCATION? and historical
ELM	S332B						To:	69	127											
WMM	S332D	**S-332D**	tser	tser	LEC	ENP	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	From L-31N (between S-176 & S-331) into detention areas north of Taylor Slough, intended to recycle seepage from the Park. A plan had set of S-332A,B,C,D of similar config. (LOCATION?)
ELM	S332D						To:	67	141											

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: To:	Cell_X Cell_X	Cell_Y Cell_Y	CanalID CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	S333 S333	**S-333**	—	—	WCA3A	ENP	Fr: To:			47 54	x	x	X	x	X	X	☐	☐	x	From L-29/L-67 in WCA-3-A to L-29 canal in NE ENP (below WCA-3B), no levee on south side L-29 below WCA-3B See also S-334, S-337
WMM ELM	S334 S334	**S-334** **S-336**	—	—	ENP	LEC	Fr: To:	 1	 1	54 	x	x	X	x	X	X	☐	☐	x	From L-29 borrow in NE ENP to L-31N borrow of LEC upstream of G-211 (but there is some recycling, see S-356A&B)
WMM ELM	S337 S337	**S-337**	—	—	WCA3B	LEC	Fr: To:	 1	 1	63 	x	x	X	x	X	X	☐	☐	x	From Miami Canal (C304) in WCA-3B into L-30 canal of LEC. See also S-31 - we've put both structures in same phys location, but S-337 is more south actually. This is moved in Restudy ALTD (also==S337_C)
WMM ELM	S339 S339	**S-339**	—	—	WCA3A	WCA3A	Fr: To:			41 42	x	x	☐	☐	☐	☐	☐	☐	☐	From L-23E to C123 (both are reaches of Miami Canal), all within WCA-3A. NOT using historical data, just virtual weir. Historical flows bad-use SFWMM v5.4 simulated flows in calibration.
WMM ELM	S34 S34	**S-34**	—	—	WCA2B	LEC	Fr: To:	 1	 1	29 	x	x	X	x	X	X	x	x	x	From NNRiver reach segment between S143 and S34, to LEC; sources of this segment of NNR are G-123 (pumps from S to N of S-34), S-141 (2B), S-142E (3A), and S-143 (2A); other outflow is S-142W
WMM ELM	S340 S340	**S-340**	—	—	WCA3A	WCA3A	Fr: To:			42 43	x	x	☐	☐	☐	☐	☐	☐	☐	From C123 to CA-3 canal (both are reaches of Miami Canal), all within WCA-3A. NOT using historical data, just virtual weir. Historical flows bad-use SFWMM v5.4 simulated flows in calibration.
WMM ELM	S343 S343	**S-343A&B**	—	—	WCA3A	ENP	Fr: To:	 41	 101	53 	x	x	X	x	X	X	☐	☐	x	From SW corner of WCA-3A into Tamiami Canal in loop road area of ENP, via sum of S-343A and S-343B (S343T name ==v2.1 name S343, but flow is diff). Historical flows bad-use SFWMM v5.4 simulated flows in
WMM ELM	S344 S344	**S-344**	—	—	WCA3A	BC_	Fr: To:			36 37	x	x	X	x	X	X	☐	☐	x	From borrow in L28 that is on east of levee in SW WCA-3A to borrow of that levee on west side in Big Cypress (i.e., borrow switches sides) See also S-343A&B. Historical flows bad-use SFWMM v5.4 simulated flows

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	S38	S-38 S-38A	—	—	WCA2A	LEC	Fr:			24	☒	☒	☒	☒	☒	☒	☒	☒	☒	From L-38 canal in SE WCA-2A into C-14 canal of LEC (see also S-38A,B)
ELM	S38						To:	1	1											
WMM	S39	S-39 S-39A	—	—	WCA1	LEC	Fr:			14	☒	☒	☒	☒	☒	☒	☒	☒	☒	From Hillsboro Canal (actually, perimeter canal in general) in SE WCA-1 into Hillsboro Canal reach in LEC. Flow partitioned into 3 equal contributions.
ELM	S39						To:	1	1											
WMM	S39_L39	S-39 S-39A	—	—	WCA1	LEC	Fr:			14	☒	☒	☒	☒	☒	☒	☒	☒	☒	From Hillsboro Canal (actually, perimeter canal in general) in SE WCA-1 into Hillsboro Canal reach in LEC. Contribution from L39 segment of perimeter canal.
ELM	S39_L39						To:	1	1											
WMM	S39_L39b	S-39 S-39A	—	—	WCA1	LEC	Fr:			14	☒	☒	☒	☒	☒	☒	☒	☒	☒	From Hillsboro Canal (actually, perimeter canal in general) in SE WCA-1 into Hillsboro Canal reach in LEC. Contribution from L39 segment of perimeter canal.
ELM	S39_L39b						To:	1	1											
WMM	S39_L40	S-39 S-39A	—	—	WCA1	LEC	Fr:			12	☒	☒	☒	☒	☒	☒	☒	☒	☒	From Hillsboro Canal (actually, perimeter canal in general) in SE WCA-1 into Hillsboro Canal reach in LEC. Contribution from L40 segment of perimeter canal.
ELM	S39_L40						To:	1	1											
WMM	S5A2NO	S-5S	—	—	WCA1	EAA	Fr:			11	☒	☒	☒	☐	☐	☐	☐	☐	☐	From north tip of WCA1 into L8/C51/LWDD (water supply), partitioned into contribution from west (L-7) and east (L-40) segments of the rim canal.
ELM	S5A2NO						To:	1	1											
WMM	S5A2NO1	S-5S	—	—	WCA1	EAA	Fr:			11	☒	☒	☒	☐	☐	☐	☐	☐	☐	From north tip of WCA1 into L8/C51/LWDD (water supply), partitioned into contribution from west (L-7) and east (L-40) segments of the rim canal. This is the L-7 flow.
ELM	S5A2NO1						To:	1	1											
WMM	S5A2NO2	S-5S	—	—	WCA1	EAA	Fr:			11	☒	☒	☒	☐	☐	☐	☐	☐	☐	From north tip of WCA1 into L8/C51/LWDD (water supply), partitioned into contribution from west (L-7) and east (L-40) segments of the rim canal. This is the L-40 flow.
ELM	S5A2NO2						To:	1	1											

ELM Water Control Structure Attributes

GO TO: Details

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Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	S5A2SO	S-5	—	—	EAA	WCA1	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-8 basin (and elsewhere) to north tip of WCA1, partitioned into contribution to west (L-7) and to east (L-40) segments of the rim canal.
ELM	S5A2SO						To:			11										
WMM	S5A2SO1	S-5	tser	tser	EAA	WCA1	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-8 basin (and elsewhere) to north tip of WCA1, partitioned into contribution to west (L-7) and to east (L-40) segments of the rim canal. This is the L-7 flow.
ELM	S5A2SO1						To:			11										
WMM	S5A2SO2	S-5	tser	tser	EAA	WCA1	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From L-8 basin (and elsewhere) to north tip of WCA1, partitioned into contribution to west (L-7) and to east (L-40) segments of the rim canal. This is the L-40 flow.
ELM	S5A2SO2						To:			11										
WMM	S6in	S-6	tser	tser	EAA	WCA1	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From EAA_NNR/HLSB basin to Hillsboro Canal in SW WCA-1. This structure is bi-directional, and this is a positive flow in this direction.
ELM	S6in						To:			19										
WMM	S6out	S-6	—	—	WCA1	EAA	Fr:			19	☒	☒	☐	☐	☐	☐	☐	☐	☐	From Hillsboro Canal in SW WCA-1 to EAA_NNR/HLSB basin. This structure is bi-directional, and this is a positive flow in this direction.
ELM	S6out						To:	1	1											
WMM	S7in	S-7	tser	tser	EAA	WCA2A	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From EAA_NNR/HLSB basin to North New River Canal in western WCA-2A. This structure is bi-directional, and this is a positive flow in this direction.
ELM	S7in						To:			27										
WMM	S7out	S-7	—	—	WCA2A	EAA	Fr:			27	☒	☒	☐	☐	☐	☐	☐	☐	☐	From North New River Canal in western WCA-2A to EAA_NNR/HLSB basin. This structure is bi-directional, and this is a positive flow in this direction.
ELM	S7out						To:	1	1											
WMM	S8in	S-8	tser	tser	EAA	WCA3A	Fr:	1	1		☒	☒	☐	☐	☐	☐	☐	☐	☐	From EAA Miami basin (Miami Canal reach) to Miami Canal (C-123) reach in northern WCA-3A. This structure is bi-directional, and this is a positive flow in this direction. (Note that Miami Canal north of S-8 is
ELM	S8in						To:			41										

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM	S8out	**S-8**	—	—	WCA3A	EAA	Fr:			41	x	x	☐	☐	☐	☐	☐	☐	☐	From Miami Canal (C-123) reach in northern WCA-3A to EAA Miami basin (Miami Canal reach). This structure is bi-directional, and this is a positive flow in this direction. (Note that Miami Canal north of S-8 is
ELM	S8out						To:	1	1											
WMM	S9	**S-9**	tser	tser	LEC	WCA3A	Fr:	1	1		x	x	X	☐	☐	☐	☐	☐	☐	From C-11W canal of LEC to C-304 canal reach in eastern WCA-3A.
ELM	S9						To:			45										
WMM		**VS_H1**	—	—	Holey L	EAA	Fr:			31	x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside Holey Land , via northern borrow
ELM	VS_H1						To:	1	1											
WMM		**VS1_06**	—	—	WCA1	WCA1	Fr:			11	x	x	X	x	X	X	x	x	x	A virtual structure linking a reach of the rim canal of west WCA1 to the western reach segment of Hillsboro (in rim of WCA1)
ELM	VS1_06						To:			19										
WMM		**VS1_07**	—	—	WCA1	WCA1	Fr:			19	x	x	X	x	X	X	x	x	x	A virtual structure linking two reaches of Hillsboro canal
ELM	VS1_07						To:			14										
WMM		**VS1_07b**	—	—	WCA1	WCA1	Fr:			11	x	x	X	x	X	X	x	x	x	A virtual structure linking two reaches of L-40 canal
ELM	VS1_07b						To:			12										
WMM		**VS1_09**	—	—	WCA1	WCA1	Fr:			12	x	x	x	x	x	x	x	x	x	A virtual structure linking the L-40 rim canal of east WCA1, southern reach with eastern reach of Hillsboro
ELM	VS1_09						To:			14										
WMM		**VS2A1**	—	—	WCA2A	LEC	Fr:			25	x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control across L36 of eastern WCA-2A boundary
ELM	VS2A1						To:	1	1											

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: / To:	Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM		**VS2A2**	—	—	WCA2A	LEC	Fr:			10	x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control across L6 of western WCA-2A boundary
ELM	VS2A2						To:	1	1											
WMM		**VS2A4**	—	—	WCA2A	WCA2A	Fr:			21	x	x	x	x	x	x	x	x	x	A virtual structure linking borrow along northeast corner of WCA2A
ELM	VS2A4						To:			22										
WMM		**VS2A5**	—	—	WCA2A	WCA2A	Fr:			22	x	x	x	x	x	x	x	x	x	A virtual structure linking borrow along eastern WCA2A to south
ELM	VS2A5						To:			23										
WMM		**VS2A6**	—	—	WCA2A	WCA2A	Fr:			23	x	x	x	x	x	x	x	x	x	A virtual structure linking borrow along SE WCA2A to L-35B
ELM	VS2A6						To:			24										
WMM		**VS2B1**	—	—	WCA2B	LEC	Fr:			28	x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA2B , via L35A borrow
ELM	VS2B1						To:	1	1											
WMM		**VS2B2**	—	—	WCA2B	LEC	Fr:			70	x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA2B , via L35A borrow
ELM	VS2B2						To:	1	1											
WMM		**VS3A1**	—	—	WCA3A	WCA3A	Fr:			39	x	x	X	x	X	X	x	x	x	A virtual structure linking reaches of L38 borrow along NE 3A
ELM	VS3A1						To:			30										
WMM		**VS3A2**	—	—	WCA3A	WCA3A	Fr:			30	x	x	X	x	X	X	x	x	x	A virtual structure linking reaches of L38 borrow and L-68A borrow along NE 3A
ELM	VS3A2						To:			46										

ELM Water Control Structure Attributes

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GO TO: Details

Model ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: Cell_X	Fr: Cell_Y	Fr: CanalID	To: Cell_X	To: Cell_Y	To: CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM VS3A3	**VS3A3**	—	—	WCA3A	WCA3A			46			47	x	x	x	x	X	X	x	x	x	A virtual structure linking reaches of L-68A & L-67A borrows.
WMM ELM VS3A6	**VS3A6**	—	—	WCA3A	WCA3A			47			53	x	x	X	x	X	X	☐	☐	x	A virtual structure linking reaches of L-67A and L-29 borrow.
WMM ELM VS3A7	**VS3A7**	—	—	WCA3A	WCA3A			43			47	x	x	x	x	X	X	☐	☐	x	A virtual structure linking reaches of Miami canal and L-67A borrow.
WMM ELM VS3B1	**VS3B1**	—	—	WCA3B	LEC			66	1	1		x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA3B , via L37
WMM ELM VS3B2	**VS3B2**	—	—	WCA3B	LEC			50	1	1		x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA3B , via L33
WMM ELM VS3B3	**VS3B3**	—	—	WCA3B	LEC			51	1	1		x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA3B , via L30
WMM ELM VS3B4	**VS3B4**	—	—	WCA3B	LEC			71	1	1		x	x	X	x	X	X	x	x	x	A variation on use of virtual structures for seepage control outside WCA3B , via L30
WMM ELM VSbr01	**VSbr01**	—	—	WCA3A	WCA3A	48	59		48	60		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley

Figure 4.22 (18 pages)

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: Cell_X	Fr: Cell_Y	Fr: CanalID	To: Cell_X	To: Cell_Y	To: CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	VSbr02	**VSbr02**	—	—	WCA3A	WCA3A	51	59		51	61		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr03	**VSbr03**	—	—	WCA3A	WCA3A	54	60		54	61		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr04	**VSbr04**	—	—	WCA3A	WCA3A	57	60		57	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr05	**VSbr05**	—	—	WCA3A	WCA3A	60	61		60	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr06	**VSbr06**	—	—	WCA3A	WCA3A	67	61		67	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr07	**VSbr07**	—	—	WCA3A	WCA3A	71	61		71	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr08	**VSbr08**	—	—	WCA3A	WCA3A	73	61		73	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
WMM ELM	VSbr09	**VSbr09**	—	—	WCA3A	WCA3A	75	61		75	62		x	x	X	x	X	X	x	x	x	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To		Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM		**VSbr10**	—	—	WCA3A	WCA3A	Fr:	76	61		☒	☒	☒	☒	☒	☒	☒	☒	☒	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
ELM	VSbr10						To:	76	62											
WMM		**VSbr11**	—	—	WCA3A	WCA3A	Fr:	78	61		☒	☒	☒	☒	☒	☒	☒	☒	☒	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
ELM	VSbr11						To:	78	62											
WMM		**VSbr12**	—	—	WCA3A	WCA3A	Fr:	79	61		☒	☒	☒	☒	☒	☒	☒	☒	☒	A virtual structure allowing (Manning's) flow under bridge of Alligator Alley
ELM	VSbr12						To:	79	62											
WMM		**VSENP1**	—	—	ENP	LEC	Fr:			52	☒	☒	☒	☒	☒	☒	☒	☒	☒	A variation on use of virtual structures for seepage control outside north ENP, via L31N
ELM	VSENP1						To:	1	1											
WMM		**VSENP2**	—	—	ENP	LEC	Fr:			61	☒	☒	☒	☒	☒	☒	☒	☒	☒	A variation on use of virtual structures for seepage control outside north ENP, via southern part of L31N
ELM	VSENP2						To:	1	1											
WMM		**VSENP4**	—	—	ENP	LEC	Fr:			76	☒	☒	☒	☒	☒	☒	☒	☒	☒	A variation on use of virtual structures for seepage control outside south ENP near Frog Pond, via upper part of ELM's C-111
ELM	VSENP4						To:	1	1											
WMM		**VSENP5**	—	—	ENP	ENP	Fr:			55	☒	☒	☒	☐	☐	☐	☐	☐	☐	A virtual structure providing physical connection between Tamiami canal and L67extension borrow.
ELM	VSENP5						To:			56										
WMM		**VSt_ABCRi1**	—	—	ENP	TIDE	Fr:			115	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions, Gulf of Mexico via Alligator Bay (AB) & Chatham River (CRi); 1 of 2 uni-directional flows at this virtual structure (outflow)
ELM	VSt_ABCRi1						To:	1	1											

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: Cell_X	Fr: Cell_Y	Fr: CanalID	To: Cell_X	To: Cell_Y	To: CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	VSt_ABCRi2	**VSt_ABCRi2**		15	TIDE	ENP	1	1				115	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions, Gulf of Mexico via Alligator Bay (AB) & Chatham River (CRi); 1 of 2 uni-directional flows at this virtual structure (inflow)
WMM ELM	VSt_ABLRi	**VSt_ABLRi**			ENP	ENP			113			112	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the estuarine bays south of Alligator Bay (AB) and the Lostmans River (LRi)
WMM ELM	VSt_BRi	**VSt_BRi**			ENP	ENP			111			110	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the eastern portion of the Broad River (BRi) and western portion of the Broad River (BRi)
WMM ELM	VSt_BRiGM	**VSt_BRiGM**			ENP	ENP			110			105	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the western portion of the Broad River (BRi) and the Gulf of Mexico (GM) boundary reach in vicinity of the
WMM ELM	VSt_HRi	**VSt_HRi**			ENP	ENP			109			108	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the eastern portion of the Harney River (HRi) and the western portion of the Harney River (HRi)
WMM ELM	VSt_HRiGM	**VSt_HRiGM**			ENP	ENP			108			104	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the western portion of the Harney River (HRi) and the Gulf of Mexico (GM) boundary reach in the vicinity of the
WMM ELM	VSt_LBLRi	**VSt_LBLRi**			ENP	ENP			114			112	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the estuarine bays near Big Lostmans Bay (LB) and the Lostmans River (LRi)
WMM ELM	VSt_LRiGM	**VSt_LRiGM**			ENP	ENP			112			105	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the western portion of the Lostmans River (LRi) and the Gulf of Mexico (GM) boundary reach in vicinity of the Broad

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To		Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2R	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	VSt_SRi	**VSt_SRi**			ENP	ENP	Fr:			106	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the eastern portion of the Shark River (SRi) and the western portion of the Shark River (SRi)
							To:			107										
WMM ELM	VSt_SRiGM	**VSt_SRiGM**			ENP	ENP	Fr:			107	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the western portion of the Shark River (SRi) and the Gulf of Mexico (GM) boundary reach in the vicinity of the
							To:			104										
WMM ELM	VSt_TRiFB	**VSt_TRiFB**			ENP	ENP	Fr:			99	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing physical connection between the Taylor River (TRi) and the eastern Florida Bay boundary reach
							To:			100										
WMM ELM	VStFB_C1	**VStFB_C1**			ENP	TIDE	Fr:			101	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), central (C) section; 1 of 2 uni-directional flows at this virtual structure (outflow)
							To:	1	1											
WMM ELM	VStFB_C2	**VStFB_C2**		30	TIDE	ENP	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), central (C) section; 1 of 2 uni-directional flows at this virtual structure (inflow)
							To:			101										
WMM ELM	VStFB_E1	**VStFB_E1**			ENP	TIDE	Fr:			100	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), eastern (E) section; 1 of 2 uni-directional flows at this virtual structure (outflow)
							To:	1	1											
WMM ELM	VStFB_E2	**VStFB_E2**		30	TIDE	ENP	Fr:	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), eastern (E) section; 1 of 2 uni-directional flows at this virtual structure (inflow)
							To:			100										
WMM ELM	VStFB_W1	**VStFB_W1**			ENP	TIDE	Fr:			102	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), west (W) section; 1 of 2 uni-directional flows at this virtual structure (outflow)
							To:	1	1											

ELM Water Control Structure Attributes

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GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To	Fr: Cell_X	Fr: Cell_Y	Fr: CanalID	To: Cell_X	To: Cell_Y	To: CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2P	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12	
WMM ELM	VStFB_W2	**VStFB_W2**		30	TIDE	ENP	1	1				102	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions in Florida Bay (FB), west (W) section; 1 of 2 uni-directional flows at this virtual structure (inflow)
WMM ELM	VStGM_BL1	**VStGM_BL1**			ENP	TIDE			105	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Gulf of Mexico region adjacent to the Broad and Lostmans Rivers (BL); 1 of 2 uni-directional flows at this
WMM ELM	VStGM_BL2	**VStGM_BL2**		30	TIDE	ENP	1	1				105	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Gulf of Mexico region adjacent to the Broad and Lostmans Rivers (BL); 1 of 2 uni-directional flows at this
WMM ELM	VStGM_CRi1	**VStGM_CRi1**			ENP	TIDE			116	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Chatham River (CRi); 1 of 2 uni-directional flows at this virtual structure (outflow)
WMM ELM	VStGM_CRi2	**VStGM_CRi2**		15	TIDE	ENP	1	1				116	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Chatham River (CRi); 1 of 2 uni-directional flows at this virtual structure (inflow)
WMM ELM	VStGM_LRi1	**VStGM_LRi1**			ENP	TIDE			112	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Lostmans River (LRi); 1 of 2 uni-directional flows at this virtual structure (outflow)
WMM ELM	VStGM_LRi2	**VStGM_LRi2**		15	TIDE	ENP	1	1				112	☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Lostmans River (LRi); 1 of 2 uni-directional flows at this virtual structure (inflow)
WMM ELM	VStGM_SH1	**VStGM_SH1**			ENP	TIDE			104	1	1		☐	☒	☐	☐	☐	☐	☐	☐	☐	Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Gulf of Mexico region adjacent to the Shark and Harney Rivers (SH); 1 of 2 uni-directional flows at this virtual

ELM Water Control Structure Attributes

Click Alt button for structure list

GO TO: Details

Model	ID	Name	TP (ppb)	TS (ppt)	Basin From	Basin To		Cell_X	Cell_Y	CanalID	Calib	Calib 2.2+	95 Bas	Bas RR2B	50 Bas	Alt A	Alt D13R	2050 wProj	MWD 12
WMM ELM	VStGM_SH2	**VStGM_SH2**		30	TIDE	ENP	Fr: To:	1 	1 	 104	☐	☒	☐	☐	☐	☐	☐	☐	☐
WMM ELM	VStGM_WB1	**VStGM_WB1**			ENP	TIDE	Fr: To:	 1	 1	103 	☐	☒	☐	☐	☐	☐	☐	☐	☐
WMM ELM	VStGM_WB2	**VStGM_WB2**		30	TIDE	ENP	Fr: To:	1 	1 	 103	☐	☒	☐	☐	☐	☐	☐	☐	☐

VStGM_SH2: Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along the Gulf of Mexico region adjacent to the Shark and Harney Rivers (SH); 1 of 2 uni-directional flows at this virtual

VStGM_WB1: Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along Cape Sable-Whitewater Bay (WB); 1 of 2 uni-directional flows at this virtual structure (outflow)

VStGM_WB2: Virtual structure, tidal influence (VSt). A virtual structure providing tidal boundary conditions along Cape Sable-Whitewater Bay (WB); 1 of 2 uni-directional flows at this virtual structure (inflow)

Global parameters for input to ELM v2.5.1 15-Jun-06

Modifications to the "Nominal" numeric values may be made in this worksheet - as long as you document it!!;

Those values and the brief supporting documentation column are mirrored in the "GlobalParms_NOM" worksheet for model input.

The GlobalParms_LO and GlobalParms_HI sheets are only used in the automated Sensitivity Analysis - modify those parameters as desired.

Ranks are based upon subregional sensitivity analyses on water depth and on surface and porewater phosphorus. See those results for more detailed documentation.

Rank: 5= unused - there are 3 such parameters;
4= not intended for modification beyond sensitivity tests - there are 27 such parameters;
3= has little to no effect on current model Performance Measures - there are 17 such parameters;
2= has observable effect on a Performance Measure - there are 17 such parameters;
1= a sensitive variable affecting multiple Performance Measures - there are 6 such parameters;

Rank	**Parameter name**	**Nominal Value**	Units	Default Value	diff?	Brief documentation	Extended documentation
4	GP_SOLOMEGA=	0.03259	dimless	0.03259		***empirical constant used in solar radiation, don't change from 0.03259	fixed value from Nikolov and Zeller (1992) solar radiation algorithm which was tested in multiple global locations
4	GP_ALTIT=	1	m	1		***regional altitude of land surface	pertinent only to applying model to other region
4	GP_LATDEG=	26.00	deg.min	26.00		***regional latitude (degrees.minutes, don't convert min to decimal deg)	pertinent only to applying model to other region
4	GP_mannDepthPow=	1.667	dimless	1.667		***power used in manning's equation water depth	for "true" manning's, use 1.667
4	GP_mannHeadPow=	0.50	dimless	0.50		***power used in manning's equation head difference	for "true" manning's, use 0.5
1	GP_calibGWat=	1.25	dimless	1.25		***calibration parameter, multiply by aquifer hydraulic conductivity, levee seepage	coarse calibration knob, used in calibrating budget to approximate SFWMM budget
5	GP_IDW_pow=	2.00	dimless	2.00		***power for (all) inverse distance^parm interpolations	have always used IDW^2 (parm=2.0) when running meteorological interpolations; no ELM-calculated interpolations in ELM v2.2 - v2.4
1	GP_calibET=	0.90	dimless	0.90		***calibration parameter, multiply potential ET input data	coarse calibration knob, used in calibrating ET budget to Abtew's (1996) rates for specific flooded habitats, and approximate SFWMM budget
4	GP_DATUM_DISTANCE=	6.00	m	6.00		***distance below NGVD'29 to base datum	not simulating deep aquifer (below 6 meters beneath NGVD '29)
4	GP_HYD_IC_SFWAT_ADD=	0.00	m	0.00		***surf water depth added to Initial Condition ponded surface water depth map (+/- m)	only used in exploratory model experiments
4	GP_HYD_IC_UNSAT_ADD=	0.00	m	0.00		***depth of unsat zone added to Initial Condition unsaturated water storage depth map (+/-m)	only used in exploratory model experiments
5	GP_HYD_RCRECHG=	0.00	m/d	0.00		***Rate of recharging of the aquifer below the base datum (loss from model system).	***should always=0.0, deep recharge effectively not implemented
4	GP_HYD_ICUNSATMOIST=	1.00	dimless	1.00		***Initial condition of the moisture proportion in the unsaturated zone.	limited spatial data; non-critical initial condition
3	GP_DetentZ=	0.01	m	0.01		***detention depth in a grid cell, below which surface flows do not occur	scale-dependent relative to topographic heterogeneity
4	GP_MinCheck=	0.0001	m	0.0001		***small threshold number, for relative error-checking (not a multiplier etc)	only used in constraining fluxes at extremely mimimal conditions
2	GP_dispLenRef=	500	m	500		***reference length for which numerical dispersion (of finite difference sol'n) approximates actual turbulent diffusion, or dispersion	code not truly established for input of actual dispersion estimates - at this point, dispersion is poorly quantified in these wetlands
2	GP_dispParm=	1.00	dimless	1.00		***calibration parameter, can be ~representative of Dispersion Number estimates; a value of 0 removes any dispersion adjustments (leaving only the numerical dispersion of model scale)	code not truly established for input of actual dispersion estimates - at this point, dispersion is poorly quantified in these wetlands
3	GP_SLRise=	0.0024	m/yr	0.0024		***rate of Sea Level Rise	based on CERP Guidance Memo 016.00
4	GP_ALG_IC_MULT=	1.0	dimless	1.0		***algal init-cond multiplier (0-1 proportion, relative to maximum attainable biomass)	intended only for use in exploratory model experiments
4	GP_alg_uptake_coef=	3.0	dimless	3.0		***parameter for exp function describing uptake kinetics	not intended for adjustment, only used to define (fixed) function behavior; set at 3.0
3	GP_ALG_SHADE_FACTOR=	1.0	dimless	1.0		***calibration parm to modify LAI in shading fcn	regulate magnitude of macrophyte shading; CALIBRATE to achieve observed periphyton biomass in dense/moderate vegetation
3	GP_algMortDepth=	0.05	m	0.05		***depth of the unsat zone below which accelerated "drydown" alg mort occurs	limited field observations
3	GP_ALG_RC_MORT_DRY=	0.0002	1/d	0.0002		***Specific mortality rate of benthic algae (periphyton) in "drydown" conditions.	limited field observations; preliminary lab experiments
2	GP_ALG_RC_MORT=	0.0001	1/d	0.0001		***Baseline specific rate of algal (periphyton) mortality. Note that this is in the presence of water.	liimited field observations relating to biomass changes
2	GP_ALG_RC_PROD=	0.05	1/d	0.05		***Maximum specific rate observed/attainable of algal (periphyton) gross primary production.	field experiments (and O2->Carbon conversion); CALIBRATE to achieve observed periphyton production rates
3	GP_ALG_RC_RESP=	0.0001	1/d	0.0001		***Max specific rate of algal respiration.	field experiments (and O2->Carbon conversion)
2	GP_alg_R_accel=	1.0	dimless	1.0		***acceleration of mortality (via assumed loss of calcareous sheath) of oligotrophic community under high phosphorus conditions	due to uncertainty of mechanism for mat loss, increase loss at elevated P concentrations; CALIBRATE to achieve biomass observations
3	GP_AlgComp=	2.0	dimless	2.0		***algal density-dep competition, with parameter >1.0 increasing competitive "ability" of oligotrophic periphyton	CALIBRATE to achieve relative biomass estimates of the two communities under low nutrient conditions
4	GP_ALG_REF_MULT=	0.01	dimless	0.01		***proportion of max attainable periphyton biomass, defining a refuge density (from losses)	this parameter multiplied by HP_ALG_MAX habitat-specific parameter to obtain refuge density; proxy for maintaining senescent stocks under severe drydown conditions
1	GP_NC_ALG_KS_P=	0.10	mg/L	0.10		***half-saturation conc of avail phosphorus for uptake kinetics, eutrophic (was non-calcareous)	Lab study; CALIBRATE to achieve plant growth rates along nutrient gradients

Figure 4.23 (3 pages)

3	GP_alg_alkP_min=	0.10	dimless	0.10		***minimum possible constraint level (0-1) on phosphorus uptake and growth; value>0 indicative of non-zero nutrient limitation due to APActivity	a proportion >0 is indicative of the observed continued (low) uptake and growth by periphyton at very low ambient P concentrations, due to alkaline phosphotase activity increasing bioavailability in low P conditions
2	GP_C_ALG_KS_P=	0.05	mg/L	0.05		***half-saturation conc of avail phosphorus for uptake kinetics, oligotrophic (was calcareous) periph	Lab study; CALIBRATE to achieve plant growth rates along nutrient gradients
4	GP_ALG_TEMP_OPT=	33	deg C	33		***Optimal temperature for algal primary production (degrees C). Also used in respiration control.	General literature estimates relative to plant type/family. Water temperature is constant across space and time in ELM v2.4, so temperature relationships are not effectively simulated.
1	GP_C_ALG_threshTP=	0.02	mg/L	0.02		***TP conc above which oligotrophic (was calcareous) periphyton have elevated mortality (via asmed loss of calcareous sheath)	due to uncertainty of mechanism for periphyton mat loss, increase respiration loss at elevated P concentrations; note that 10 ppb is estimate supported by multiple research efforts
2	GP_ALG_C_TO_OM=	0.48	gC/gOM	0.48		***Mass ratio of organic carbon to total organic material in algae (ash free dry weight).	multiple glades field and lab observations
4	GP_alg_light_ext_coef=	0.005	1/m	0.005		***light extinction parameter, currently used to fully define (statically) extinction	fixed extinction coef for clear water
3	GP_ALG_LIGHT_SAT=	550	cal/cm^2/d	550		***Saturating light intensity for algal photosyn (langley/d = cal/cm^2 per day)	assume max normal radiation is saturation
2	GP_ALG_PC=	0.003	gP/gC	0.003		***Initial phophorus:carbon ratio in all algae/periphyton	multiple glades field and lab observations
1	GP_DOM_RCDECOMP=	0.001	1/d	0.001		***Maximum observed/attainable specific rate of organic matter decomposition (w/o limitations)	field and lab studies, glades peat-systems
2	GP_DOM_DECOMPRED=	0.30	dimless	0.30		***under anaerobic conditions, proportional reduction of the maximum rate of aerobic decomposition	glades lab experiments
4	GP_calibDecomp=	0.60	dimless	0.60		***calibration parameter, multiply soil/floc decomposition flux calculation	Sensitive parameter, but duplicative of another: This is directly correlated to (multiplies) the GP_DOM_RCDECOMP; maintained from older model configuration
4	GP_DOM_decomp_coef=	3.0	dimless	3.0		***parameter for exp function describing decomposition kinetics with respect to phosphorus availability/quality	not intended for adjustment, only used to define (fixed) function behavior; set at 3.0
1	GP_DOM_DECOMP_POPT=	0.45	mg/L	0.45		***Optimal phosphorus concentration in water for maximal decomposition of organic matter	generalized from glades lab experiments
4	GP_DOM_DECOMP_TOPT=	33	deg C	33		***Optimal temperature for maximal decomposition of organic matter	assume max normal temperature is optimum. Water temperature is constant across space and time in ELM v2.4, so temperature relationships are not effectively simulated.
2	GP_sorbToTP=	0.01	dimless	0.01		***initial condition only, the ratio of sorbed phosphorus to total phosphorus in soil	generalization of soilTP conc initial condition
4	GP_IC_BATHY_MULT=	1.0	dimless	1.0		***Bathymetry initial condition multiplier, mutiply by the bathymetry initial condition (actually static) map	intended only for use in exploratory model experiments
4	GP_IC_TPtoSOIL_MULT=	1.0	dimless	1.0		***Soil TP concentration initial condition multiplier, mutiply by the TPsoil initial condition map	at least one Performance Measure is sensitive to this parameter; this global multiplier is intended only for use in exploratory model experiments
4	GP_IC_DOM_BD_MULT=	1.0	dimless	1.0		Organic bulk density initial condition multiplier, mutiply by the Organic Bulk Density initial condition map	intended only for use in exploratory model experiments
4	GP_IC_BulkD_MULT=	1.0	dimless	1.0		***Soil bulk density initial condition multiplier, mutiply by the soil bulk density initial condition (actually static) map	several Performance Measures have some sensitivity to this parameter; this global multiplier is intended only for use in exploratory model experiments
4	GP_IC_ELEV_MULT=	1.0	dimless	1.0		***Land elevation initial condition multiplier, mutiply by the elevation initial condition map	multiple Performance Measures are sensitive to this parameter; this global multiplier is intended only for use in exploratory model experiments
4	GP_MAC_IC_MULT=	1.0	dimless	1.0		***macrophyte initial condition multiplier (0-1 proportion, relative to maximum attainable (photo, non-photo) biomass)	several Performance Measures show some sensitivity; parameter intended only for use in exploratory model experiments
4	GP_MAC_REFUG_MULT=	0.01	dimless	0.01		***proportion of max attainable macrophyte biomass, defining a refuge density (from losses)	not sensitive; this parameter multiplied by HP_PH{NPH}BIO_MAX to obtain refuge density; proxy for maintaining a seed source
4	GP_mac_uptake_coef=	3.0	dimless	3.0		***parameter for exp function describing nutrient uptake kinetics	only used to define (fixed) function behavior
4	GP_mann_height_coef=	0.15	dimless	0.15		***proportion of height at which macrophyte starts to bend over in flowing systems	used in determining appropriate breakpoint in manning's n; use other parameters for adjusting/calibrating Manning's N
2	GP_Floc_BD=	20	mg/cm3	20		***bulk density of floc layer (mg/cm3 == kg/m3)	generalized from multiple soil cores
3	GP_FlocMax=	0.1	m	0.1		***max floc depth observed/attainable	generalized from multiple soil cores
3	GP_TP_P_OM=	0.012	gP/gOM	0.012		***phosphorus to organic matter ratio of particulate phosphorus (ash-free masses)	standard redfield ratios
2	GP_Floc_rcSoil=	0.01	1/d	0.01		***baseline rate of floc layer consolidation into the soil matrix (under flooded conditions)	CALIBRATE to achieve spatial and temporal distribution in floc depth
3	GP_TP_DIFFCOEF=	0.0000088	cm^2/sec	0.0000088		***Phosphorus molecular (surface-soil water) diffusion coefficient.	general literature value
2	GP_TP_K_INTER=	40	mg/L	40		***intercept for Freundlich soil sorption eqn	porewater P responds to this parameter; value from lab study (Richardsonet al. 1994)
3	GP_TP_K_SLOPE=	-50	dimless	-50		***slope for Freundlich soil sorption eqn	lab study (Richardsonet al. 1994)
5	GP_WQMthresh=	0.15	m	0.15		***UNUSED in ELM - EWQM implementation ONLY: water depth threshold below which settling stops (EWQM used 0.15m)	ONLY used to emulate Everglades Water Quallity Model, in ELM cell_dyn13

Figure 4.23 (3 pages)

2	GP_PO4toTP=	0.54	dimless	0.54		***slope of empirical linear regression of predicting PO4 from TP from long-term historical data, northern Everglades locations	synoptic (northern) glades monitoring; data more variable than a constant slope
2	GP_TP_IN_RAIN=	0.02	mg/L	0.02		***TP concentration in rainfall (will be switching to new data for versions > ELMv2.4)	glades literature estimates; to incorporate recent reviews of data; concentration of 0.02 mg/L results in ~25 mg TP/m2/yr loading
3	GP_PO4toTPint=	-0.003	mg/l	-0.003		***intercept of empirical regression of predicting PO4 from TP from long-term historical data, northern Everglades locations	synoptic (northern) glades monitoring
3	GP_TP_ICSFWAT=	0.01	mg/L	0.01		***initial TP concentration, surface water	global estimate
3	GP_TP_ICSEDWAT=	0.001	mg/L	0.001		***initial TP concentration, soil pore water	global estimate
2	GP_TPpart_thresh=	0.1	mg/L	0.1		***TP conc used in predicting relative proportion of particulate P in Total Phosphorus	used to estimate particulate P for potential physical settling loss from water column; generalized estimate from (relatively limited) POC and TP observations
3	GP_TP_DIFFDEPTH=	0.1	m	0.10		***depth of surface-soil water diffusion zone	large depth due to poorly defined soil-water interface (w/ floc)
2	GP_settlVel=	0.4	m/d	0.40		***ELM (NOT EWQM emulation) mean settling velocity of particulate phosphorus (NOT of Total Phosphorus)	Calibrated parameter: "Black-box" to incorporate particulate settling and microbial uptake at high concentrations/particulate levels
Count:	70						

Figure 4.23 (3 pages)

Habitat-specific parameters for input to ELM

v2.5.2 23-May-06

Modifications to the parameter values may be made in each Modules' worksheet - as long as you document it!!
Parameter values (but not other documentation) are mirrored in the "Parms_NOM" worksheet that is input to model.
The Parms_LO and Parms_HI sheets are only used in the automated Sensitivity Analysis - modify those parameters as desired.

Note: Succession module not invoked in regional ELMv2.4, thus the associated parameters are unranked.

Ranks are based upon subregional sensitivity analyses on water depth and on surface and porewater phosphorus. See those results for more detailed documentation.

Rank: 5= unused - there are 4 such parameters;
4= not intended for modification beyond sensitivity tests - there are 1 such parameters;
3= has little to no effect on current model Performance Measures - there are 22 such parameters;
2= has observable effect on a Performance Measure - there are 12 such parameters;
1= a sensitive variable affecting multiple Performance Measures - there are 1 such parameters;

Rank	Parameter Name	Type	VarType	Units	Parameter Definition
	Periphyton				
2	HP_ALG_MAX	hab-spec	float	gC/m^2	Maximum attainable (observed) algal biomass density.
	Floc				
3	HP_FLOC_IC	hab-spec	float	kgOM/m^2	Initial mass of floc organic material (ash free dry weight).
3	HP_FLOC_IC_CTOOM	hab-spec	float	dimless	Initial mass ratio of organic carbon to total organic material in floc (ash free dry weight).
3	HP_FLOC_IC_PC	hab-spec	float	dimless	Initial mass ratio of phosphorus to carbon in floc organic matter (ash free dry weight).
	Soils				
3	HP_DOM_MAXDEPTH	hab-spec	float	m	Maximum depth (positive, from sediment surface) of Deposited Organic Matter to consider in model. This determines the depth of the active DOM zone for all model dynamics via: 1) decomposition, 2) sorption/desorption of nutrients, and 3) nutrient uptake by macrophytes. This generally should be <= the max root depth parm (less than root depth in case of trees).
3	HP_DOM_AEROBTHIN	hab-spec	float	m	The thin aerobic zone in a flooded wetland. Note that aerobic total depth is defined to include any zone of soil/sediment that is unsaturated or devoid of water.
	Hydrology				
3	HP_HYD_RCINFILT	hab-spec	float	m/d	Rate of infiltration into the unsaturated water storage zone.
2	HP_HYD_SPEC_YIELD	hab-spec	float	dimless	Proportion of total sediment/soil volume, for a given soil type, that represents water able to be drained by gravity. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization.
2	HP_HYD_POROSITY	hab-spec	float	dimless	Porosity of the aquifer, average from the sediment to base datum. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization. Must be non-zero.
	Phosphorus				
3	HP_TP_CONC_GRAD	hab-spec	float	dimless	For concentration gradient, provide the ratio of this nutrient in the inactive DOM zone to that in the active DOM zone. Used in partioning the mass of sediment nutrients to different concentrations in the shallow active DOM zone and the deeper inactive zone.
	Salt/tracer				
3	HP_SALT_ICSEDWAT	hab-spec	float	g/L	Initial salt concentration in the sediment water.
3	HP_SALT_ICSFWAT	hab-spec	float	g/L	Initial salt concentration in the surface water.
	Macrophytes				
2	HP_PHBIO_MAX	hab-spec	float	kgC/m^2	Maximum attainable (observed) biomass density of photosynthetic tissue.
3	HP_NPHBIO_MAX	hab-spec	float	kgC/m^2	Maximum attainable (observed) biomass density of nonphotosynthetic tissue.
2	HP_MAC_MAXHT	hab-spec	float	m	Maximum observed/attainable height of mature plant community (associated with a unit plant density at maturity).

Figure 4.24 (2 pages)

2	HP_NPHBIO_ROOTDEPTH	hab-spec	float	m	Depth of roots below the sediment/soil zone (positive value) for the community.
2	HP_MAC_MAXROUGH	hab-spec	float	d/(m^(1/3))	The maximum Manning's n roughness associated with present vegetation when fully inundated by water. The relation of the total manning's n to water depth ranges along the continuum from the roughness due to sediment only and roughness imparted by inundation of plants by water depth. Be sure this max value > the minimum roughness coeff.
2	HP_MAC_MINROUGH	hab-spec	float	d/(m^(1/3))	The minimum Manning's roughness coefficient for minimal/no vegetation. Be sure this value is less than the roughness coeff for the vegetation.
2	HP_MAC_MAXLAI	hab-spec	float	dimless	Maximum observed/attainable Leaf Area Index for a mature community (= area of leaves/area of ground).
5	HP_MAC_MAXCANOPCOND	hab-spec	float	mol/m^2/sec	UNUSED (v2.2+)Maximum canopy conductance (units mol LEAFm-2 sec-1) for plant that is NOT water stressed. For simplicitly, assume canopy conductance = unweighted mean of all leaves in canopy, using lit. values for leaf conductance. See Jarvis & McNaughton 1986.
5	HP_MAC_CANOPDECOUP	hab-spec	float	dimless	UNUSED (v2.2+)Canopy couple/decouple factor describing how closely the saturation deficit at the canopy surface is linked to the saturation deficit outside the Planetary Boundary Layer. SCALE dependent; this algorithm assumes model is geared towards large field, scale of hundreds to several thousand meters size. See Jarvis 1986. Values near 0 (perfectly coupled) for many tree canopies, near 1 for grassland-type canopies.
4	HP_MAC_TEMPOPT	hab-spec	float	deg C	Optimal temperature for maximum primary production growth rate. Air temperature is constant across space and time in ELM v2.4, so temperature relationships are not effectively simulated.
3	HP_MAC_LIGHTSAT	hab-spec	float	cal/cm^2/d	Saturating light intensity (langleys/d = cal/cm^2 per day) for macrophyte growth kinetics.
2	HP_MAC_KSP	hab-spec	float	mgP/L	Half saturation coeff of phosphorus for the nutrient uptake kinetics of macrophytes.
1	HP_PHBIO_RCNPP	hab-spec	float	1/d	Maximum observed/attainable specific rate of net primary production.
2	HP_PHBIO_RCMORT	hab-spec	float	1/d	Baseline specific rate of photobiomass mortality.
3	HP_MAC_WAT_TOLER	hab-spec	float	m	Depth of ponded surface water above which plant growth becomes restricted. Used in growth control function. Should be at least a very small positive number: A value of zero will be reset to 5mm in code.
5	HP_MAC_SALIN_THRESH	hab-spec	float	g/L	UNUSED (v2.2, v2.3)Salinity threshold, above which plant growth decreases linearly with increasing salinity.
3	HP_PHBIO_IC_CTOOM	hab-spec	float	gC/gOM	Initial ratio of organic carbon to total organic material in PhotoBiomass (ash free dry weight).
3	HP_NPHBIO_IC_CTOOM	hab-spec	float	gC/gOM	Initial ratio of organic carbon to total organic material in NonPhotoBiomass (ash free dry weight).
2	HP_PHBIO_IC_PC	hab-spec	float	gP/gC	Initial phosphorus:carbon ratio in PhotoBiomass (ash free dry weight).
3	HP_NPHBIO_IC_PC	hab-spec	float	gP/gC	Initial phosphorus:carbon ratio in NonPhotoBiomass (ash free dry weight).
3	HP_MAC_TRANSLOC_RC	hab-spec	float	1/d	Simple, bi-directional baseline translocation rate between Non-photo and Photo biomass; consider this gradual equilibrium as placeholder for a more process-based algorithm
	Succession				
3	HP_SfDepthLo	hab-spec	float	m	Lower Depth tolerance for Surface Water Depth
3	HP_SfDepthHi	hab-spec	float	m	Higher Depth tolerance for Surface Water Depth
3	HP_SfDepthInt	hab-spec	float	days	Time Interval for staying within Surface Water Depth range
3	HP_PhosLo	hab-spec	float	mgP/kg soil	Lower concentration tolerance for soil total Phosphorus
3	HP_PhosHi	hab-spec	float	mgP/kg soil	Higher concentration tolerance for soil total Phosphorus
3	HP_PhosInt	hab-spec	float	days	Time Interval for staying within soil total Phosphorus range
5	HP_FireInt	hab-spec	float	days	UNUSED. Time Interval since last Fire

40	Parameters
28	Habitats (shown in other worksheets)
1120	Potentially-unique parameter values
138	Actually-unique pararmeter values (shown in other worksheets)

(64 unique values of 13 "important" parameters across 28 habitats)

Figure 4.24 (2 pages)

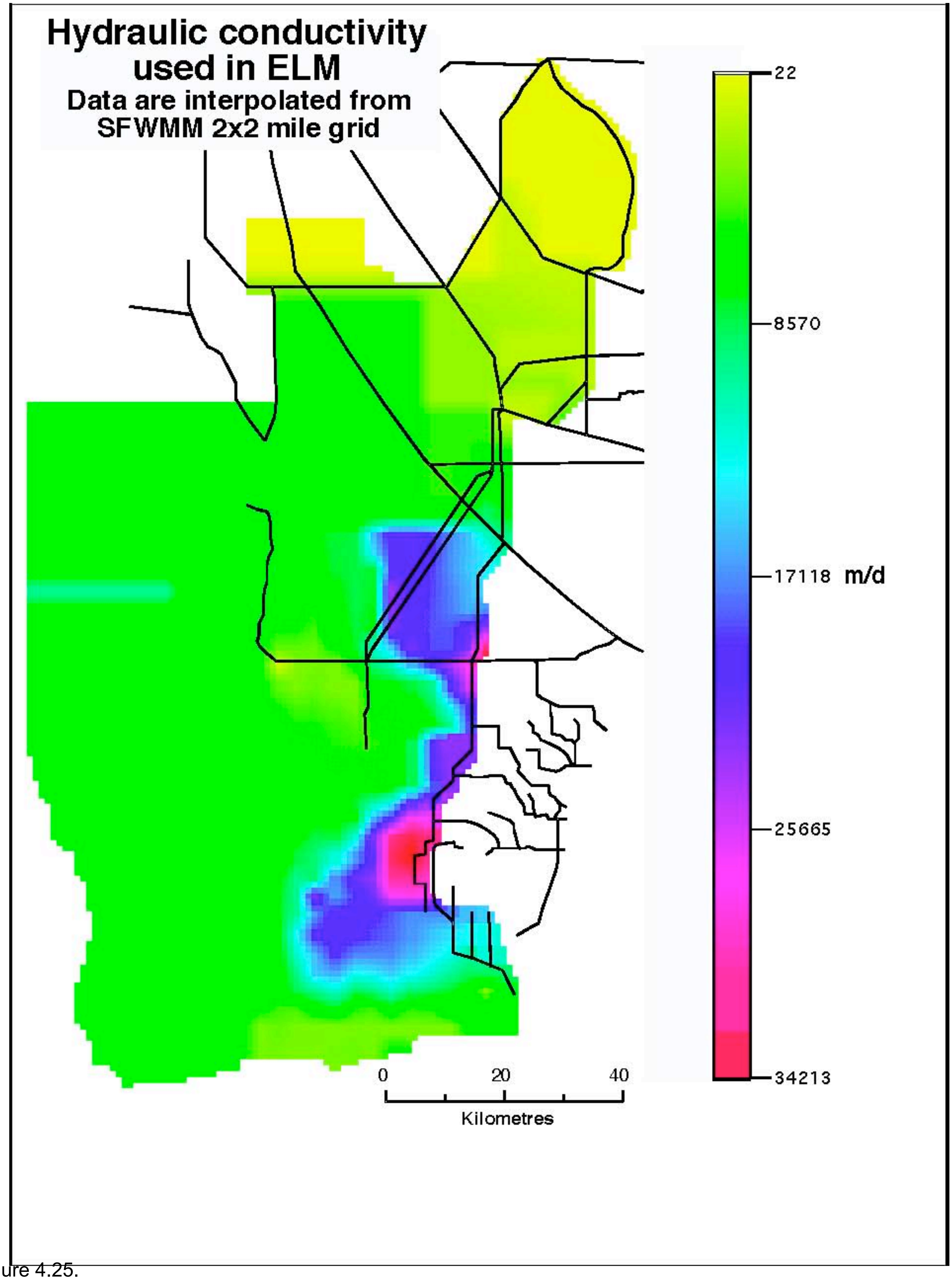

Hydraulic conductivity used in ELM
Data are interpolated from SFWMM 2x2 mile grid
22
8570
17118
m/d
25665
34213
0
20
40
Kilometres

Figure 4.25.

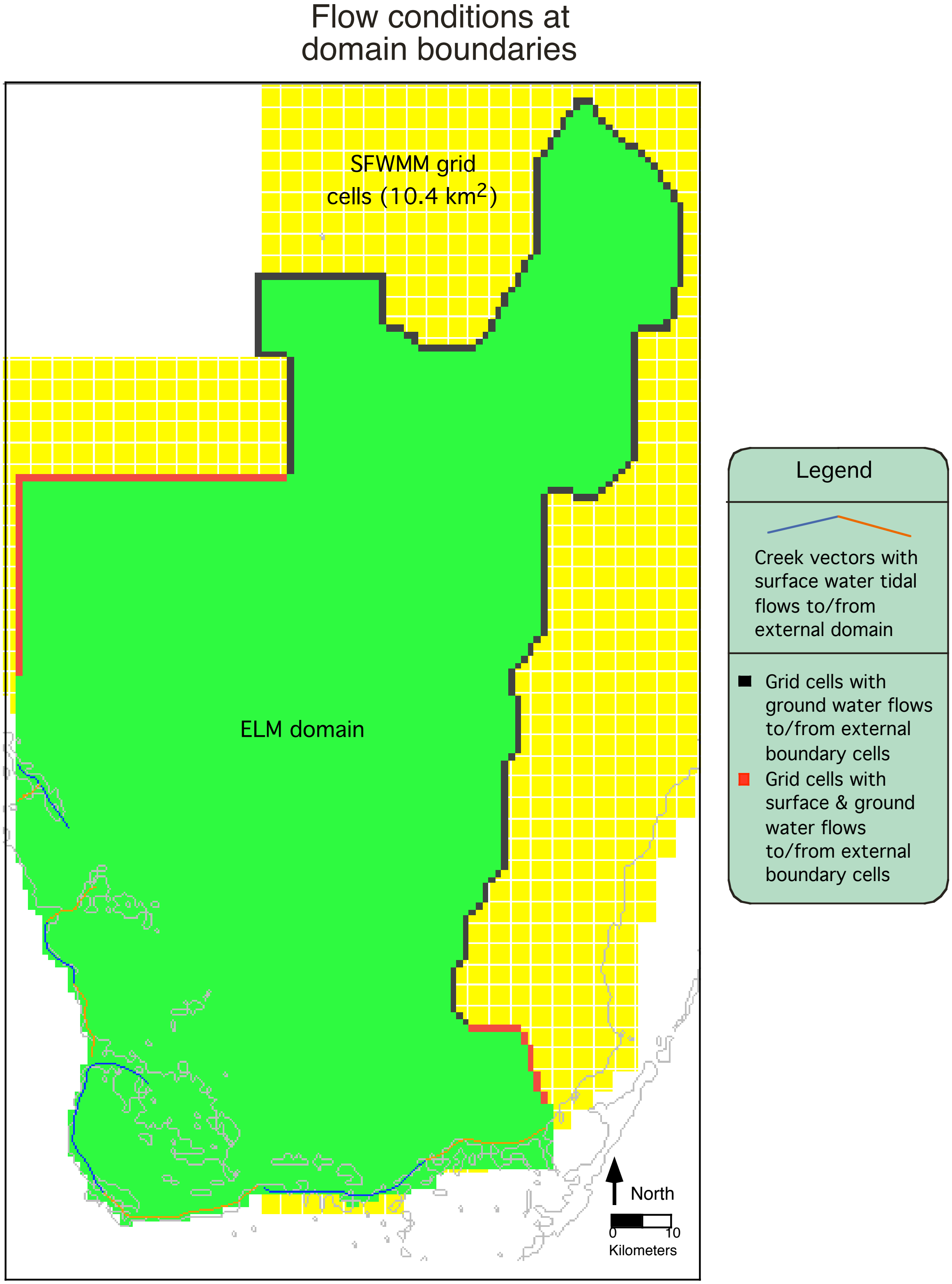
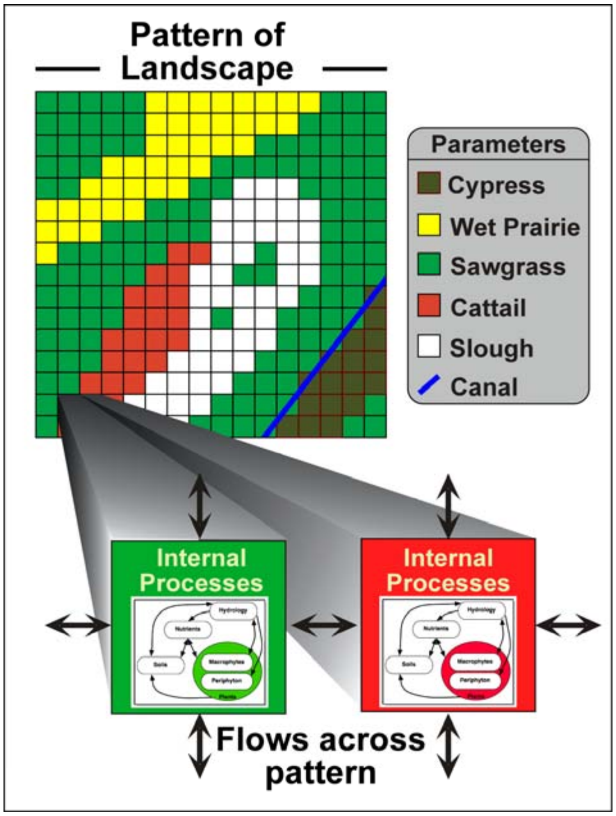

Flow conditions at domain boundaries
SFWMM grid cells (10.4 km^2)
ELM domain
Legend
Creek vectors with surface water tidal flows to/from external domain
■ Grid cells with ground water flows to/from external boundary cells
🟥 Grid cells with surface & ground water flows to/from external boundary cells
North
0
10
Kilometers

Figure 4.26.

Documentation of the Everglades Landscape Model:

ELM v2.5

Chapter 5: Model Structure



http://my.sfwmd.gov/elm

July 10, 2006

Chapter 5: Model Structure

5.1 Overview

The Everglades Landscape Model (ELM) is a spatially distributed simulation using integrated hydro-ecological process modules. With a structured programming approach, the hydrologic, biogeochemical, and biological processes (such as evapotranspiration, soil oxidation, and plant growth) are contained in code modules that are activated by the user at runtime. Being "data-driven", the model relies on databases to modify scenarios of water management, while computer source code remains constant.

This Chapter on Model Structure is organized in a hierarchical fashion that parallels the model structure itself, starting with an overview of the modeling framework. The bulk of the Chapter is then devoted to parsing the simple conceptual model into a higher level of detail for each dynamic module. For each hydro-ecological module, a conceptual model diagram shows the internal interactions and their linkages with other modules. A module Overview provides a text summary of the module's purpose, followed by a verbal and mathematical description of the assumptions and all of the associated equations, variables, and parameters. To most readily understand the important interactions of the dynamic hydro-ecological modules, we recommend that the reader uses the hyper-linked version of this Chapter found on the ELM web site.

A separate User's Guide Chapter includes information on the required computing environment[1] and the basic steps needed to install and use an ELM project.

Using an Open Source[2] philosophy, we hope to encourage collaboration in the modeling community. Towards that end, all source code (and data) necessary for an ELM project is available for download on the ELM web site, and all code in the ELM project is documented in detail using the automated "Doxygen" documentation system. This online, source-code level documentation extends beyond the scientific algorithms described in this Chapter, including details of all of the functions that are compiled in the (ANSI C) code project.

We recommend viewing the hyper-linked version of the algorithm interactions and equations on the ELM web site (Development tab at http://my.sfwmd.gov/elm).

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[1] Unix operating system (Linux, Darwin, or Solaris) using Open Source software.

[2] http://www.opensource.org/

5.1.1 ELM conceptual model

The General Ecosystem Conceptual Model presented in an earlier Chapter (Conceptual Model Chapter) forms the basis for the quantitative formulation of the ELM. For this version of ELM, we explicitly integrate fully dynamic flux equations of hydrology, nutrients, plants, and soils within a hydro-ecological “unit” model (Figure 5.1). We hypothesize that these capture the fundamental characteristics of habitats within the Everglades landscape: the dynamic ecological interactions among hydrology, biogeochemistry, and plant biology are critical to understanding and predicting changes within this ever-changing wetland system.

Within this framework of the “unit” model, we sought to quantify the simplest set of ecosystem processes that are fundamental to changes in habitats, or assemblages of vegetation types. Note that, compared to the General Ecosystem Conceptual Model presented earlier, the ELM is simpler in that the effects of fire and consumer interactions are assumed to be inherent in hydrologic disturbances and the long-term dynamic storages and fluxes of the plants. In some respects the modeled interactions are quite simplistic. Importantly, however, we made considerable effort to optimize the balance between realism, which tends to increase model complexity, and (the relative paucity of) supporting data/knowledge, which tends to “scale-back” and simplify a model implementation.

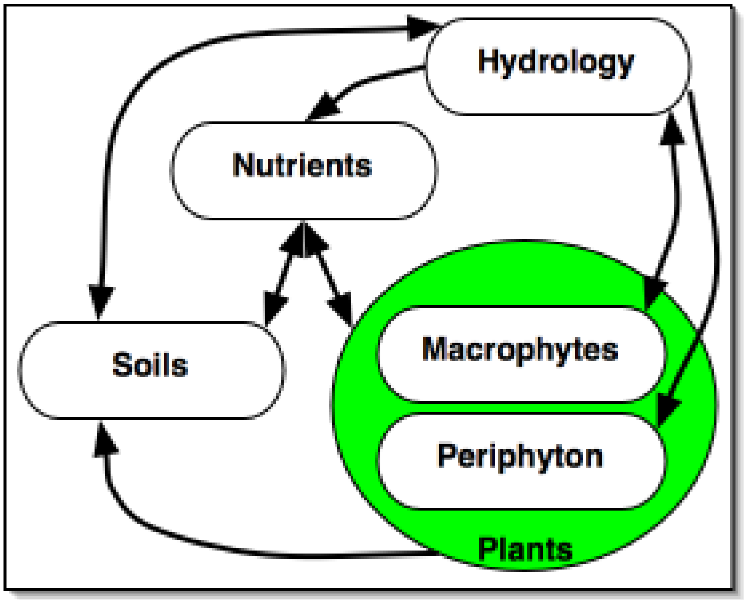


Figure 5.1. The conceptual “unit” model of general ecosystem dynamics incorporated into the ELM.

Within the “unit” model, we assumed that the dynamics occur within a homogenous spatial unit. Significant insights into ecosystem processes may be achieved by focusing on a particular site or homogenous area. However, imperative to understanding landscapes such as the Everglades is the acknowledgement of spatial heterogeneity. In the ELM, ecosystem dynamics are made spatially-explicit by considering the flows and interactions across habitat types that are heterogeneously distributed across a regular model grid (Figure 5.2). The processes internal to grid cells can vary according to habitat type, each of which may have different hydro-ecological parameter sets. Flows of water and nutrients among grid cells are thus affected by changes within cells of the habitat mosaic, and this pattern can change over time as cumulative conditions in grid cells become more favorable for one habitat vs. another.

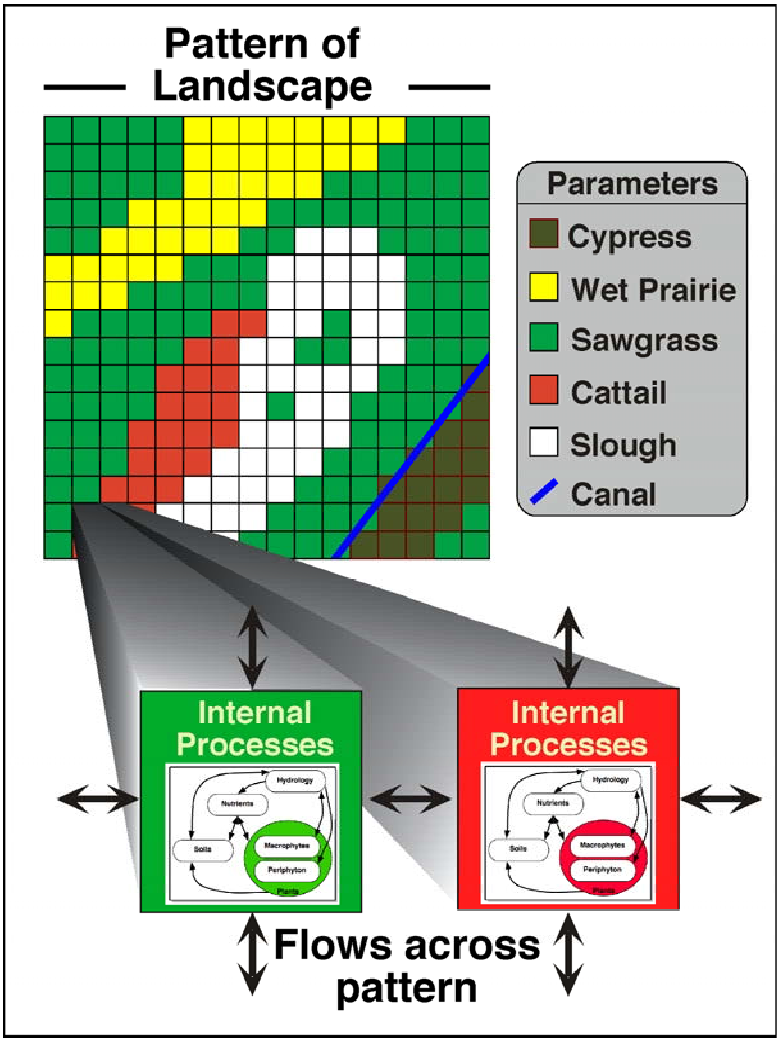


Figure 5.2. The conceptualization of how the "unit" model of general ecosystem dynamics is applied across the heterogeneous spatial grid of different habitat types. Each habitat type within the patterned landscape can be parameterized differently, affecting the internal process dynamics within different grid cells. In turn, the results of the internal processing can affect the direction and magnitude of the flows of water and nutrients across the landscape pattern. Succession, or switching, of habitat types can occur as cumulative conditions warrant.

While the "unit" model dynamics are relatively simple approximations of ecosystems, model complexity arises in its application as a distributed hydro-ecological simulation. The ELM hydrologic processes are relatively simple in their details, with the model simulating the primary hydrologic "drivers" of the Everglades wetlands. The ELM incorporates both overland and subsurface groundwater flows, coupling the surface and ground water exchanges at each time step. Vital to surface (and subsurface) hydrology in the Everglades are the managed flows through water control structures, which are directed into canal vector networks and/or into marsh grid cells of the model. These managed flows transport nutrients through the system, and have major impacts on the spatial pattern of nutrient loads and distribution – and thus the ecology of the landscape.

5.1.2 State variables

The ELM conceptual model presented above shows the fundamental interactions that are captured in the simulation. Further details of how this is implemented may be seen in the diagram of the within-cell interactions among the major state variables[3] (Figure 5.3). These dynamic interactions shown in Figure 5.3 can be split into those occurring above-ground and below-ground, with the same code (but different parameter sets) used in all habitat types distributed through the landscape, from sloughs to forested uplands. Spatial flows that affect these variables are summarized in the later Chapter sections that describe each of the "Horizontal solutions".

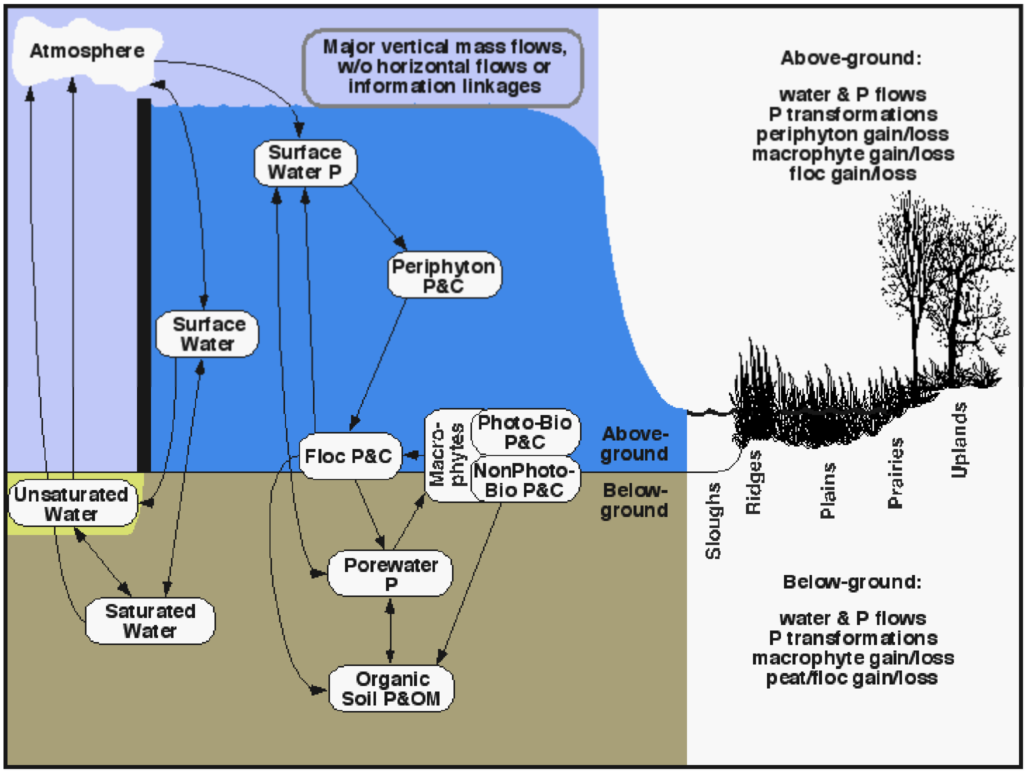


Figure 5.3. The details of the conceptual model of the ELM. State variables are in oval boxes, linked by the major flow pathways among those variables. Abbreviations: P = Phosphorus; C = Carbon; OM = Organic Matter; Photo-Bio = Photosynthetic Biomass of macrophytes; NonPhoto-Bio = NonPhotosynthetic Biomass of macrophytes; Floc = Flocculent layer on/above soil.

For hydrologic dynamics, the surface, unsaturated and saturated storage state variables are measured in terms of the height of water volumes within a grid cell (or canal). Phosphorus in the surface water and porewater storages are known as masses within the cell or canal. Carbon mass is the common unit of flux among the biotic storages of

---

[3] Because the salt/tracer constituent does not currently affect model dynamics, the two state variables associated with this module are not shown.

periphyton and macrophytes, along with the storage in abiotic flocculent organic material (floc). Carbon is converted to mass of organic material when considering storage in the consolidated soil beneath the floc layer. Mass of phosphorus is maintained via parallel state variables associated with these carbon and organic matter fluxes. Mass balance is strictly maintained (and verified) in the model.

5.1.2.1 Solution methods

To update the state variables, the method of solving the model's finite difference equations is the simple Euler method of integration, without complexities such as forward looking methods. Daily time steps are used in all of the "unit" model vertical solutions, whereas the horizontal solutions are generally dependent on grid cell resolution for the appropriate time step, as described later in the relevant modules' sections. (The regional 1km^2 ELM application uses a 2-hour time step for most horizontal solutions). The User's Guide Chapter discusses topics such as selection of time steps and the associated run times[4] of the model at different scales. We note here, however, that the horizontal solutions that are primarily hydrologic in origin comprise ~75% of the total model runtime. The following is a breakdown of relative CPU time[5] for generalized classes of modules in the regional implementation:

- 51% total CPU time on water management fluxes
- 26% total CPU time on surface/ground water raster fluxes (incl. vertical integration)
- 19% total CPU time on unit model "vertical" fluxes
- 4% total CPU time on other tasks (budgets, input/output, etc)

5.1.3 Format of algorithm descriptions

We separate the descriptions of the algorithms into those primarily involving solutions of vertical flows/processes, and those involving horizontal flows. The vertical solutions are primarily those involving the "unit" model, while the horizontal solutions involve spatial flows of water and constituents among raster grid cells and/or canal vectors. Prior to the sections that describe each module of vertical and horizontal solutions, we present the main program's sequence of principal function calls. The nature of the input data functions is then briefly presented.

In the descriptions of the algorithms in each module, a common format is used. Text descriptions of the basic assumptions are followed by "pseudo-code" of all of the equations used in algorithm calculations within the module, organized as follows:

- *State variables:* The difference equation(s) that is solved to update the state variable, such as surface water height or carbon biomass of periphyton. These equations are shown first in the presentations of each module, but they are actually dependent on the below intermediate calculations.

---

[4] On a 2.66 GHz laptop, it takes somewhat more than one hour to run a 20-year, regional application of ELM.

[5] Expressed in percent of total CPU seconds for each aggregation of tasks; profiling was done on the ELM v2.3 code in a 19-year simulation, using the Analyzer in Sun Forte Developer 6.

- *Attributes:* These may include calculations of intermediate variables such as the depth of the unsaturated zone, or the current concentration of phosphorus in the water column.
- *Control functions:* These may include the relationship between root depth & the current water levels relative to transpiration demand, or the degree of nutrient limitation on periphyton growth.
- *Fluxes:* The potential and actual fluxes, constrained by the attributes and control functions previously described; these may include actual evapotranspiration losses, or gross primary production gains by periphyton.

Following the equations are tables containing the units and definitions of all state variables, intermediate variables, and parameters used in that function. A listing and location reference is given for all dependent variables whose values are calculated in another module. At the end of each module description is a glossary of any intrinsic functions (e.g., Abs(x) = Absolute value of x) that are used in the pseudo-code.

5.1.3.1 Navigational tool

Most of the remainder of this Chapter is used to describe the algorithms in each module, including the interaction among modules. The Model Structure section of the ELM web site contains this same text and figures, but provides hyper-links among the conceptual diagrams of each module. This method of perusing the ELM algorithms is highly recommended in order to more readily understand the important linkages among modules.

5.2 Source code

The ANSI C language source code of the entire ELM project is fully documented using the automated documentation tool Doxygen[6]. All ELM source code (and requisite data) is available for download from the ELM web site[7], and the Doxygen-generated documentation is available in that same location of the web site (not in this document). This web-based source code documentation is primarily targeted to an audience of programmers, but its easy navigation can be useful to clarify a user’s understanding of details of dependencies, methods, etc.

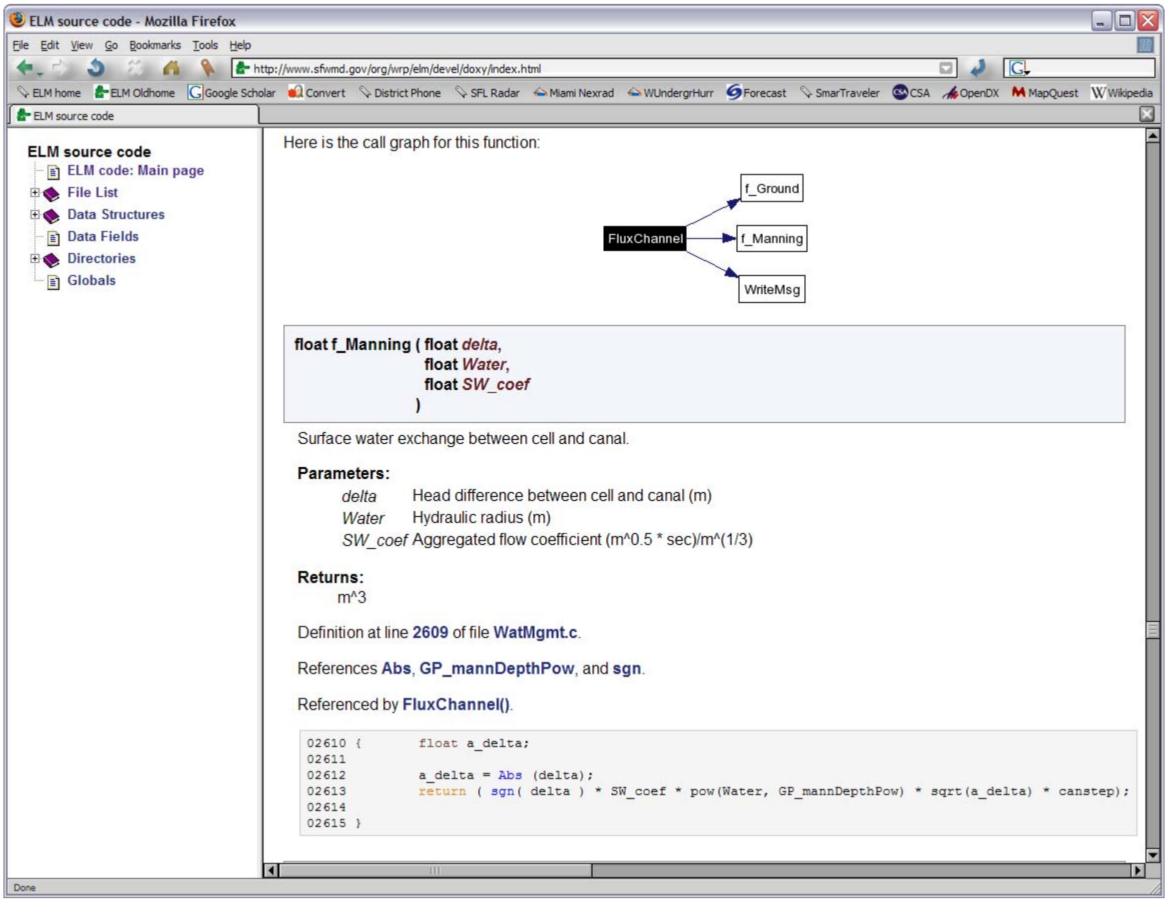
Figure 5.4 below shows a simple example of Doxygen-generated documentation of the “f_Manning” function (also described in a later Chapter section on Water Management: Canal-Marsh Flux Module). This function contains the Manning’s equation for surface water exchange between a cell and canal. The Figure shows a call graph that indicates “f_Manning” is called by the parent function of “FluxChannel” (that iterates the water and nutrient fluxes between a canal vector and it’s adjoining grid cells). Briefly defined are the parameters that are passed into the function, along with the value that is returned by the function. The definitions of functions/macros (Abs, sgn) and a parameter (GP_mannDepthPow) that it references are available via hyperlinks. The actual C code (with hyperlinked functions and parameter) is listed at the end of the example.

---

[6] The Open Source Doxygen application is available at http://www.stack.nl/~dimitri/doxygen/

[7] Source code link in the Development tab at http://my.sfwmd.gov/elm

The remainder of this Chapter specifically avoids the syntax and complexities of source code and Doxygen-generated web pages, and instead focuses on the scientific understanding of the model algorithms.



Here is the call graph for this function:

float f_Manning (float *delta*,
float *Water*,
float *SW_coef*
)

Surface water exchange between cell and canal.

Parameters:

delta	Head difference between cell and canal (m)
Water	Hydraulic radius (m)
SW_coef	Aggregated flow coefficient (m^0.5 * sec)/m^(1/3)

Returns:
m^3

Definition at line **2609** of file **WatMgmt.c**.

References **Abs**, **GP_mannDepthPow**, and **sgn**.

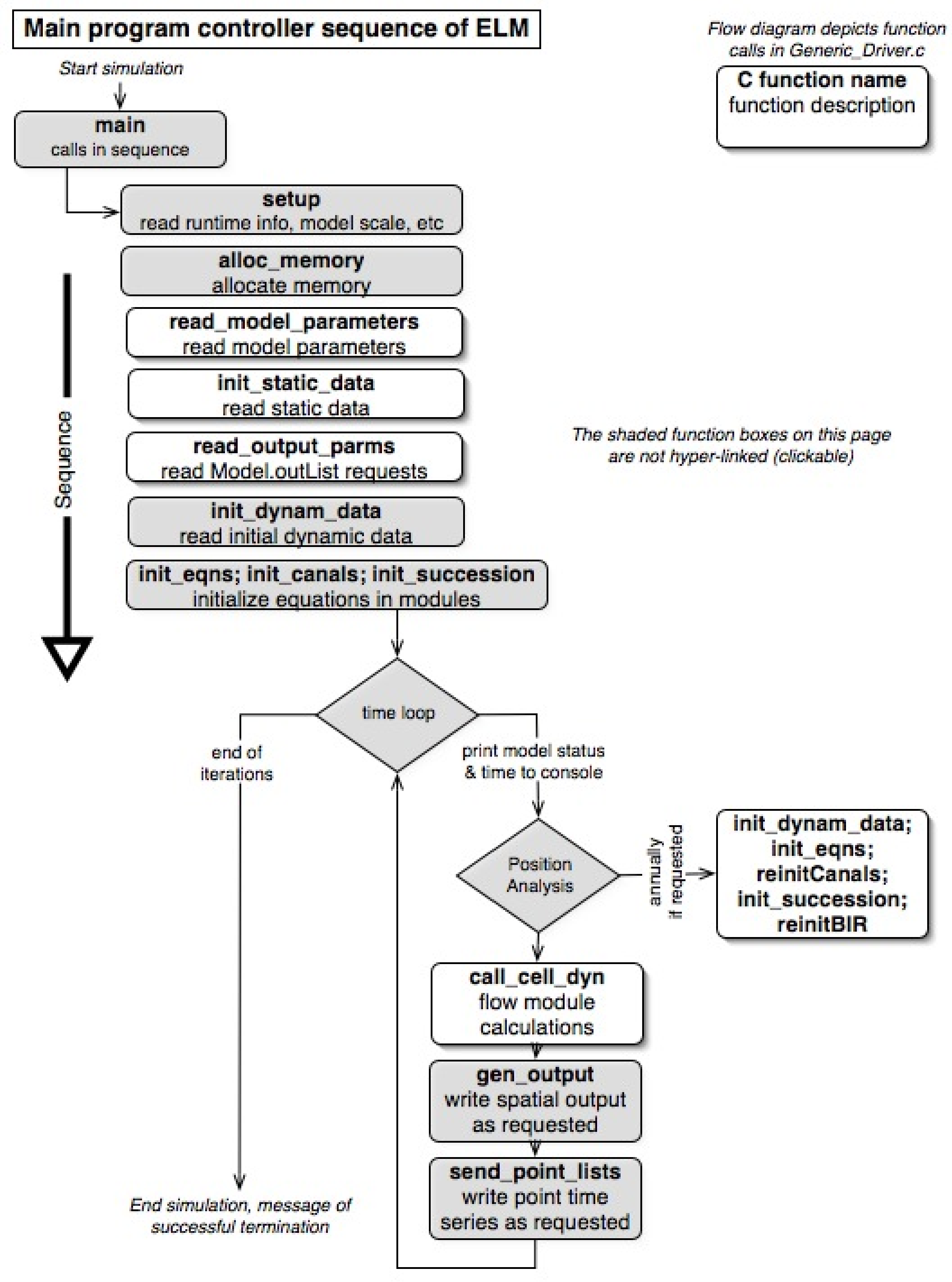
Referenced by **FluxChannel()**.

```
02610 {        float a_delta;
02611
02612          a_delta = Abs (delta);
02613          return ( sgn( delta ) * SW_coef * pow(Water, GP_mannDepthPow) * sqrt(a_delta) * canstep);
02614
02615 }
```

Figure 5.4. Source code documentation example. Primarily intended for an audience of programmers , this is an example of the web-based documentation of a function in the C source code of ELM. After the ELM developers populated the source code with specific “tags”, the Open Source program Doxygen automatically generated well-structured web pages that describe all functions compiled in the ELM project, showing call graphs, descriptions of the purpose of each function, hyperlinked dependencies, definitions of data structures, variables, and many other aspects of the source code, The call graph shown was actually generated for the preceding function (that calls “f_Manning”). The remainder of this Chapter does not use the detailed Doxygen-based information. For the Doxygen-generated documentation, see the Development tab, Hyper-linked source code documentation link at http://my.sfwmd.gov/elm .

5.3 Main controller

The Figure below summarizes all of the primary function calls during an execution of the ELM. The "call_cell_dyn" and the data input functions are expanded upon in the next sections of this Chapter.



5.4 Data-input modules

Open Source software is all that is necessary to make full use of the ELM project (see User's Guide Chapter). All model input files are either ASCII text (i.e., exported from Open Office spreadsheet databases), generic binary map data (created/read in GRASS or any other spatial tool), or "grid_io" (spatial time series format used in SFWMM input/output, with editing tools freely available). The MySQL relational databases, that will replace Open Office spreadsheet databases[8], have not been completed for the current ELM version. GRASS is the primary GIS tool used for ELM, and is recommended due to its advanced raster GIS capabilities, and the availability of ELM scripts for visualizing input and output data in raster, vector, and point formats.

The Figure on the following page provides an overview of the pre-processing tools and the input methods within the ELM code. The Doxygen-generated source code documentation can be consulted (on ELM web site) for further information on source code input/output methods.

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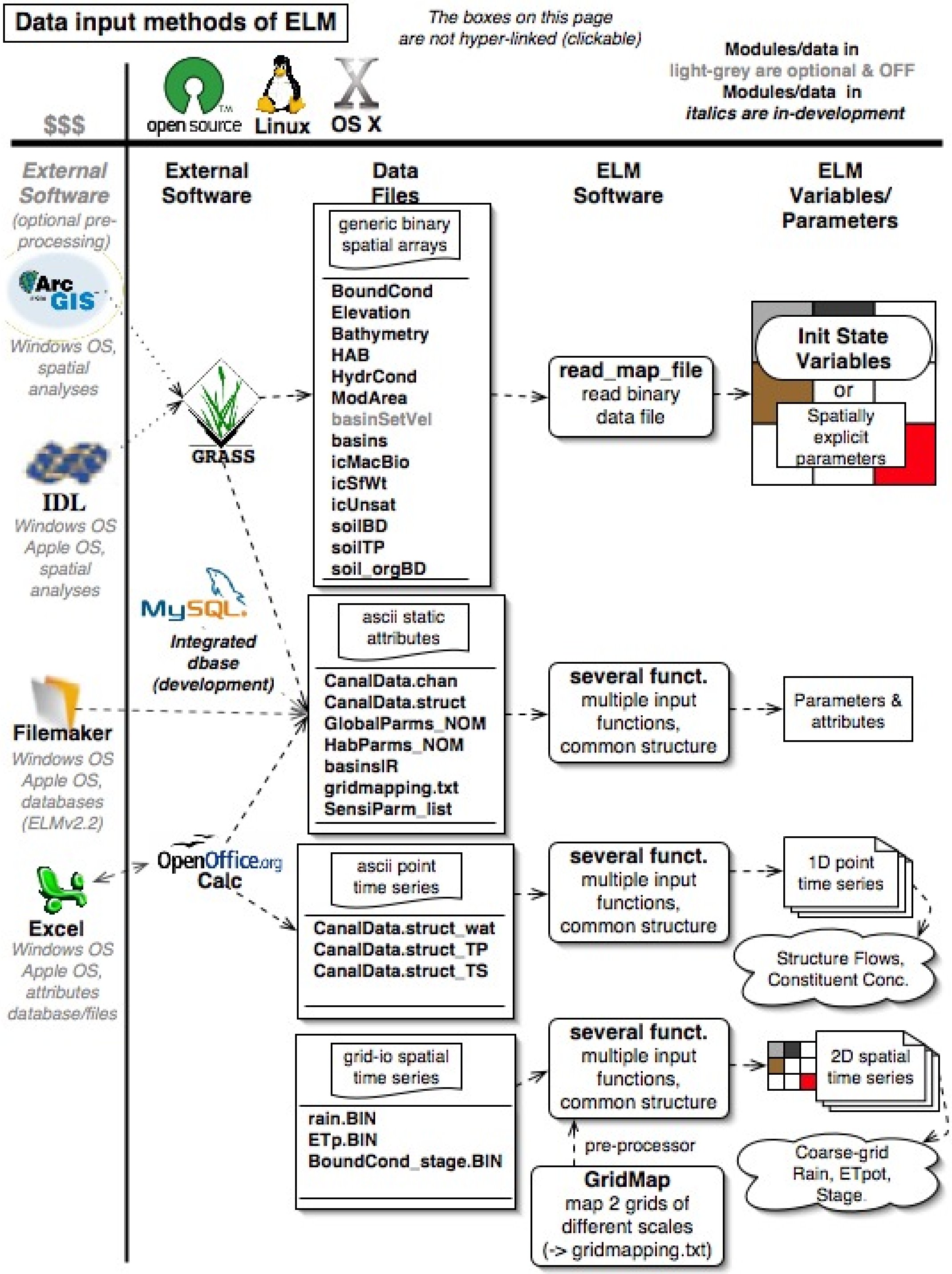
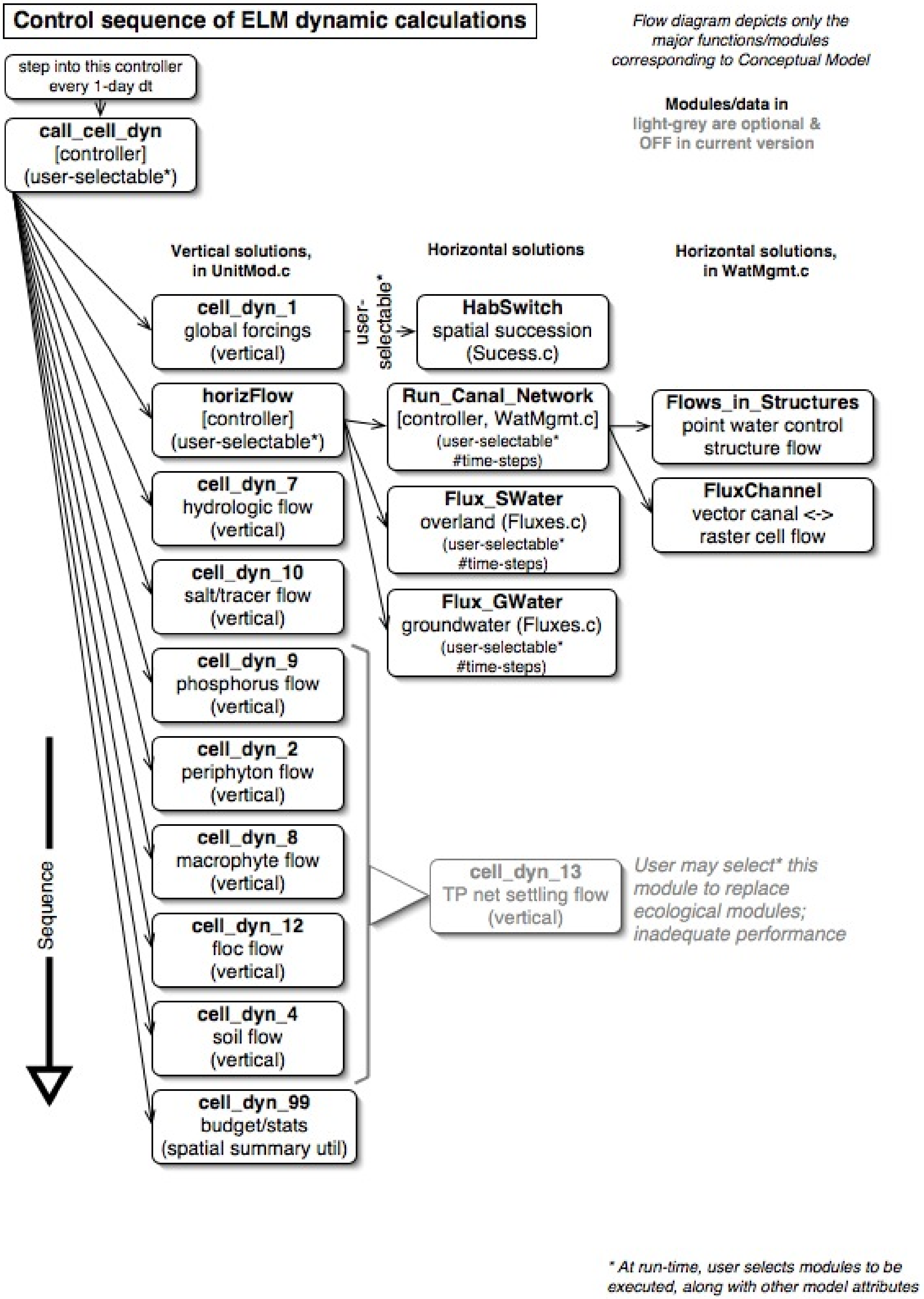
[8] FileMaker Pro databases were used in prior versions of ELM. The relational database of water control structure attributes remains in FileMaker Pro, but its functionality is not required to use ELM.


Data input methods of ELM
The boxes on this page are not hyper-linked (clickable)
Modules/data in light-grey are optional & OFF
Modules/data in italics are in-development
$$$
open source
Linux
OS X
External Software (optional pre-processing)
External Software
Data Files
ELM Software
ELM Variables/ Parameters
ArcGIS
Windows OS, spatial analyses
IDL
Windows OS Apple OS, spatial analyses
Filemaker
Windows OS Apple OS, databases (ELMv2.2)
Excel
Windows OS Apple OS, attributes database/files
GRASS
MySQL
Integrated dbase (development)
OpenOffice.org Calc
generic binary spatial arrays
BoundCond
Elevation
Bathymetry
HAB
HydrCond
ModArea
basinSetVel
basins
icMacBio
icSfWt
icUnsat
soilBD
soilTP
soil_orgBD
ascii static attributes
CanalData.chan
CanalData.struct
GlobalParms_NOM
HabParms_NOM
basinsIR
gridmapping.txt
SensiParm_list
ascii point time series
CanalData.struct_wat
CanalData.struct_TP
CanalData.struct_TS
grid-io spatial time series
rain.BIN
ETp.BIN
BoundCond_stage.BIN
read_map_file read binary data file
several funct. multiple input functions, common structure
several funct. multiple input functions, common structure
several funct. multiple input functions, common structure
pre-processor
GridMap map 2 grids of different scales (-> gridmapping.txt)
Init State Variables
or
Spatially explicit parameters
Parameters & attributes
1D point time series
Structure Flows, Constituent Conc.
2D spatial time series
Coarse-grid Rain, ETpot, Stage

5.5 Dynamic solutions: sequencing

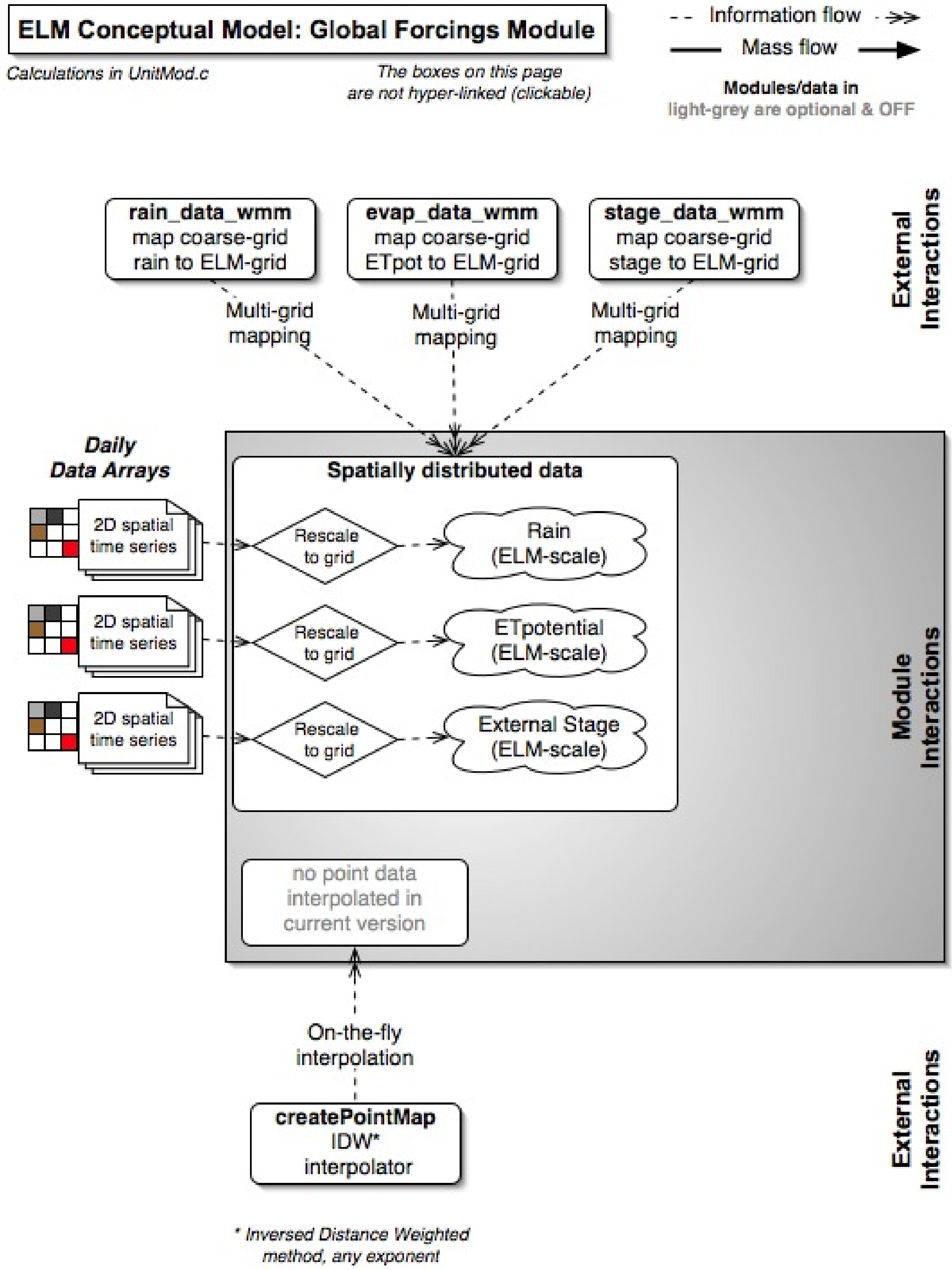
The “call_cell_dyn” controller function calls dynamic modules in the order (changeable by the user) shown in the diagram below. Each of the dynamic modules is described in a separate section of this Chapter.


Control sequence of ELM dynamic calculations
Flow diagram depicts only the major functions/modules corresponding to Conceptual Model
Modules/data in light-grey are optional & OFF in current version
step into this controller every 1-day dt
call_cell_dyn [controller] (user-selectable*)
Vertical solutions, in UnitMod.c
Horizontal solutions
Horizontal solutions, in WatMgmt.c
cell_dyn_1 global forcings (vertical)
user-selectable*
HabSwitch spatial succession (Sucess.c)
horizFlow [controller] (user-selectable*)
Run_Canal_Network [controller, WatMgmt.c] (user-selectable* #time-steps)
Flows_in_Structures point water control structure flow
FluxChannel vector canal <-> raster cell flow
Flux_SWater overland (Fluxes.c) (user-selectable* #time-steps)
Flux_GWater groundwater (Fluxes.c) (user-selectable* #time-steps)
cell_dyn_7 hydrologic flow (vertical)
cell_dyn_10 salt/tracer flow (vertical)
cell_dyn_9 phosphorus flow (vertical)
cell_dyn_2 periphyton flow (vertical)
cell_dyn_8 macrophyte flow (vertical)
cell_dyn_12 floc flow (vertical)
cell_dyn_4 soil flow (vertical)
cell_dyn_99 budget/stats (spatial summary util)
cell_dyn_13 TP net settling flow (vertical)
User may select* this module to replace ecological modules; inadequate performance
Sequence
* At run-time, user selects modules to be executed, along with other model attributes

5.6 Vertical solutions

These modules calculate the vertical solutions for all of the physical, chemical, and biological dynamics of the ecological "unit" model (Fitz et al. 1996). That manuscript can be consulted for further background on these active modules, along with other modules that are not used in the current ELM application. See the above/previous diagram on sequencing of these modules.

5.6.1 Globals module



Overview: Globals Module

The Globals Module serves primarily as an data-processing function for meteorological data that are either heterogeneously or homogenously distributed across ELM grid cells, depending on the data type. The call to the habitat succession module is made in this Globals module.

Globals Module Description

Because potential evapotranspiration (ET) is input data instead of being calculated from individual meteorological variables (as done in ELMv2.1), this module serves basically two active functions in the current version. A series of pre-calibrated equations (Nikolov and Zeller 1992) calculate the daily solar radiation incoming to the upper atmosphere, while data-distribution functions provide a daily time series of potential ET and rainfall at the ELM grid scale. The former (radiation) is globally distributed (homogenous) across all grid cells in the model domain. This solar radiation algorithm calculates daily solar radiation at the top of the atmosphere based on julian date, latitude, solar declination, and other factors. The input data of 1) potential ET, 2) rainfall, and 3) stage are input to the ELM at the coarse grid cells of the data source (SFWMM v5.4), and mapped in this module to the grid resolution of the ELM. The call to the habitat-switching function is made in this module.

Globals Module Equations

State Variable update calculations

calculated within spatial loop across model grid rows, columns

function call to habitat switching module

HAB = HabSwitch (ix, iy, SURFACE_WAT, TPtoSOIL, FIREdummy, HAB)

Dependent upon:

1) attribute calculations

none

2) control function calculations

none

3) flux calculations

none

4) attribute calculations, only used in other modules

##Nikolov and Zeller(1992) generic algorithm to calculate SOLRADATMOS (single spatial value that is uniform across model domain, intermediate calculations shown)

DAYJUL = (Mod(TIME,365.0) >0.0) ? (Mod(TIME,365.0)) : (365.0)

DAYLENGTH = AMPL*Sin((DAYJUL-79.0)*0.01721)+12.0

SOLDEC1 = 0.39785*Sin(4.868961+0.017203*DAYJUL
+0.033446*Sin(6.224111+0.017202*DAYJUL))

SOLCOSDEC = sqrt(1.0-SOLDEC1*SOLDEC1)

SOLELEV_SINE = Sin(***GP_LATRAD***)*SOLDEC1+Cos(***GP_LATRAD***)*SOLCOSDEC

SOLALTCORR = (1.0-Exp(-0.014*(***GP_ALTIT***-274.0)/(SOLELEV_SINE*274.0)))

SOLDEC = Arctan(SOLDEC1/sqrt(1.0-SOLDEC1*SOLDEC1))

SOLRISSET_HA1 = -Tan(***GP_LATRAD***)*Tan(SOLDEC)

SOLRISSET_HA = ((SOLRISSET_HA1==0.0)) ? (PI*0.5) : (((SOLRISSET_HA1<0.0)) ? (PI+Arctan(sqrt(1.0-SOLRISSET_HA1*SOLRISSET_HA1)/SOLRISSET_HA1)) : (Arctan(sqrt(1.0-SOLRISSET_HA1*SOLRISSET_HA1)/SOLRISSET_HA1)))

SOLRADATMOS = 458.37*2.0*(1.0+0.033*Cos(360.0/365.0*PI/180.0*DAYJUL)) * (Cos(***GP_LATRAD***)*Cos(SOLDEC)*Sin(SOLRISSET_HA) + SOLRISSET_HA*180.0/(57.296*PI)*Sin(***GP_LATRAD***)*Sin(SOLDEC))

External variables used

total julian day count, GenericDriver.c
TIME

SURFACE_WAT (see Hydrology module)

TPtoSOIL (see Soils module)

FIRE_DIRECT (Fire module not used, fire data not needed)

calculated once during initialization
AMPL = Exp(7.42+0.045****LATRAD****180.0/PI)/3600.0

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
SOLRADATMOS	attribute	cal/cm^2/d	solar radiation received at the top of the atmosphere
AIR_TEMP	attribute	deg C	Air temperature, daily average at ground level
HAB	state	dimless	Habitat, or vegetation community type (integer attribute, defining database parameter lookups)

Time series forcing data

function call to map rainfall data (tenths of mm/d) to model grid cells
stat=rain_data_wmm(wmm_rain)

function call to map potential ET data (tenths of mm/d) to model grid cells
stat=evap_data_wmm(wmm_evap)

air temperature is constant data in v2.2 only
AIR_TEMP = 25.0

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
GP_ALTIT	global	m	regional altitude of land surface
GP_LATDEG	global	deg.min	regional latitude (degrees.minutes, don't convert min to decimal deg)
GP_LATRAD	global	radians	regional latitude, calculated conversion to radians during

			initialization

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description

none

Intrinsic C or ELM functions

exp(x) = Exp(x) => e raised to the x^{th} power

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

Mod(x,y) = modulus (remainder) of x divided by y

Sin(x) => sine of (x in radians)

Cos(x) => cosine of (x in radians)

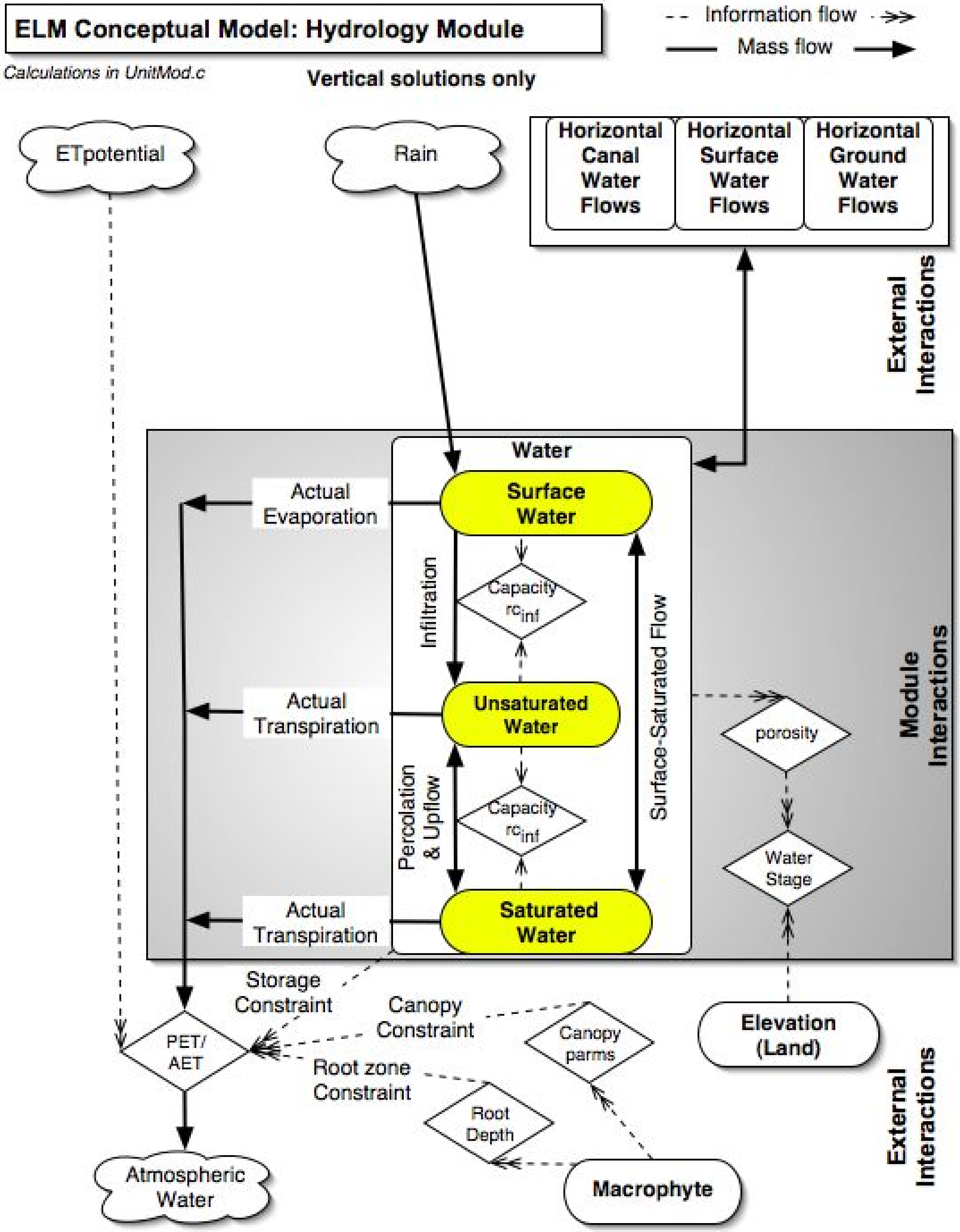
Arctan(x) => arc tangent of (x in radians)

Tan(x) => tangent of (x in radians)

PI => the constant pi

sqrt(x) => square root of (x)

5.6.2 Hydrology module



Overview: Hydrology Module

This Hydrology Module serves primarily to update the grid-cell water storages due to vertical fluxes among surface, unsaturated, and saturated storage state variables. Hydrology is a critical "driver" of the landscape, in that it is necessary to understand and get the water "right" in order to sustain a healthy Everglades. Vertical flows among those storages involve rainfall, evaporation, infiltration, percolation, and transpiration. Hydrology is one of the "fast" processes that can change significantly on time scales on the order of hours, but climate change can produce decadal shifts in dynamics of the regional hydrologic cycle. While rainfall in south Florida is seasonal, it is variable both within seasons and among years. Intense rainfall events are often heterogeneously distributed at local scales; tropical disturbances can deluge the entire region. The pattern of water distribution (hydropattern) across the landscape is driven not only by rainfall inputs and (atmospheric- and macrophyte- mediated) evapotranspiration losses, but is intensively managed via the operations of the water management infrastructure (canals, levees, water control structures, see Water Management Modules). Changes to water depths and flows can alter the habitat because different macrophyte species and algal/periphyton assemblages have distinct hydrologic adaptations. Likewise, changing water depths can alter the soils through increased accretion rates when wet for prolonged periods (i.e., long hydroperiods). On the other hand, soil losses increase with the oxidation occurring under short hydroperiods. This increased soil oxidation increases the nutrient availability surface/soil waters. Soil nutrient chemistry is also affected by water exchanges between surface and soil/sediment water storages, a vertical advective process driven by groundwater losses due to plant transpiration and/or horizontal groundwater flows (Raster Flux Modules).

Hydrology Module Description

Water is held in three state variables: 1) SURFACE_WAT is water that is stored above the sediment/soil surface; 2) UNSAT_WAT is stored in the pore spaces of the sediment/soil complex, but not saturating that zone; and 3) SAT_WAT is water saturating the pore spaces of the sediment/soil complex. Simulating the fluxes among these variables allows the depiction of wet, moist and dry environments. Flux among the variables depends on a variety of processes. Horizontal flow of surface and saturated ground water is simulated in other code modules. We ignore details of processes that occur on a time scale faster than the daily time step, such as vertical movement of a saturated wetting front in infiltration events. The longer-term results of storage in a small landscape can be effectively captured within the day-to-weekly time scale.

Surface water loss to storage in the sediment/soil can occur via two pathways: 1) infiltration from the surface water to an unsaturated soil water zone, based on measured infiltration rates for different soil types, and 2) surface water flow to the saturated water storage at a rate that depends on the rate of water loss in saturated storage. Any remaining surface water is available for evaporation. Surface water evaporation is simulated separately from water loss due to transpiration by plants. Total potential evapotranspiration is input as pre-processed data provided by the SFWMM developers. Loss of water by plant transpiration occurs either from the unsaturated or saturated water storages depending on the presence/absence of roots within the zone.

Vertical fluxes of water occur among all three of the water storage compartments. If surface water is present, and there is available volume in the unsaturated storage of the sediment, then water infiltrates into the unsaturated zone at a rate determined by the infiltration rate for the habitat type. The available capacity of the unsaturated zone is calculated from the porosity and current volume of water in unsaturated storage, which also determines the moisture proportion in unsaturated storage. We assume that the water in unsaturated storage is distributed homogeneously within that zone, ignoring the presence of any wetted front and the heterogeneities associated with processes occurring on faster time scales.

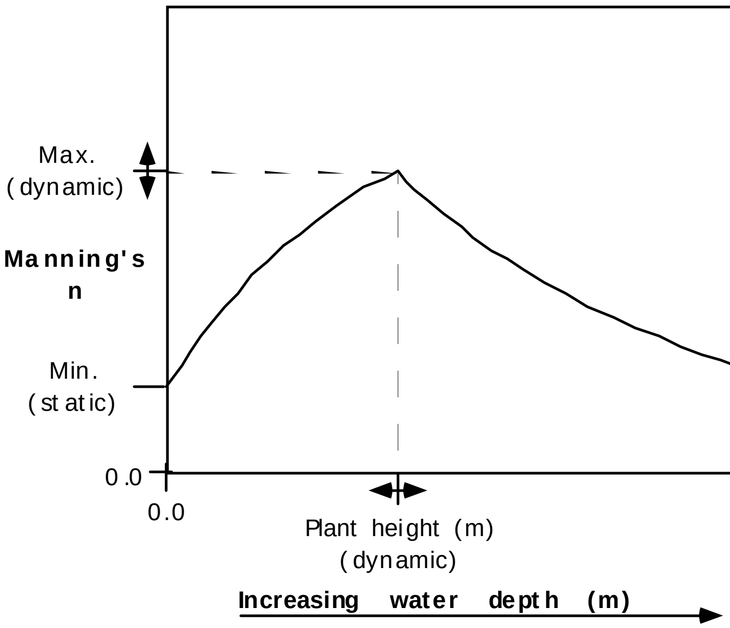
When the sediment is fully saturated, surface water may flow into the saturated layer to replace outflow from the saturated storage at the rate determined by the loss of saturated water. We assume that the rate of vertical movement of water from the surface to the saturated zone is at least as fast as that of losses from saturated storage via horizontal flows and transpiration. Because the unsaturated zone varies in depth, the model determines the relative degree to which surface water flows towards the unsaturated and saturated storage zones in the transition from significant depths of ponded surface water to little surface water and increasing depths of unsaturated storage. This allows for the presence of a vanishingly small unsaturated depth in the presence of small depth of overlying surface water.

Any moisture in excess of field capacity may percolate from the unsaturated storage to saturated storage, determined by the hydraulic conductivity of the sediment for unsaturated conditions. The unsaturated hydraulic conductivity for each habitat (sediment) type is decreased from the saturated hydraulic conductivity as a function of decreasing sediment moisture.

We developed an algorithm that incorporates the effects of dynamic vegetation height and biomass on hydrologic flows (Fitz et al. 1996, Fitz and Sklar 1999):

$$n = n_{\max} - \left|\left(n_{\max} - n_{\min}\right)\left(2^{\left(1 - {}^{h}\!/_{mac}\right)} - 1\right)\right|$$

where n is the dynamic Manning's roughness coefficient, n_{min} and n_{max} are the respective minimum and maximum roughness parameters associated with a cell's macrophyte/soil characteristics, h is water depth (m), and mac is the macrophyte height. As shown in the below Figure, this function returns a positive roughness coefficient whose value ranges from a vegetation-free minimum to a maximum at the point of full plant immersion (Petryk et al. 1975). As water depth increases over that of the macrophyte height, the roughness decreases to an asymptote at the baseline sediment roughness (Nalluri and Judy 1989). The roughness coefficient is calculated in this module, for application to spatial fluxes in horizontal solution modules.



The positive relationship of Manning's n with increased depth has been demonstrated by USGS (Everglades-specific) flume and Everglades field studies (Jenter and Schaffranek 1996, Carter et al. 1999, Lee and Carter 1999, 2002). As pointed out by Jenter and Schaffranek (1996), "...for a uniform stand of sawgrass with no litter layer, the value of n increases with flow depth.". We use this relationship in the ELM Manning's n calculation, and it is used by the USGS SICS[9] model. As water depth further increases[10], the ELM algorithm decreases Manning's n as the plants bend and are overtopped by water in a strata with no vegetation resistance.

Hydrology Module Equations

State Variable update calculations

calculated within spatial loop across model grid rows, columns

SURFACE_WAT = SURFACE_WAT + (SF_WT_FROM_RAIN - SF_WT_EVAP - SF_WT_INFILTRATION - SF_WT_TO_SAT_DOWNFLOW) * ***DT***

UNSAT_WATER = UNSAT_WATER + (SF_WT_INFILTRATION - UNSAT_TO_SAT_FL - UNSAT_TRANSP) * ***DT***

SAT_WATER = SAT_WATER + (UNSAT_TO_SAT_FL + SF_WT_TO_SAT_DOWNFLOW - SAT_WT_TRANSP) * ***DT***

Dependent upon:

1) attribute calculations

calculated within spatial loop across model grid rows, columns

SAT_WT_HEAD = SAT_WATER/***HP_HYD_POROSITY***;

UNSAT_DEPTH = SED_ELEV-SAT_WT_HEAD;

---

[9] Southern Inland and Coastal Systems numerical model for the SE region of ENP

[10] To a habitat-specific threshold depth

UNSAT_CAP = UNSAT_DEPTH****HP_HYD_POROSITY***

UNSAT_MOIST_PRP = (UNSAT_CAP>0.0) ? (Min(UNSAT_WATER/UNSAT_CAP,1.0)) : (1.0)

UNSAT_WT_POT = Max(UNSAT_CAP-UNSAT_WATER,0.0)

UNSAT_AVAIL = Max(UNSAT_MOIST_PRP-***field_cap***/***HP_HYD_POROSITY***,0.0)

LAI_eff = (MAC_HEIGHT>0.0) ? (Max(1.0 - SURFACE_WAT/MAC_HEIGHT, 0.0)*MAC_LAI) : (0.0)

f_LAI_eff = exp(-LAI_eff)

2) control function calculations

calculated within spatial loop across model grid rows, columns

SatWat_Root_CF = Exp(-10.0* Max(UNSAT_DEPTH- ***HP_NPHBIO_ROOTDEPTH***,0.0));

HYD_WATER_AVAIL = (UNSAT_DEPTH > ***HP_NPHBIO_ROOTDEPTH***) ? (Max(UNSAT_MOIST_PRP, SatWat_Root_CF)) : (1.0)

MAC_WATER_AVAIL_CF = graph8(0x0,HYD_WATER_AVAIL)

SAT_VS_UNSAT = 1/Exp(100.0*Max((SURFACE_WAT-UNSAT_DEPTH),0.0))

UNSAT_HYD_COND_CF = graph7(0x0,UNSAT_MOIST_PRP)

3) flux calculations

calculated within spatial loop across model grid rows, columns

HYD_EVAP_CALC = wmm_evap * 0.0001* ***GP_calibET***

HYD_TOT_POT_TRANSP = HYD_EVAP_CALC *(1.0-f_LAI_eff);

HYD_SAT_POT_TRANS = HYD_TOT_POT_TRANSP*SatWat_Root_CF;

HYD_UNSAT_POT_TRANS = (UNSAT_DEPTH > ***HP_NPHBIO_ROOTDEPTH***) ? (HYD_TOT_POT_TRANSP*MAC_WATER_AVAIL_CF) : (0.0)

SF_WT_FROM_RAIN = wmm_rain*0.0001

SF_WT_TO_SAT_DOWNFLOW = ((1.0-SAT_VS_UNSAT) *UNSAT_WT_POT****DT***>SURFACE_WAT) ? (SURFACE_WAT/***DT***) : ((1.0-SAT_VS_UNSAT)*UNSAT_WT_POT)

SF_WT_POT_INF = ((SAT_VS_UNSAT* ***HP_HYD_RCINFILT***+ SF_WT_TO_SAT_DOWNFLOW) ****DT***>SURFACE_WAT) ? ((SURFACE_WAT-SF_WT_TO_SAT_DOWNFLOW****DT***)/***DT***) : (SAT_VS_UNSAT****HYD_RCINFILT***)

SF_WT_INFILTRATION = (SF_WT_POT_INF****DT*** > (UNSAT_WT_POT-SF_WT_TO_SAT_DOWNFLOW****DT***)) ? ((UNSAT_WT_POT-SF_WT_TO_SAT_DOWNFLOW****DT***)/***DT***) : (SF_WT_POT_INF)

SFWAT_PR1 = SF_WT_INFILTRATION+SF_WT_TO_SAT_DOWNFLOW

SF_WT_EVAP = ((f_LAI_eff*HYD_EVAP_CALC+SFWAT_PR1)****DT***>SURFACE_WAT) ? ((SURFACE_WAT-SFWAT_PR1****DT***)/***DT***) : (f_LAI_eff*HYD_EVAP_CALC)

UNSAT_PERC = Min(***HP_HYD_RCINFILT****UNSAT_HYD_COND_CF,UNSAT_AVAIL*UNSAT_WATER)

UNSAT_TO_SAT_FL = (UNSAT_PERC****DT*** > UNSAT_WATER) ? (UNSAT_WATER/***DT***) : (UNSAT_PERC)

UNSAT_TRANSP = ((HYD_UNSAT_POT_TRANS+UNSAT_TO_SAT_FL)****DT***>UNSAT_WATER) ? ((UNSAT_WATER-UNSAT_TO_SAT_FL****DT***)/***DT***) : (HYD_UNSAT_POT_TRANS)

SAT_WT_TRANSP = ((HYD_SAT_POT_TRANS)****DT*** > SAT_WATER) ? ((SAT_WATER)/***DT***) : (HYD_SAT_POT_TRANS);

4) attribute calculations, only used in other modules

calculated within spatial loop across model grid rows, columns

mann_height = Max((***GP_mann_height_coef****MAC_HEIGHT)*(***GP_mann_height_coef****MAC_HEIGHT), 0.01)

N_density = Max(***HP_MAC_MAXROUGH*** * MAC_REL_BIOM, ***HP_MAC_MINROUGH***)

HYD_MANNINGS_N = Max(-Abs((N_density- ***HP_MAC_MINROUGH***) *(pow(2.0,(1.0-SURFACE_WAT/mann_height))-1.0)) + N_density, ***HP_MAC_MINROUGH***);

HYD_DOM_ACTWAT_VOL = (Min(***HP_DOM_MAXDEPTH***[HAB],UNSAT_DEPTH)*UNSAT_MOIST_PRP + Max(***HP_DOM_MAXDEPTH***[HAB]-UNSAT_DEPTH, 0.0)* ***HP_HYD_POROSITY***) * ***CELL_SIZE***

HYD_DOM_ACTWAT_PRES = (HYD_DOM_ACTWAT_VOL > ***CELL_SIZE****0.01) ? (1.0) : (0.0)

HYD_SED_WAT_VOL = (SAT_WATER+UNSAT_WATER)****CELL_SIZE***

SFWT_VOL = SURFACE_WAT****CELL_SIZE***

HydTotHd = SAT_WT_HEAD+SURFACE_WAT

H2O_TEMP= AIR_TEMP

External variables used

MAC_HEIGHT (see Macrophyte module)

MAC_LAI (see Macrophyte module)

MAC_REL_BIOM (see Macrophyte module)

AIR_TEMP (see Globals module)

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
HYD_DOM_ACTWAT_PRES	attribute	dimless	Logical flag (true or false) denoting PRESence of WATer in the DOM_ACTive zone depth (DOM_MAXDEPTH)
HYD_DOM_ACTWAT_VOL	stateConvert	m^3	HYDrologic, water VOLume storage in the DOM_ACTive zone depth (DOM_MAXDEPTH)
HYD_EVAP_CALC	ratePotential	m/d	HYDrologic, total potential EVAPotranspiration (was calculated variable in v2.1, now data input)
HYD_MANNINGS_N	attribute	d/(m^(1/3))	HYDrologic, calculated MANNING'S N surface roughness, (based on empirically-derived surface roughness

			coeficient)
HYD_SAT_POT_TRANS	ratePotential	m/d	HYDrologic, POTential TRANSpiration loss from SATurated water storage
HYD_SED_WAT_VOL	stateConvert	m^3	HYDrologic, WATer VOLume stored in soil/SEDiment storage
HYD_TOT_POT_TRANSP	ratePotential	m/d	HYDrologic, total POTential TRANSpiration loss (from saturated and unsaturated water storages)
HYD_TRANSP	rateActual	m/d	HYDrologic, sum of actual TRANSPiration loss from saturated and unsaturated water storages (reporting purposes only)
HYD_UNSAT_POT_TRANS	ratePotential	m/d	HYDrologic, POTential TRANSpiration loss from UNSATurated water storage
HYD_WATER_AVAIL	controlFunction	dimless	HYDrologic, control function (0-1) of proportion of WATer in upper soil profile that is AVAILable for plant uptake, including unsaturated storage withdrawal, and small capillary withdrawal from saturated storage, depending on relative depths
HydTotHd	stateConvert	m	Hydrologic, Total hydraulic Head (or stage), not used in calculations, only for reporting purposes
MAC_WATER_AVAIL_CF	controlFunction	dimless	empirical data as a (0-1) control function, the proportion (Y) of water available to plants as a function of proportion (0-1) of water available in upper soil profile (X, HYD_WATER_AVAIL (generally, simply 1:1 relationship)
SAT_VS_UNSAT	controlFunction	dimless	control function (0-1), determining relative magnitude of potential surface- to SATurated VS UNSATurated storage flow, having effects under conditions of extremely shallow ponded depths (ca. a couple cm or less)
SAT_WATER	state	m	height of the SATurated WATER storage volume (excluding soil/sediment volume)
SAT_WT_HEAD	stateConvert	m	SATurated WaTer hydraulic HEAD (does not include any overlying surface water)
SAT_WT_TRANSP	rateActual	m/d	actual TRANSPiration loss from SATurated WaTer storage
SatWat_Root_CF	controlFunction	dimless	control function (0-1) that is intermediate calculation used in HYD_WATER_AVAIL
SF_WT_EVAP	rateActual	m/d	actual EVAPoration loss from SurFace WaTer storage
SF_WT_FROM_RAIN	rateA	m/d	RAINfall gain to the SurFace WaTer

	ctual		storage
SF_WT_INFILTRATION	rateActual	m/d	SurFace WaTer loss due to INFILTRATION into the unsaturated storage zone
SF_WT_POT_INF	ratePotential	m/d	SurFace WaTer POTential loss due to INFiltration into the unsaturated storage zone
SF_WT_TO_SAT_DOWNFLOW	rateActual	m/d	SurFace WaTer DOWNFLOW TO SATurated storage
SFWT_VOL	stateConvert	m^3	SurFace WaTer storage VOLume
SURFACE_WAT	state	m	height of the SurFace WaTer storage VOLume
UNSAT_AVAIL	attribute	dimless	proportion (0-1) of UNSATurated water storage in pore space that is AVAILable for gravitational flow (above field capacity)
UNSAT_CAP	attribute	m	potential total storage CAPacity (pore space) in the height of the current UNSATurated zone
UNSAT_DEPTH	stateConvert	m	DEPTH (height) of the UNSATurated zone (including pore space)
UNSAT_HYD_COND_CF	controlFunction	dimless	empirical data as a control function (0-1), the proportion (Y) of maximum vertical water infiltration rate through soil as a function of soil moisture proportion (0-1) (X, UNSAT_MOIST_PRP)
UNSAT_MOIST_PRP	attribute	dimless	MOISTure PRoPortion (0-1) in UNSATurated storage
UNSAT_PERC	ratePotential	m/d	potential PERColation loss from UNSATurated storage to saturated storage
UNSAT_TO_SAT_FL	rateActual	m/d	PERColation loss from UNSATurated storage to saturated storage
UNSAT_TRANSP	rateActual	m/d	actual TRANSPiration loss from UNSATurated water storage
UNSAT_WATER	state	m	height of the UNSATurated WATER storage volume (excluding soil/sediment volume)
UNSAT_WT_POT	attribute	m	UNSATurated WaTer storage POTential storage that is not filled (<= UNSAT_CAP)
H2O_TEMP	attribute	deg C	Temperature of ponded surface water, daily average (=AIR_TEMP in v2.1)

Time series forcing data

wmm_evap (see Globals module, units= tenths of mm/d)

wmm_rain (seeGlobals module, units= tenths of mm/d)

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_mann_height_coef	global	dimless	proportion of height at which macrophyte starts to bend over in flowing systems
GP_calibET	global	dimless	calibration parameter, multiply potential ET input data

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_HYD_RCINFILT	hab-spec	m/d	Rate of infiltration into the unsaturated water storage zone.
HP_HYD_POROSITY	hab-spec	dimless	Porosity of the aquifer, average from the sediment to base datum. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization. Must be non-zero.
HP_HYD_SPEC_YIELD	hab-spec	dimless	Proportion of total sediment/soil volume, for a given soil type, that represents water able to be drained by gravity. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization.
field_cap = ***HP_HYD_POROSITY*** - ***HP_HYD_SPEC_YIELD***	hab-spec	dimless	Proportion of total sediment/soil volume, for a given soil type, that represents water able to be drained by gravity.
HP_NPHBIO_ROOTDEPTH	hab-spec	m	Depth of roots below the sediment/soil zone (positive value) for the community.
HP_MAC_MAXROUGH	hab-spec	d/(m^(1/3))	The maximum Manning's n roughness associated with present vegetation when fully inundated by water. The relation of the total manning's n to water depth ranges along the continuum from the roughness due to sediment only and roughness imparted by inundation of plants by water depth. Be sure this max value > the minimum roughness coeff.
HP_MAC_MINROUGH	hab-spec	d/(m^(1/3))	The minimum Manning's roughness coefficient for minimal/no vegetation. Be sure this value is less than the roughness coeff for the vegetation.

Intrinsic C or ELM functions

exp(x) = Exp(x) => e raised to the x^{th} power

Max(x,y) => maximum of variable x or y

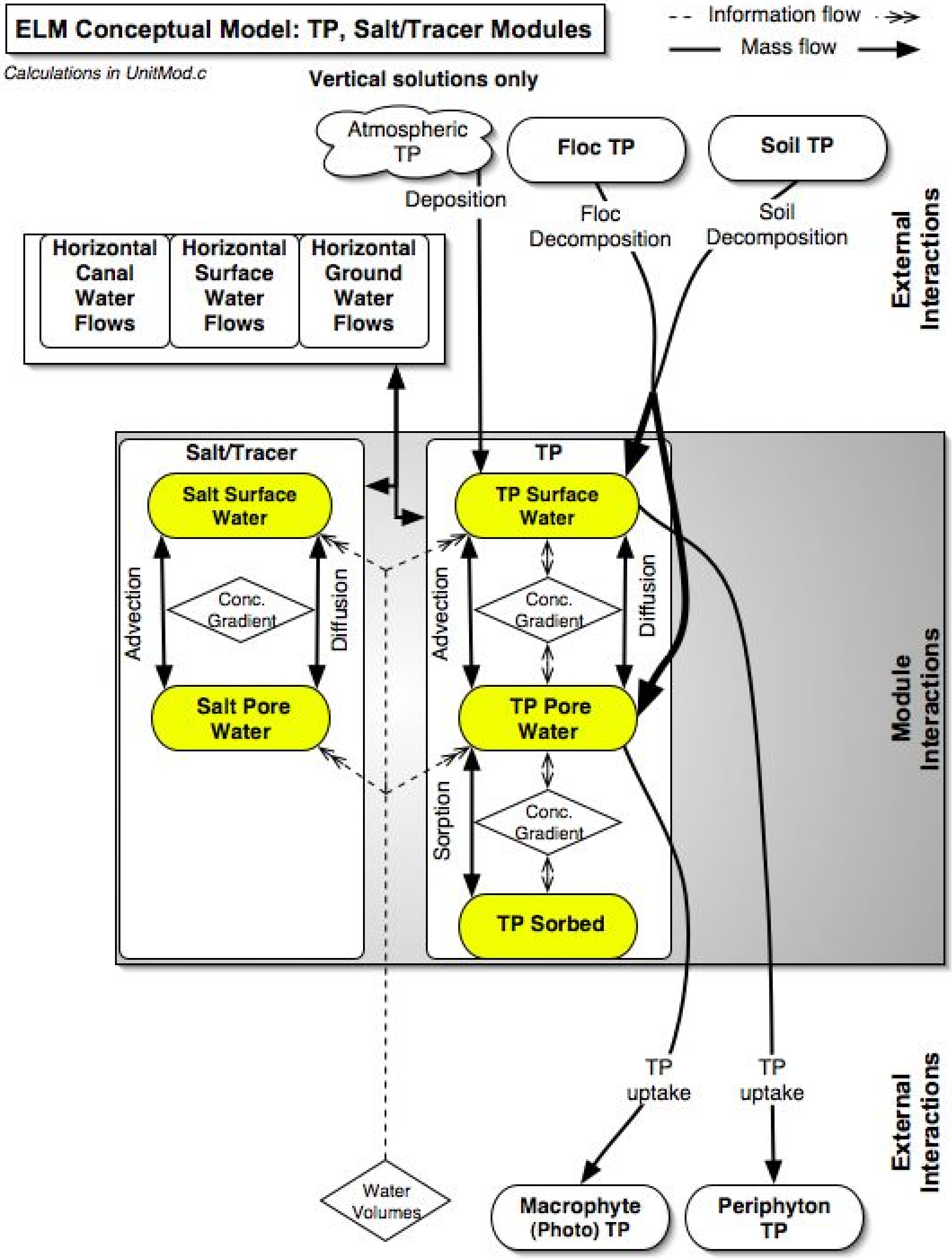
Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

yVar = graph_(0x0, xVar) => empirical data graph, returning value of yVar as function of current xVar value

pow(x,y) => x raised to the y^{th} power (generally avoided if possible due to execution time of C library)

5.6.3 Phosphorus, salt/tracer modules



Overview: Phosphorus and Salt/Tracer Modules

These Modules serve primarily to update the constituent state variables of phosphorus and salt/tracer, in response to the vertical fluxes among the surface water and sediment/soil storages. Water quality has been responsible for shifts in primary productivity and species composition of macrophyte and periphyton communities, and is another primary "driver" of the landscape at fast (weekly to annual) time scales. Because the predominant "native" Everglades macrophyte and periphyton communities have adapted to oligotrophic (low nutrient) waters, increases in nutrients (i.e., eutrophication) can be detrimental to the structure and the function of those communities. Phosphorus is generally the more limiting nutrient in the freshwater Everglades, while nitrogen (currently inoperative in ELM) tends to govern plant productivity rates in the southern Everglades/Florida bay where estuarine gradients occur. Typically, anthropogenic (manmade) loading of otherwise-limiting nutrients causes ecological imbalance, shifting the structure and function of the ecosystem. Management of flows through water control structures and canals (Water Management Modules) has significantly modified the distribution of these nutrient loads and concentrations across the landscape. Different macrophyte and periphyton communities can uptake nutrients at varying rates (see respective plant Modules), changing the ambient water quality (and changing the plant tissues and growth). As water exchanges among surface and soil/sediment porewaters, the associated nutrient fluxes can alter the microbially mediated rates of soil/sediment decomposition (Soil and Floc Modules), releasing nutrients in inorganic forms that are more available for biotic uptake. Along with nutrient availability, salinity gradients in the southern Everglades/Florida Bay have the potential to modify communities that have adapted to particular environmental conditions.

Phosphorus Module Description

The principal objective of the current Phosphorus module is to simulate vertical atmospheric deposition and the vertical diffusive and advective phosphorus fluxes, as a part of the broader objective of capturing inter-annual and seasonal trends in the regional gradients of water column phosphorus. In the Phosphorus Module, total atmospheric deposition of phosphorus is considered by applying a constant concentration to rainfall to achieve a long term, region-wide annual deposition rate (approximately 27 mg P/m^2/yr in the current model version).

The processes of soil sorption-desorption are calculated using a modified Freunlich equation (Richardson and Vaithiyanathan 1995):

$$P\_sorb(t) = P\_sorb(t - 1) + \left(k_{sb} {P_{pwat}}^{0.8} - P\_sorb(t - 1)\right)dt$$

where P_sorb(time) is sorbed phosphorus at time t or time t-1, k_{sb} is the adsorption coefficient (L kg^{-1}), P_{pwat} is the P concentration in the soil pore water (mg L^{-1}), and dt is the time increment.

Uptake by live plants and implicit microbial soil communities are considered in those respective modules. Common to both the Phosphorus and Salt/Tracer Modules are the downward advection of constituents from surface water storage, and the two-way diffusive flux across the soil/sediment and surface water storages. Upflow due to horizontal subsurface flows are accommodated in the integration of surface water and groundwater in the Groundwater Flux Module.

Phosphorus Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations

TP_SF_WT = TP_SF_WT + (TP_UPFLOW + TP_FR_RAIN - TP_DNFLOW) * ***DT***

TP_SED_WT = TP_SED_WT + (TP_DNFLOW - TP_UPFLOW - TP_SORBTION) * ***DT***

TP_SED_WT_AZ = TP_SED_WT_AZ + (TP_DNFLOW - TP_UPFLOW - TP_SORBTION) * ***DT***

TP_SORB = TP_SORB + (TP_SORBTION) * ***DT***

##TP_SF_WT calculated second time, after first difference equation update of TP_SF_WT
TP_SF_WT = TP_SF_WT - TP_settl * ***DT***

Dependent upon:

1) attribute calculations

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

PO4Pconc = Max(TP_SFWT_CONC****GP_PO4toTP*** + 0.001* ***GP_PO4toTP***int,0.0)

TP_SED_CONC = (HYD_SED_WAT_VOL>0.0) ? (TP_SED_WT / HYD_SED_WAT_VOL) : (0.0)

TP_SED_WT_AZ = TP_SED_CONC * TP_Act_to_Tot * HYD_DOM_ACTWAT_VOL

TP_SEDWT_CONCACT =(HYD_DOM_ACTWAT_PRES > 0.0) ? (TP_SED_WT_AZ/HYD_DOM_ACTWAT_VOL) : (TP_SED_CONC)

TP_K = Max(***GP_TP_K_SLOPE****TP_SORBCONC+ ***GP_TP_K_INTER***,0.0)

2) control function calculations

none

3) flux calculations

TP_FR_RAIN = SF_WT_FROM_RAIN****CELL_SIZE**** ***GP_TP_IN_RAIN****0.001

*## 8.64 = sec/day * 1e-4 m^2/cm^2*
TP_UPFLOW_POT = Max((TP_SEDWT_CONCACT-PO4Pconc) * ***GP_TP_DIFFCOEF****8.64/ ***GP_TP_DIFFDEPTH*******CELL_SIZE***,0.0)

TP_UPFLOW = ((TP_UPFLOW_POT)****DT***>TP_SED_WT_AZ) ? ((TP_SED_WT_AZ)/***DT***) : (TP_UPFLOW_POT)

TP_SORB_POT = (HYD_DOM_ACTWAT_PRES>0.0) ? (0.001 *(TP_K*(pow(Max(TP_SEDWT_CONCACT,0.0),0.8)) *0.001*(DEPOS_ORG_MAT****CELL_SIZE***+DIM)-TP_SORB)) : (0.0)

if (TP_SORB_POT>0.0) then TP_SORBTION = ((TP_SORB_POT+TP_UPFLOW)****DT***>TP_SED_WT_AZ) ? ((TP_SED_WT_AZ-TP_UPFLOW****DT***)/***DT***) : (TP_SORB_POT)

if (TP_SORB_POT<=0.0) then TP_SORBTION = ((-TP_SORB_POT)****DT***>TP_SORB) ? ((-TP_SORB)/***DT***) : (TP_SORB_POT)

TP_DNFLOW_POT = (SF_WT_INFILTRATION+SF_WT_TO_SAT_DOWNFLOW)****CELL_SIZE****TP_SFWT_CONC + Max((PO4Pconc-TP_SEDWT_CONCACT) * ***GP_TP_DIFFCOEF****8.64/ ***GP_TP_DIFFDEPTH****CELL_SIZE***,0.0)

TP_DNFLOW = ((TP_DNFLOW_POT)****DT*** > TP_SF_WT) ? ((TP_SF_WT)/***DT***) : (TP_DNFLOW_POT)

4) attribute calculations, only used in other modules

TP_SED_CONC = (HYD_SED_WAT_VOL>0.0) ? (TP_SED_WT / HYD_SED_WAT_VOL) : (0.0)

TP_SEDWT_CONCACT = (HYD_DOM_ACTWAT_PRES > 0.0) ? (TP_SED_WT_AZ/HYD_DOM_ACTWAT_VOL) : (TP_SED_CONC)

TP_SEDWT_CONCACTMG = TP_SEDWT_CONCACT* ***conv_kgTOg***

TP_SORBCONC = ((DEPOS_ORG_MAT****CELL_SIZE*** + DIM)>0.0) ? (TP_SORB* ***conv_kgTOg*** / (DEPOS_ORG_MAT****CELL_SIZE*** + DIM)) : (0.0)

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

TP_SFWT_CONC_MG = (SURFACE_WAT > ***GP_DetentZ***) ? (TP_SFWT_CONC* ***conv_kgTOg***) : (0.0)

##Below are calculated after first difference equation update of TP_SF_WT (in later version, may be incorporated into cell_dyn13 instead of this module)

PO4Pconc = Max(TP_SFWT_CONC_MG* ***GP_PO4toTP*** + ***GP_PO4toTPint***,0.0)

nonPO4Pconc = Max(TP_SFWT_CONC_MG-PO4Pconc,0.0)

TPpartic = nonPO4Pconc * (1.0-exp(-nonPO4Pconc/ ***GP_TPpart_thresh***)) *0.001 * SFWT_VOL

TPsettlRat = (SURFACE_WAT > ***GP_DetentZ***) ? (***GP_settlVel***/SURFACE_WAT) : 0.0

TP_settl_pot = TPsettlRat * TPpartic

TP_settl = ((TP_settl_pot)****DT*** > TPpartic) ? ((TPpartic)/***DT***) : (TP_settl_pot)

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

TP_SFWT_CONC_MG = (SURFACE_WAT > ***GP_DetentZ***) ? (TP_SFWT_CONC* ***conv_kgTOg***) : (0.0)

External variables used

SFWT_VOL (see Hydrology Module)

HYD_SED_WAT_VOL (see Hydrology Module)

HYD_DOM_ACTWAT_VOL (see Hydrology Module)

HYD_DOM_ACTWAT_PRES (see Hydrology Module)

SF_WT_FROM_RAIN (see Hydrology Module)

SF_WT_INFILTRATION (see Hydrology Module)

SF_WT_TO_SAT_DOWNFLOW (see Hydrology Module)

TP_Act_to_Tot (see Soils Module)

DEPOS_ORG_MAT (see Soils Module)

DIM (see Soils Module)

Phosphorus Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
nonPO4Pconc	attribute	mgP/L	concentration of ~bio-unavailable form of total phosphorus (loosely stated, "non-PO4") storage in water column (note units of mgP/L)
PO4Pconc	attribute	mgP/L	concentration of inorganic PO4 (~bio-available) form of total phosphorus storage in water column (note units of mgP/L)
TP_DNFLOW	rateActual	kgP/d	Total Phosphorus DowNFLOW loss from surface water TP storage to saturated water TP storage via advection and diffusion
TP_DNFLOW_POT	ratePotential	kgP/d	Total Phosphorus DowNFLOW POTential loss from surface water TP storage to saturated water TP storage via advection and diffusion
TP_FR_RAIN	rateActual	kgP/d	Total Phosphorus DowNFLOW gained from atmospheric deposition (via a rainfall TP concentration)
TP_K	attribute	mgP/L	Total Phosphorus K value calculated for Freundlich sorption eqn
TP_SED_CONC	attribute	kgP/m^3	Total Phosphorus CONCentration in entire SEDiment/soil water volume
TP_SED_WT	state	kgP	Total Phosphorus stored in entire SEDiment/soil WaTer volume
TP_SED_WT_AZ	state	kgP	Total Phosphorus stored in Active Zone of SEDiment/soil WaTer volume
TP_SEDWT_CONCACT	attribute	kgP/m^3	Total Phosphorus CONCentration in ACTive SEDiment/soil WaTer volume
TP_SEDWT_CONCACTMG	attribute	mgP/L	Total Phosphorus CONCentration in ACTive SEDiment/soil WaTer volume
TP_settl	rateActual	kgP/d	Total Phosphorus settled (deposited) out of storage in surface water (Everglades Water Quality Model module calc'd differently from ELM phosphorus module)
TP_settl_pot	ratePotential	kgP/d	Total Phosphorus that may potentially be settled (deposited) out of storage in surface water (Everglades Water Quality Model module calc'd differently from ELM phosphorus module)
TP_SF_WT	state	kgP	Total Phosphorus stored in SurFace WaTer volume
TP_SFWT_CONC	attribute	kgP/m^3	Total Phosphorus CONCentration in SurFace WaTer volume
TP_SFWT_CONC_MG	attribute	mgP/L	Total Phosphorus CONCentration in SurFace WaTer volume
TP_SORB	state	kgP	Total Phosphorus storage that is SORBed to sediment/soils

TP_SORB_POT	ratePotential	kgP/d	Total Phosphorus POTential flux of adSORBtion to (positive) or deSORBtion from (negative) sediment/soils (Note the negative values in this flux variable: neg values are not accomodated in default unsigned char map output)
TP_SORBCONC	attribute	gP/kg_soil	Total Phosphorus CONCentration SORBed to (organic and inorganic) soil mass (note units of gP/kg_soil)
TP_SORBTION	rateActual	kgP/d	Total Phosphorus flux of adSORBTION to (positive) or deSORBTION from (negative) sediment/soils
TP_UPFLOW	rateActual	kgP/d	Total Phosphorus UPFLOW gain to surface water TP storage from saturated water TP storage via diffusion (advection handled separately in surface-ground water integration module within fluxes.c source)
TP_UPFLOW_POT	ratePotential	kgP/d	Total Phosphorus UPFLOW POTential gain to surface water TP storage from saturated water TP storage via diffusion (advection handled separately in surface-ground water integration module within fluxes.c source)
TPpartic	attribute	kgP	mass of particulate form of total phosphorus storage in water column (<= mass of nonPO4Pconc)
TPsettlRat	rateActual	1/d	Total Phosphorus settling rate (Everglades Water Quality Model module calc'd differently from ELM phosphorus module)

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
conv_kgTOg	global	dimless	conversion, kg->g
GP_DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
GP_PO4toTP	global	dimless	slope of empirical regression of predicting PO4 from TP from long-term historical data, northern Everglades locations
GP_PO4toTPint	global	mg/l	intercept of empirical regression of predicting PO4 from TP from long-term historical data, northern

			Everglades locations
GP_TP_K_SLOPE	global	dimless	slope for Freundlich soil sorption eqn
GP_TP_K_INTER	global	mg/L	intercept for Freundlich soil sorption eqn
GP_TP_DIFFCOEF	global	cm^2/sec	Phosphorus molecular (surface-soil water) diffusion coefficient.
GP_TP_DIFFDEPTH	global	m	depth of surface-soil water diffusion zone
GP_TP_IN_RAIN	global	mg/L	TP concentration in rainfall (will be switching to new data for versions > ELMv2.2)
GP_TPpart_thresh	global	mg/L	TP conc used for predicting particulate P for settling
GP_settlVel	global	m/d	ELM (NOT EWQM emulation) mean settling velocity of particulate phosphorus (NOT of Total Phosphorus)

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description

none

Intrinsic C or ELM functions

Max(x,y) => maximum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

pow(x,y) => x raised to the yth power (generally avoided if possible due to execution time of C library)

Salt/Tracer Module Description

The principal objective of the current Salt/Tracer module is to simulate the vertical diffusive and advective fluxes of conservative water column constituents, as a part of the broader objective of capturing inter-annual and seasonal trends in the regional gradients of this constituent. In a very simple implementation, this module only considers the downward advection of constituents from surface water storage, and the two-way diffusive flux across the soil/sediment and surface water storages. Upflow due to horizontal subsurface flows are accomodated in the integration of surface water and groundwater in the Groundwater Flux Module. Currently (ELM v2.2), the model considers a single conservative constituent, with the primary focus on the use of Chloride input data as a “conservative” tracer to aid in understanding relative rates of horizontal water flow (see Water Management and Raster Flux Modules) in different parts of the system.

Salt/Tracer Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations

SALT_SED_WT = SALT_SED_WT + (SALT_SFWAT_DOWNFL - SALT_SED_TO_SF_FLOW) * ***DT***

SALT_SURF_WT = SALT_SURF_WT + (SALT_SED_TO_SF_FLOW - SALT_SFWAT_DOWNFL) * ***DT***

Dependent upon:

1) attribute calculations

SAL_SF_WT_mb = (SFWT_VOL > 0.0) ? (SALT_SURF_WT/SFWT_VOL) : (0.0)

SAL_SED_WT = (HYD_SED_WAT_VOL>0.0) ? (SALT_SED_WT/HYD_SED_WAT_VOL) : (0.0)

2) control function calculations

none

3) flux calculations

*## 8.64 = sec/day * 1e-4 m^2/cm^2*

SALT_SFWAT_DOWNFL_POT = (SF_WT_INFILTRATION + SF_WT_TO_SAT_DOWNFLOW)* ***CELL_SIZE****SAL_SF_WT_mb+ Max((SAL_SF_WT_mb-SAL_SED_WT) * ***GP_TP_DIFFCOEF****8.64/ ***GP_TP_DIFFDEPTH********CELL_SIZE***,0.0)

SALT_SFWAT_DOWNFL = (SALT_SFWAT_DOWNFL_POT****DT***>SALT_SURF_WT) ? (SALT_SURF_WT/***DT***) : (SALT_SFWAT_DOWNFL_POT)

SALT_SED_TO_SF_FLOW_pot = Max((SAL_SED_WT-SAL_SF_WT_mb) * ***GP_TP_DIFFCOEF****8.64/ ***GP_TP_DIFFDEPTH********CELL_SIZE***,0.0)

SALT_SED_TO_SF_FLOW = (SALT_SED_TO_SF_FLOW_pot****DT***>SALT_SED_WT) ? (SALT_SED_WT/***DT***) : (SALT_SED_TO_SF_FLOW_pot)

4) attribute calculations, only used in other modules

none

External variables used

SFWT_VOL (see Hydrology Module)

HYD_SED_WAT_VOL (see Hydrology Module)

SF_WT_INFILTRATION (see Hydrology Module)

SF_WT_TO_SAT_DOWNFLOW (see Hydrology Module)

Salt/Tracer Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
SAL_SED_WT	attribute	kgSalt/ m^3	SALinity in SEDiment/soil WaTer storage (can be any conservative solute w/ consistent units - salt/tracer does not affect any other calculation in v2.2)
SAL_SF_WT	attribute	kgSalt/ m^3	SALinity in SurFace WaTer storage (can be any conservative solute w/

			consistent units - salt/tracer does not affect any other calculation in v2.2)
SALT_SED_TO_SF_FLOW	rateActual	kgSalt/d	SALT FLOW from SEDiment/soil water storage TO SurFace water storage via diffusion (advection handled separately in surface-ground water integration module within fluxes.c source)
SALT_SED_TO_SF_FLOW_pot	ratePotential	kgSalt/d	SALT FLOW potential from SEDiment/soil water storage TO SurFace water storage via diffusion (advection handled separately in surface-ground water integration module within fluxes.c source)
SALT_SED_WT	state	kgSalt	SALT mass in SEDiment/soil WaTer storage (can be any conservative solute w/ consistent units - salt/tracer does not affect any other calculation in v2.2)
SALT_SFWAT_DOWNFL	rateActual	kgSalt/d	SALT DOWNFLow from SurFace WATer storage to sediment/soil water storage via diffusion and advection
SALT_SFWAT_DOWNFL_POT	ratePotential	kgSalt/d	SALT DOWNFLow POTential from SurFace WATer storage to sediment/soil water storage via diffusion and advection
SALT_SURF_WT	state	kgSalt	SALT mass in SURFace WaTer storage (can be any conservative solute w/ consistent units - salt/tracer does not affect any other calculation in v2.2)

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	m/d	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_TP_DIFFCOEF	global	cm^2/sec	Phosphorus molecular (surface-soil water) diffusion coefficient.
GP_TP_DIFFDEPTH	global	m	depth of surface-soil water diffusion zone

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description

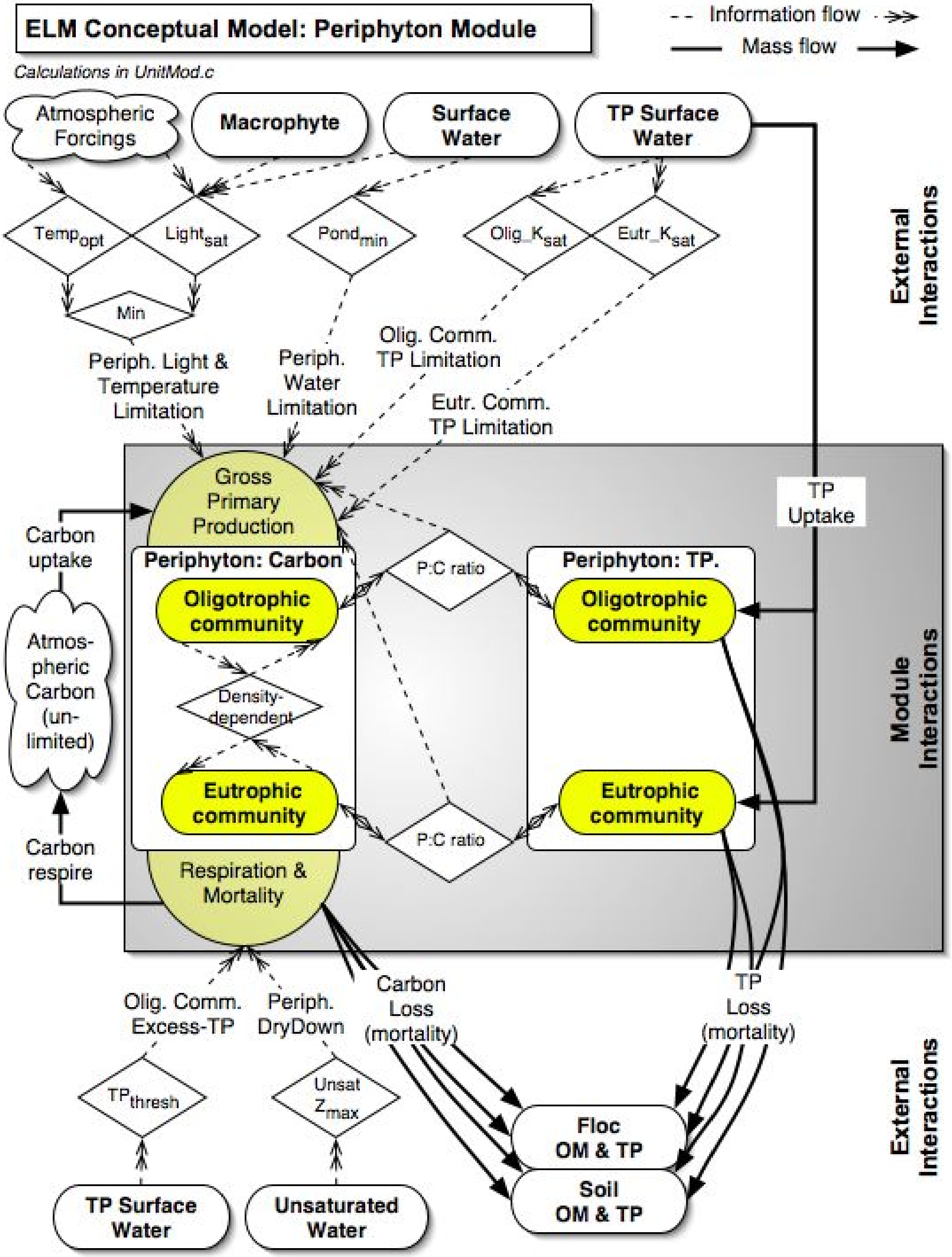
none

Intrinsic C or ELM functions

Max(x,y) => maximum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

5.6.4 Periphyton module



Overview: Periphyton Module

Periphyton are found attached to macrophyte stems, floating as mats in the water column, and as a benthic layer on top of the soil. Long considered an integral part of the animal food web, periphyton respond rapidly to changes in water quality and hydroperiod. Like macrophytes, "native" periphyton are adapted to oligotrophic (low nutrient) conditions, while a variety of other periphyton are common in eutrophic (high nutrient) waters. Another important control on periphyton and algae is light availability: at intermediate and high plant densities (such as in high nutrient areas), emergent marsh macrophytes shade periphyton, and (to some extent) prevent healthy communities from developing. Capable of senescing during dry periods and coming back to high growth levels upon rehydration, there are a variety of different types of periphyton species & communities, depending on the subregion of the Everglades and its local environmental conditions.

Periphyton Module Description

The general form of the equations that describe changes to a periphyton carbon stock is:

$$S(t) = S(t-1) + (P - R - M)dt\,,$$

where $S(time)$ is the standing stock of periphyton (g C m^{-2}) at time t or t-1, P is the gross primary production gain (g C m^{-2} d^{-1}), R is the respiration loss (g C m^{-2} d^{-1}), M is the mortality loss (g C m^{-2} d^{-1}), and dt is the time interval (days). The actual rates are products of the periphyton stock and maximum specific rates that are constrained by control functions:

$$P = S(t-1)\cdot P_{max}CF_P$$

$$R = S(t-1)\cdot R_{max}CF_R$$

$$M = S(t-1)\cdot M_{max}CF_M$$

where P_{max}, R_{max}, and M_{max} are the maximum specific rates (d^{-1}) of, respectively, gross primary production, respiration, and mortality; the CF_P, CF_R, and CF_M are the (dimensionless, 0 – 1) control functions constraining gross production, respiration, and mortality, respectively.

The control function constraining gross primary production includes a density-dependent feedback and a control function involving several environmental parameters. This combined control function is a multiplicative expression of relative effects of light intensity (e.g., macrophyte shading), temperature (seasonality), and nutrient availability.

The dimensionless control function due to light intensity in the water column is based on Steele’s (1965) photoinhibition formulation integrated over depth (Bowie et al. 1985). The temperature control function (Jorgensen 1976) describes the biological responses to temperature relative to a temperature optimum and a minimum. Whereas earlier ELM versions (Fitz et al. 1996, Fitz and Sklar 1999) quantified nutrient limitation using Monod half-saturation kinetics, this relationship appeared to behave inadequately in the oligotrophic conditions of much of the Everglades, apparently with excessive constraint on growth under those ambient conditions. There is evidence that phosphatase activity of the periphyton assemblage tends to increase under low nutrient conditions (Newman et al. 2003), thus potentially making phosphorus less limiting and deviating from Monod kinetics. Moreover, while some experimental data existed for half-saturation values of periphyton (Scinto and Reddy submitted) in laboratory settings, there was little information available on growth responses at low nutrient concentrations. Our alternative nutrient control function formulation uses an exponential function, and a relationship to the parameter whose definition remains related to saturation kinetic experiments.

The periphyton module considers two communities of periphyton[11]: those adapted to oligotrophic ("calcareous") and eutrophic ("non-calcareous") conditions such as those observed along Everglades nutrient gradients (McCormick et al. 1996). Both periphyton communities are simulated with the same form of dynamic equations, but have different nutrient limitation parameters, different mortality responses to elevated phosphorus concentrations, and have simple density-dependent inter-community competition.

Periphyton Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations

NC_ALG = NC_ALG + (NC_ALG_GPP - NC_ALG_RESP - NC_ALG_MORT) * DT

C_ALG = C_ALG + (C_ALG_GPP - C_ALG_RESP - C_ALG_MORT) * DT

Dependent upon:

1) attribute calculations

ALG_REFUGE = ***HP_ALG_MAX**** ***GP_ALG_REF_MULT***

ALG_SAT = ***HP_ALG_MAX****0.9

NC_ALG_AVAIL_MORT = Max(NC_ALG-ALG_REFUGE,0)

C_ALG_AVAIL_MORT = Max(C_ALG-ALG_REFUGE,0)

bio-avail P (PO4) is calc'd from TP, using pre-processed regression for predicting PO4 from TP

assume that periphyton (microbial) alkaline phosphatase activity keeps PO4 at least 10% of TP conc

PO4Pconc = Max(TP_SFWT_CONC_MG* ***GP_PO4toTP*** + ***GP_PO4toTPint***, 0.10 * TP_SFWT_CONC_MG)

light, water, temperature controls apply to both calc and non-calc

ALG_LIGHT_EXTINCT = ***GP_alg_light_ext_coef***

algal self-shading implicit in density-dependent constraint function later

ALG_INCID_LIGHT = SOLRADGRD*Exp(-MAC_LAI* ***GP_ALG_SHADE_FACTOR***)

Z_extinct = SURFACE_WAT*ALG_LIGHT_EXTINCT

I_ISat = ALG_INCID_LIGHT/***GP_ALG_LIGHT_SAT***

2) control function calculations

averaged over whole water column (based on Steele 1965)

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[11] The names of the periphyton state variables are rooted in the term "algae", originating from the generalized nature of the module that was developed for algal communities. While periphyton are actually assemblages of microbial and algal biota, the aggregate, net-carbon fixing behavior of this assemblage is explicitly considered in its parameterization. Similarly, the somewhat archaic identifiers of "calcareous" and "non-calcareous" are more properly described as oligotrophic and eutrophic communities, as the calcitic attributes of the periphyton are not considered in the model.

ALG_LIGHT_CF = (Z_extinct > 0.0) ? (2.718/Z_extinct * (Exp(-I_ISat * Exp(-Z_extinct)) - Exp(-I_ISat))) : (I_ISat*Exp(1.0-I_ISat))

low-water growth constraint ready for something better based on data
ALG_WAT_CF = (SURFACE_WAT>0.0) ? (1.0) : (0.0)

Jorgensen 1976; 5 deg C is minimum temperature parameter
ALG_TEMP_CF = Exp(-2.3 * ABS((H2O_TEMP- ***GP_ALG_TEMP_OPT***)/(***GP_ALG_TEMP_OPT***-5.0)))

min_litTemp = Min(ALG_LIGHT_CF,ALG_TEMP_CF)

the 2 communities have same form of growth response to avail phosphorus
NC_ALG_NUT_CF = Exp(-***GP_alg_uptake_coef*** * Max(***GP_NC_ALG_KS_P***-PO4Pconc, 0.0)/ ***GP_NC_ALG_KS_P***)

C_ALG_NUT_CF = Exp(-***GP_alg_uptake_coef*** * Max(***GP_C_ALG_KS_P***-PO4Pconc, 0.0)/ ***GP_C_ALG_KS_P***)

the form of the control function assumes that at very low P conc, the alkaline phosphatase activity of the microbial assemblage scavenges P, maintaining a minimum nutrient availability to community
NC_ALG_PROD_CF = Min(min_litTemp,ALG_WAT_CF)*Max(NC_ALG_NUT_CF, ***alg_alkP_min***)

C_ALG_PROD_CF = Min(min_litTemp,ALG_WAT_CF)*Max(C_ALG_NUT_CF, ***GP_alg_alkP_min***)

3) flux calculations

NC_ALG_RESP_POT = (UNSAT_DEPTH> ***GP_algMortDepth***) ? (0.0) : (***GP_ALG_RC_RESP****ALG_TEMP_CF*NC_ALG_AVAIL_MORT)

C_ALG_RESP_POT = (UNSAT_DEPTH> ***GP_algMortDepth***) ? (0.0) : (***GP_ALG_RC_RESP****ALG_TEMP_CF *C_ALG_AVAIL_MORT)

NC_ALG_RESP = (NC_ALG_RESP_POT*DT>NC_ALG_AVAIL_MORT) ? (NC_ALG_AVAIL_MORT/DT) : (NC_ALG_RESP_POT)

C_ALG_RESP = (C_ALG_RESP_POT*DT>C_ALG_AVAIL_MORT) ? (C_ALG_AVAIL_MORT/DT) : (C_ALG_RESP_POT)

this is the threshold control function that increases calcareous/native periph mortality (likely due to loss of calcareous sheath) as P conc. increases
C_ALG_thresh_CF = Min(exp(***GP_alg_R_accel****Max(TP_SFWT_CONC_MG-***GP_C_ALG_threshTP***,0.0)/***GP_C_ALG_threshTP***), 100.0)

NC_ALG_MORT_POT = (UNSAT_DEPTH>***GP_algMortDepth***) ? (NC_ALG_AVAIL_MORT* ***GP_ALG_RC_MORT_DRY***) : (NC_ALG_AVAIL_MORT* ***GP_ALG_RC_MORT***)

C_ALG_MORT_POT = (UNSAT_DEPTH> ***GP_algMortDepth***) ? (C_ALG_AVAIL_MORT* ***GP_ALG_RC_MORT_DRY***) : (C_ALG_thresh_CF * C_ALG_AVAIL_MORT* ***GP_ALG_RC_MORT***)

NC_ALG_MORT = ((NC_ALG_MORT_POT+NC_ALG_RESP)*DT>NC_ALG_AVAIL_MORT) ? ((NC_ALG_AVAIL_MORT-NC_ALG_RESP*DT)/DT) : (NC_ALG_MORT_POT)

C_ALG_MORT = ((C_ALG_MORT_POT+C_ALG_RESP)*DT>C_ALG_AVAIL_MORT) ? ((C_ALG_AVAIL_MORT-C_ALG_RESP*DT)/DT) : (C_ALG_MORT_POT)

gross production of the 2 communities, with density constraint on both noncalc and calc, competition effect accentuated by calc algae
NC_ALG_GPP = NC_ALG_PROD_CF* ***GP_ALG_RC_PROD****NC_ALG * Max((1.0-(***GP_AlgComp****C_ALG+NC_ALG)/ ***HP_ALG_MAX***),0.0)

C_ALG_GPP = C_ALG_PROD_CF* ***GP_ALG_RC_PROD****C_ALG * Max((1.0-(C_ALG+NC_ALG)/ ***HP_ALG_MAX***),0.0)

P uptake is dependent on available P and is relative to a maximum P:C ratio for the tissue
NC_ALG_GPP_P = NC_ALG_GPP * ***GP_ALG_PC*** * NC_ALG_NUT_CF * Max(1.0-NC_ALG_PC/ ***GP_ALG_PC***, 0.0)

C_ALG_GPP_P = C_ALG_GPP * ***GP_ALG_PC*** * C_ALG_NUT_CF * Max(1.0-C_ALG_PC/ ***GP_ALG_PC***, 0.0)

check for available P mass (the nutCF does not) (unit conversion to g P)
PO4P = Min(PO4Pconc * SFWT_VOL, 1000.0*TP_SF_WT)

reduc = ((NC_ALG_GPP_P+C_ALG_GPP_P) > 0) ? (PO4P / ((NC_ALG_GPP_P+C_ALG_GPP_P)*CELL_SIZE*DT)) : (1.0)

can have high conc, but low mass of P avail, in presence of high peri biomass and high demand, reduce the production proportionally if excess demand is found
if (reduc < 1.0) NC_ALG_GPP = NC_ALG_GPP * reduc

if (reduc < 1.0) NC_ALG_GPP_P = NC_ALG_GPP_P * reduc

if (reduc < 1.0) C_ALG_GPP = C_ALG_GPP * reduc

if (reduc < 1.0) C_ALG_GPP_P = C_ALG_GPP_P * reduc

4) phosphorus associated with carbon stocks & flows

mortPot = NC_ALG_MORT * NC_ALG_PC

NC_ALG_MORT_P = (mortPot*DT>NC_ALG_P) ? (NC_ALG_P/DT) : (mortPot)

mortPot = C_ALG_MORT * C_ALG_PC

C_ALG_MORT_P = (mortPot*DT>C_ALG_P) ? (C_ALG_P/DT) : (mortPot)

NC_ALG_P = NC_ALG_P + (NC_ALG_GPP_P - NC_ALG_MORT_P) * DT

C_ALG_P = C_ALG_P + (C_ALG_GPP_P - C_ALG_MORT_P) * DT

default to 3% of max P:C
NC_ALG_PC = (NC_ALG>0.0) ? (NC_ALG_P/ NC_ALG) : (***GP_ALG_PC*** * 0.03)

C_ALG_PC = (C_ALG>0.0) ? (C_ALG_P/ C_ALG) : (***GP_ALG_PC*** * 0.03)

gP/m2 => kg P
TP_SFWT_UPTAK = (NC_ALG_GPP_P+C_ALG_GPP_P)*0.001*CELL_SIZE

TP_SF_WT = TP_SF_WT - TP_SFWT_UPTAK * DT

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

used for reporting and other modules to evaluate P conc when water is present
TP_SFWT_CONC_MG = (SURFACE_WAT > DetentZ) ? (TP_SFWT_CONC*1000.0) : (0.0)

External variables used

TP_SF_WT (see TP/Salt module)

TP_SFWT_CONC_MG (see TP/Salt module)

SOLRADGRD (see Globals module)

MAC_LAI (see Macrophyte module)

SURFACE_WAT (see Hydrology module)

SFWT_VOL (see Hydrology module)

UNSAT_DEPTH (see Hydrology module)

H2O_TEMP (see Hydrology module)

Periphyton Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
C_ALG_AVAIL_MORT	attribute	gC/m^2	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) biomass AVAILable for MORTality losses
NC_ALG_AVAIL_MORT	attribute	gC/m^2	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) biomass AVAILable for MORTality losses
ALG_LIGHT_CF	controlFunction	dimless	total periphyton (generalized, ALGae) growth Control Function (0-1) of degree of LIGHT limitation
ALG_TEMP_CF	controlFunction	dimless	total periphyton (generalized, ALGae) growth Control Function (0-1) of degree of TEMPerature limitation
ALG_WAT_CF	controlFunction	dimless	total periphyton (generalized, ALGae) growth Control Function (0-1) of degree of WATer limitation
C_ALG_NUT_CF	controlFunction	dimless	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) growth Control Function (0-1) of degree of NUTrient limitation
C_ALG_PROD_CF	controlFunction	dimless	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) growth Control Function (0-1) of degree of combined limitations on gross carbon primary PRODuction
NC_ALG_NUT_CF	controlFunction	dimless	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) growth Control Function (0-1) of degree of NUTrient limitation
NC_ALG_PROD_CF	controlFunction	dimless	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) growth Control Function (0-1) of degree of combined limitations on PRODuction
ALG_INCID_LIGHT	forcing	cal/cm^2/d	for ALGal growth, INCIDint LIGHT intensity reaching the water surface through macrophyte canopy
TP_SFWT_UPTAK	rateActual	kgP/d	Total Phosphorus UPTAKe from SurFace WaTer due to periphyton primary production
C_ALG_GPP	rateActual	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) Gross Primary Production gains
C_ALG_MORT	rateActual	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) MORTality losses
C_ALG_NPP	rateActual	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) Net

			Primary Production gains
C_ALG_RESP	rateActual	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) RESPiration losses
NC_ALG_GPP	rateActual	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) Gross Primary Production gains
NC_ALG_MORT	rateActual	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) MORTality losses
NC_ALG_NPP	rateActual	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) Net Primary Production gains
NC_ALG_RESP	rateActual	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) RESPiration losses
C_ALG_MORT_POT	ratePotential	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) MORTality POTential losses
C_ALG_RESP_POT	ratePotential	gC/m2/d	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) RESPiration POTential losses
NC_ALG_MORT_POT	ratePotential	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) MORTality POTential losses
NC_ALG_RESP_POT	ratePotential	gC/m2/d	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) RESPiration POTential losses
C_ALG	state	gC/m^2	oligotrophic periphyton (archaic, Calcareous, generalized, ALGae) biomass
NC_ALG	state	gC/m^2	eutrophic periphyton (archaic, NonCalcareous, generalized, ALGae) biomass
ALG_REFUGE	static	gC/m^2	total periphyton (generalized, ALGae) biomass REFUGE, below which resp/mortality losses do not occur (static, set= ***ALG_REF_MULT*** * ***ALG_MAX***[habitat] parameters)
ALG_LIGHT_EXTINCT	static	1/m	for ALGal growth, LIGHT EXTINCTion through suspended particles etc in surface water column (STATIC, set= ***alg_light_ext_coef***)

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell

conv_kgTOg	global	dimless	conversion, kg to g
GP_alg_alkP_min	global	dimless	minimum possible constraint level (0-1) on phosphorus uptake and growth; value>0 indicative of non-zero nutrient limitation due to APActivity
GP_alg_light_ext_coef	global	dimless	light extinction parameter, currently used to fully define (statically) extinction
GP_ALG_LIGHT_SAT	global	cal/cm^2/d	Saturating light intensity for algal photosyn (langley/d = cal/cm^2 per day)
GP_ALG_PC	global	gP/gC	Initial phophorus:carbon ratio in all algae/periphyton
GP_alg_R_accel	global	dimless	acceleration of mortality (via assumed loss of calcareous sheath) of oligotrophic community under high phosphorus conditions
GP_ALG_RC_MORT	global	1/d	Baseline specific rate of algal (periphyton) mortality. Note that this is in the presence of water.
GP_ALG_RC_MORT_DRY	global	1/d	Specific mortality rate of benthic algae (periphyton) in "drydown" conditions.
GP_ALG_RC_PROD	global	1/d	Maximum specific rate observed/attainable of algal (periphyton) gross primary production.
GP_ALG_RC_RESP	global	1/d	Max specific rate of algal respiration.
GP_ALG_REF_MULT	global	dimless	proportion of max attainable periphyton biomass, defining a refuge density (from losses)
GP_ALG_SHADE_FACTOR	global	dimless	calibration parm to modify LAI in shading fcn
GP_ALG_TEMP_OPT	global	deg C	Optimal temperature for algal primary production (degrees C). Also used in respiration control.
GP_alg_uptake_coef	global	dimless	parameter for exp function describing uptake kinetics
GP_AlgComp	global	dimless	algal density-dep competition, with parameter >1.0 increasing competitive "ability" of oligotrophic periphyton
GP_algMortDepth	global	m	depth of the unsat zone below which accelerated "drydown" alg mort occurs
GP_C_ALG_KS_P	global	mg/L	half-saturation conc of avail phosphorus for uptake kinetics, oligotrophic (was calcareous) periph
GP_C_ALG_threshTP	global	mg/L	TP conc above which oligotrophic (was calcareous) periphyton have elevated mortality (via assumed loss of calcareous sheath)
GP_NC_ALG_KS_P	global	mg/L	half-saturation conc of avail phosphorus for uptake kinetics, eutrophic (was non-calcareous)
GP_PO4toTP	global	dimless	slope of empirical regression of predicting PO4 from TP from long-term historical data, northern

			Everglades locations
GP_PO4toTPint	global	mg/l	intercept of empirical regression of predicting PO4 from TP from long-term historical data, northern Everglades locations

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_ALG_MAX	habspec	gC/m^2	Maximum attainable (observed) algal biomass density.

Intrinsic C or ELM functions

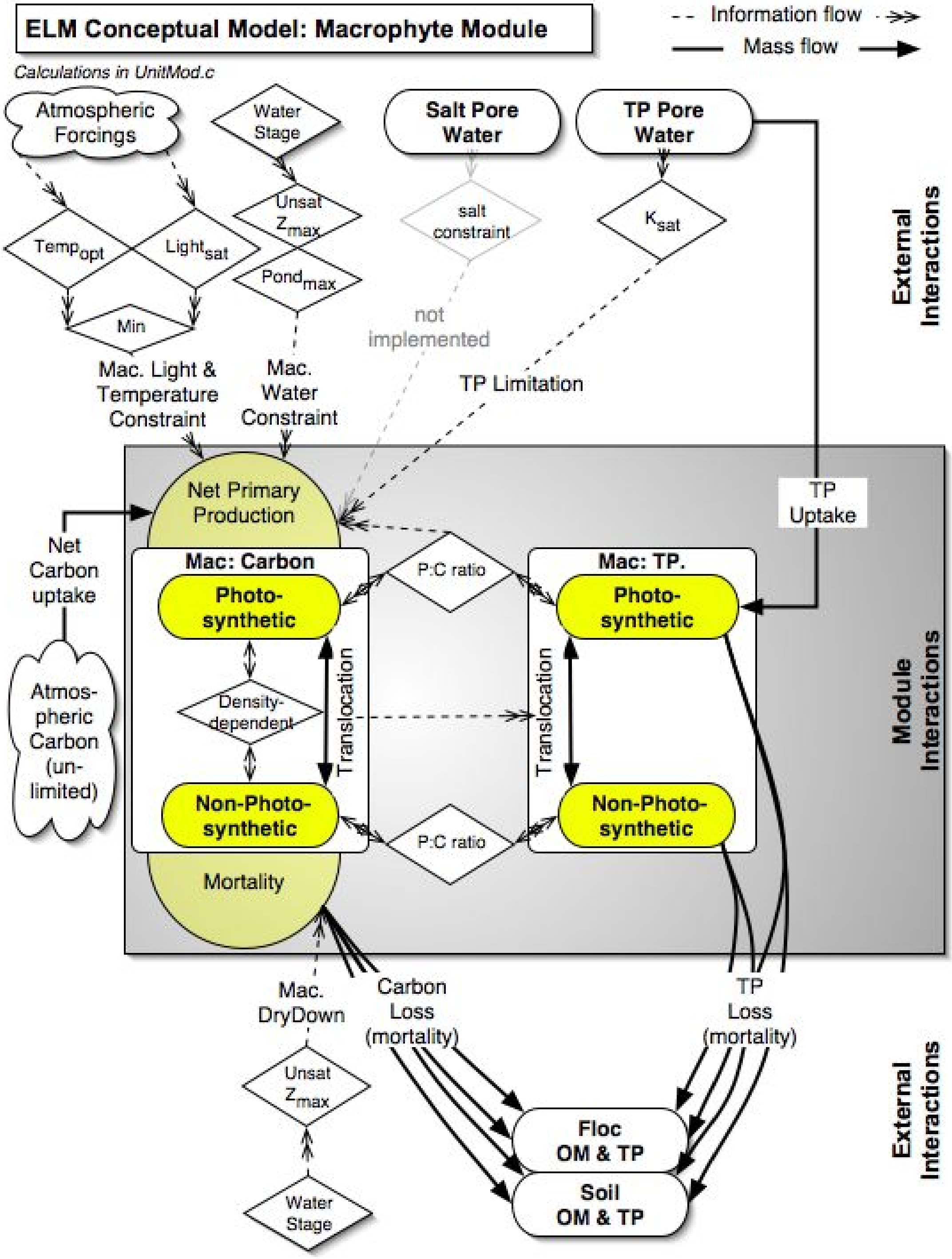
exp(x) = Exp(x) => e raised to the xth power

Max(x,y) => maximum of variable x or y

Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

5.6.5 Macrophyte module



Overview: Macrophyte Module

Macrophytes are a primary determinant of the habitat quality in the Everglades landscape, which is largely defined by its heterogeneous mosaic of macrophytic vegetation that is dynamic over both annual and decadal time scales. There is a high diversity of plants in this region, ranging from emergent marsh plants such as the ubiquitous sawgrass, to hardwood trees of tree islands and mangrove forests. These, and many other common species, form a wide variety of plant communities with very different nutrient requirements, distinct hydrologic needs, and dynamic effects on the hydrologic cycle itself. Different adaptations by these plants create the habitat mosaic in response to a changing environment. For example, cattail is a "nuisance" species that grows rapidly in response to elevated nutrient availability, has morphological characteristics that allow it to thrive in flooded conditions, and easily colonizes areas that have been disturbed. Sawgrass, on the other hand, is a very dominant species in much of the Everglades where there are oligotrophic (low nutrient) conditions and "natural" fluctuations of water levels and disturbances. With mortality or dieback of leaves and roots of these plants, comes the accumulation of organic matter in the form of peat soils. Where regions of the Everglades have undergone successional shifts in plant communities, animal communities (not considered in ELM) are invariably affected. The ELM assumes that the higher trophic levels respond to these changes in habitat, without the animal communities affecting the regional landscape over long time periods.

Macrophyte Module Description

Macrophytes are simulated using two state variables, photosynthetic and non-photosynthetic carbon biomass. This partition is used to represent variations in plant carbon storage and the concomitant carbon:nutrient ratios in subsequent detrital dynamics from the two stocks. As in the Periphyton Module, this module aggregates all macrophyte species into one stock using average parameter values. While all macrophytes communities (or habitat types) are simulated by one set of equations, their behavior varies according to set of parameters that are specific to each habitat type (see Data Chapter). The Succession Module (separate section in this Chapter) provides the mechanism for switching among habitat types as the cumulative environmental conditions warrant it.

The general form of the equations that describe changes to a macrophyte photosynthetic carbon stock is:

$$S(t) = S(t-1) + (P - TR - M)dt,$$

where *S(time)* is the standing stock of macrophytes (kg C m^{-2}) at time *t* or *t-1*, *P* is the net primary production gain (kg C m^{-2} d^{-1}), *TR* is the translocation loss/gain (kg C m^{-2} d^{-1}), *M* is the mortality loss (kg C m^{-2} d^{-1}), and *dt* is the time interval (days). The actual rates are products of the macrophyte stock and maximum specific rates that are constrained by control functions:

$$P = S(t-1) \cdot P_{max} CF_P$$

$$M = S(t-1) \cdot M_{max} CF_M$$

where P_{max} and M_{max} are the maximum specific rates (d^{-1}) of, respectively, net primary production and mortality; the CF_P and CF_M are the (dimensionless, 0 – 1) control functions constraining net production and mortality, respectively.

Biomass is added to macrophytes through the photosynthetic pathway that determines net production of photosynthetic biomass, with the maximum rate of net production limited by a production control function that considers the most limiting constraint due to either light, temperature, or water, multiplied by the nutrient constraint. Using a form similar to that for periphyton gross production, the rate is further constrained by maximum density considerations.

The nutrient control function is similar to that for periphyton and soil (i.e., implicit microbial) modules, but responds to phosphorus in the soil/sediment water instead of in the surface water. Whereas earlier ELM versions quantified nutrient limitation using Monod half-saturation kinetics (Fitz et al. 1996) (Fitz and Sklar 1999), this relationship appeared to behave inadequately in the oligotrophic conditions of much of the Everglades, with excessive constraint on growth under low (often ambient) conditions. The Monod form assumes enzyme kinetics, with a linear response below saturating nutrient concentrations. There is evidence that phosphatase activity tends to increase under low nutrient conditions (Newman et al. 2003), thus potentially making phosphorus less limiting in general, and deviating from Monod kinetics.

The light control function is based on a simple Steele (1965) formula representing the effects of light limitation and photoinhibition, without self-shading. The temperature control function (Jorgensen 1976) describes the biological responses to air temperature relative to a temperature optimum and a minimum, using the same form as that in the soil (i.e., implicit microbial) and periphyton modules. Water availability to plants is a function of the soil moisture, the depth of the unsaturated zone and the root depth. Water is not limiting at all if the roots reach the saturated zone. When the unsaturated water table is shallower than the root zone depth, the value returned is the moisture proportion in the unsaturated zone plus an exponentially decreasing amount from the saturated zone. Thus water may be available to the root system when the roots do not reach the saturated zone due to the capillary draw of water from a nearby saturated layer.

If carbon fixed by the photosynthetic pathway is in excess of that needed for net growth of shoot and leaf biomass, that carbon is translocated to the nonphotosynthetic stock, thus assuming a very simple homeostatic mechanism between roots and shoots.

Mortality within the photosynthetic stock is determined from current water stress. The maximum specific rate of mortality is limited by the water stress limitation. Mortality of the nonphotosynthetic module is assumed to occur at a constant rate. The effects of salinity and other factors simulated in the model could be incorporated into a control function depending on the model requirements.

Macrophytes have direct feedbacks on the physical hydrology that are important to overall model dynamics. The areal density of stems and trunks is calculated based on data for the plant type such as Steward and Ornes (1975) for a subtropical sedge. These data and the plant height are used in determining a Manning's roughness coefficient (see the Hydrology Module) for each community type.

Macrophyte Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations (carbon only)

MAC_NOPH_BIOMAS = MAC_NOPH_BIOMAS + (NPHBIO_TRANSLOC - NPHBIO_MORT - PHBIO_TRANSLOC) * ***DT***

MAC_PH_BIOMAS = MAC_PH_BIOMAS + (PHBIO_TRANSLOC + PHBIO_NPP - PHBIO_MORT - NPHBIO_TRANSLOC) * ***DT***

Dependent upon:

1) attribute calculations

these thresholds need updating when a habitat type of a grid cell changes

MAC_MAX_BIO = ***HP_NPHBIO_MAX***+ ***HP_PHBIO_MAX***

NPHBIO_REFUGE = ***HP_NPHBIO_MAX**** ***GP_MAC_REFUG_MULT***

NPHBIO_SAT = ***HP_NPHBIO_MAX****0.9

PHBIO_REFUGE = ***HP_PHBIO_MAX**** ***GP_MAC_REFUG_MULT***

PHBIO_SAT = ***HP_PHBIO_MAX****0.9

MAC_PHtoNPH_Init = ***HP_PHBIO_MAX*** / ***HP_NPHBIO_MAX***

MAC_PHtoNPH = (MAC_NOPH_BIOMAS>0.0) ? (MAC_PH_BIOMAS / MAC_NOPH_BIOMAS) : (MAC_PHtoNPH_Init)

phbio_ddep = Max(1.0-Max((PHBIO_SAT-MAC_PH_BIOMAS) /(PHBIO_SAT-PHBIO_REFUGE),0.0),0.0)

PHBIO_AVAIL = MAC_PH_BIOMAS*phbio_ddep

nphbio_ddep = Max(1.0-Max((NPHBIO_SAT-MAC_NOPH_BIOMAS)/(NPHBIO_SAT-NPHBIO_REFUGE),0.0),0.0)

NPHBIO_AVAIL = MAC_NOPH_BIOMAS*nphbio_ddep

2) control function calculations

MAC_LIGHT_CF = SOLRADGRD/***MAC_LIGHTSAT****Exp(1.0-SOLRADGRD/***HP_MAC_LIGHTSAT***)

Jorgensen 1976; 5 deg C is minimum temperature parameter

MAC_TEMP_CF = Exp(-2.3 * ABS((AIR_TEMP- ***HP_MAC_TEMPOPT***)/(***HP_MAC_TEMPOPT-5.0***)))

MAC_WATER_CF = Min(MAC_WATER_AVAIL_CF, Max(1.0-Max((SURFACE_WAT-***HP_MAC_WAT_TOLER***)/ ***HP_MAC_WAT_TOLER***,0.0),0.0))

MAC_NUT_CF = Exp(***-GP_mac_uptake_coef*** * Max(***HP_MAC_KSP-***TP_SEDWT_CONCACTMG, 0.0)/ ***HP_MAC_KSP***)

min_litTemp = Min(MAC_LIGHT_CF, MAC_TEMP_CF)

MAC_PROD_CF = Min(min_litTemp,MAC_WATER_CF)*MAC_NUT_CF

3) flux calculations

PHBIO_NPP = ***HP_PHBIO_RCNPP****MAC_PROD_CF*MAC_PH_BIOMAS * (1.0-MAC_TOT_BIOM/MAC_MAX_BIO)

NPP_P = PHBIO_NPP * ***HP_PHBIO_PC*** * Max(MAC_NUT_CF*2.0,1.0) * Max(1.0-mac_ph_PC/ ***HP_PHBIO_PC***, 0.0)

check for available P mass that will be taken up from sed water in active zone (nutCF does not)

reduc = (NPP_P > 0.0) ? (TP_SED_WT_AZ / (NPP_P****CELL_SIZE****DT***)) : (1.0)

if (reduc < 1.0) PHBIO_NPP = PHBIO_NPP * reduc

if (reduc < 1.0) NPP_P = NPP_P * reduc

NPHBIO_TRANSLOC_POT = (MAC_PHtoNPH>MAC_PHtoNPH_Init) ? (exp(***HP_MAC_TRANSLOC_RC*** *(MAC_PHtoNPH-MAC_PHtoNPH_Init)) - 1.0) : (0.0)

NPHBIO_TRANSLOC = (NPHBIO_TRANSLOC_POT****DT*** >PHBIO_AVAIL) ? (PHBIO_AVAIL/***DT***) : (NPHBIO_TRANSLOC_POT)

PHBIO_MORT_POT = ***HP_PHBIO_RCMORT*** * PHBIO_AVAIL * (1.0 + (1.0-MAC_WATER_AVAIL_CF))/2.0

PHBIO_MORT = ((PHBIO_MORT_POT+NPHBIO_TRANSLOC)****DT***>PHBIO_AVAIL) ? ((PHBIO_AVAIL-NPHBIO_TRANSLOC****DT***)/***DT***) : (PHBIO_MORT_POT)

PHBIO_TRANSLOC_POT = (MAC_PHtoNPH<MAC_PHtoNPH_Init) ? (exp(***HP_MAC_TRANSLOC_RC*** *(MAC_PHtoNPH_Init-MAC_PHtoNPH)) - 1.0) : (0.0)

PHBIO_TRANSLOC = (PHBIO_TRANSLOC_POT****DT*** >NPHBIO_AVAIL) ? (NPHBIO_AVAIL/***DT***) : (PHBIO_TRANSLOC_POT)

decreased non-photobiomass mortality w/ increasing photobiomass

NPHBIO_MORT_POT = NPHBIO_AVAIL* ***HP_PHBIO_RCMORT*** * (1.0 + Max(1.0-MAC_PH_BIOMAS/ ***HP_PHBIO_MAX***,0.0))/2.0

NPHBIO_MORT = ((PHBIO_TRANSLOC+NPHBIO_MORT_POT)****DT***>NPHBIO_AVAIL) ? ((NPHBIO_AVAIL-PHBIO_TRANSLOC****DT***)/***DT***) : (NPHBIO_MORT_POT)

4) attribute calculations, used in other modules

MAC_TOT_BIOM = MAC_PH_BIOMAS+MAC_NOPH_BIOMAS

MAC_REL_BIOM = (MAC_TOT_BIOM > 0.0) ? MAC_TOT_BIOM/MAC_MAX_BIO : ***0.0001***

MAC_HEIGHT = pow(MAC_REL_BIOM,***0.33***)* ***HP_MAC_MAXHT***

MAC_LAI = MAC_REL_BIOM* ***HP_MAC_MAXLAI***

5) phosphorus and organic matter associated with carbon stocks & flows

change of grid-cell habitat (including macrophyte) type necessitates dynamic accounting of all variables

P and OM fluxes

phbio_npp_P = NPP_P /* within-plant variable stoichiometry */

phbio_npp_OM = PHBIO_NPP / ***HP_PHBIO_CTOOM*** /* habitat-specfic stoichiometry */

phbio_mort_P = PHBIO_MORT * mac_ph_PC

phbio_mort_OM = PHBIO_MORT / mac_ph_CtoOM

phbio_transl_P = PHBIO_TRANSLOC * mac_nph_PC

phbio_transl_OM = PHBIO_TRANSLOC / mac_nph_CtoOM

nphbio_transl_P = NPHBIO_TRANSLOC * mac_ph_PC

nphbio_transl_OM = NPHBIO_TRANSLOC / mac_ph_CtoOM

nphbio_mort_P = NPHBIO_MORT * mac_nph_PC

nphbio_mort_OM = NPHBIO_MORT / mac_nph_CtoOM

mac_nph_P = mac_nph_P + (nphbio_transl_P - nphbio_mort_P - phbio_transl_P) * ***DT***

default to 0.3 of max for habitat

mac_nph_PC = (MAC_NOPH_BIOMAS > 0.0) ? (mac_nph_P / MAC_NOPH_BIOMAS) : 0.3 * ***HP_NPHBIO_PC***

mac_nph_OM = mac_nph_OM + (nphbio_transl_OM - nphbio_mort_OM - phbio_transl_OM) * ***DT***

mac_nph_CtoOM = (mac_nph_OM > 0.0) ? (MAC_NOPH_BIOMAS / mac_nph_OM) : ***HP_NPHBIO_CTOOM***

mac_ph_P = mac_ph_P + (phbio_transl_P + phbio_npp_P - phbio_mort_P - nphbio_transl_P) * ***DT***

default to 0.3 of max for habitat
mac_ph_PC = (MAC_PH_BIOMAS > 0.0) ? (mac_ph_P / MAC_PH_BIOMAS) : 0.3 * ***HP_PHBIO_PC***

mac_ph_OM = mac_ph_OM + (phbio_transl_OM + phbio_npp_OM - phbio_mort_OM - nphbio_transl_OM) * ***DT***

mac_ph_CtoOM = (mac_ph_OM > 0.0) ? (MAC_PH_BIOMAS / mac_ph_OM) : ***HP_PHBIO_CTOOM***

TP_SEDWT_UPTAKE = phbio_npp_P****CELL_SIZE***

TP_SED_WT = TP_SED_WT - (TP_SEDWT_UPTAKE) * ***DT***

TP_SED_CONC = (HYD_SED_WAT_VOL>0.0) ? (TP_SED_WT / HYD_SED_WAT_VOL) : (0.0)

*## this is the active zone, where uptake, sorption, and mineralization take place */*
TP_SED_WT_AZ = TP_SED_WT_AZ - (TP_SEDWT_UPTAKE) * ***DT***

TP_SEDWT_CONCACT = (HYD_DOM_ACTWAT_PRES > 0.0) ? (TP_SED_WT_AZ/HYD_DOM_ACTWAT_VOL) : (TP_SED_CONC)

TP_SEDWT_CONCACTMG = TP_SEDWT_CONCACT*conv_kgTOg /

External variables used

SOLRADGRD (see Globals module)

AIR_TEMP (see Globals module)

TP_SED_WT (see TP/Salt module)

TP_SED_WT_AZ (see TP/Salt module)

TP_SEDWT_CONCACTMG (see TP/Salt module)

SURFACE_WAT (see Hydrology module)

HYD_SED_WAT_VOL (see Hydrology module)

HYD_DOM_ACTWAT_PRES (see Hydrology module)

HYD_DOM_ACTWAT_VOL (see Hydrology module)

MAC_WATER_AVAIL_CF (see Hydrology module)

Macrophyte Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
mac_nph_PC_rep	attribute	mgP/kgC	macrophyte nonphotosynthetic tissues Phosphorus to Carbon concentration (units converted for reporting purposes)

mac_ph_PC_rep	attribute	mgP/kgC	macrophyte photosynthetic tissues Phosphorus to Carbon concentration (units converted for reporting purposes)
MAC_HEIGHT	attribute	m	HEIGHT of MACrophytes above ground surface
NPHBIO_AVAIL	attribute	kgC/m^2	NonPHototsynthetic macrophyte BIOmass AVAILable for losses via mortality and translocation
PHBIO_AVAIL	attribute	kgC/m^2	PHototsynthetic macrophyte BIOmass AVAILable for losses via mortality and translocation
MAC_LAI	attribute	dimless	MACrophyte Leaf Area Index of the proportion of leaf surface area to ground surface area
MAC_REL_BIOM	attribute	dimless	proportion of MACrophyte BIOMass RELative to its maximum attainable
MAC_LIGHT_CF	controlFunction	dimless	MACrophyte growth Control Function (0-1) of degree of LIGHT limitation
MAC_NUT_CF	controlFunction	dimless	MACrophyte growth Control Function (0-1) of degree of NUTrient limitation
MAC_PROD_CF	controlFunction	dimless	MACrophyte growth Control Function (0-1) of degree of combined limitations on net carbon primary PRODuction
MAC_TEMP_CF	controlFunction	dimless	MACrophyte growth Control Function (0-1) of degree of TEMPerature limitation
MAC_WATER_CF	controlFunction	dimless	MACrophytes growth Control Function (0-1) of degree of WATer limitation
MAC_SALT_CF	controlFunction	dimless	MACrophyte growth Control Function (0-1) of degree of SALT constraint; inoperative in v2.2, hardwired=1.0
TP_SEDWT_UPTAKE	rateActual	kgP/d	Total Phosphorus UPTAKE from SEDment/soil WaTer due to macrophyte net primary production
NPHBIO_MORT	rateActual	kgC/m^2/d	NonPHototsynthetic macrophyte BIOmass MORTality losses
NPHBIO_TRANSLOC	rateActual	kgC/m^2/d	NonPHotosynthetic macrophyte biomass TRANSLOCation gain from photosynthetic biomass
PHBIO_MORT	rateActual	kgC/m^2/d	PHototsynthetic macrophyte BIOmass MORTality losses
PHBIO_NPP	rateActual	kgC/m^2/d	PHototsynthetic macrophyte BIOmass Net Primary Production growth gain
PHBIO_TRANSLOC	rateActual	kgC/m^2/d	PHotosynthetic macrophyte biomass TRANSLOCation gain from non-photosynthetic biomass
NPHBIO_MORT_POT	ratePotential	kgC/m^2/d	NonPHototsynthetic macrophyte macrophyte BIOmass MORTality POTential losses
NPHBIO_TRANSLOC_POT	rateP	kgC/m^	NonPHotosynthetic macrophyte

	otential	2/d	biomass TRANSLOCation POTential gain from photosynthetic biomass
PHBIO_MORT_POT	ratePotential	kgC/m^2/d	PHototsynthetic macrophyte macrophyte BIOmass MORTality POTential losses
PHBIO_TRANSLOC_POT	ratePotential	kgC/m^2/d	PHotosynthetic macrophyte biomass TRANSLOCation POTential gain from non-photosynthetic biomass
mac_nph_P	state	kgP/m^2	macrophytes live non-photosynthetic tissue (Phosphorus) biomass
mac_ph_P	state	kgP/m^2	macrophytes live photosynthetic tissue (Phosphorus) biomass
mac_nph_OM	state	kgOM/m^2	macrophytes live non-photosynthetic tissue (Organic Matter) biomass (bookeeping, only used for mass balance when cell changes habitats)
mac_ph_OM	state	kgOM/m^2	macrophytes live photosynthetic tissue (Organic Matter) biomass (bookeeping, only used for mass balance when cell changes habitats)
MAC_NOPH_BIOMAS	state	kgC/m^2	MACrophytes live NOn-PHotosynthetic tissue (carbon) BIOMASs
MAC_PH_BIOMAS	state	kgC/m^2	MACrophytes live PHotosynthetic tissue (carbon) BIOMASs
MAC_TOT_BIOM	stateConvert	kgC/m^2	MACrophytes live TOTal tissue BIOMASs
MAC_MAX_BIO	static	kgC/m^2	MACrophytes MAXimum attainable BIOmass (sum of two parameters)
NPHBIO_REFUGE	static	kgC/m^2	NonPHototsynthetic macrophyte BIOmass REFUGE density (from losses)
NPHBIO_SAT	static	kgC/m^2	NonPHotosynthetic macrophyte BIOmass SATuration density (90% of the maximum attainable)
PHBIO_REFUGE	static	kgC/m^2	PHototsynthetic macrophyte BIOmass REFUGE density (from losses)
PHBIO_SAT	static	kgC/m^2	PHotosynthetic macrophyte BIOmass SATuration density (90% of the maximum attainable)

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_MAC_REFUG_MULT	global	dimless	proportion of max attainable macrophyte biomass, defining a refuge density (from losses)

GP_mac_uptake_coef	global	dimless	parameter for exp function describing nutrient uptake kinetics

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_NPHBIO_MAX	habspec	kgC/m^2	Maximum attainable (observed) biomass density of nonphotosynthetic tissue.
HP_PHBIO_MAX	habspec	kgC/m^2	Maximum attainable (observed) biomass density of photosynthetic tissue.
HP_MAC_KSP	habspec	mgP/L	Half saturation coeff of phosphorus for the nutrient uptake kinetics of macrophytes.
HP_MAC_MAXLAI	habspec	dimless	Maximum observed/attainable Leaf Area Index for a mature community (= area of leaves/area of ground).
HP_MAC_LIGHTSAT	habspec	cal/cm^2/d	Saturating light intensity (langleys/d = cal/cm^2 per day) for macrophyte growth kinetics.
HP_MAC_MAXHT	habspec	m	Maximum observed/attainable height of mature plant community (associated with a unit plant density at maturity).
HP_MAC_TEMPOPT	habspec	deg C	Optimal temperature for maximum primary production growth rate.
HP_NPHBIO_CTOOM	habspec	gC/gOM	Initial ratio of organic carbon to total organic material in NonPhotoBiomass (ash free dry weight).
HP_NPHBIO_PC	habspec	gP/gC	Initial phosphorus:carbon ratio in NonPhotoBiomass (ash free dry weight).
HP_PHBIO_CTOOM	habspec	gC/gOM	Initial ratio of organic carbon to total organic material in PhotoBiomass (ash free dry weight).
HP_PHBIO_PC	habspec	gP/gC	Initial phosphorus:carbon ratio in PhotoBiomass (ash free dry weight).
HP_PHBIO_RCNPP	habspec	1/d	Maximum observed/attainable specific rate of net primary production.
HP_PHBIO_RCMORT	habspec	1/d	Baseline specific rate of photobiomass mortality.
HP_MAC_WAT_TOLER	habspec	m	Depth of ponded surface water above which plant growth becomes restricted. Used in growth control function.
HP_MAC_TRANSLOC_RC	habspec	1/d	Simple, bi-directional baseline translocation rate between Non-photo and Photo biomass; a gradual equilibrium used, while evaluating a more process-based algorithm

Intrinsic C or ELM functions

exp(x) = Exp(x) => e raised to the xth power

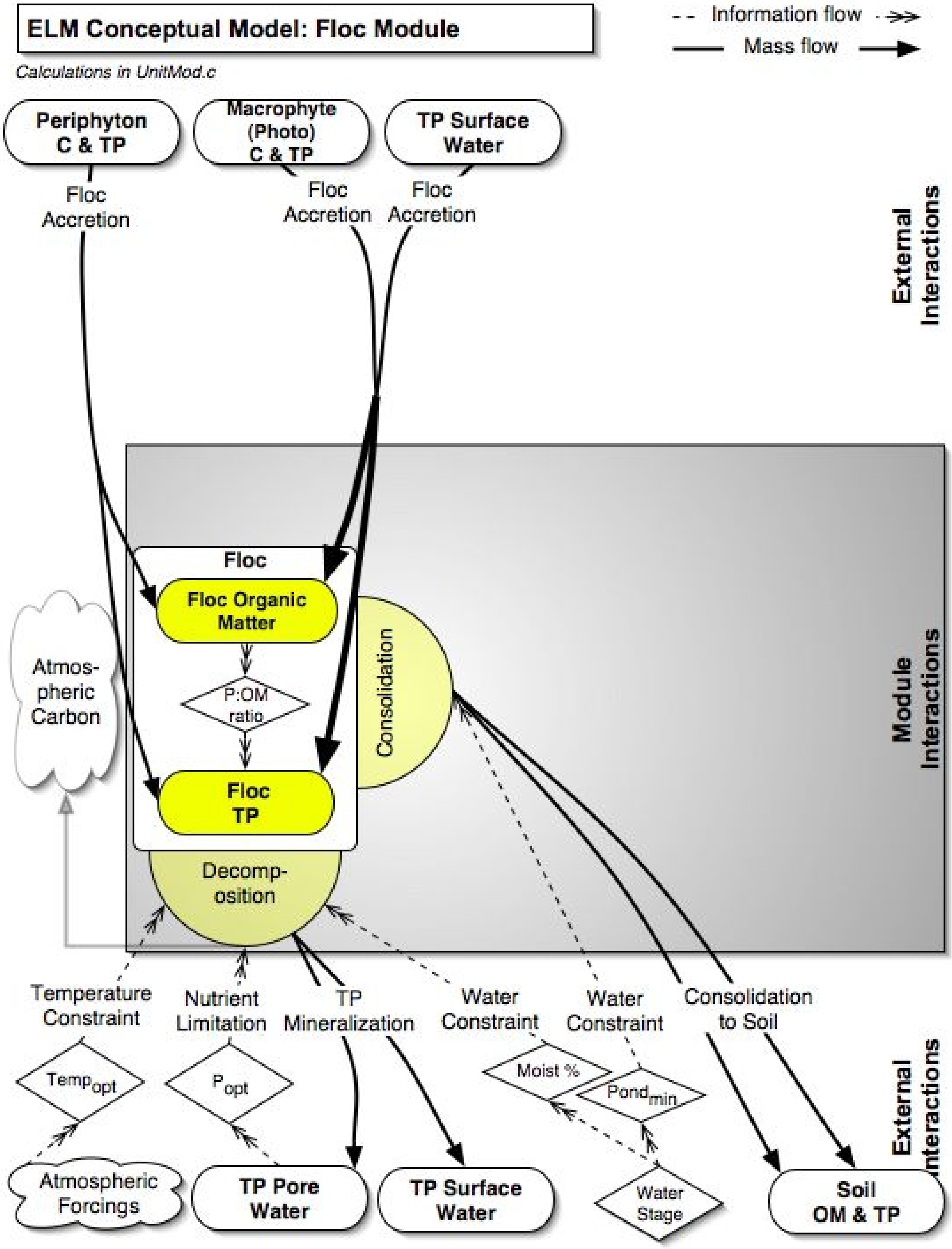
Max(x,y) => maximum of variable x or y

Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

pow(x,y) => x raised to the yth power (generally avoided if possible due to execution time of C library)

5.6.6 Floc module



Overview: Floc Module

This module updates the vertical dynamics of the flocculent organic material that is at the interface between the consolidated soil and the surface water column. Throughout much of the Everglades is an upper-soil layer of flocculent (fluffy) organic material that is partly live periphyton, but principally the organic material from dead periphyton and macrophytes. This "floc" appears to play a critical role in nutrient cycling and transport of organic material among habitats and, potentially forms part of a detrital food web for animals.

Floc Module Description

This “Floc” matter is very fine-grained organic detritus, and is assumed to be highly labile and relatively transient relative to the underlying soil matrix. Organic matter and phosphorus are added to the Floc state variable due to settling from water column and mortality of periphyton and macrophytes. Using the same form of equations in the Soil Module, floc is lost through aerobic decomposition that is constrained by temperature, nutrients, and moisture (in absence of surface water). Floc depositional losses to the underlying soil occur at a baseline rate, with more rapid consolidation into soil as the floc layer becomes deeper or when surface water is absent (with the highest rate potential). As a module that was added to ELM (v2.1) in order to better match fluxes and stocks of nutrients in the water column, soil and periphyton, the Floc appears to be (at least) an important biogeochemical driver of the nutrient status of the ecosystem. However, there are significant gaps in our understanding of Floc dynamics under the wide range of conditions in the Everglades, and thus the module is very basic compared to the complex dynamics that likely exist in the ecosystem(s).

Floc Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations

FLOC = FLOC + (Floc_settl + Floc_fr_phBio + FLOC_FR_ALGAE - FLOC_DECOMP - FLOC_DEPO) * ***DT***

FlocP = FlocP + (FlocP_settl + FlocP_PhBio + FlocP_FR_ALGAE - FlocP_DECOMP - FlocP_DEPO) * ***DT***

Dependent upon:

1) attribute calculations

FLOC_FR_ALGAE = (C_ALG_MORT + NC_ALG_MORT) / ***GP_ALG_C_TO_OM****0.001

FlocP_FR_ALGAE = (NC_ALG_MORT_P + C_ALG_MORT_P) * 0.001

Floc_fr_phBio = phbio_mort_OM

FlocP_PhBio = phbio_mort_P

FlocP_settl = TP_settl / ***CELL_SIZE***

Floc_settl = FlocP_settl / ***GP_TP_P_OM***

FLOC_Z = FLOC / ***GP_Floc_BD***

FlocP_OM = (FLOC>0.0) ? (FlocP/FLOC) : (0.0)

2) control function calculations

FLOC_DECOMP_QUAL_CF = Exp(-***GP_DOM_decomp_coef*** * Max(***GP_DOM_DECOMP_POPT-*** (TP_SFWT_CONC_MG+TP_SEDWT_CONCACTMG)/2.0, 0.0)/ ***GP_DOM_DECOMP_POPT***)

soil_MOIST_CF = (UNSAT_DEPTH> ***HP_DOM_AEROBTHIN***) ? (Max(UNSAT_MOIST_PRP,0.0)) : (1.0)

3) flux calculations

the Floc substrate quality is 10x greater than that of bulk soil

FLOC_DECOMP_POT = ***GP_calibDecomp*** * ***10.0**** DOM_RCDECOMP*FLOC*DOM_TEMP_CF *FLOC_DECOMP_QUAL_CF * soil_MOIST_CF

FLOC_DECOMP = ((FLOC_DECOMP_POT)****DT***>FLOC) ? ((FLOC)/***DT***) : (FLOC_DECOMP_POT)

FlocP_DECOMP_pot = FLOC_DECOMP * FlocP_OM

FlocP_DECOMP = ((FlocP_DECOMP_pot)****DT***>FlocP) ? ((FlocP)/***DT***) : (FlocP_DECOMP_pot)

FLOC_DEPO_POT = (SURFACE_WAT > ***GP_DetentZ***) ? (FLOC_Z/ ***GP_FlocMax*** * FLOC* ***GP_Floc_rcSoil***) : (FLOC* ***GP_Floc_rcSoil***)

FLOC_DEPO = ((FLOC_DEPO_POT+FLOC_DECOMP)****DT***>FLOC) ? ((FLOC-FLOC_DECOMP****DT***)/***DT***) : (FLOC_DEPO_POT)

FlocP_DEPO_pot = FLOC_DEPO * FlocP_OM

FlocP_DEPO = ((FlocP_DEPO_pot+FlocP_DECOMP)****DT***>FlocP) ? ((FlocP-FlocP_DECOMP****DT***)/***DT***) : (FlocP_DEPO_pot)

4) attributes calculated after floc updates, used in other modules

90% of the decomp contributes to soil/sediment; 10% to surface water P

TP_SED_MINER = ***0.90*** * FlocP_DECOMP * ***CELL_SIZE***

TP_SFWT_MINER = ***0.10*** * FlocP_DECOMP * ***CELL_SIZE*** ;

state variable updates

TP_SED_WT = TP_SED_WT + (TP_SED_MINER) * ***DT***;

TP_SED_WT_AZ = TP_SED_WT_AZ + (TP_SED_MINER) * ***DT***;

TP_SF_WT = TP_SF_WT + (TP_SFWT_MINER) * ***DT***

TP_SED_CONC = (HYD_SED_WAT_VOL>0.0) ? (TP_SED_WT / HYD_SED_WAT_VOL) : (0.0)

TP_SEDWT_CONCACT = (HYD_DOM_ACTWAT_PRES > 0.0) ? (TP_SED_WT_AZ/HYD_DOM_ACTWAT_VOL) : (TP_SED_CONC)

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

External variables used

DOM_TEMP_CF (see Soils module)

C_ALG_MORT (see Periphyton module)

C_ALG_MORT_P (see Periphyton module)

NC_ALG_MORT (see Periphyton module)

NC_ALG_MORT_P (see Periphyton module)

phbio_mort_OM (see Macrophyte module)

phbio_mort_P (see Macrophyte module)

TP_settl (see TP/Salt module)

TP_SFWT_CONC_MG (see TP/Salt module)

TP_SEDWT_CONCACTMG (see TP/Salt module)

UNSAT_DEPTH (see Hydrology module)

UNSAT_MOIST_PRP (see Hydrology module)

SURFACE_WAT (see Hydrology module)

Floc Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
FlocP_OMrep	attribute	mgP/kgOM	Phosphorus concentration of the Flocculent Organic Matter (units converted to this for reporting purposes)
FlocP_OM	attribute	kgP/kgOM	Phosphorus concentration in the Flocculent Organic Matter
FLOC_DECOMP_QUAL_CF	controlFunction	dimless	FLOCculent organic matter - DECOMPosition Control Function (0-1) of degree of nutrient QUALity limitation
soil_MOIST_CF	controlFunction	dimless	Deposited Organic Matter Control Function of degree of MOISTure limitation
FlocP_FR_ALGAE	rateActual	kgP/m^2/d	Phosphorus in the FLOCculent organic matter gained from FRom mortality of periphyton (generalized, ALGAE)
FlocP_PhBio	rateActual	kgP/m^2/d	Phosphorus in the FLOCculent organic matter gained from mortality of photosynthetic Biomass of macrophytes
FlocP_settl	rateActual	kgP/m^2/d	Phosphorus in the FLOCculent organic matter gained from (flocculation &) settling out of water column
FlocP_DECOMP	rateActual	kgP/m^2/d	Phosphorus in the FLOCculent organic matter - DECOMPosition losses
FlocP_DEPO	rateActual	kgP/m^2/d	Phosphorus in the FLOCculent organic matter - DEPosition losses
TP_SED_MINER	rateActual	kgP/d	Total Phosphorus gained in SEDiment/soil water due to floc MINERalization
TP_SFWT_MINER	rateActual	kgP/d	Total Phosphorus gained in SurFace WaTer due to floc MINERalization
Floc_fr_phBio	rateActual	kgOM/m^2/d	FLOCculent organic matter gained from mortality of photosynthetic Biomass of macrophytes
Floc_settl	rateA	kgOM/m	FLOCculent organic matter gained

	ctual	^2/d	from (flocculation &) settling out of water column
FLOC_DECOMP	rateActual	kgOM/m^2/d	FLOCculent organic matter - DECOMPosition losses
FLOC_DEPO	rateActual	kgOM/m^2/d	FLOCculent organic matter - DEPosition losses
FLOC_FR_ALGAE	rateActual	kgOM/m^2/d	FLOCculent organic matter gained FRom mortality of periphyton (generalized, ALGAE)
FlocP_DECOMP_pot	ratePotential	kgP/m^2/d	Phosphorus in the FLOCculent organic matter - DECOMPosition potential losses
FlocP_DEPO_pot	ratePotential	kgP/m^2/d	Phosphorus in the FLOCculent organic matter - DEPosition potential losses
FLOC_DECOMP_POT	ratePotential	kgOM/m^2/d	FLOCculent organic matter - DECOMPosition POTential losses
FLOC_DEPO_POT	ratePotential	kgOM/m^2/d	FLOCculent organic matter - DEPosition POTential losses
FlocP	state	kgP/m^2	Phosphorus in the FLOCculent organic matter at the interface between soil and surface water
FLOC	state	kgOM/m^2	FLOCculent organic matter at the interface between soil and surface water
FLOC_Z	stateConvert	m	FLOCculent organic matter depth at the interface between soil and surface water

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
GP_calibDecomp	global	dimless	calibration parameter, multiply potential decomposition rate of organic matter
GP_ALG_C_TO_OM	global	gC/gOM	Mass ratio of organic carbon to total organic material in algae (ash free dry weight).
GP_DOM_decomp_coef	global	dimless	parameter for exp function describing decomposition kinetics
GP_DOM_DECOMP_POPT	global	mg/L	Optimal phosphorus concentration in water for maximal decomposition of organic matter
GP_TP_P_OM	global	gP/gOM	phosphorus to organic matter ratio of

			particulate phosphorus (ash-free masses)
GP_Floc_BD	global	mg/cm3	bulk density of floc layer (mg/cm3 == kg/m3)
GP_FlocMax	global	m	max floc depth observed/attainable
GP_Floc_rcSoil	global	1/d	baseline rate of floc layer consolidation into the soil matrix (under flooded conditions)

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_DOM_AEROBTHIN	hab-spec	m	The thin aerobic zone in a flooded wetland. Note that aerobic total depth is defined to include any zone of soil/sediment that is unsaturated or devoid of water.

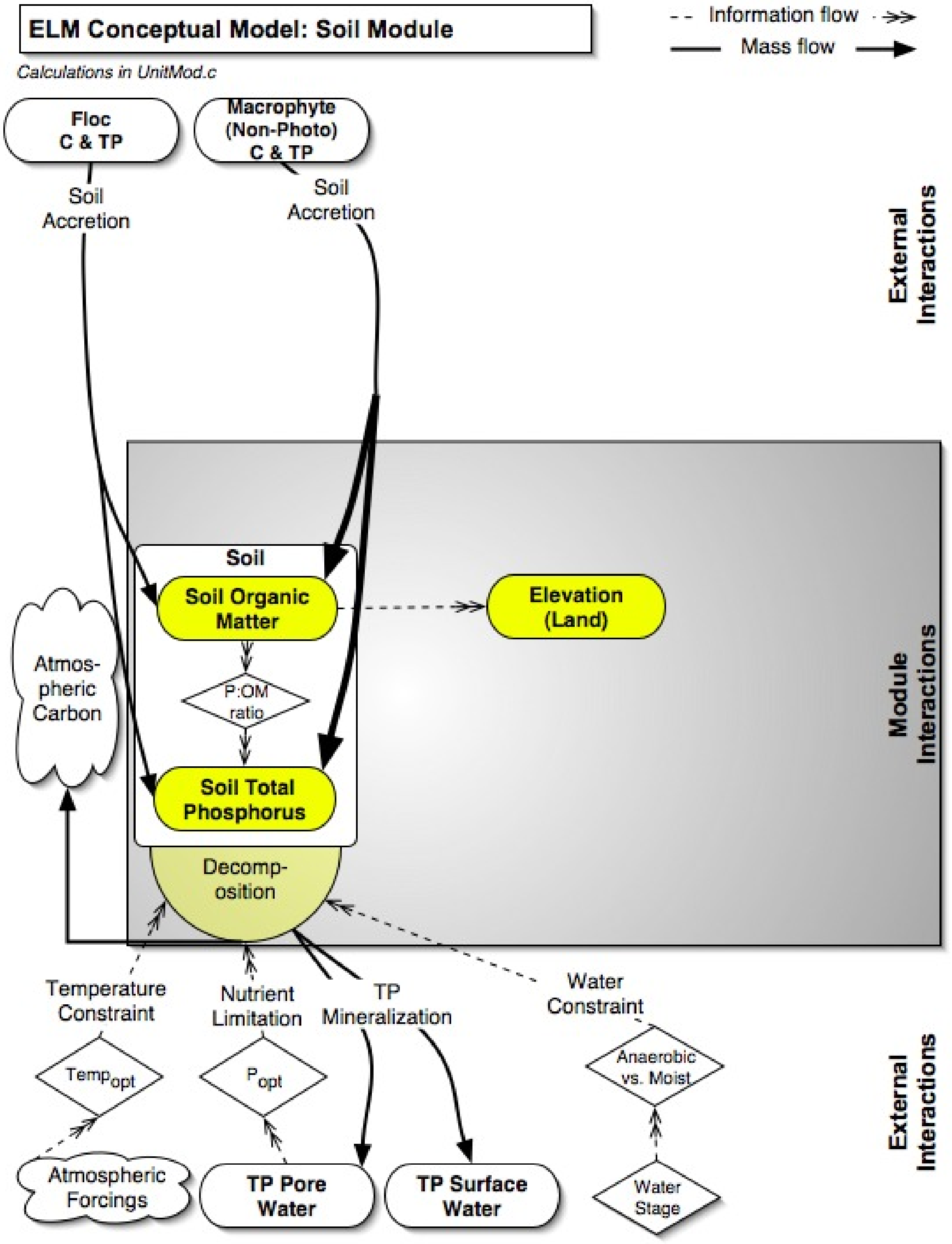
Intrinsic C or ELM functions

exp(x) = Exp(x) => e raised to the x^{th} power

Max(x,y) => maximum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

5.6.7 Soils module



Overview: Soils Module

This module updates the vertical dynamics of the soil, with dynamic changes in the Deposited Organic Matter and the associated Deposited Organic Phosphorus (excluding floc matter). Soils and sediments are in a long-term balance between processes of accumulation and oxidation, closely integrated with the development of different habitats. In regions of long hydroperiods, where water ponds for much of the year, peat soils tend to accrete organic material resulting from plant mortality and floc consolidation. Under shorter hydroperiods, when those soils are exposed more frequently to the air (and thus more aerobic conditions), oxidation of the organic matter reduces the depth of peat. This process is governed by microbial dynamics, and can be accelerated with higher nutrient availability. The oxidation (mineralization) of soil releases nutrients from tightly bound organic forms into inorganic chemical forms that are more readily available to plants and microbes. Disturbances such as severe droughts can have significant impacts on peat soils, oxidizing the organic carbon, but leaving behind much of the phosphorus to which the ecosystem may respond.

Soils Module Description

The principal objectives of the current soil module are to capture multi-decadal trends in the regional gradients in organic soil accretion/oxidation and phosphorus concentration of the upper soil matrix. The soil organic matter and phosphorus content variables are assumed homogenous in vertical profile, overlain by the separate Floc variable (that is calculated in a separate Module described in this Chapter). The general form of this critical soil dynamic is:

$$S(t) = S(t-1) + (A-D)dt,$$

where $S(time)$ is the standing stock of organic matter (OM) of soil (kg OM m^{-2}) at time t or $t\text{-}1$, A is the accretion gain (kg OM m^{-2} d^{-1}), D is the decomposition loss (kg OM m^{-2} d^{-1}), and dt is the time interval (days). The actual rate of accretion is determined in the donor (macrophyte and floc) modules. The actual decomposition is the product of the soil organic matter stock and the maximum specific decomposition rate that is constrained by control functions: depending on water levels, soil is lost through aerobic and anaerobic decomposition that is constrained by temperature, nutrients, and moisture. The maximum depth of the active soil zone in which these dynamics occur is determined by a habitat-specific parameter (generally ca. 30 cm, similar to the macrophyte root zone depth).

The mass of Deposited Organic Matter and the mass of phosphorus associated with that stock are updated as separate variables, and thus the phosphorus ratio of the soil changes in response to the phosphorus concentrations of its input masses. The inorganic component of the soil remains constant at the mass that was initialized in the simulation. The relative magnitudes of organic matter accretion and decomposition determines the change in land surface elevation, assuming a fixed soil bulk density. These simplifying assumptions may be relaxed as increased information becomes available on soil processes such as decomposition rates under varying conditions, flocculation and compaction rates of different soils, and other principal dynamics.

Soils Module Equations

all calculated within spatial loop across model grid rows, columns

State Variable update calculations

DEPOS_ORG_MAT = DEPOS_ORG_MAT + (DOM_fr_nphBio + DOM_FR_FLOC - DOM_DECOMP) * ***DT***

DOP = DOP + (DOP_nphBio + DOP_FLOC - DOP_DECOMP) * ***DT***

Dependent upon:

1) attribute calculations

DOM_SED_AEROB_Z = Min(Max(UNSAT_DEPTH, ***HP_DOM_AEROBTHIN***), ***HP_DOM_MAXDEPTH***);

DOM_SED_ANAEROB_Z = ***HP_DOM_MAXDEPTH***-DOM_SED_AEROB_Z;

DOM_fr_nphBio = nphbio_mort_OM

DOM_FR_FLOC = FLOC_DEPO

DOP_nphBio = nphbio_mort_P

DOP_FLOC = FlocP_DEPO

2) control function calculations

DOM_QUALITY_CF = Min(Exp(-***GP_DOM_decomp_coef*** * Max(***GP_DOM_DECOMP_POPT***-TP_SEDWT_CONCACTMG, 0.0)/ ***GP_DOM_DECOMP_POPT***),1.0)

Jorgensen 1976 ; 5 deg C is minimum temperature parameter

DOM_TEMP_CF = Exp(-2.3 * ABS((H2O_TEMP - ***GP_DOM_DECOMP_TOPT***) / (***GP_DOM_DECOMP_TOPT*** - 5.0)))

3) flux calculations

DOM_DECOMP_POT = ***GP_calibDecomp*** * ***GP_DOM_RCDECOMP*** * DOM_QUALITY_CF * DOM_TEMP_CF * DEPOS_ORG_MAT * (Min(DOM_SED_AEROB_Z/ ***GP_DOM_MAXDEPTH***,1.0) * soil_MOIST_CF + ***GP_DOM_DECOMPRED*** * Min(DOM_SED_ANAEROB_Z/ ***HP_DOM_MAXDEPTH***,1.0))

DOM_DECOMP = (DOM_DECOMP_POT****DT*** > DEPOS_ORG_MAT) ? (DEPOS_ORG_MAT/***DT***) : (DOM_DECOMP_POT)

DOP_DECOMP = DOM_DECOMP * DOM_P_OM

4) attributes calculated after DOM/DOP updates, used in other modules

DOM_Z = DEPOS_ORG_MAT / DOM_BD

SED_ELEV = DOM_Z+Inorg_Z+SED_INACT_Z

DOM_P_OM = (DEPOS_ORG_MAT>0.0) ? (DOP / DEPOS_ORG_MAT) : (0.0)

TPsoil = DOP * ***CELL_SIZE*** + TP_SORB

TPtoSOIL = ((DEPOS_ORG_MAT * ***CELL_SIZE*** + DIM) > 0.0) ? (TPsoil / (DEPOS_ORG_MAT * ***CELL_SIZE*** + DIM)) : (0.0)

TPtoVOL = (***CELL_SIZE*** * DOM_Z>0.0) ? (TPsoil / (***CELL_SIZE*** * DOM_Z)) : (0.0)

TP_sedMin = (1.0 - ***HP_DOM_AEROBTHIN*** / ***HP_DOM_MAXDEPTH***) * DOP_DECOMP * ***CELL_SIZE***

TP_SED_WT = TP_SED_WT + TP_sedMin * ***DT***;

TP_SED_WT_AZ = TP_SED_WT_AZ + TP_sedMin * ***DT***;

TP_SED_CONC = (HYD_SED_WAT_VOL>0.0) ? (TP_SED_WT / HYD_SED_WAT_VOL) : (0.0)

TP_SEDWT_CONCACT = (HYD_DOM_ACTWAT_PRES > 0.0) ? (TP_SED_WT_AZ/HYD_DOM_ACTWAT_VOL) : (TP_SED_CONC)

TP_SEDWT_CONCACTMG = TP_SEDWT_CONCACT*1000.0

TP_Act_to_Tot = 1.0 / ***HP_TP_CONC_GRAD***

if there is no surface water present, assume that this relative contribution will be an additional sorbed component that is introduced to surface water column immediately upon hydration with surface water

TP_sfMin = ***HP_DOM_AEROBTHIN*** / ***HP_DOM_MAXDEPTH*** * DOP_DECOMP * ***CELL_SIZE***

TP_SF_WT = TP_SF_WT + TP_sfMin * ***DT***

TP_SFWT_CONC = (SFWT_VOL > 0.0) ? (TP_SF_WT/SFWT_VOL) : (0.0)

TP_SFWT_CONC_MG = (SURFACE_WAT > ***GP_DetentZ***) ? (TP_SFWT_CONC*1000.0) : (0.0)

used only for output as Performance Measure (with unit conversions)

P_SUM_CELL = ((C_ALG_P + NC_ALG_P) * 0.001 * ***CELL_SIZE*** + (mac_nph_P + mac_ph_P) * ***CELL_SIZE*** + TP_SORB + (FlocP + DOP) * ***CELL_SIZE*** + TP_SED_WT + TP_SF_WT) /CELL_SIZE * 1000.0

Constant attributes calculated only at model initialization (outside Module)

BulkD = input data

DOM_BD = input data

ELEVATION = input data

Bathymetry = input data

SED_INACT_Z = ELEVATION-Bathymetry+***DATUM_DISTANCE***- ***HP_DOM_MAXDEPTH***

Inorg_Z = (1.0 - (DOM_BD / BulkD)) * ***HP_DOM_MAXDEPTH***

DIM = (BulkD - DOM_BD) * ***HP_DOM_MAXDEPTH*** * ***CELL_SIZE***

External variables used

nphbio_mort_OM (see Macrophyte module)

nphbio_mort_P (see Macrophyte module)

FLOC_DEPO (see Floc module)

FlocP_DEPO (see Floc module)

soil_MOIST_CF (see Floc module)

TP_SEDWT_CONCACTMG (see TP/Salt module)

TP_SORB (see TP/Salt module)

UNSAT_DEPTH (see Hydrology module)

HYD_SED_WAT_VOL (see Hydrology module)

HYD_DOM_ACTWAT_VOL (see Hydrology module)

HYD_DOM_ACTWAT_PRES (see Hydrology module)

SFWT_VOL (see Hydrology module)

H2O_TEMP (see Hydrology module)

Soils Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
DOM_SED_AEROB_Z	attribute	m	Deposited Organic Matter SEDiment/soil AEROBic profile depth (Z) (incl. pore space)
DOM_SED_ANAEROB_Z	attribute	m	Deposited Organic Matter SEDiment/soil ANAEROBic profile depth (Z) (incl. pore space)
SED_ELEV	attribute	m	total land surface ELEVation of the entire SEDiment/soil complex, including model DATUM_DISTANCE depth below NGVD 1929)
TPtoVOL	attribute	kgP/m^3_soil	Total Phosphorus concentration in soil VOLume
DOM_P_OM	attribute	kgP/kgOM	Deposited Organic Matter Phoshorus concentration (relative to Organic Matter)
TPtoSOIL	attribute	kgP/kg_soil	Total Phosphorus concentration in SOIL mass
P_SUM_CELL	attribute	gP/m^2	SUM of all (biotic/abiotic) storages of Phosphorus (in CELLs) (for reporting only, thus units converted to gP/m^2)
DOM_QUALITY_CF	controlFunction	dimless	Deposited Organic Matter Control Function of degree of limitation by surrounding nutrient availability, i.e., QUALITY
DOM_TEMP_CF	controlFunction	dimless	Deposited Organic Matter Control Function of degree of TEMPerature limitation
DOP_DECOMP	rateActual	kgP/m^2/d	Deposited Organic Phosphorus DECOMPosition losses
TP_sedMin	rateActual	kgP/d	Total Phosphorus gained in sediment/soil water due to deposited organic matter (soil) Mineralization
TP_sfMin	rateActual	kgP/d	Total Phosphorus gained in surface water due to deposited organic matter (soil) Mineralization
DOM_fr_nphBio	rateActual	kgOM/m^2/d	Deposited Organic Matter gained from mortality of non-photosynthetic Biomass of macrophytes
DOM_DECOMP	rateActual	kgOM/m^2/d	Deposited Organic Matter DECOMPosition losses
DOM_FR_FLOC	rateActual	kgOM/m^2/d	Deposited Organic Matter gained FRom FLOCculent organic matter deposition
DOM_DECOMP_POT	rateP	kgOM/m	Deposited Organic Matter

	otential	^2/d	DECOMPosition POTential losses
DOP	state	kgP/m^2	Deposited Organic Phosphorus (better name is accreted organic phosphorus AOP) mass in upper soil zone (not including floc layer, sorbed P, nor water P storage)
DEPOS_ORG_MAT	state	kgOM/m^2	DEPOSited ORGanic MATter (better name is accreted organic matter, AOM) mass in upper soil zone (not including floc layer)
DOM_Z	state Convert	m	Deposited Organic Matter mass in upper soil zone converted to depth (Z) (organic component only, accounting for bulk density)
DIM	static	kg InorgM	Deposited Inorganic Matter mass in upper soil zone (inorganic component only)
Inorg_Z	static	m	deposited Inorganic matter in upper soil zone mass converted to depth (Z) (inorganic component only, accounting for bulk density)
ELEVATION	static	m	initial land surface ELEVATION of the entire sediment/soil complex (m NGVD 1929), not including the model DATUM_DISTANCE depth below NGVD 1929
Bathymetry	static	m	Bathymetry of estuarine areas, as depth of the sediment/soil surface below NGVD 1929, positive values not including the model DATUM_DISTANCE depth below NGVD 1929
SED_INACT_Z	static	m	SEDiment/soil INACTive Zone height (=distance below DOM_MAXDEPTH parameter)
BulkD	static	kgSoil/m^3soil	Bulk Density of soil
DOM_BD	static	kgOM/m^3soil	Bulk Density of (only) the Deposited Organic Matter component of the soil
TP_Act_to_Tot	static	dimless	Total Phosphorus concentration in the upper Active DOM zone relative to average concentration the Total soil/sediment zone down to base_datum; algorithm will change to a dynamic variable

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description

DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_DATUM_DISTANCE	global	m	distance below NGVD'29 to base datum
GP_DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
GP_calibDecomp	global	dimless	calibration parameter, multiply potential decomposition rate of organic matter
GP_DOM_RCDECOMP	global	1/d	Maximum observed/attainable specific rate of organic matter decomposition (w/o limitations)
GP_DOM_DECOMPRED	global	dimless	under anaerobic conditions, proportional reduction of the maximum rate of aerobic decomposition
GP_DOM_decomp_coef	global	dimless	parameter for exp function describing decomposition kinetics
GP_DOM_DECOMP_POPT	global	mg/L	Optimal phosphorus concentration in water for maximal decomposition of organic matter
GP_DOM_DECOMP_TOPT	global	deg C	Optimal temperature for maximal decomposition of organic matter
GP_sorbToTP	global	dimless	initial condition only, the ratio of sorbed phosphorus to total phosphorus in soil

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_DOM_MAXDEPTH	habspec	m	Maximum depth (positive, from sediment surface) of Deposited Organic Matter to consider in model. This determines the depth of the active DOM zone for all model dynamics via: 1) decomposition, 2) sorption/desorption of nutrients, and 3) nutrient uptake by macrophytes. This generally should be <= the max root depth parm (less than root depth in case of trees).
HP_DOM_AEROBTHIN	habspec	m	The thin aerobic zone in a flooded wetland. Note that aerobic total depth is defined to include any zone of soil/sediment that is unsaturated or devoid of water.
HP_TP_CONC_GRAD	habspec	dimless	For concentration gradient, provide the ratio of this nutrient in the inactive DOM zone to that in the active DOM zone. Used in partitioning the mass of sediment nutrients to different concentrations in the shallow active DOM zone and the deeper inactive zone.

Intrinsic C or ELM functions

exp(x) = Exp(x) => e raised to the x^{th} power

Max(x,y) => maximum of variable x or y

Min(x,y) => minimum of variable x or y

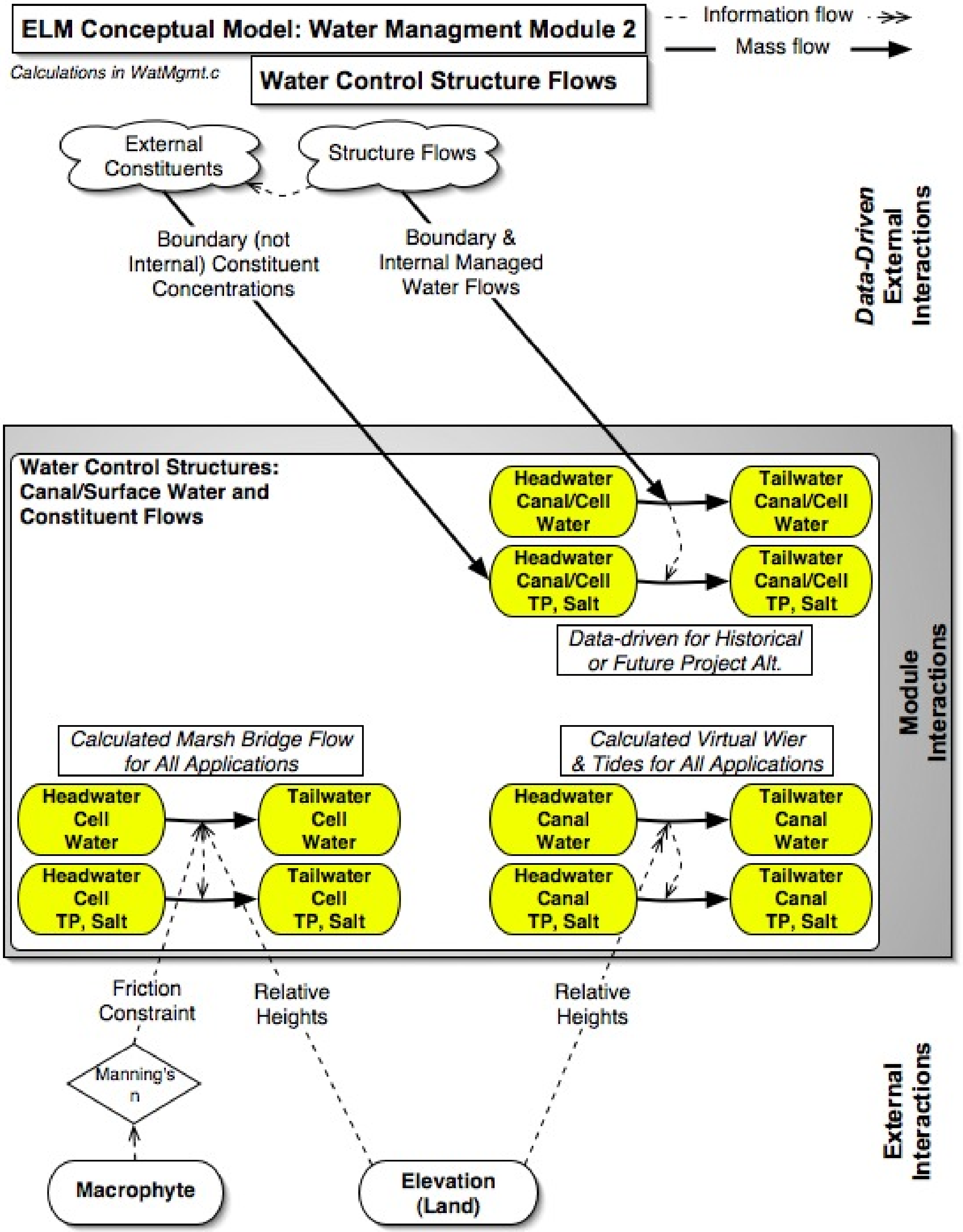
(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

ABS(x) => absolute value of (x)

5.7 Horizontal solutions

These modules calculate spatial flows of surface water, groundwater, and associated constituents (phosphorus and salt/tracer) in the (mostly) horizontal dimensions across raster grid cells and vector canals.

5.7.1 Water management: Structure flows module



Overview: Water Control Structure Flows Module

The Water Management Modules provide the mechanisms for distributing managed flows of water and constituents (phosphorus and salt/tracer) in a network of canals, levees, and water control structures. This Water Control Structure Flows Module describes the water and constituent flows into and out of canals and grid cells through point water control structures. All managed daily flows are derived from either historical observations or output from other models such as the South Florida Water Management Model (SFWMM), but un-managed flows are calculated internal to the model.

Water Control Structure Flows Module Description

The attributes of the water control structures are defined in a relational (FilemakerPro) database, and exported into an ASCII (text) input file for the model. Among the variety of attributes in this database are the definitions of the source (canal ID or cell ID[12]) and destination (canal ID or cell ID) water and constituent storages. The database also defines whether flows are to be driven by time-series input data or to be calculated in the model. As indicated in the Water Management Canal-Marsh Flux Module section, because some canals extend over large distances, the model segments a number of Everglades canal reaches into model canal reaches that are separated by “virtual” water control structures that equilibrate stages in two canals at every time step. This segmentation minimizes the potential grid-cell dispersion of constituents (nutrients and salt/tracer) from canals along very long canal reaches, as homogeneity of constituents is assumed along the length of the reach.

All managed water control structures (i.e., “real-world” structures) require daily time series data from historical observations or output from other models such as the SFWMM. Additionally, any water control structure that introduces water into the model domain must have some estimate of the associated constituents to flux with that “new” water. The constituent concentration may either be a fixed, long term mean value, or a daily time series of concentrations (derived from observations or from other models). Daily water and constituent flows are passed through a water control structure using one of four source-destination relationships: 1) flow from a canal to a canal, 2) flow from a cell to a cell, 3) flow from a canal to a cell, or 4) flow from a cell to a canal.

The data-driven flows are simple functions of the input data, with checks on any source-volume constraint. External boundary condition flows (into or out of the active domain of the model) are fluxes to or from a reserved cell (row 1, column 1) that is outside of the model domain.

In the case of “virtual” structures that equilibrate two canal reaches (that are portions of a longer, continuous “real-world” canal), a simple mass-balance equilibrium is sought between the two segments at each canal time step. The elevation drop along the length of the reach from the upstream to downstream end is known, and the land surface height at the midpoint each canal reach is used in estimating stage along both continuous reaches: stages based on those elevations are equilibrated at every time step (in the positive

---

[12] The cell ID is the row and column grid location, which is calculated in the database from the geographic coordinates of the structure, and is thus independent of the scale of the model application.

downstream direction only). In the case of an under-bridge “virtual” structure between wetland grid cells, the overland flow equation for grid cell fluxes is called to calculate the overland flow using an open-water Manning’s n coeficient (see Surface Water Raster Flux Module for equation description). In another use of virtual structures, tidal boundary conditions are imposed with a data-driven head/tail water target stage that is imposed on virtual structures associated with vectors of tidal rivers/creeks (aka “canals”) and cells external to the model domain. A long-term monthly mean tidal stage recurs annually through use of a input graph function, and the data are interpolated to daily head or the tail water target stages for the river vector. A high flow coefficient is imposed on the potential flux due to the head difference between target and the internal vector, exchanging water between the river vector and the target. A constant salinity selected by the user is imposed on each tidal flux. As with any “canal” vector, river vectors are segmented and joined by equilibrating virtual structures as described above.

Constraints for mass balance are imposed on the data-driven and the calculated water control structure flows during each time step, preventing head reversals or flows greater than the volume available in the donor grid cell or canal. Again, mass of constituents (nutrients, salt/tracer) is passed along in a mass-balance calculation based upon the water volume flux from the source storage.

Water Control Structure Flows Module Equations

Flux calculations

```
## The below calculations are performed inside a ("while") loop through each individual water
   control structure.
## While most flows are data-driven using either historical observations or output from other
   models (primarily the SFWMM), there are special cases of calculated flows (virtual structure
   flows between marsh cells (under-bridge) and canal-canal or canal->cell virtual structure
   flows).
## Depending on the source and destination of a water control structure, there are four
   combinations of canal and grid-cell flows through the structures.

## Canal-to-canal flow (always internal to model domain)
##
## Calculate the data-driven flow demand through the current structure during this iteration
   flow = arrayPump * canstep

## In a cycle across all structures, the current iteration flow is summed with any other (current
   iteration) data-driven flows from the current source-water reach
   ChanHistOut = ChanHistOut + flow

## If the sum of all data-driven outflows from the canal reach during this iteration exceeds the
   volume available, all flows are reduced by the necessary (equal) proportion for mass balance
   (and warnings are printed to the file "Driver1.out").
## The mass of constituents are calculated for each flow in a mass balance transfer.
## After completing this cycle through all outflows from a reach, (and reducing the flow volumes if
   necessary), the actual water volume and constituent mass flows are summed for use in the
   Water Management Canal-Marsh Flux Module.  However, water volumes and constituent
   masses flowing into any grid-cell destinations update those cell storages at this point.
## Once processed through such a cycle, a structure flow from the source canal reach is not
   processed again.
##
## Calculate flow if current structure is a virtual structure.
```

```
## Virtual structures are always processed AFTER all data-driven demands are met (due to omission from cycling through the structure-list during any volume-available checks, and due to their order in the water control structure list).
    HeadH_drop = 0.5 * elev_drop_fr

    HeadT_drop = 0.5 * elev_drop_to

## In both head and tail, add net data-driven flows to determine hydraulic potential (grid cell elevation, SED_ELEV, is at water control structure)
    HeadH = HeadH_drop + SED_ELEV - depth_fr + wat_depth_fr + (sumHistIn_fr - sumHistOut_fr)/area_fr

## In tailwater only, check to see if other virtual struct has added water already (cumulative "sumRuleIn"), add to head
    HeadT = -HeadT_drop + SED_ELEV - depth_to + wat_depth_to + ( sumRuleIn + sumHistIn_to - sumHistOut_to)/area_to

## Flow is only considered in the positive (head to tail water) direction
    flow = area_fr * area_to / (area_fr + area_to) * (HeadH - HeadT)

## The actual water volume and constituent mass flows are summed (including data-driven flows) for use in the Water Management Canal-Marsh Flux Module.


## Cell-to-cell flow (can involve flows to/from cells external to model domain)
##
## Calculate the data-driven flow demand through the current structure during this iteration
    flow = arrayPump * canstep

## Unlike a canal reach, a single grid cell can be source-water for at most one water control structure - a check is made to ensure the flow is not greater than the currently available volume in the cell.
## The water volume flow is used to update the volumes in the source and destination grid cells, along with sums of the constituent mass, for use in the Water Management Canal-Marsh Flux Module.
##
## Calculate flow if current structure is a virtual structure.
## The only case allowed for here is under-bridge flow (e.g., Alligator Alley bridges) parameterized with an model domain-wide array of Manning's n that is encoded as open-water, n=0.05.
## Using water depths and elevations of the source and destinations cells, a call is made to the raster surface water flux functions (see Surface Water Raster Flux Module), updating water and constituents in the source and recipient cells.

## Canal-to-cell flow (can involve flows to cells external to model domain)
##
## Calculate the data-driven flow demand through the current structure during this iteration
    flow = arrayPump * canstep

## In a cycle across all structures, the current iteration flow is summed with any other (current iteration) data-driven flows from the current source-water reach
    ChanHistOut = ChanHistOut + flow

## If the sum of all data-driven outflows from the canal reach during this iteration exceeds the volume available, all flows are reduced by the necessary (equal) proportion for mass balance (and warnings are printed to the file "Driver1.out").
## The mass of constituents are calculated for each flow in a mass balance transfer.
## After completing this cycle through all outflows from a reach, (and reducing the flow volumes if necessary), the actual water volume and constituent mass flows are summed for use in the
```

Water Management Canal-Marsh Flux Module. However, water volumes and constituent masses flowing into any grid-cell destinations update those cell storages at this point.

Once processed through such a cycle, a structure flow from the source canal reach is not processed again.

Cell-to-canal flow (can involve flows from cells external to model domain)

##

Calculate the data-driven flow demand through the current structure during this iteration

flow = arrayPump * ***canstep***

Unlike a canal reach, a single grid cell can be source-water for at most one water control structure - a check is made to ensure the flow is not greater than the currently available volume in the cell.

The water volume flow is used to update the volumes in the source and destination grid cells, along with sums of the constituent mass, for use in the Water Management Canal-Marsh Flux Module.

Process the next water control structure within the ("while") loop

External cell-based variables used

SED_ELEV (see Soils module)

SURFACE_WAT (see Hydrology module)

HYD_MANNINGS_N (see Hydrology module)

SALT_SURF_WT (see Salt/Tracer module)

TP_SF_WT (see Phosphorus module)

External canal-based variables used

none (in abbreviated equations)

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
flow	RateActual	m^3/***canstep***	water flow volume through structure for an iteration
ChanHistOut	attribute	m^3	temporary variable, summing all data-driven flows during one iteration from a particular source canal or grid-cell
elev_drop_fr	attribute	m	land surface elevation difference from beginning to end of a source canal reach
elev_drop_to	attribute	m	land surface elevation difference from beginning to end of a destination canal reach
HeadH	attribute	m	Hydraulic Head in Headwater (source)
HeadT	attribute	m	Hydraulic Head in Tailwater (destination)

Time series forcing data

Variable Name	Type	Units	Description
arrayPump	RatePotenti	m^3/d	input data array of daily time-series water volume flows through managed

	al		structures
arrayP	attribute	kgP/m^3	input data array of daily time-series of Total Phosphorus concentration associated with structures that flow into model from external regions (variable not used in abbreviated equations)
arrayS	attribute	kgSalt/m^3	input data array of daily time-series of Salt/tracer concentration associated with structures that flow into model from external regions (variable not used in abbreviated equations)

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
hyd_iter	global	dimless	number of horizontal iterations per ***DT***
canstep= DT/hyd_iter	local	day	time step for horizontal canal solutions

Static canal-specific parameters

Parameter Name	Type	Units	Description
area_fr, area_to	attribute	m^2	area of entire canal reach, the source (fr), destination (to) reaches

Static structure-specific parameters

none of below parameters used in abbreviated equations

Parameter Name	Type	Units	Description
#flag	attribute	dimless	attribute indicating operational status of structure (<0 = off, 0 = calculated, >0 = data-driven)
#S_nam	attribute	dimless	structure name
#histTP	attribute	dimless or mgP/L	attribute indicating a single long-term mean TP concentration, or pointer to time series input data
#histTS	attribute	dimless or gSalt/L	attribute indicating a single long-term mean Salt/tracer concentration, or pointer to time series input data
#str_cell_i	attribute	dimless	row location of structure
#str_cell_j	attribute	dimless	column location of structure
#canal_fr	attribute	dimless	canal ID of structure water source
#canal_to	attribute	dimless	canal ID of structure water destination
#cell_i_fr	attribute	dimless	row location of structure water source
#cell_j_fr	attribu	dimless	column location of structure water

	te		source
#cell_i_to	attribute	dimless	row location of structure water destination
#cell_j_to	attribute	dimless	column location of structure water destination

Static habitat-specific parameters (linked to HAB value of grid-cell)

none

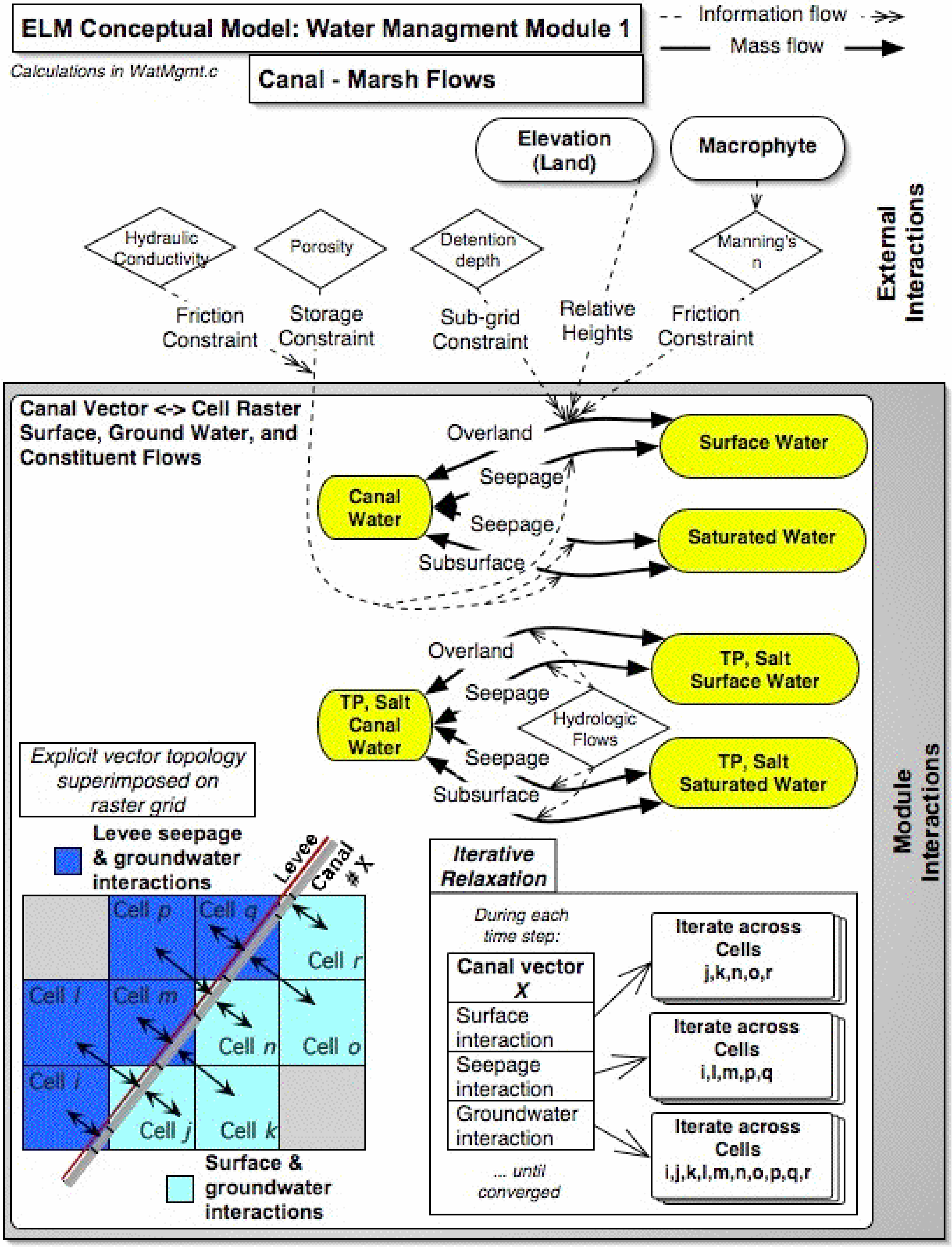
Static spatially-distributed parameters

none

Intrinsic C or ELM functions

none (in abbreviated equations)

5.7.2 Water management: Canal-marsh flux module



Overview: Water Management Canal-Marsh Flux Module

The Water Management Modules provide the mechanisms for distributing managed flows of water and constituents in a network of canals, levees, and water control structures. This Canal-Marsh Flux Module dynamically exchanges surface/ground- water and constituents among the canal vectors and the raster grid cells. The topology of the network is calculated such that the vectors overlie cells in their true geographic orientation and maintain the correct area of interaction among the raster and vector object types. Flux equations determine the flow of water and constituents along canals, with exchange of water and nutrients among grid cells and canal vectors via overland, seepage, or groundwater flow. The Water Management Water Control Structure Flows Module describes the flows into and out of canals and grid cells through point water control structures.

Water Management Canal-Marsh Flux Module Description

The attributes of the canal reaches in the network are defined in an ASCII (text) datafile that is input to the model. (A script is used to import the canal data into the GRASS GIS for visualization and editing of the canal network topology). Canal reaches are assumed to have homogenous width, depth, slope, levee (if present) hydraulic conductivity, and constituent concentration throughout the length of the canal reach. A levee is assumed to have negligible width. At initialization time of the model, the geometric relationships of the canal vectors and raster grid cells is calculated. Canal reaches are defined by vectors of any shape, beginning and ending with water control structure points. Because some canals extend over large distances, the model segments a number of Everglades canal reaches into model canal reaches that are separated by “virtual” water control structures (see Water Management Water Control Structure Flows Module). This segmentation minimizes the potential grid-cell dispersion of constituents (nutrients and salt/tracer) from canals along very long canal reaches, as homogeneity of constituents is assumed along the length of the reach.

The exact geographic coordinates of the multiple points forming a curved or straight canal reach (and the exact locations of grid cells) are used to determine the area of interactions among each segment (piece of a reach along a grid cell) of a canal reach vector with the adjacent grid cells. (Canal reaches intersect grid cells at any angle, and the area of interaction is known from the geometry). In this scheme, the mode of interaction of a grid cell with a canal (e.g., levee seepage vs. overland flow) is determined by the placement of the vector canal (and levee, if any) relative to the center of the grid cell. By comparing where a vector segment lies relative to the center of a cell, it is first determined whether a cell should be marked as being to the left or right of the vector (as shown in conceptual model diagram). For example, if more than half of the cell area lies to the right of the vector, then the cell is assigned as a right cell. Note (as shown in the figure) that it is not only the transected cells that can be marked as interacting with the canal vector. This set of interacting grid cells becomes associated as an object (in a C data structure) for a canal reach that defines its interacting cells. Based upon this determination of interacting cells, the presence or absence of a levee(s) associated with each canal reach (none, both sides, left side, right side) is used to calculate (and statically store) the allowable flow directions in the raster grid cells (modifying the “ON_MAP” array attributes for use in the Surface Water Raster Flux Module).

While we developed this unique raster-vector topology for cell-canal relationships, the ELM uses the fundamentals of the mass balance approach for canal-cell fluxes that was originally developed for the South Florida Water Management Model. This method is applied to the Water Management Canal-Marsh Module to calculate the exchange of water and constituents between a vector canal reach and the multiple grid cells that interact with that reach. Additions or subtractions to/from the canal reach from water control structure flows are known at the start of a canal time step (Water Management Water Control Structure Flows Module). In an iterative relaxation (not true equilibration) procedure during a single canal time step, a new canal depth is estimated and the canal-cell exchanges along the entire reach are calculated. Comparing the new estimated depth with the past depth adjusted for all flow exchanges, the error in the estimate is quickly decreased to a threshold value (10 microns in recent versions, including current) to converge on a solution. In calculating the exchange of canal surface waters with either surface water or subsurface groundwater in interacting cells, the model uses simple applications of the Manning's equation or Darcy's equation, respectively within an explicit, finite-difference framework (see Surface Water and Groundwater Flux Modules for equations and further background). Surface water exchange can occur between surface storages in the canals and in interacting cells. Levee-seepage exchange occurs between surface water in canals and surface or groundwater in interacting cells. Groundwater storage in interacting grid cells can exchange with surface water in canals. Constraints for stability and mass balance are imposed on the calculated flux during each time step, preventing head reversals or flows greater than the volume available in the donor grid cell or canal. Mass of constituents (nutrients, salt/tracer) is passed along in a mass-balance calculation based upon the water volume flux between cells and canal.

Water Management Canal-Marsh Flux Module Equations

Geometry calculations

At model initialization time (Canal_Network_Init function), the geometry of canal and grid cell attributes is used to determines which grid cells interact with canal vectors, and their mode of interaction.

A canal reach is defined by two (upstream & downstream) water control structures, with each reach having a unique numeric ID.

Canal vector geographic coordinates are defined in the input CanalData.chan text file (see DataRead Module).

The water control structures may be actual water management structures, or "virtual structures" used in partitioning long, continuous actual canals into multiple model reaches.

Canal reaches may be straight lines or curves, with the area of interaction of (grid-cell associated) segments of each with adjoining grid cells known from the geometry calculations during initialization.

Flux calculations

The below calculations are performed inside an iterative ("do-while") relaxation routine for EACH individual canal reach, exchanging water among the canal reach and adjoining cells, then estimating the new canal water depth.

After each iteration, the estimate of the new canal depth is compared to the old-depth-plus the (positive/negative) canal-cell and water control structure exchanges: when the error between those estimates becomes less than the chosen threshold ***(F_ERROR****, in input file= CanalData.chan), we have the solution for the new canal depth.*

This "iterative relaxation" routine is the same concept that is documented for the South Florida Water Management Model.

This procedure is calculated only for grid cells that are inside the active model domain (where ON_MAP is true, >0).

```
## Start the iterative relaxation routine
## At the start of an iteration of the relaxation routine, make a new estimate of the water depth in
   the canal.
## The first estimate is a very crude one, and the relaxation routine refines that quickly by
   modifying "factor" based upon the error in the last iteration.  (In this, “factor” is
   increased/decreased or changed in sign, depending on the direction of the error).
   CanWatDep = CanWatDep + factor


## During one iteration, start of the loop across all grid cells belonging to a canal reach
## cellLoc_i = address of grid cell at row x, column y
## account for (non-zero) increased roughness associated with edge of canal
   SW_coef = ( HYD_MANNINGS_N[cellLoc_i] == 0.0 ) ? 0 : SW_flow_coef /
       (edgeMann > 0 ? (HYD_MANNINGS_N[cellLoc_i] + edgeMann)/2.0 :
       HYD_MANNINGS_N[cellLoc_i] )

   GW_head = SAT_WATER[cellLoc_i]/HP_HYD_POROSITY[cellLoc_i]

   tot_head = SURFACE_WAT[cellLoc_i] + SED_ELEV[cellLoc_i]

   CH_bottElev = SED_ELEV[cellLoc_i] - depth

   dh = ( CH_bottElev + CanWatDep ) - tot_head

   H_rad_ch =   ( seg_area * ramp(CanWatDep - depth) + SURFACE_WAT[cellLoc_i] *
       (CELL_SIZE-seg_area) ) / CELL_SIZE

   H_rad_cell = (seg_area * ramp(CanWatDep - depth) + SURFACE_WAT[cellLoc_i] *
       (CELL_SIZE- seg_area) ) / CELL_SIZE


## For positive flows from canal (dh > 0.0), two calculations for cross sectional heights:
   h_GWflow = Min(depth, CanWatDep)

   h_SPflow = Max(CH_bottElev + CanWatDep - SED_ELEV[cellLoc_i], 0.0);

## For negative flows into canal (dh < 0.0), two calculations for cross sectional heights:
   h_GWflow = Max(GW_head-CH_bottElev, 0.0);

   h_SPflow = Max(tot_head-SED_ELEV[cellLoc_i], 0.0);


## Depending on the location of levee(s), if any, a choice of canal-cell flux calculations is made:

## Levee on both sides of canal reach
## Levee seepage, fluxL, and Groundwater, fluxG, flows along both sides of reach */
   fluxL =  (h_SPflow > 0.0) ? (dh * l_Length * SPG_coef / (0.5*celWid) * h_SPflow * canstep )
       : (0.0);

   fluxG =  (h_GWflow > 0.0) ? (dh * l_Length * GW_coef / (0.5*celWid) * h_GWflow * canstep
       ) : (0.0);


## Levee absent from both sides of canal reach
## Overland Surface flow, fluxS, along both sides of reach */
##     For positive slope, flux from canal ( dh > 0 ):
         fluxS = sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) *
       canstep)

##     For negative slope, flux from cell into canal provided SURFACE_WAT[cellLoc_i] > DetentZ :
         fluxS =  sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) *
       canstep)
```

```
##     Constrain flow from cell to volume available
           if (-fluxS > (SURFACE_WAT[cellLoc_i]-GP_DetentZ) *CELL_SIZE ) fluxS = -(SURFACE_WAT[cellLoc_i]-DetentZ)*CELL_SIZE;

## Subsurface Groundwater, fluxG, flow along both sides of reach
    fluxG =  (h_GWflow > 0.0) ? (dh * I_Length * GW_coef / (0.5*celWid) * h_GWflow * canstep ) : (0.0);


## Levee on left side of canal reach
## Overland flow, fluxS, along right side of reach */
##     For positive slope, flux from canal ( dh > 0 ):
           fluxS = sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) * canstep)

##     For negative slope, flux from cell into canal provided SURFACE_WAT[cellLoc_i] > GP_DetentZ :
           fluxS =  sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) * canstep)

##     Constrain flow from cell to volume available
           if (-fluxS > (SURFACE_WAT[cellLoc_i]- GP_DetentZ) *CELL_SIZE ) fluxS = -(SURFACE_WAT[cellLoc_i]- GP_DetentZ)*CELL_SIZE

## Levee seepage flow, fluxL, along left side of reach
    fluxL =  (h_SPflow > 0.0) ? (dh * I_Length * SPG_coef / (0.5*celWid) * h_SPflow * canstep ) : (0.0)

## Subsurface Groundwater, fluxG, flow along both sides of reach
    fluxG =  (h_GWflow > 0.0) ? (dh * I_Length * GW_coef / (0.5*celWid) * h_GWflow * canstep ) : (0.0);


## Levee on right side of canal reach
## Overland flow, fluxS, along left side of reach */
##     For positive slope, flux from canal ( dh > 0 ):
           fluxS = sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) * canstep)

##     For negative slope, flux from cell into canal provided SURFACE_WAT[cellLoc_i] > DetentZ:
           fluxS =  sgn( dh ) * SW_coef * pow(H_rad_cell, GP_mannDepthPow) * sqrt(Abs(dh)) * canstep)

##     Constrain flow from cell to volume available
           if (-fluxS > (SURFACE_WAT[cellLoc_i]- GP_DetentZ) *CELL_SIZE ) fluxS = -(SURFACE_WAT[cellLoc_i]- GP_DetentZ)*CELL_SIZE

## Levee seepage flow, fluxL, along right side of reach
    fluxL =  (h_SPflow > 0.0) ? (dh * I_Length * SPG_coef / (0.5*celWid) * h_SPflow * canstep ) : (0.0)

## Subsurface Groundwater, fluxG, flow along both sides of reach
    fluxG =  (h_GWflow > 0.0) ? (dh * I_Length * GW_coef / (0.5*celWid) * h_GWflow * canstep) : (0.0);


## After fluxing water between a grid cell and canal reach, make three head and volume flow constraints:
## The first constraint reduces the magnitude of the positive surface flux if the receiving cell would have a hydraulic head greater than the canal.
```

The second constaint reduces the magnitude of the negative surface flux if the receiving canal would have a hydraulic head greater than the cell.
The third constraint reduces the magnitude of the positive fluxes if the canal would be drained below its minimum depth.

Ending the loop across all grid cells belonging to a canal reach,
sum the total canal-cell fluxes along all grid cells of the canal reach during this iteration

T_flux_S = T_flux_S + fluxS

T_flux_G = T_flux_G + fluxG

T_flux_L = T_flux_L + fluxL

Now that all of the grid cell-canal fluxes have been estimated, determine the error between the newly estimated canal water depth and the previous canal water depth plus calculated flows.
error = (CanWatDep - wat_depth) - (Qin - Qout - T_flux_S - T_flux_G - T_flux_L)/ ***area***;

Still in the iterative relaxation routine, this error is used in start (top) of next iteration in the iterative relaxation routine above

At this point after solution convergence in the iterative relaxation routine, the canal reach water depth is updated with that from the converged solution.
wat_depth = CanWatDep

The water and constituent state variables in the canal reach and grid cells are updated in a set of mass balance calculations using the mass in the donor cell or canal storage variables and the water flux between those storages.

External cell-based variables used

SED_ELEV (see Soils module)

SURFACE_WAT (see Hydrology module)

SAT_WATER (see Hydrology module)

HYD_MANNINGS_N (see Hydrology module)

SALT_SURF_WT (see Salt/Tracer module)

TP_SF_WT (see Phosphorus module)

SALT_SED_WT (see Salt/Tracer module)

TP_SED_WT (see Phosphorus module)

External canal-based variables used

Qin (see Water Management Water Control Structure Flows module)

Qout (see Water Management Water Control Structure Flows module)

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
SW_coef	attribute	m^0.5 sec/(d/(m^(1/3)))	Surface Water flow coefficient (includes dynamic Manning’s n)
GW_head	attribute	m	groundwater head

tot_head	attribute	m	total hydraulic head
CH_bottElev	attribute	m	elev of bottom of canal at cell location
wat_depth	attribute	m	depth of water in canal from the previous canal time step
CanWatDep	attribute	m	estimated depth of water in canal during relaxation procedure
factor	attribute	dimless	the factor by which the CanWatDepth estimate is additively increased/decreased after an iteration of the relaxation routine
error	attribute	m	error between the newly estimated canal water depth and the previous canal water depth plus calculated flows
dh	attribute	m	difference in depths between canal reach and cell
H_rad_ch	attribute	m	hydraulic radius of canal reach for overland flow out of reach (canal and cell share same)
H_rad_cell	attribute	m	hydraulic radius of cell for overland flow into canal reach (canal and cell share same)
h_GWflow	attribute	m	height of the water cross section associated with the groundwater reach-cell flow
h_SPflow	attribute	m	height of the water cross section associated with the seepage reach-cell flow
fluxS	RateActual	m^3/d	Surface water flux between a segment of a canal reach and grid cell
fluxL	RateActual	m^3/d	Levee-seepage water flux between a segment of a canal reach and grid cell
fluxG	RateActual	m^3/d	Groundwater flux between a segment of a canal reach and grid cell
T_flux_S	RateActual	m^3/d	Total sum of Surface water fluxes between an entire canal reach and all grid cells associated with that reach
T_flux_L	RateActual	m^3/d	Total sum of Levee-seepage water fluxes between an entire canal reach and all grid cells associated with that reach
T_flux_G	RateActual	m^3/d	Total sum of Groundwater fluxes between an entire canal reach and all grid cells associated with that reach

Time series forcing data

none

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions

hyd_iter	global	dimless	number of horizontal iterations per ***DT***
canstep= DT/hyd_iter	local	day	time step for horizontal canal solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
celWid= CELL_SIZE^0.5	local	m	width of grid cell
sec_per_day = 86400	local	sec	number of seconds in a day
GP_DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
GP_mannDepthPow	global	dimless	power used in manning's equation water depth
GP_calibGWat	global	dimless	calibration parameter, multiply groundwater cell-cell flow calculation

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HYD_POROSITY	hab-spec	dimless	Porosity of the aquifer, average from the sediment to base datum. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization. Must be non-zero.

Static spatially-distributed parameters

Parameter Name	Type	Units	Description
HYD_RCCONDUCT	distributed	m/d	HYDraulic CONDUCTvity Rate Constant of surficial aquifer
GW_coef= HYD_RCCONDUCT * GP_calibGWat * HYD_POROSITY	distributed	m/d	aggregated GroundWater flow coeficient

Static canal-global parameters

Parameter Name	Type	Units	Description
F_ERROR	attribute	m	maximum allowable error in estimate of new water height in the canal-cell iterations
C_F	attribute	dimless	flow acceleration parameter, reserved for sensitivity experiments only (=1.0)

Static canal-specific parameters

Parameter Name	Type	Units	Description
depth	attribute	m	depth of canal, from bottom to rim of canal reach (not including levee)
width	attribute	m	width of canal reach (negative widths cause reach to be ignored)
cond	attribute	m/d	levee hydraulic conductivity, calibration parameter
length	attribute	m	length of entire canal reach

area	attribute	m^2	area of entire canal reach = length * width
edgeMann	attribute	d/(m^ (-1/3))	Manning's n associated w/ edge of canal, to accommodate topographic lip/berm and/or denser veg along canal length
l_Length	attribute	m	mean length of cells along reach (cell-associated) segments
seg_area= ***l_Length * width***	attribute	m^2	mean area of reach segments along each reach
SW_flow_coef= ***sqrt(l_Length) * sec_per_day * C_F***	attribute	m^0.5 sec	overland flow coefficient (C_F is multiplier only used for sensitivity)
SPG_coef= ***cond * GP_calibGWat***	attribute	m/d	aggregated seepage flow coefficient

Intrinsic C or ELM functions

sgn(x) => returns the sign (positive or negative, -1 or 1) of (x)

Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

ABS(x) = Abs(x) => absolute value of (x)

ramp(x) => negative (x) set =0, otherwise =(x) {precaution only for infinitesimally negative values - mass balance is evaluated (always output in budg_XYZ output files) at multiple spatial scales (several cell, whole-domain) and temporal scales, w/o losses: computational error in water storage height is on the order of +/- 10 microns accumulated over 20 years, maximum magnitude of (positive/negative) error is on the order of 1 micron accumulated over a 30-day period}

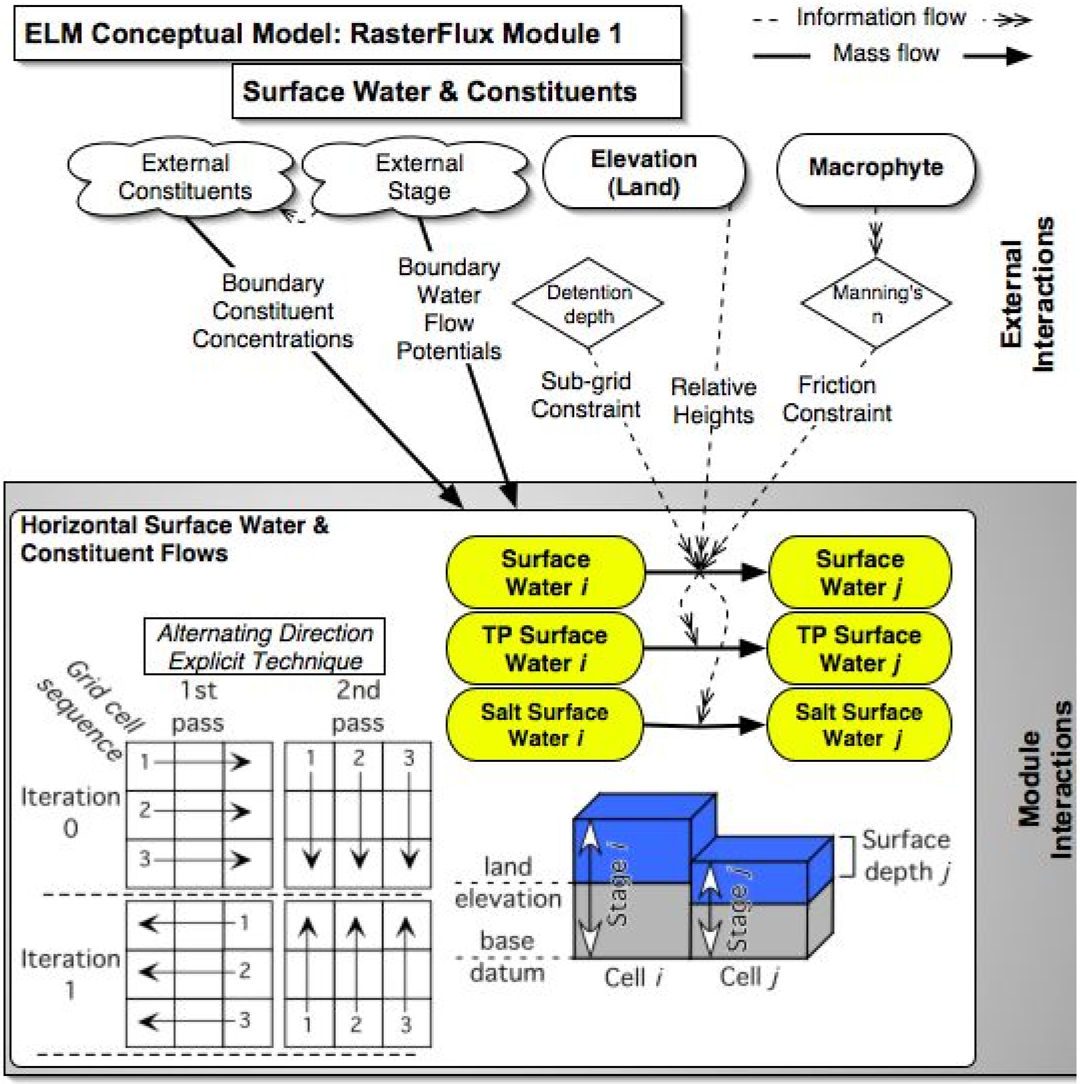
(x) != (y) => logical condition where (x) is not equal to (y)

if (x) equation => if (x) condition is true (==1), then execute "equation"

T(x,y) => single-integer array address of grid cell at location row x, column y (used in [cellLoc_])

sqrt(x) => square root of (x)

5.7.3 Overland flow module



External Interactions

Overview: Surface Water Raster Flux Module

This Surface Water Raster Flux Module serves to update the surface water storage state variable due to horizontal overland flow among (raster) grid cells. The (vertical)

Hydrology Module describes many of the dynamics associated with ELM hydrology, while this module description is specific to overland flow. These surface water flows are an important transport mechanism for constituents (phosphorus and salt/tracer) in the landscape, and canal fluxes can more rapidly transport water and constituents across long distances (see Water Management Modules). The overland surface flows are highly dependent upon the resistance to flow by macrophytes, while groundwater flows (Groundwater Raster Flux Module) and seepage through levees (Water Management Module) vary significantly across the region depending on aquifer (or levee) transmissivity.

Surface Water Raster Flux Module Description

Flow restrictions among grid cells are evaluated first. Based upon the geometry of levee vectors relative to square grid cells (calculated in the Water Management Module), grid cell flows may either not be allowed, allowed in the north-south direction, allowed in the east-west direction, or allowed in the direction of both axes. Flow restrictions between grid cells inside the model domain and grid cells outside the domain along the boundary are determined from a static input map layer: if overland surface flows are allowed, the stage and constituent concentration of an exterior boundary cell are determined. These stage data are daily values from another model such as the SFWMM.

The flow between two adjacent cells is determined from a simplification of the well-known open channel, diffusion flow model in an explicit, finite-difference framework. Omitting any inertial or acceleration terms, the continuity equation is simply a two-dimensional flux driven by differences in slope of the water surfaces. The flux between a pair of grid cells in the model domain’s array is described by the empirical Manning's equation for overland flow:

$$Q = \frac{D^{\frac{5}{3}} L^{\frac{1}{2}} \Delta h^{\frac{1}{2}}}{n}$$

where Q is the volumetric flow velocity (m^3 d^{-1}), D is the water depth (= hydraulic radius, m) above ground elevation, L is the length of a grid cell (m), Δh is the difference (m) in water stage between the source and destination cells, and n is the empirically-derived Manning’s roughness coefficient. Using an explicit numerical method, the solution is iterated in both the row-wise and the column-wise directions during each time step, the direction alternates (east-west and west-east, north-south and south-north) after each time step. This Alternating Direction Explicit solution minimizes the directional bias that is associated with a uniform- direction solution. Constraints for stability and mass balance are imposed on the calculated flux during each time step, preventing head reversals or flows greater than the volume available in the donor grid cell. The mass of constituents (nutrients, salt/tracer) is passed along in a mass-balance calculation based upon the water volume flux between cells.

Numerical dispersion of constituents (due to grid scale and time step in the finite difference solution) is calculated, and numerical dispersive flux adjusted to equal that associated with a user-selected grid cell length using a simple Anti-Numerical Dispersion algorithm. This algorithm is extended to increase/decrease dispersion (via a dispersion number parameter) to approximate actual dispersive flux in the simulated system (Wool et al. in press).

Surface Water Raster Flux Module Equations

Flux calculations

All equations shown are calculated within an Alternating Direction (each iteration) spatial loop across model grid rows, columns
[cellLoci] defines model grid address of cell "i"
[cellLocj] defines model grid address of cell "j"
Flux is positive/negative, from cell "i" to cell "j"

Pairs of grid cells are checked for (static) flow attributes in the spatial loop.
For a cell at [cellLoc_], the possible flow attributes are:
ON_MAP[cellLoc_]=0 => External to the model active domain
ON_MAP[cellLoc_]=1 => Allow (internal) flow in no direction (due to calculated levee-interaction geometry)
ON_MAP[cellLoc_]=2 => Allow (internal) flow to east<->west (due to calculated levee-interaction geometry)
ON_MAP[cellLoc_]=3 => Allow (internal) flow to south<->north (due to calculated levee-interaction geometry)
ON_MAP[cellLoc_]=4 => Allow (internal) flow in all directions (due to calculated (no) levee-interaction geometry)

If a single cell in a pair is external to the model domain (example, ON_MAP[cellLoci]=0),
allowance of internal<->external flow depends on an attribute of the other cell (i.e., [cellLocj]):
BCondFlow[cellLocj]=1 => Allow no flows external to model domain
BCondFlow[cellLocj]=3 => Allow surface water flows to/from external boundary cell
BCondFlow[cellLocj]=4 => Allow groundwater flows to/from external boundary cell

The function "Flux_SWcells" calculates and returns a cell-to-cell Flux in height units (m)
The case is shown for when both cell i and j are internal to the model domain, with flow allowed between the cells.
When one of the cells is external to the domain, and the pair of cells has been defined as allowing surface water boundary flows, the stage of that external cell (cellLoci in this example) is estimated as: HEADi = SED_ELEV[cellLocj] + Max(SURFACE_WAT[cellLocj]-0.05,0.0)
Code exists, but is not executed in v2.2, to replace the estimated stage/head value with input data from another model (e.g., SFWMM).

MANNINGS_N = (***HYD_MANNINGS_N***[cellLoci] + ***HYD_MANNINGS_N***[cellLocj])/2.0

HEADi = SURFACE_WAT[cellLoci] + SED_ELEV[cellLoci]

HEADj = SURFACE_WAT[cellLocj] + SED_ELEV[cellLocj]

deltaHEAD = HEADi - HEADj

a_deltaHEAD = ABS (deltaHEAD)

For positive head differences (deltaHEAD > 0), execute these four equations:
if(SURFACE_WAT[cellLoci] < ***DetentZ***) ## do nothing (return a Flux value of 0.0)

Flux = (MANNINGS_N != 0) ? (pow(a_deltaHEAD, ***GP_mannHeadPow***) * ***sec_per_day*** / MANNINGS_N * pow(SURFACE_WAT[cellLoci], ***GP_mannDepthPow***)****step_Cell***) : (0.0)

Flux = (Flux > ramp(SURFACE_WAT[cellLoci] - ***GP_DetentZ***)) ? (ramp(SURFACE_WAT[cellLoci] - ***DetentZ***)) : (Flux) if ((HEADi - Flux) < (HEADj + Flux))Flux = Min (deltaHEAD/2.0, ramp(SURFACE_WAT[cellLoci] - ***GP_DetentZ***))

For negative head differences (deltaHEAD < 0), execute these four equations:
if (SURFACE_WAT[cellLocj] < ***GP_DetentZ***) ## do nothing (return a Flux value of 0.0)

Flux = (MANNINGS_N != 0) ? (- pow(a_deltaHEAD, ***GP_mannHeadPow***) * ***sec_per_day*** / MANNINGS_N * pow(SURFACE_WAT[cellLocj], ***GP_mannDepthPow***)****step_Cell***) : (0.0)

Flux = (-Flux > ramp(SURFACE_WAT[cellLocj] - ***GP_DetentZ***)) ? (-ramp(SURFACE_WAT[cellLocj] – ***GP_DetentZ***)) : (Flux)

if ((HEADi - Flux) > (HEADj + Flux)) Flux = - Min (a_deltaHEAD/2.0, ramp(SURFACE_WAT[cellLocj] - ***GP_DetentZ***))

Result is the water flux between cells

The function "Flux_SWstuff" calculates the mass of constituents that move with the cell-to-cell Flux, updating the water and constituent state variables
Dispersion of constituents dependent on water velocity, calculated in "Disp_Calc" function
water velocity
veloc = Abs(Flux) * celWid/((Flux >0.0) ? (depth_i) : (depth_j)) / (sfstep)

numerical dispersion
disp_num = 0.5 * veloc * (celWid - veloc * sfstep)

velocity adjusted for numerical dispersion
veloc_adj = (veloc * celWid - disp_num)/celWid

Flux adjusted for numerical dispersion, and actual (parameter-based) dispersion
FluxAdj = dispParm_scaled * veloc_adj * sfstep * ((Flux >0.0) ? (depth_i) : (depth_j))/celWid

use adjusted Flux to determine the proportion of flow to use in constituent flux
fl_prop_i = (SURFACE_WAT[cellLoci]>0.0) ? (Max(Flux-FluxAdj,0.0) / SURFACE_WAT[cellLoci]) : (0.0)

fl_prop_j = (SURFACE_WAT[cellLocj]>0.0) ? (Min(Flux+FluxAdj,0.0) / SURFACE_WAT[cellLocj]) : (0.0)

fl_prop_i = Min(fl_prop_i, 1.0)

fl_prop_j = Min(fl_prop_j, 1.0)

For positive Flux values, execute these two equations to calculate mass of the constituent flux:
m1 = SALT_SURF_WT[cellLoci]*fl_prop_i

m3 = TP_SF_WT[cellLoci]*fl_prop_i

For negative Flux values, execute these two equations to calculate mass of the constituent flux:
m1 = SALT_SURF_WT[cellLocj]*fl_prop_j

m3 = TP_SF_WT[cellLocj]*fl_prop_j

update the constituent and water state variables
SALT_SURF_WT[cellLocj] += m1

TP_SF_WT[cellLocj] += m3

SALT_SURF_WT[cellLoci] -= m1

TP_SF_WT[cellLoci] -= m3

SURFACE_WAT[cellLocj] += Flux

SURFACE_WAT[cellLoci] -= Flux

External variables used

SED_ELEV (see Soils module)

HYD_MANNINGS_N (see Hydrology module)

SURFACE_WAT (see Hydrology module)

SALT_SURF_WT (see Salt/Tracer module)

TP_SF_WT (see Phosphorus module)

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
HEADi, HEADj	attribute	m	hydraulic head in cell `i`, and in cell `j`
deltaHEAD	attribute	m	difference between hydraulic heads in cell `i`, and in cell `j`
a_deltaHEAD	attribute	m	absolute value of difference between hydraulic heads in cell `i`, and in cell `j`
Flux	attribute	m	water fluxed between cell `i`, and cell `j`
m1	attribute	kg	mass of constituent 1 fluxed from donor cell
m3	attribute	kg	mass of constituent 3 fluxed from donor cell

Time series forcing data

none (v2.3 and higher will have dynamic stage input data for grid cells along domain border)

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
GP_DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
GP_mannDepthPow	global	dimless	power used in manning's equation water depth
GP_mannHeadPow	global	dimless	power used in manning's equation head difference
GP_dispParm	global	dimless	calibration parameter, can be ~representative of Dispersion Number estimates; a value of 0 removes any dispersion adjustments (leaving only the numerical dispersion of model scale)
GP_dispLenRef	global	m	reference length for which numerical dispersion (of finite difference sol'n) approximates actual turbulent diffusion, or dispersion

dispParm_scaled = (1.0 - GP_dispLenRef/celWid) * GP_dispParm	global	dimless	aggregated dispersion parameter
hyd_iter	global	dimless	number of horizontal iterations per ***DT***
sfstep = DT/hyd_iter	local	day	time step for horizontal surface water solutions
sq_celWid = CELL_SIZE^0.25	local	m^0.5	square root of cell width
celWid = CELL_SIZE^0.5	local	m	cell width
step_Cell = sq_celWid * sfstep/CELL_SIZE	local	m^(-1.5) * day	aggregation of static parameters (to reduce number of calculations per ***sfstep***)
sec_per_day = 86400	local	sec	number of seconds in a day

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description

none

Intrinsic C or ELM functions

Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

pow(x,y) => x raised to the yth power (generally avoided if possible due to execution time of C library)

ABS(x) => absolute value of (x)

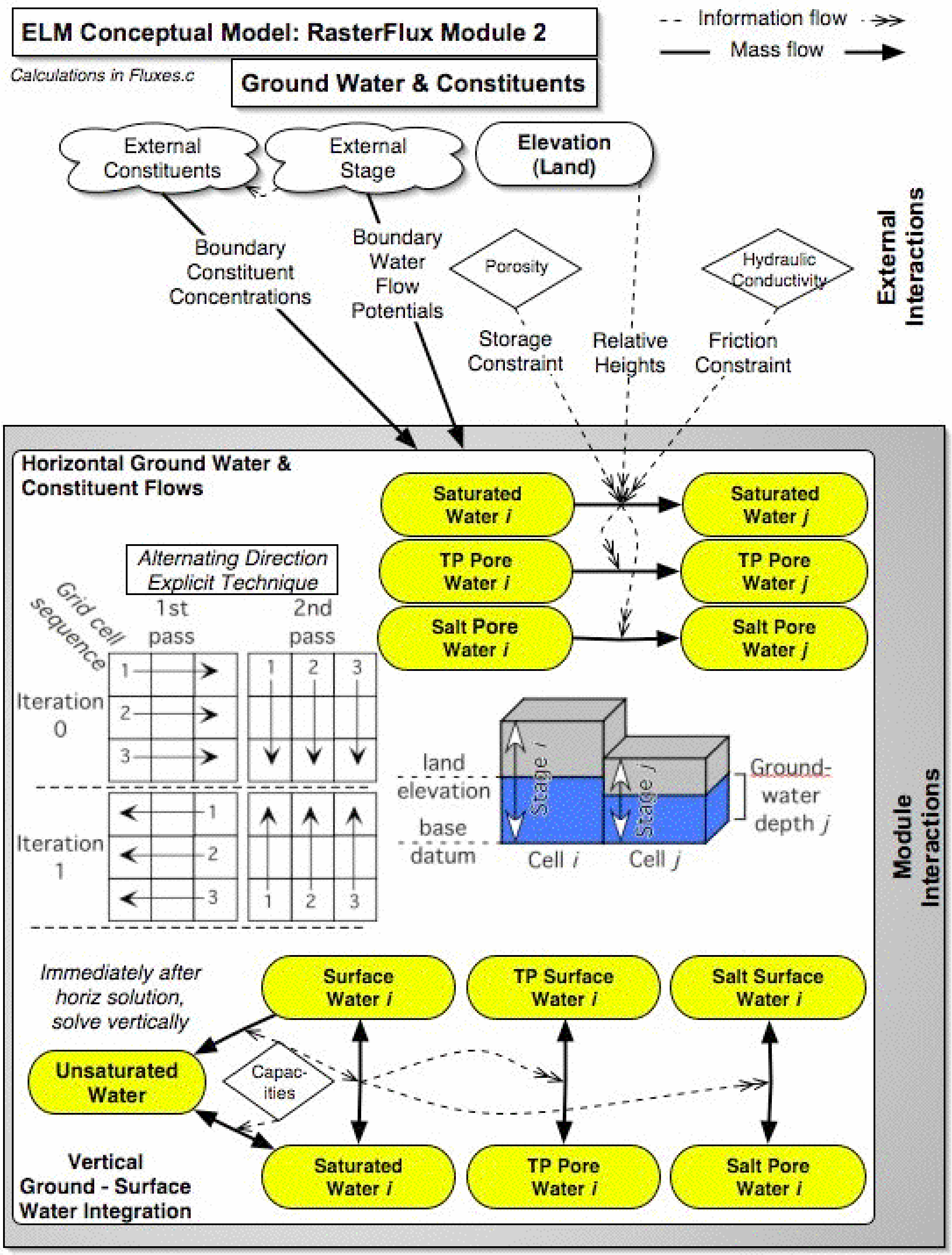
ramp(x) => negative (x) set =0, otherwise =(x) (precaution only for infinitesimally negative values - mass balance is evaluated (always output in budg_XYZ output files) at multiple spatial scales (several cell, whole-domain) and temporal scales, w/o losses: computational error in water storage height is on the order of +/- 10 microns accumulated over 20 years, maximum magnitude of (positive/negative) error is on the order of 1 micron accumulated over a 30-day period)

(x) != (y) => logical condition where (x) is not equal to (y)

if (x) equation => if (x) condition is true (==1), then execute `equation`

T(x,y) => single-integer array address of grid cell at location row x, column y (used in [cellLoc_])

5.7.4 Groundwater flow module



Overview: Groundwater Raster Flux Module

This Groundwater Raster Flux Module serves to update the ground water storage state variable due to horizontal subsurface flow among (raster) grid cells. The (vertical) Hydrology Module describes many of the dynamics associated with ELM hydrology, while this module description is specific to subsurface horizontal flow and its integration with surface water. These groundwater flows transport the constituents (phosphorus and salt/tracer) in addition to water in the landscape, and are highly dependent upon the aquifer transmissivity. Particularly in the central/southern extent of the eastern domain of the Everglades (esp. WCA-3B), the very high transmissivities make groundwater flows an important component of the overall hydrologic budget. Because the ELM domain encompasses only the "natural" wetlands of the greater Everglades, groundwater flows calculations use a very simple computational scheme, explicitly excluding highly transient aquifer dynamics associated with wellfields and related urban/agricultural features. While a number of vertical processes are solved in the (vertical) Hydrology Module, the explicit integration of surface water and groundwater (with associated constituents) is determined in this Groundwater Module immediately following the horizontal (surface and) groundwater flux calculations.

Groundwater Raster Flux Module Description

As with surface water flows, flow restrictions among grid cells are evaluated first. However, the only restriction for the groundwater system is that of the domain boundary. this determination of allowable flow between grid cells inside the model domain and grid cells outside the domain along the boundary are determined from a static input map layer: if subsurface groundwater flows are allowed, the stage and constituent concentration of an exterior boundary cell are determined. These stage data are daily values from another model such as the SFWMM.

The flow between two adjacent cells is determined from a simple application of the well-known Darcy's Law:

$$Q = K\frac{(h_1 - h_2)}{L}W \cdot D$$

where Q = flow (m^3 d^{-1} per m^2), K = hydraulic conductivity of aquifer (m d^{-1}), h_1 & h_2 are hydraulic heads measured along flow path (m), L = distance between heads (m), W = width of cross-sectional flow (m), and D = height of cross-sectional flow (m). Within an explicit, finite-difference framework, omitting any inertial or acceleration terms, the continuity equation is simply a two-dimensional flux driven by differences in slope of the hydraulic heads and the thickness of the saturated layer within an unconfined, vertically homogenous aquifer. Cell-cell head gradients are assumed to be small relative to the thickness of the aquifer down to the model base datum (which extends many meters below the land surface). The flux between a pair of grid cells in the rectangular array is described by the empirical Darcy's equation for saturated media, using an explicit numerical solution. The time step for horizontal groundwater flows is twice that of the horizontal surface water flows. Iterated in both the row-wise and the column-wise directions during each time step, the direction alternates (east-west and west-east, north-south and south-north) after each time step. This Alternating Direction Explicit solution minimizes the directional bias that is associated with a uni-directional solution. Constraints for stability and mass balance are imposed on the calculated flux during each time step, preventing head reversals or flows greater than the volume available in the donor grid cell. Mass of constituents (nutrients, salt/tracer) is passed along in a mass-balance calculation based upon the water volume flux between cells. Numerical dispersion due to the 1 km^2 grid scale and associated horizontal groundwater time step is assumed to approximate the (poorly known) actual physical dispersion associated with water flow velocities in this regional aquifer.

Groundwater Raster Flux Module Equations

Flux calculations

```
## All equations shown are calculated within an Alternating Direction (each iteration) spatial loop across model grid rows, columns
## [cellLoci] defines model grid address of cell "i"
## [cellLocj] defines model grid address of cell "j"
## Flux is positive/negative, from cell "i" to cell "j"

## Pairs of grid cells are checked for (static) flow attributes in the spatial loop.
## For a cell at [cellLoc_], the possible flow attributes are:
## ON_MAP[cellLoc_]=0 => External to the model active domain
## ON_MAP[cellLoc_]=1 => Allow (internal) flow in no direction (due to calculated levee-interaction geometry)
## ON_MAP[cellLoc_]=2 => Allow (internal) flow to east<->west (due to calculated levee-interaction geometry)
## ON_MAP[cellLoc_]=3 => Allow (internal) flow to south<->north (due to calculated levee-interaction geometry)
## ON_MAP[cellLoc_]=4 => Allow (internal) flow in all directions (due to calculated (no) levee-interaction geometry)

## If a single cell in a pair is external to the model domain (example, ON_MAP[cellLoci]=0),
## allowance of internal<->external flow depends on an attribute of the other cell (i.e., [cellLocj]):
## BCondFlow[cellLocj]=1 => Allow no flows external to model domain
## BCondFlow[cellLocj]=3 => Allow surface water flows to/from external boundary cell

## The function "Flux_GWcells" calculates and returns a cell-to-cell Flux in height units (m)
## The case is shown for when both cell i and j are internal to the model domain, with flow allowed between the cells.
## When one of the cells is external to the domain, and the pair of cells has been defined as allowing groundwater boundary flows, the stage of that external cell (cellLoci in this example) is estimated using:
##   HP_HYD_POROSITY[cellLoci] = HP_HYD_POROSITY[cellLocj]
##   and, when internal stage (tot_head_j) is greater than internal land surface elevation plus 20cm (SED_ELEV[cellLocj] + 0.20), estimates are:
##     SAT_WATER[cellLoci] = SAT_WATER[cellLocj]
##     SURFACE_WAT[cellLoci] = Max(SURFACE_WAT[cellLocj] - 0.3, 0.0)
##   or, when internal stage (tot_head_j) is less than/equal to internal land surface elevation plus 20cm (i.e., SED_ELEV[cellLocj] + 0.20), estimates are:
##     SAT_WATER[cellLoci] = SAT_WATER[cellLocj]-0.05
##     SURFACE_WAT[cellLoci] =  0.0
## Code exists, but is not executed in v2.2, to replace the estimated values with input stage data from another model (e.g., SFWMM).


    RCCONDUCT = (HYD_RCCONDUCT[cellLoci] + HYD_RCCONDUCT[cellLocj])/2.0
```

```
    tot_head_i = SURFACE_WAT[cellLoci] + SAT_WATER[cellLoci] / HP_HYD_POROSITY[cellLoci]

    tot_head_j = SURFACE_WAT[cellLocj] + SAT_WATER[cellLocj] / HP_HYD_POROSITY [cellLocj]

    deltaHEAD = tot_head_i - tot_head_j


## For positive head differences (if the deltaHEAD > GP_DetentZ),  assign the donor and recipient cell location attributes
    cell_don = cellLoci, cell_rec = cellLocj, sign = 1

## For negative head differences (if the deltaHEAD < - GP_DetentZ), assign the donor and recipient cell location attributes
    cell_don=cellLocj, cell_rec=cellLoci, sign = -1


## Potential cell-cell horizontal flux eqn (Darcy's eqn simplified to slope across square cells).
## This is the maximum (height of) water vol to flux under fully saturated conditions.
    Flux = Min(Abs(deltaHEAD) * GP_calibGWat * RCCONDUCT * SAT_WATER[cell_don] / CELL_SIZE * gwstep , SAT_WATER[cell_don]);


## The below is an iterative ("do while") routine that (1) integrates the surface, saturated, and unsaturated water, and (2) checks to ensure the heads do not reverse in a time step due to large fluxes.
## If heads do reverse, the total Flux is decremented in an iterative manner until there is no reversal

## The total potential flux is apportioned to (1) the horizontal component that fluxes to an adjacent cell and (2) the vertical component that remains in the donor cell after the horizontal outflow from a donor cell.
## Thus, an unsaturated zone is created, or increased in size, with loss of saturated water from the donor cell; this lateral gravitational flow leaves behind the field capacity moisture in an unsat zone. (If donor-cell surface water is present, it potentially will replace the unsaturated soil capacity within the same time step in this routine).

    fluxTOunsat_don = Flux / HP_HYD_POROSITY [cell_don] * (HP_HYD_POROSITY [cell_don] – HP_HYD_SPEC_YIELD[cell_don])

    fluxHoriz = Flux - fluxTOunsat_don


## Donor cell, new **post-flux** capacities
    UnsatZ_don  =   SED_ELEV[cell_don] - (SAT_WATER[cell_don]- fluxHoriz) / HP_HYD_POROSITY [cell_don]

    UnsatCap_don =  UnsatZ_don * HP_HYD_POROSITY [cell_don]

    UnsatPot_don  = UnsatCap_don - (UNSAT_WATER[cell_don]+fluxTOunsat_don)


## Donor cell, determining the pathway of flow (to sat vs. unsat) of surface water depending on depth of an unsat zone relative to the surface water.  With a relatively deep unsat zone, this downflow tends to zero (infiltration occurs within the vertical hydrology module of UnitMod.c)
    Sat_vs_unsat  = 1/Exp(100.0*Max((SURFACE_WAT[cell_don]-UnsatZ_don),0.0))
```

```
## Donor cell, sf-unsat-sat fluxes
## Surface water downflow is assumed to be as fast as horizontal groundwater outflows.
## In presence of surface water in the donor cell (only), the surface-to-saturated flow is determined.
    sfTOsat_don  = ( (1.0-Sat_vs_unsat)*UnsatPot_don>SURFACE_WAT[cell_don] ) ? ( SURFACE_WAT[cell_don] ) : ( (1.0-Sat_vs_unsat)*UnsatPot_don)

## With downflow of surface water into an unsat zone, the proportion of that height  that is made into saturated storage is allocated to the sat storage variable
    ## If surface volume downflow is larger than the unsaturated capacity, i.e., (sfTOsat_don >= UnsatPot_don)
        sfTOsat_don = UnsatPot_don

        unsatTOsat_don = UNSAT_WATER[cell_don]

    ##  Otherwise, allocate to saturated storage whatever proportion of unsat zone that is now saturated by sfwat downflow
        unsatTOsat_don = (UnsatZ_don > 0.0) ? ( (sfTOsat_don/ HP_HYD_POROSITY [cell_don] ) / UnsatZ_don * UNSAT_WATER[cell_don] ) : (0.0)

    H_pot_don = (SAT_WATER[cell_don] - fluxTOunsat_don - fluxHoriz + sfTOsat_don + unsatTOsat_don ) / HP_HYD_POROSITY [cell_don] +(SURFACE_WAT[cell_don] - sfTOsat_don)


## Recipient cell,  **pre-flux** capacities
    UnsatZ_rec  =   SED_ELEV[cell_rec] - SAT_WATER[cell_rec] / HP_HYD_POROSITY [cell_rec]

    UnsatCap_rec =  UnsatZ_rec * HP_HYD_POROSITY [cell_rec]

    UnsatPot_rec  = UnsatCap_rec - UNSAT_WATER[cell_rec]


## Recipient cell, sf-unsat-sat fluxes
    horizTOsat_rec = fluxHoriz

    satTOsf_rec = Max(fluxHoriz - UnsatPot_rec, 0.0)


## Recipient cell, incorporation of unsat moisture into sat storage with rising water table due to horiz inflow
    unsatTOsat_rec = (UnsatZ_rec > 0.0) ? ( ((horizTOsat_rec-satTOsf_rec)/ HP_HYD_POROSITY [cell_rec] ) / UnsatZ_rec * UNSAT_WATER[cell_rec] ) : (0.0)

    H_pot_rec = (SAT_WATER[cell_rec] + horizTOsat_rec + unsatTOsat_rec - satTOsf_rec) / HP_HYD_POROSITY [cell_rec] + (SURFACE_WAT[cell_rec] + satTOsf_rec) ;


## Check for a head reversal - if  a head reversal is > MinCheck, reduce the potential Flux by 10%, and cycle through above donor-recipient calculations until an equilibrium is achieved

## Update the water state variables
    SURFACE_WAT[cell_don]  += (-sfTOsat_don);

    UNSAT_WATER[cell_don]  += ( fluxTOunsat_don - unsatTOsat_don) ;

    SAT_WATER[cell_don] += (sfTOsat_don + unsatTOsat_don - fluxTOunsat_don - fluxHoriz);
```

```
SURFACE_WAT[cell_rec]  += ( satTOsf_rec);

UNSAT_WATER[cell_rec]  += (-unsatTOsat_rec);

SAT_WATER[cell_rec] += (horizTOsat_rec + unsatTOsat_rec - satTOsf_rec); /*
      (horizTOsat_rec + satTOsf_rec) = fluxHoriz */
```

The constituent state variables are updated in a set of mass balance calculations using the mass in the donor cell storage variables and the water flux among the variables

External variables used

SED_ELEV (see Soils module)

DOM_MAXDEPTH (see Soils module)

SURFACE_WAT (see Hydrology module)

UNSAT_WATER (see Hydrology module)

SAT_WATER (see Hydrology module)

SALT_SURF_WT (see Salt/Tracer module)

TP_SF_WT (see Phosphorus module)

SALT_SED_WT (see Salt/Tracer module)

TP_SED_WT (see Phosphorus module)

Module Variable and Parameter Definitions

Module variables

Variable Name	Type	Units	Description
Flux	rateActual	m/d	potential/actual horizontal flux of groundwater between grid cells
fluxTOunsat_don	ratePotential	m/d	donor cell, field capacity volume (height) remaining in unsaturated zone associated with a horizontal flux
fluxHoriz	ratePotential	m/d	the actual water volume (height) that may flux horizontally (leaving field capacity in donor cell)
Sat_vs_unsat	controlFunction	dimless	same control function (0,1) used in Hydrologic Module to determine relative pathway of flow from surface storage (into saturated vs. unsaturated)
RCCONDUCT	attribute	m/d	mean hydraulic conductivity of the donor and recipient cells
UnsatZ_don	attribute	m	donor cell, new unsat zone depth after calculated groundwater flow
UnsatZ_rec	attribute	m	recipient cell, old unsat zone depth before calculated groundwater flow
UnsatCap_don	attribute	m	donor cell, maximum pore space capacity in the depth of new unsaturated zone
UnsatCap_rec	attribute	m	recipient cell, maximum pore space capacity in the depth of old unsaturated zone
UnsatPot_don	attribu	m	donor cell, (height of) the volume of

	te		pore space (soil "removed") that is unoccupied in the unsat zone
UnsatPot_rec	attribute	m	recipient cell, (height of) the volume of pore space (soil "removed") that is unoccupied in the unsat zone
sfTOsat_don	ratePotential	m/d	donor cell, surface to saturated flow
unsatTOsat_don	ratePotential	m/d	donor cell, unsaturated to saturated flow
unsatTOsat_rec	ratePotential	m/d	recipient cell, unsaturated to saturated flow
H_pot_don	attribute	m	donor cell, potential new head
H_pot_rec	attribute	m	recipient cell, potential new head
horizTOsat_rec	ratePotential	m/d	recipient cell, horizontal inflow to soil into saturated storage (== fluxHoriz)
satTOsf_rec	ratePotential	m/d	recipient cell, upflow to surface beyond soil capacity

Time series forcing data

none (v2.3 and higher will have dynamic stage input data for grid cells along domain border)

Static global parameters (all grid-cells)

Parameter Name	Type	Units	Description
DT	global	day	Time step for vertical solutions
CELL_SIZE	global	m^2	surface area of a model grid cell
DetentZ	global	m	detention depth in a grid cell, below which surface flows do not occur
MinCheck	global	dimless	small threshold number, for relative error-checking (not a multiplier etc)
GP_calibGWat	global	dimless	calibration parameter, multiply groundwater cell-cell flow calculation
hyd_iter	global	dimless	number of horizontal iterations per ***DT***
gwstep = DT/hyd_iter/2	local	day	time step for horizontal groundwater solutions

Static habitat-specific parameters (linked to HAB value of grid-cell)

Parameter Name	Type	Units	Description
HP_HYD_POROSITY	hab-spec	dimless	Porosity of the aquifer, average from the sediment to base datum. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization. Must be non-

			zero.
HP_HYD_SPEC_YIELD	hab-spec	dimless	Proportion of total sediment/soil volume, for a given soil type, that represents water able to be drained by gravity. Field capacity = porosity - specific yield; ensure that alterations to porosity and specific yield are consistent in your parameterization.

Static spatially-distributed parameters

Parameter Name	Type	Units	Description
HYD_RCCONDUCT	distributed	m/d	HYDraulic CONDUCTvity Rate Constant of surficial aquifer

Intrinsic C or ELM functions

Min(x,y) => minimum of variable x or y

(x) ? (y) : (z) => if (x is true, or 1), then (return value y), else (return value z)

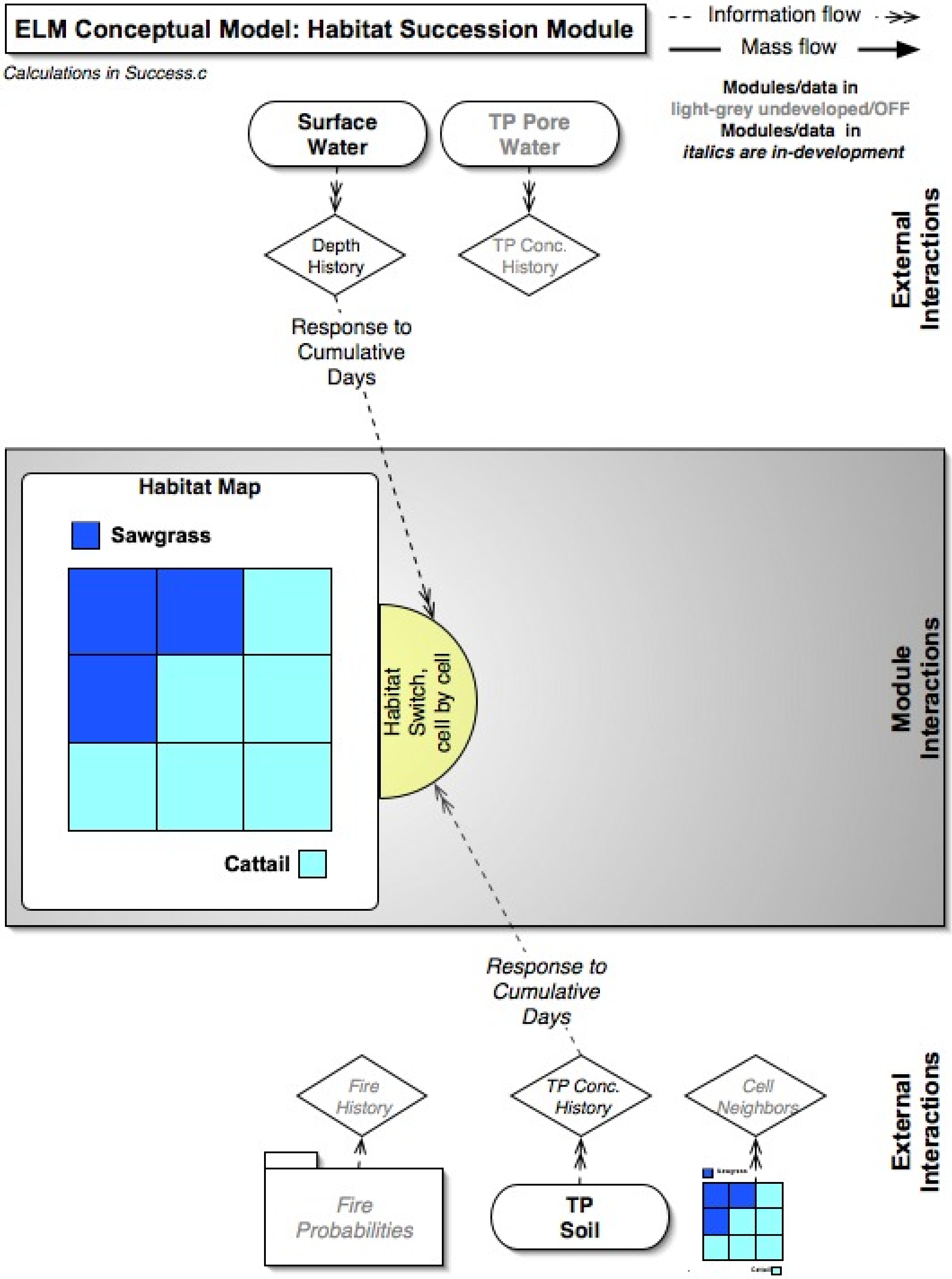
ABS(x) = Abs(x) => absolute value of (x)

(x) != (y) => logical condition where (x) is not equal to (y)

if (x) equation => if (x) condition is true (==1), then execute `equation`

T(x,y) => single-integer array address of grid cell at location row x, column y (used in [cellLoc_])

5.8 Habitat succession module



Overview: Succession Module

The habitat succession module in ELM v2.5 is a simple switching algorithm that responds to cumulative history of surface water and soil phosphorus. The design and performance was described in an earlier version (ELM v1.0) of a subregional application (Fitz and Sklar 1999).

Succession Module Description

Habitat succession was simulated by simple switching algorithm based on the cumulative impacts of both soil phosphorus and water depth. For each cell we evaluated the number of weeks that contained conditions favorable for each targeted habitat type, switching to the new habitat type when conditions merited. Each model cell was evaluated on a daily basis to determine if a) the soil phosphorus concentration was within the range defined by the habitat-specific parameters HP_PhosLo and HP_PhosHi and b) the ponded surface water depth was within the range defined by HP_SfDepthLo and HP_SfDepthHi. If a cell met either criteria for a targeted habitat, a counter was incremented for that habitat type, regardless of the cell's current habitat type designation. When counters for phosphorus and water depth conditions in a cell exceeded the criteria for the elapsed number of weeks defined by HP_PhosInt and HP_SfDepthInt, respectively, for a different habitat, the cell's habitat type classification switched to the new type and counters were set to 0. For this version, we considered the switching among three habitat types: sawgrass, cattail, and a mixture of sawgrass and cattail.

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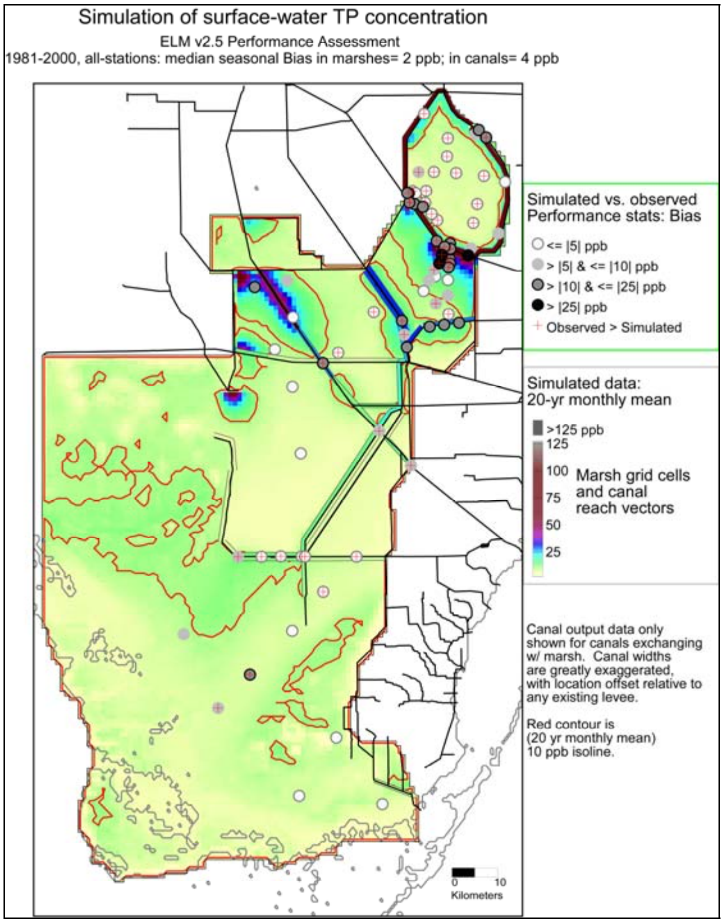
Documentation of the
Everglades Landscape Model:
ELM v2.5

Chapter 6: Model Performance



Simulation of surface-water TP concentration

ELM v2.5 Performance Assessment

1981-2000, all-stations: median seasonal Bias in marshes= 2 ppb; in canals= 4 ppb

Canal output data only shown for canals exchanging w/ marsh. Canal widths are greatly exaggerated, with location offset relative to any existing levee.

Red contour is (20 yr monthly mean) 10 ppb isoline.

http://my.sfwmd.gov/elm

July 10, 2006

Chapter 6: Model Performance

6.1 Overview

As described in the Introduction Chapter of this documentation, an overarching Goal of the ELM is to understand and predict ecological dynamics across the greater Everglades landscape. For the current ELM v2.5, the specific Objectives of the model application are those of the two ecological Performance Measures that involve the "water quality" aspect of ecosystem dynamics across the landscape: 1) surface water phosphorus concentration, and 2) accumulation (net load) of phosphorus in the ecosystem.

The overall approach of (developing and) calibrating the ELM was to start by simplifying the complex Everglades ecosystems by processes and by space. Generally, this involved first considering the most important ecosystem "drivers" within a simplified spatial domain. The hydrology and water quality drivers were evaluated using a variety of statistical and visualization methods. Hydrologic performance was generally evaluated and calibrated first, followed by water quality and its associated ecosystem dynamics. A stepwise, hierarchical process followed, evaluating each module of the total system behavior. In this context of the fully integrated ELM, specific aspects of water column phosphorus calibration are required to be associated with reasonable behavior in other ecosystem properties. The best model parameter set becomes that which provides acceptable performance of the primary model application Performance Measures, while maintaining other ecosystem dynamics that are, at minimum, consistent with our best understanding of the Everglades.

In its regional (~10,000 km^2) application at 1 km^2 grid resolution, the current ELM version 2.5 is available to assess relative differences in ecological performance of Everglades water management plans - at decadal time scales. Hydrologic performance of the ELM is comparable to the South Florida Water Management Model within the Everglades. While consistency with that primary tool for Everglades water management is important, the focus of ELM is on the associated ecological assessment. Extensive data are available for calibrating-validating surface water phosphorus (P) concentrations; during a 2-decade period, the model had a 2 ug L^{-1} (ppb) median bias in predictions of that Performance Measure within the marshes and canals. Predicted P accumulation along a multiple- decade eutrophication gradient showed a high degree of concordance with P accumulation estimates from radionuclide markers. With other predicted ecological attributes and rates being consistent with available observations, there is cumulative, strong evidence of model skill in predicting phosphorus trends in the regional Everglades landscape at the relevant decadal time scales.

6.2 Performance expectations

6.2.1 Model application niches

For model users and stakeholders, a fundamental concern is simply: how well does the model work? To be useful, it is critical that model goals and objectives are clearly stated, and that the design and performance of the model is shown to meet those goals. Towards this end, it is critical that a model is understood within the context of its "application niche" (as discussed by D.P. Loucks[1]). The application niche should be a juxtaposition of A) the real or perceived needs of the "users" and B) the realistic capabilities portrayed by the model developers. The intersection of A & B is the intended target of the model application – a basic point that is sometimes lost in practice as a result of inadequate communication.

6.2.2 ELM v2.5 application niche

The ELM application niche is broadly defined in the Introduction Chapter of this documentation, is specified in detail in the Model Application Chapter, and demonstrated in practice in this Model Performance Chapter. The model Performance Measures to be used in comparing relative benefits of alternative management plans define the specific Objectives of the model, including the spatio-temporal scale of application. While there are requests (and expectations) for ELM to address a larger suite of ecological questions, the relatively narrower subset of *current* model Objectives defined by the Model Developers should be considered to be the *current* application niche of the ELM. It is this application niche that is to be considered when evaluating the ELM.

As described in the Introduction Chapter of this documentation, an overarching Goal of the ELM is to understand and predict ecological dynamics across the greater Everglades landscape. For the current ELM v2.5, we emphasize that the available ecological Performance Measures are those involving the "water quality" aspect of ecosystem dynamics across the landscape: 1) surface water phosphorus concentration, and 2) net accumulation of phosphorus in the ecosystem.

6.2.3 Establishing performance expectations

6.2.3.1 ELM

The expectations of hydrologic simulations in the Everglades are reasonably well-understood by most users. Perhaps this is largely due to the context of hydrologic modeling in south Florida, which has a multi-decadal history of applications, with a relatively well monitored system in which the physics are reasonably well understood.

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[1] D.P. Loucks of Cornell University made a variety of recommendations on modeling and peer review to the South Florida Water Management District in: Loucks, D. P. 2003. Modeling and Peer Review Protocols for Use in HSM (OOM) and IMC for CERP and RECOVER. Report to SFWMD, West Palm Beach.

There is less of a common understanding of the expected performance of regional Everglades models that simulate ecological (including water quality) dynamics. Nutrients are subject to many more processes (such as uptake by plants, release by soils, etc) than are water depths. Moreover, there is about an order of magnitude fewer observed data available relative to hydrologic data (in the Everglades): the quantity of water flowing into a basin may be reasonably well-known on a daily basis, but the associated nutrients are generally sampled less than 5 - 10% of that time (see the Data and the Uncertainty Chapters). Observations in the marsh, used to compare to the model output, can be even less frequent than those input data. This combination of very infrequent data collections in the Everglades, along with highly-variable, random processes, necessitates the more complex assumptions for any water quality or ecological model relative to those involving physical hydrology.

6.2.3.2 Other Everglades hydrologic models

The South Florida Water Management Model (SFWMM, sometimes referred to as the "2x2") is the primary tool used to evaluate managed hydrology in the south Florida landscape, including the greater Everglades region. This model was used to evaluate relative hydrologic benefits under different water management alternatives for the Comprehensive Everglades Restoration Plan (USACE and SFWMD 1999), in addition to a wide variety of other planning applications. The two-mile by two-mile square (~10.4 km^2) grid of the SFWMM has a relative accuracy in predicting stage that has been well-accepted for evaluating water management alternatives for the greater Everglades and much of south Florida in general. The documentation for the SFWMM v5.5 is available at:

http://www.sfwmd.gov/org/pld/sfwmm_doc/menu.htm

which includes statistical evaluations of the model performance in predicting stage in the greater Everglades. For the 82 marsh stage monitoring locations common to the ELM domain, the statistical comparisons of SFWMM daily output data to daily observed data indicated very good performance, as indicated by the median values for each statistic: $R^2 = 0.81$, Nash-Sutcliffe Efficiency = 0.67, Root Mean Square Error = 0.12 m, and Bias = 0.0 m. The computational methods used in these statistics are the same as those defined later in this chapter.

As a "second generation" simulator of managed hydrology in south Florida, the South Florida Regional Simulation Model (SFRSM,

http://www.sfwmd.gov/site/index.php?id=342)

is designed to have significantly increased flexibility and model performance relative to the current SFWMM. While portions of the SFRSM are still under development, its advanced design, and the very good performance of early prototypes, indicate that it will provide significant improvements as a replacement for the SFWMM in the future.

6.2.3.3 Other Everglades water quality models

A modeling effort that was accepted to evaluate water quality throughout most of the Everglades region is the Everglades Water Quality Model (EWQM). The EWQM was used in evaluating phosphorus surface water quality under different water management alternatives for the Comprehensive Everglades Restoration Plan (CERP) (USACE and SFWMD 1999). Raghunathan et al. (2001) presented evidence that the model was reasonably well calibrated relative to its objectives of predicting phosphorus transport and fate under different strategies of reducing phosphorus inputs across this large region. Specific statistics were provided in a referenced report (Limno-Tech 1997), which showed that (during the 1979 to 1989 simulation period) the mean observed vs. predicted phosphorus concentrations within most of the hydrologic basins differed by 6 – 23 ug l^{-1}, while one basin (WCA-1) exhibited differences >100 ug l^{-1}. The presented range of spatial and temporal variations in modeled phosphorus accumulation rates within WCA-2A usually overlapped the point estimates of measured phosphorus accumulation rates. As a tool for making relative comparisons of project alternatives within most Everglades basins, the model was judged acceptable for CERP planning purposes. However, refinement of the model was discontinued, and it is no longer available.

6.3 Performance evaluation methods

The methods of evaluating and improving the performance of a distributed, integrated ecological model are wide ranging, usually involving both analytic tools and science-based judgments. Ultimately one seeks to communicate the cumulative evidence of how well the model meets its objectives: an evaluation of the model performance in history-matching is a fundamental component of that communication. Here we attempt to summarize the methods that we used in evaluating the ELM performance.

6.3.1 Calibration process

Definitions abound, but a reasonably concise definition of the calibration of distributed simulation models is “the adjustment of model parameters in order to improve the match between simulated and observed spatio-temporal dynamics”. Improving this history-match for a model, however, involves much more than parameter adjustments. Model performance is the net result of multiple model development & refinement decisions, including the selection of algorithms and their aggregation, the influence of initial & dynamic boundary conditions, and the understanding and accounting for the wide range of other uncertainties associated with models (e.g., see Uncertainty Chapter). In this methodological summary, we do not attempt to characterize the past decade of ELM refinement and calibration, with performance improvements as our understanding (i.e., data) of the landscape advanced. Rather, we generically summarize how to take advantage of the basic design of the model to evaluate the model performance, and improve the history-match via selective adjustment of the most sensitive, or important, parameters.

Thus, this methodological section does not explicitly describe the interplay between research and modeling, nor the decisions made in improving algorithms or in data synthesis. The rationale for, and results of, those critical modeling decisions are described in the Data, the Model Structure, and the Uncertainty Chapters (each including references to associated publications). Given an “acceptable” assemblage of model code and boundary condition data, the basic steps in parameter adjustment to best meet the ELM goals and objectives are summarized here.

6.3.1.1 Parameter optimization

Parameter optimization is optionally part of the process of calibrating models. Towards this end, automated parameter optimization procedures are rapidly becoming an integral component of calibrating simulation models, most notably for physically based groundwater and other hydrologic models. Although we have recently explored methods for parameter optimization in integrated ecological models (Villa et al. 2004), we have not yet utilized formal, automated optimization methods. One conceptual constraint has been the development of objective functions (for the targeted behaviors) that incorporate the non-linear spatial and temporal interactions among multiple variables. Nevertheless, for optimizing specific (e.g., hydrologic) variables in a model such as the ELM, there may be increasing feasibility in using newer parameter optimization methods to improve model performance. At this point, in lieu of automated calibration procedures, we employ “manual” calibration methods in a hierarchical, or stepwise, process of increasing complexity associated with the modeled processes and spatio-temporal scales.

6.3.1.2 Calibrating integrated ecosystem models

The ELM simulation involves the dynamic spatio-temporal interaction among a suite of fundamental ecosystem variables and processes. As discussed in the earlier Chapter on “Ecological Models: Wetlands”, the number of interacting model processes increases the complexity of this modeling approach. An integrated ecosystem design, however, can lessen the degree to which the model is dependent upon historical correlations, increasing the degree to which the model responds mechanistically to (previously unobserved) input forcing data. An integrated model that explicitly considers such responses can potentially be applied across a broader range of input conditions than a more statistically-derived model that is restricted to envelopes of past observations.

Another important aspect of this integrated design is that each of the whole- ecosystem components (or modules) are explicitly evaluated in space and time, enforcing the need to verify that each component of the ecosystem behaves realistically. Our modeling process does not “allow” for final performance evaluations to be restricted to an isolated component of the system; the dynamics of each fundamental component are explicitly considered to some level.

Achieving integrated and balanced cycles of elements in models of complex ecosystems requires a significant investment of effort in system understanding and synthesis. The cybernetic nature of ecosystems has evolved over millennia, and it is unlikely that its actual complexity can be captured by computer simulation anytime in the near future. However, synthesizing the fundamental drivers and emergent properties of basic ecosystem interactions is a feasible goal – as outlined in this ELM documentation report.

The ELM described in this documentation, with its core General Ecosystem Model (Fitz et al. 1996), simulates a simple yet complete carbon cycle of an ecosystem: atmospheric carbon is fixed by living plants, incorporated into dead organic matter, and lost from the system via oxidation. Likewise, a comprehensive phosphorus cycle is incorporated, including dynamic stoichiometry associated with the flows among the fundamental “live” and “dead” phosphorus storages. The hydrologic cycle is also complete, considering surface and subsurface storages and flows. A calibration of one ecosystem component in ELM must be achieved in tandem with realistic behavior in the rest of the ecosystem components. This is not the case in simpler models of (an) isolated ecosystem component(s), in which the behavior of the remaining ecosystem components is not considered.

Thus, the calibration goals of ELM extend beyond the specific Performance Measure to be used in model applications. In integrating a simple representation of a complex ecosystem, one ELM calibration goal is to obtain output of principal ecosystem properties that not only are mass-balanced[2], but that exhibit realistic dynamics across space and time. The definition of this realism is dependent on the spatial and temporal quality of available data that are specific to the Everglades, as presented in the results of this Chapter. More specific calibration goals involve the scrutiny of formal Performance Measures that are specific to the intended applications.

For the current ELM v2.5, our intended applications target phosphorus “water quality” Performance Measures (see Model Application Chapter). In this context of the fully integrated ELM, specific aspects of water column phosphorus calibration are required to be associated with reasonable behavior in other ecosystem properties. For example, in early development efforts we observed model parameter sets that exhibited statistically-acceptable water column P concentrations, but which were suboptimal because they also were associated with less-realistic rates of processes such as soil accretion or periphyton growth. The best parameter set becomes that which provides acceptable performance of the primary model application Performance Measures, while maintaining other ecosystem dynamics that are, at minimum, consistent with our best understanding of the Everglades.

There is no mathematical “guarantee” that the current parameter set is unique and optimal. However, the tightly interactive nature of the algorithms highly constrains the range of parameter values that result in acceptable whole-ecosystem dynamics. These “final” results (for any particular model version) are intended to demonstrate realistic ecosystem behaviors across a heterogeneous, regional landscape within decadal time scales of ecological relevance. Thus, the methods of evaluating the general performance, and the more specific application Performance Measures, are intended to demonstrate a reasonable degree of confidence in the application of the ELM under widely varying environmental inputs.

6.3.1.3 Processes and scales

The overall approach of (developing and) calibrating the ELM was to start by simplifying the complex Everglades ecosystems by processes, by space, and to some extent by time. Generally, this involved first considering the most important ecosystem drivers within a simplified spatial domain. The calibration procedure paralleled that used in our stepwise, hierarchical sensitivity analysis (see Uncertainty Chapter). The intensively studied and spatially simple domain of Water Conservation Area 2A (WCA-2A) was used as an important test bed for improving our understanding of simulated and observed behaviors. Hydrologic and nutrient transport/fate were considered important ecosystem drivers, and their dynamics were scrutinized in the subregional application. This model testing and parameter refinement process was iterated until the performance of the targeted

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[2] Mass balance is ensured by the code design, and is verified in detailed budget outputs at multiple spatial and temporal scales. See the User’s Guide Chapter for further details.

variable(s) was deemed suitable for interim calibration purposes. That iterative sequence then expanded in scope, evaluating a broader suite of model ecosystem components along with those important ecosystem drivers. Where appropriate, the lessons-learned from this intensively studied area were subsequently applied at the larger spatial domain of the regional Everglades landscape.

From the perspective of numerical solutions, the ELM was designed to be scaleable, in that the same source code, parameters, and (where appropriate) boundary conditions are used in model applications at different grid scales and domains. For example, in the case of processes which are usually scale-dependent, such as horizontal dispersion of surface water constituents, the algorithms were designed to ensure consistency of results across a range of grid scales, as described in the Model Structure Chapter. Of course, if raw data support higher resolution variables such as initial land surface elevation, processes such as water flows will potentially respond differently to fine vs. coarse scale spatial data. However, if coarse-resolution (e.g., 1000 m) input map data are simply resampled into finer grid resolutions, the results across scales are very similar. Depending on the application, some differences can still exist when using such resampled data because of the influence of scale-dependent implementations of other boundary condition grid data, and scale-dependent raster-vector topology of water management features (i.e., canals and water control structures). While of interest for landscape pattern and other analyses, such scaling considerations are not explored in detail in this documentation, which primarily focuses on the regional (greater Everglades) 1000 m grid scale application.

While the subregional model applications can be used to address specific questions that involve processes and patterns at fine spatial resolution, these applications were developed largely as a learning tool in order to improve the performance of the regional ELM. Relative to the greater Everglades region, there are substantially fewer habitat types and less complex water management features in a basin such as WCA-2A. Additionally, finer-scaled subregional applications aided our understanding of the influence of boundary conditions, and helped determine optimal ways to represent fine-scaled features at the 1000 m regional grid scale. For example, the 500 m grid scale subregional application was used to explore finer scaled spatial patterns and flows in WCA-2A, relative to the 1000 m subregional application for that domain, and relative to the 1000 m grid regional (greater Everglades) application. Similarly, a 200 m grid subregional application in Water Conservation Area 1 (WCA-1, or A.R.M. Loxahatchee National Wildlife Refuge) provided useful insights into the complexity of the topographic relationships in the marsh-canal (raster-vector) hydrologic exchanges along the uninterrupted “perimeter” canal bordering that entire basin’s domain.

Because even the regional simulation run-times are short[3], most simulations included the entire 1981 – 2000 period of record, with post-processing evaluations made either on the initial 1981-1995 calibration period, the 1996-2000 validation period, or the entire simulation period. However, the model can simulate any user-selected time period for which initial and dynamic boundary condition data are available. As indicated in the

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[3] See User’s Guide Chapter; a modern PC executes a 20-year simulation of the regional ELM in slightly over one hour.

Model Application Chapter, meteorological (but not water control structure flow) boundary condition data are available for the period from 1965 – 2000.

6.3.1.4 Hydrologic calibration

The first step in the ELM calibration process is to "get the water right", as the physics of the Everglades are a primary driver of the other ecological dynamics across the landscape. The user can edit the ELM runtime configuration file to select the desired combination of vertical and horizontal solution modules. By simply "turning off" all vertical modules except those of hydrology and a tracer, the ELM can be run as a stand-alone hydrologic model, without any dynamic feedbacks from time-varying vegetation or soils.

The model sensitivity analysis in the Uncertainty Chapter provides a summary of the relative sensitivity of the global (GP_*) and habitat-specific (HP_*) parameters, which are fully defined in the Data Chapter. The following are the principal parameters that were adjusted in hydrologic calibration:

- Evapotranspiration (GP_calibET, HP_MAC_MAXLAI)
- Surface roughness (HP_MAC_MAXROUGH, and to some extent, HP_MAC_MINROUGH)
- Groundwater flows & storage (GP_calibGWat, and to some extent, HP_HYD_POROSITY)
- Levee seepage & (spatially rare) canal berm/lip-roughness (Seep, edgeMann)

Depending on the status of the calibration process (i.e., seeking preliminary ball-park accuracy, or more accurate near-final history-matching), a variety of comparisons were made between output and target data. Some targets were "soft" performance indicators, such as basin-wide flow budgets from the SFWMM that included groundwater and levee seepage flows. The primary calibration targets were more rigorous comparisons of simulated and observed stage elevations at monitoring sites distributed throughout the landscape. While short-term (ca. hours/days) overland flow velocities were not explicitly calibrated (due to lack of data), spatial and temporal distributions of a longer-term chloride "natural" tracer were evaluated after fundamental within-basin budget characteristics were deemed reasonable.

When the objectives of the current iteration of the calibration process were completed, the remaining (non-hydrologic) ecological modules were invoked in the configuration file, and the performance re-evaluated and refined if needed. Generally at this point, the calibration process moved into phosphorus water quality calibration, with its associated ecosystem dynamics.

6.3.1.5 Ecological calibration

The next major step in the ELM v2.5 calibration process was refinement of the phosphorus water quality performance characteristics. Because of the tightly-coupled code among soils, floc, macrophytes, periphyton, and surface/ground- water phosphorus, all (or none) of those modules must be executed during ecological simulations, i.e., selected in the runtime configuration file[4]. While the primary application goal for this ELM v2.5 is related to “water quality”, we emphasize that water column phosphorus and its associated model performance evaluation is coupled to multiple ecosystem processes, and the demarcations among “water quality” and the rest of the ecosystem are somewhat blurred in the process of model calibration.

The model sensitivity analysis in the Uncertainty Chapter provides a summary of the relative sensitivity of the global (GP_*) and habitat-specific (HP_*) parameters, which are fully defined in the Data Chapter. Without repeating those that also significantly affect hydrologic performance, the following are the principal parameters that were adjusted in water quality (and associated ecological) calibration:

- Periphyton (GP_ALG_RC_MORT, GP_ALG_RC_PROD, GP_C_ALG_KS_P)
- Soils (GP_DOM_DECOMP_POPT, GP_DOM_RCDECOMP, GP_TP_K_SLOPE)
- Water column P (GP_TPpart_thresh)

Other parameters, such as the net production and the mortality rate of macrophytes (HP_PHBIO_RCMORT , HP_PHBIO_RCMORT) were adjusted primarily in the context of improving performance characteristics of other components of the ecosystem. In that context, the primary calibration parameters in the list above were not necessarily always adjusted for water column phosphorus performance goals, but for capturing other ecosystem dynamic characteristics: soils, in particular, were a truly fundamental integrator of the model ecosystem dynamics. The spatial and temporal relationships among 1) the production and mortality of plants with 2) the concomitant rates of soil accretion, in 3) response to wetting/drying and phosphorus inflows, determined the degree to which the model captured the basic dynamics of the Everglades wetlands.

6.3.2 Validation process

More so than in the case of calibration, there are many interpretations of the definition of model “validation”. As discussed in the Uncertainty Chapter, whether “classical validation” can be effectively used in the practice of model applications is questionable. A model may be claimed to be validated in the classical sense when the period of simulation is extended somewhat in time with previously- unused input data, even when the important drivers (e.g., rainfall, nutrient loads) in the new period of simulation are effectively similar to those observed during the calibration period. Importantly, after a “classical” validation, any change to model code or parameters requires that the new model version be validated again. Most desirable for confidence in model utility is the demonstration of useful model performance across as large a range of system drivers as possible. Thus, without attempting to subjectively define “validation” requirements, the confidence in the model utility can advance as knowledge of the system behavior

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[4] During initial development and refinement of the ELM (prior to v2.1), the algorithms’ code supported the ability to turn off (not execute) any combination of the vertical solution modules, maintaining the associated variables at constant values throughout the simulation. Subsequent development has encoded an even tighter integration among non-hydrologic modules, with some state variables being updated in multiple modules. Thus, all of the non-hydrologic modules need to be executed during an ecological simulation; otherwise, phosphorus mass balance violations will be shown in the budget outputs. In order to facilitate the initial testing of new modules, such as nitrogen biogeochemistry, the ELM code will be revised to once again provide that option for running a simulation with static variables in any of the modules.

advances, with concomitant advances in model refinement. The objective is thus to increase the confidence in the model capabilities.

Despite the difficulties in attempting to define and adhere to validation paradigms, we “classically” validated the ELM with the update from ELM v2.1 to the interim ELM v2.2. We had previously demonstrated the ELM calibration performance during the 17-year period from January 1979 – December 1995 (ELM_Team 2002). Because the behavior of the entire regional domain of ELM during those years had been used in the calibration, the “classical” validation of the model involved the period of simulation update from January 1996 – December 2000. This interim update to ELM v2.2 was used to demonstrate the “classical” validation of the model in predicting water stage and surface water phosphorus concentrations.

As described in the Data Chapter and another section of this Chapter, important forcing data within the calibration period were modified as a result of quality assurance processes at the South Florida Water Management District. Time constraints prevented us from formally recalibrating the ELM during the previously-used 1979-1995 period for the interim v2.2, and instead we evaluated the model performance when using all of the newly available (and theoretically improved) data. For purposes of validating the algorithms and parameters used in the ELM v2.1, the ELM v2.2 had no changes to dynamic calculations in the equations, nor were there effectively changes[5] to model parameters. Statistical evaluations of the differences in observed vs. simulated water stage and surface water phosphorus concentrations were used to evaluate the (1981-1995) calibration and (1996-2000) validation performance of ELM v2.2, in addition to comparing ELM v2.2 and v2.1 during their common period of simulation. As noted in another section of this Chapter, some model refinements were subsequently made to take advantage of enhanced Everglades understanding (data), leading to the current release of ELM v2.5.

6.3.3 Performance evaluation methods

6.3.3.1 Statistical metrics

Simulated data were compared with observations obtained from the South Florida Water Management District’s databases (see Chapter on Data Description). For statistical evaluations of the hydrologic performance, at each monitoring site distributed throughout the region we compared daily predicted and observed stages using calculations of the correlation coefficient (R^2), Bias, root-mean-square-error (RMSE), and Nash-Sutcliffe Efficiency (Eff). These statistical metrics are the same as those used for the SFWMM

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[5] While the intent was to leave all parameters identical to those in ELMv2.1, two parameters were modified due to the use of potential evapotranspiration (pET) input data, in lieu of internal calculations of that potential from raw meteorological data that was input to ELM v2.1. In that version, part of the method of determining pET involved calculating plant canopy transpiration in response to the calculated saturation vapor pressure deficit. In v2.2 (& higher), the plant-contribution to actual ET required adjustment through the maximum Leaf Area Index in some habitats (that had relatively high maximum values) in order to approximately match actual ET in ELMv2.1 and v2.2. Specifically, the maximum Leaf Area Index parameter for several habitats required a reduction to a value of no greater than 3.5 in any habitat, and the global (across the domain) pET calibration mulitplier parameter was modified slightly (from 1.05 to 0.90). These parameters were modified prior to viewing output from the 1996-2000 extension of the simulation.

(and other hydrologic models), and are well- supported by the spatial and temporal scales and quality of the input data.

For evaluating the water quality performance, we compared temporal aggregations of predicted total phosphorus (TP) concentration in surface water, using metrics of the Bias and RMSE (ug l^{-1}). For these evaluations, the simulated and observed TP concentration data were aggregated into "bins" of arithmetic means within wet (May 1 – September 30) and dry (October 1 – April 30) seasons within each water year of the simulation period. The input data do not support useful time series comparisons for these water quality evaluations (see the earlier section in this Chapter, and supporting data analyses in the Uncertainty Chapter). Moreover, the application Performance Measures are targeted to long term eutrophication trends. For these reasons, the statistical metrics of model performance did not include time series goodness of fit measures, the dynamics of which are subject to the data uncertainties discussed elsewhere. Rather, we determined the magnitude of offsets between observed and simulated data at the monitoring sites, in order to evaluate how well the model captured the long term, spatially distributed (gradients of) eutrophication of the ecosystems across the greater Everglades spatial domain.

See the Appendix A of this Chapter for computational methods for these statistics.

6.3.3.2 Graphical indicators

In order to further evaluate the model performance, we used a variety of quantitative graphical methods that are useful relative indicators of performance through space and time. Stage hydrographs of simulated and observed data (shown relative to the dynamic land surface elevation) at each monitoring site provide insight into any specific periods of time when the simulated stage departs from corresponding observed data. These graphical comparisons are shown at several levels of temporal aggregation: none (daily), seasonal, and water-year, including the 95% Confidence Intervals of data for the temporally-aggregated data. Cumulative Frequency Distributions (and 95% Confidence Intervals) of simulated and observed stages are provided for each location, providing a rapidly- visualized period-of-simulation performance summary within and among monitoring sites. Similarly, time series and Cumulative Frequency Distributions are provided for comparing observed and simulated TP concentrations in surface water at each monitoring site. To minimize the potential for users to "erroneously" infer instantaneous point comparisons at each monitoring site, we only present the temporally-aggregated data, with their associated 95% Confidence Intervals.

An important component of determining the performance of this model involves an evaluation of eutrophication gradients in the Everglades. The most intensively studied area (with respect to length of time and number of processes/variables) is the strong eutrophication gradient in Water Conservation Area 2A (WCA-2A). Two research and monitoring transects downstream of inflow water control structures have been used to document and understand phosphorus eutrophication in the Everglades (multiple references, with many summarized in (McCormick et al. 2002)). Comparisons of simulated and observed data on water column phosphorus concentration, net accumulation of phosphorus in the ecosystem, and other ecosystem attributes are shown relative to the distance from the upstream source of the water and nutrient loading.

6.3.3.3 Indicators of consistency

The above statistical and graphical comparisons of simulated and observed data are a fundamental component of evaluating the “model skill” in capturing the specific Performance Measures and related ecosystem dynamics. Beyond those comparisons, there are other indicators of how well the model performs, including indicators of its consistency relative to other models and relative to other, less rigorously quantified, ecological patterns and trends. These indicators of consistency may involve varying degrees of numerical analyses, but their presentation is intended to increase the cumulative weight of evidence that the model realistically portrays the landscape dynamics.

Hydrologic flows

One useful hydrologic flow indicator is the relative comparison of the basin-wide hydrologic budgets of the ELM and the SFWMM. The SFWMM is currently accepted for management applications, and is used to provide output data on managed water control structure flows to other models such as the ELM when simulating future scenarios. It is therefore useful to provide another measure of its consistency with the SFWMM, beyond the two models’ stage calibration statistics. We make these budget-comparisons through a quantitative graphical comparison for each of the principal flows constituting the managed hydrologic budget for each year in the simulation. For a finer scaled comparison in space, we also present side by side summary maps of the long-term hydroperiod in the greater Everglades domain that is common to both models.

Another indicator of the relative accuracy of water flows is an evaluation of the simulated vs. observed data on chloride concentration in surface waters. As discussed in the Data Chapter, chloride is assumed to be a conservative tracer of flows, although the available spatial and temporal sampling constrains its use to that of relatively coarse indicator of relative water flow regimes. In the freshwater Everglades, the chloride input concentrations are sampled at the same frequency (with similar missing data constraints), at most of the same input water control structures, as phosphorus. Thus, the same temporal data quality constraints apply to chloride model inputs, and the associated analyses of model performance are simply presented as the percent difference in the mean simulated and observed values, relative to the observed values[6]. As with the surface water phosphorus graphical analyses, the aggregated time series and Cumulative Frequency Distributions are provided for comparing observed and simulated chloride concentrations in surface water at each monitoring site distributed throughout the greater Everglades.

Landscape patterns

The spatial patterns of ecosystem dynamics are integral to the overall goals this landscape model. In the above method descriptions, we summarize a rigorous suite of analyses of the spatial and temporal trends in model and observed data that relate to the phosphorus “water quality” Performance Measures intended for ELM v2.5 application. In particular,

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[6] This simple relative index is generally more useful for chloride than for phosphorus, as the latter is commonly found in background (or unimpacted-region) concentrations that are extremely low (<10 ug l-1, close to the detection limit of 4 ug l-1). Thus, at a site whose mean is 8 ug l-1, a 4 ug l-1 difference between simulated and observed data is well within the margin of data uncertainty and appropriate modeling expectations, yet would exhibit a high relative error of 50%.

the spatial distribution of these measures of performance are an important consideration in evaluating the ELM. Beyond the gradients of those spatially distributed “point” measures, we present summary output maps as general indicators of the model consistency with spatial patterns of eutrophication gradients. These multi-decadal summaries of variables related to phosphorus eutrophication are shown for visualization of the spatial trends in variables that include soil phosphorus concentrations and cattail succession. These spatial summaries are not part of the intended model application Performance Measures, and are thus provided only as indicators of the degree to which the regional landscape trends are captured in the simulation.

There are existing observed data that can be used to generate landscape maps of soil attributes and habitat types, and we have made spatial comparisons of simulated and observed patterns in earlier subregional versions of ELM (Fitz and Sklar 1999). Those types of comparisons will be extended in spatial domain, and expanded with respect to their evaluation methods. Moreover, we have initiated potential collaborations[7] to investigate the application of multivariate geographic clustering applications (Hargrove and Hoffman 2005, Hoffman et al. 2005) to synthesize the multiple outputs of ELM into aggregate habitat types involving more than vegetation type alone. We anticipate that the next release, ELM v3.0, will be used to evaluate more of the spatial and temporal patterns of ecosystem variables distributed across the greater Everglades landscape.

6.4 Model updates

As described in other Chapters, the current release[8] ELM v2.5 has a number of improvements over the last release, ELM v2.1. However, the principal dynamic algorithms and most of the associated parameters used in ELM v2.5 are largely the same as those in the prior v2.1. Some of the primary differences among versions are associated with updated data used for boundary conditions, including some initial conditions (primarily land surface elevation). As discussed in an earlier section of this Chapter, prior to adjusting most parameters or source code, we evaluated the model performance using those improved data sets, including an extended period-of-simulation that encompassed the years 1981-2000 (vs. through-1995 in v2.1). That first interim data-driven update (v2.2) was used to “classically” validate the response of the model to new data forcing data.

In updating from the interim ELM v2.2 to the current ELM v2.5, the primary modifications that influenced model calculations involved the inclusion of dynamic stage input data along the edges of the domain boundary. This included daily stage along freshwater (generally urban and agricultural) lands, and monthly tidal fluctuations along the Florida Bay and Gulf of Mexico boundaries. The calculated slope of canal reach vectors was modified to be constant from beginning to ending points (instead of following land surface contours), and a canal parameter was added to allow the incorporation of a “lip” or berm along the side of a canal that does not include a levee.

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[7] Personal communication, W. Hargrove, Environmental Sciences Division, Oak Ridge National Laboratory

[8] For simplicity, any full public release version is denoted only by the primary and secondary version attributes (see Model Refinement Chapter). The tertiary version attribute of this July 10, 2006 model release is ELM v2.5.2. Any subsequent public model release will be denoted by v2.6 or higher.

Related modifications were made to canal segmentation in Water Conservation Area 1 (A.R.M. Loxahatchee National Wildlife Refuge), improving the flow regimes between the continuous "perimeter" canal and adjacent marshes, including subsequent outflows from the S-10 structures that flow into Water Conservation Area 2A. Summaries of the data and code modifications since ELM v2.1 are found in the Model Refinements Chapter. Full descriptions of the current algorithms and data are found in the Data and Model Structure Chapters.

6.5 Model configuration

In ELM v2.5, the model was configured to simulate historical conditions inclusive of the years 1981 – 2000. The domain was that of the regional ELM, employing a 1 km^2 grid mesh encompassing all of the Water Conservation Areas, Holey Land, Rotenberger Tract, parts of the Model Lands near the C-111 canal region, and most of Everglades National Park and Big Cypress National Preserve. The vector topology of the canal/levee network and the point locations of water control structures were constant during the simulation period. The habitat succession module was operating, as were all other ecological modules, providing dynamic feedbacks among the physics, chemistry, and biology of the mosaic of ecosystems in the landscape. Dynamic boundary conditions included daily data on rainfall, potential evapotranspiration, managed water control structure flows with associated constituent concentrations, and stage (along the borders of the domain, including annually-recurring, monthly mean tidal amplitudes). Full descriptions of the requisite data and the functionality of the algorithms and source code are provided in other Chapters of this documentation.

6.6 Performance results

6.6.1 Ecological performance

6.6.1.1 Surface water P concentration: statistical metrics

The marsh and canal TP concentration monitoring locations used in evaluating the model performance are shown in Figure 6.1. Table 6.1 shows the statistical performance metrics for the simulated vs. observed total phosphorus concentration data at each location during the 1981-2000 simulation period. The median Bias of all predicted TP concentrations in the marsh for the 1981-2000 period of record was 2 ug l^{-1} (ppb), and slightly higher (4 ug l^{-1}) in canal predictions. The spatial distribution of the long-term mean surface water concentration (Figure 6.2) indicates strong gradients of eutrophication in northern WCA-2A, the Miami Canal inputs to northern WCA-3A, and a localized band encircling the interior perimeter of WCA-1. Biases lower than 5 ppb do not appear in any spatial trend, but higher variability associated with high mean concentrations resulted in higher biases in and immediately adjacent to canals.

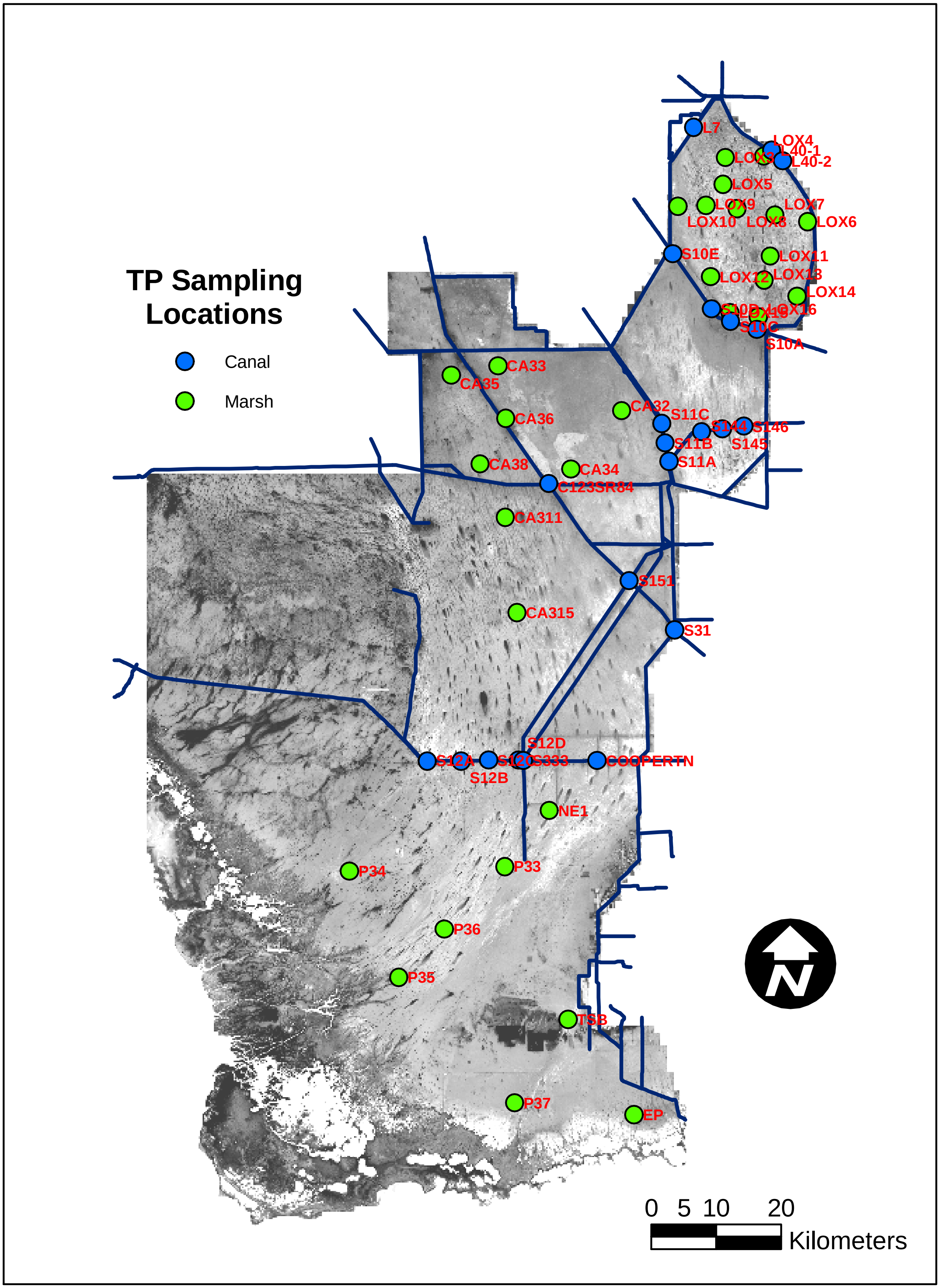


Figure 6.1 Map of most TP and CL monitoring site locations (see also Figure 6.1b).

Figure 6.1b. Map of water quality monitoring locations in WCA-1 and WCA-2A. Note that the scale of the grid-cell interactions with canal vectors results in effectively zero-distance from the canals for a number of the monitoring sites, particularly in WCA-1 (A.R.M. Loxahatchee National Wildlife Refuge).

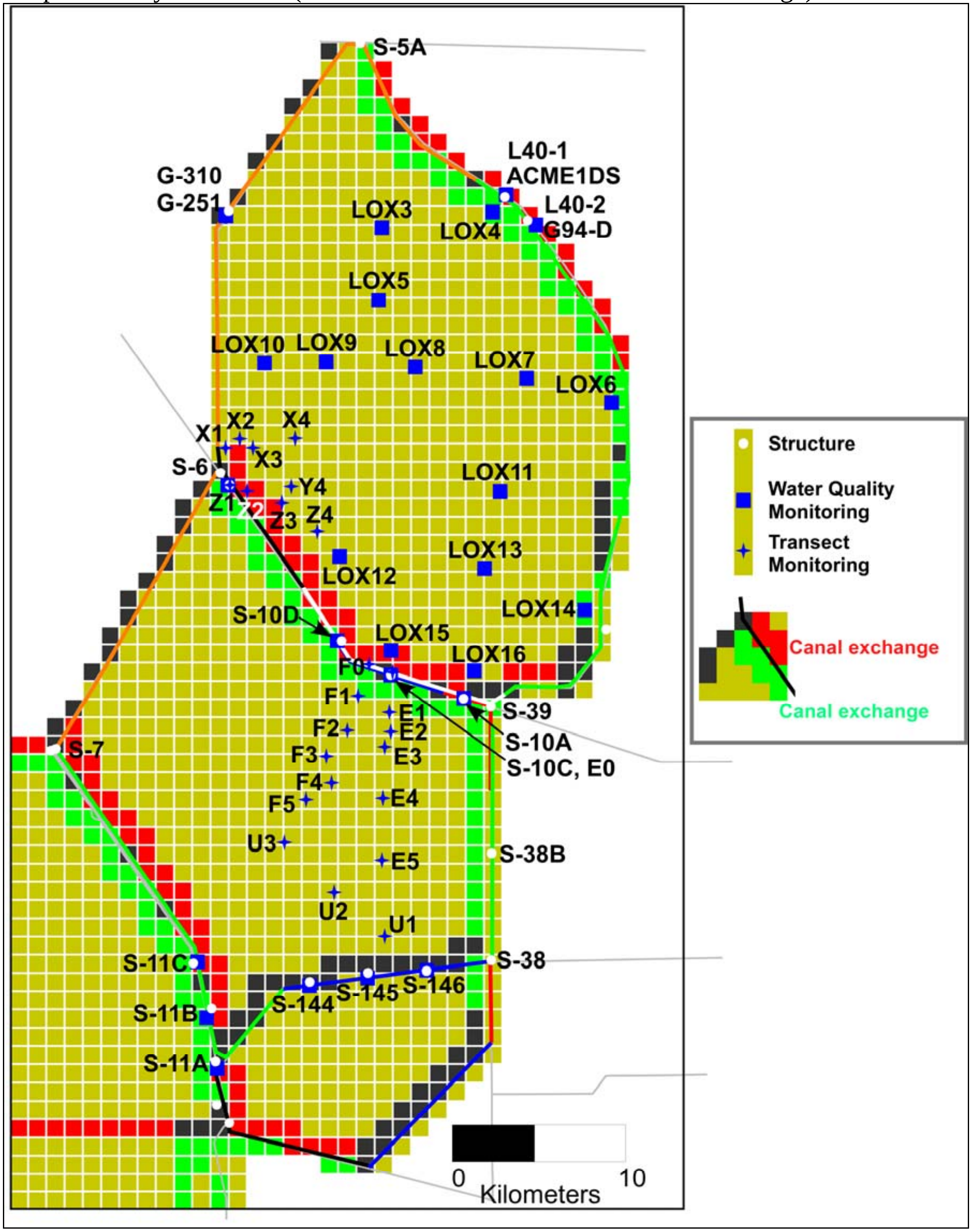
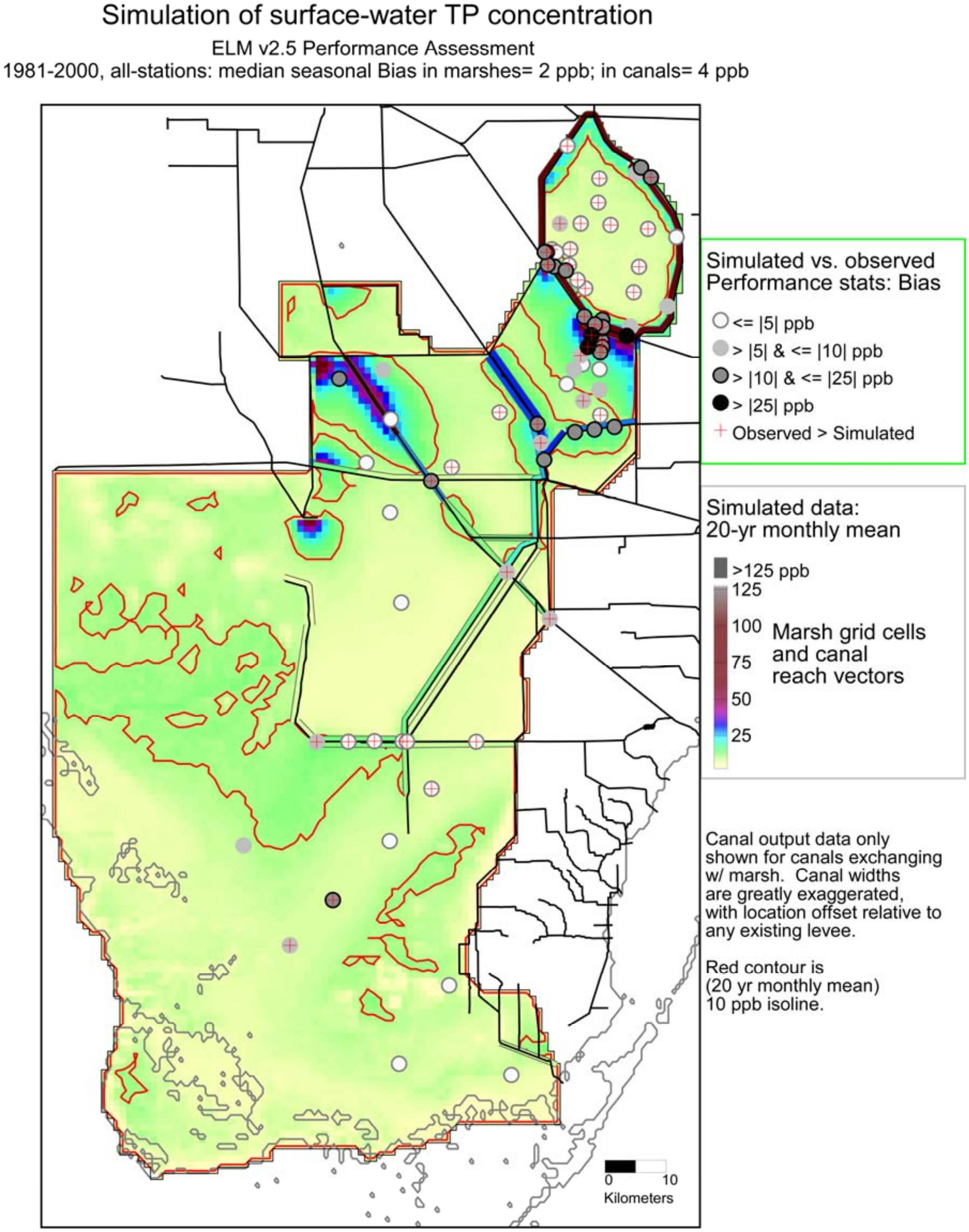


Figure 6.2 Map of statistical bias in model predictions of observed total phosphorus (TP) concentrations in marsh and canal locations. Background map is the simulated mean monthly TP concentration during 1981-2000. Statistics are detailed in Table 6.1.



Canal output data only shown for canals exchanging w/ marsh. Canal widths are greatly exaggerated, with location offset relative to any existing levee.

Red contour is (20 yr monthly mean) 10 ppb isoline.

Table 6.1. Statistical evaluation of simulated vs. observed surface water phosphorus concentration, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are ug l^{-1} (ppb).

			1981-2000				
Site	Basin	Site type	N	ObsMean	RelBias	Bias	RMSE
LOX4	WCA1	Marsh	12	10	-0.92	-9	11
LOX3	WCA1	Marsh	11	11	0.43	5	7
LOX5	WCA1	Marsh	13	10	0.32	3	5
LOX9	WCA1	Marsh	13	9	0.44	4	5
LOX10	WCA1	Marsh	12	10	0.53	5	6
LOX8	WCA1	Marsh	14	9	0.31	3	4
LOX7	WCA1	Marsh	14	8	0.32	3	3
LOX6	WCA1	Marsh	14	8	-0.43	-3	5
LOX11	WCA1	Marsh	14	9	0.46	4	5
LOX12	WCA1	Marsh	14	8	0.32	2	3
LOX13	WCA1	Marsh	14	9	0.45	4	5
LOX14	WCA1	Marsh	14	8	-1.22	-10	11
LOX15	WCA1	Marsh	14	8	-1.87	-14	16
LOX16	WCA1	Marsh	14	9	-0.70	-6	7
CA33	WCA3A	Marsh	14	13	-0.46	-6	8
CA35	WCA3A	Marsh	14	12	-1.74	-21	22
CA32	WCA3A	Marsh	14	8	0.13	1	2
CA36	WCA3A	Marsh	14	30	-0.13	-4	10
CA38	WCA3A	Marsh	14	9	-0.15	-1	4
CA34	WCA3A	Marsh	14	10	0.21	2	4
CA311	WCA3A	Marsh	14	6	-0.66	-4	5
CA315	WCA3A	Marsh	14	6	-0.11	-1	2
NE1	ENP	Marsh	29	10	0.43	4	7
P33	ENP	Marsh	30	8	-0.03	0	3
P34	ENP	Marsh	26	6	-0.91	-6	6
P36	ENP	Marsh	30	17	0.64	11	24
P35	ENP	Marsh	29	13	0.57	8	16
TSB	ENP	Marsh	30	8	-0.53	-4	6
P37	ENP	Marsh	28	6	-0.66	-4	5
EP	ENP	Marsh	27	6	-0.22	-1	3
X1	WCA1	Mar. Trans.	10	40	0.58	23	33
X2	WCA1	Mar. Trans.	10	16	0.22	3	7
X3	WCA1	Mar. Trans.	10	11	-0.40	-5	10
X4	WCA1	Mar. Trans.	9	10	0.44	5	5
Y4	WCA1	Mar. Trans.	10	12	0.31	4	13
Z1	WCA1	Mar. Trans.	10	42	0.07	3	14
Z2	WCA1	Mar. Trans.	9	14	-1.35	-19	23
Z3	WCA1	Mar. Trans.	10	10	-1.73	-17	19
Z4	WCA1	Mar. Trans.	10	9	0.34	3	6
E1	WCA2A	Mar. Trans.	13	65	0.24	15	30
E2	WCA2A	Mar. Trans.	12	58	0.33	19	29
E3	WCA2A	Mar. Trans.	12	39	0.28	11	21
E4	WCA2A	Mar. Trans.	13	15	-0.28	-4	7
E5	WCA2A	Mar. Trans.	13	9	-0.76	-6	8
F1	WCA2A	Mar. Trans.	14	120	0.27	32	72
F2	WCA2A	Mar. Trans.	13	67	0.49	33	47
F3	WCA2A	Mar. Trans.	13	29	0.30	9	13
F4	WCA2A	Mar. Trans.	13	19	-0.01	0	5
F5	WCA2A	Mar. Trans.	13	11	-0.51	-6	8
U1	WCA2A	Mar. Trans.	13	11	0.00	0	8
U2	WCA2A	Mar. Trans.	13	14	0.41	6	29
U3	WCA2A	Mar. Trans.	14	9	-0.45	-4	7

Table continued on next page...

Table 6.1 continued. Statistical evaluation of simulated vs. observed surface water phosphorus concentration, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are ug l^{-1} (ppb).

			1981-2000 (continued)				
Site	Basin	Site type	N	ObsMean	RelBias	Bias	RMSE
L7	WCA1	Canal	8	118	0.04	4	54
L40-1	WCA1	Canal	20	62	-0.16	-10	34
L40-2	WCA1	Canal	20	84	0.16	13	30
S10A	WCA1	Canal	25	54	-0.79	-43	60
S10C	WCA1	Canal	26	81	-0.21	-17	41
S10D	WCA1	Canal	39	99	0.11	11	37
S10E	WCA1	Canal	23	88	0.17	15	40
X0	WCA1	Can. Trans.	8	53	-0.26	-14	26
Z0	WCA1	Can. Trans.	8	60	-0.10	-6	19
E0	WCA1	Can. Trans.	13	86	0.20	17	36
F0	WCA2A	Can. Trans.	12	93	0.23	22	35
S144	WCA2A	Canal	29	19	-0.56	-11	19
S145	WCA2A	Canal	35	16	-0.77	-13	19
S146	WCA2A	Canal	29	16	-0.78	-13	20
S11A	WCA2A	Canal	33	27	-0.49	-13	26
S11B	WCA2A	Canal	32	44	0.13	6	23
S11C	WCA2A	Canal	39	55	0.43	23	32
C123SR84	WCA2A	Canal	26	46	0.48	22	27
S151	WCA3A	Canal	40	27	0.29	8	19
S12A	WCA3A	Canal	39	16	0.33	5	20
S12B	WCA3A	Canal	39	14	0.19	3	14
S12C	WCA3A	Canal	40	14	0.09	1	7
S12D	WCA3A	Canal	40	14	0.14	2	6
S333	WCA3A	Canal	39	15	0.22	3	8
COOPERTN	WCA3A	Canal	20	11	0.35	4	5
S31	WCA3B	Canal	26	21	0.38	8	17
		Median All:	14	14	0.13	2	11
		Median Canal:	28	45	0.13	4	24
		Median Marsh:	14	10	0.10	2	7

6.6.1.2 Surface water P concentration: graphical indicators

These visualizations of the temporal trends in simulated and observed data are an important component of understanding the model performance, particularly with respect to recognizing any unique aspects of the data dynamics at a particular site. Figure 6.3a shows an example of the time series of seasonally-averaged phosphorus concentrations in canals. The model effectively captured the spatial differences between northern Everglades canals with relatively high (ca 70 ppb) mean concentrations, down to canals in the central/southern portions of the system with lower (ca. 10 ppb) mean concentrations. Within the marsh (Figure 6.3b), the model likewise generally stays within the range of observed data, in an area ranging from high (ca. 50 ppb) to low (<10 ppb) ambient concentrations.

Figure 6.3 (following 2 pages). Example plots of time series and Cumulative Frequency Distributions (CFD) of simulated and observed phosphorus concentrations in canal (Figure 6.3a) and marsh (Figure 6.3b) sites.

The constant dashed line indicates the TP field sampling Detection Limit (DL = 4 ug l^{-1} for the model period of record), which was the minimum value used for observed data in plots and statistics. To enable equivalent comparisons, any simulated value which was below the DL was set equal to the DL. The model grid cell column and row locations (col_row) or canal reach identifier (single integer) are shown in parentheses of each plot's title.

Time series plots: All data were aggregated into arithmetic mean values by wet and dry seasons within water years; the continuous lines pass through mean of all daily data points for each season; the mean of paired simulated and observed values are shown in red boxes and black diamonds, respectively; the 95% Confidence Interval (CI) of the paired means are shown by the "__" symbols in the red for the model and black for the observed data.

Cumulative Frequency Distributions: The CFDs of the simulated and observed (raw, un-aggregated) data; the 95% confidence interval for observed data is shown in the dashed black lines. Note that only paired simulated and observed data points are used.

Appendix B. The complete set of graphics for all monitoring sites in the greater Everglades is provided in Appendix B.

Figure 6.3a. Time series and CFDs of simulated and observed phosphorus concentrations for <u>canal</u> sites with high concentrations (L40-2, WCA-1) and low concentrations (S12-D, flowing into Everglades National Park). The time series plots have different scales.

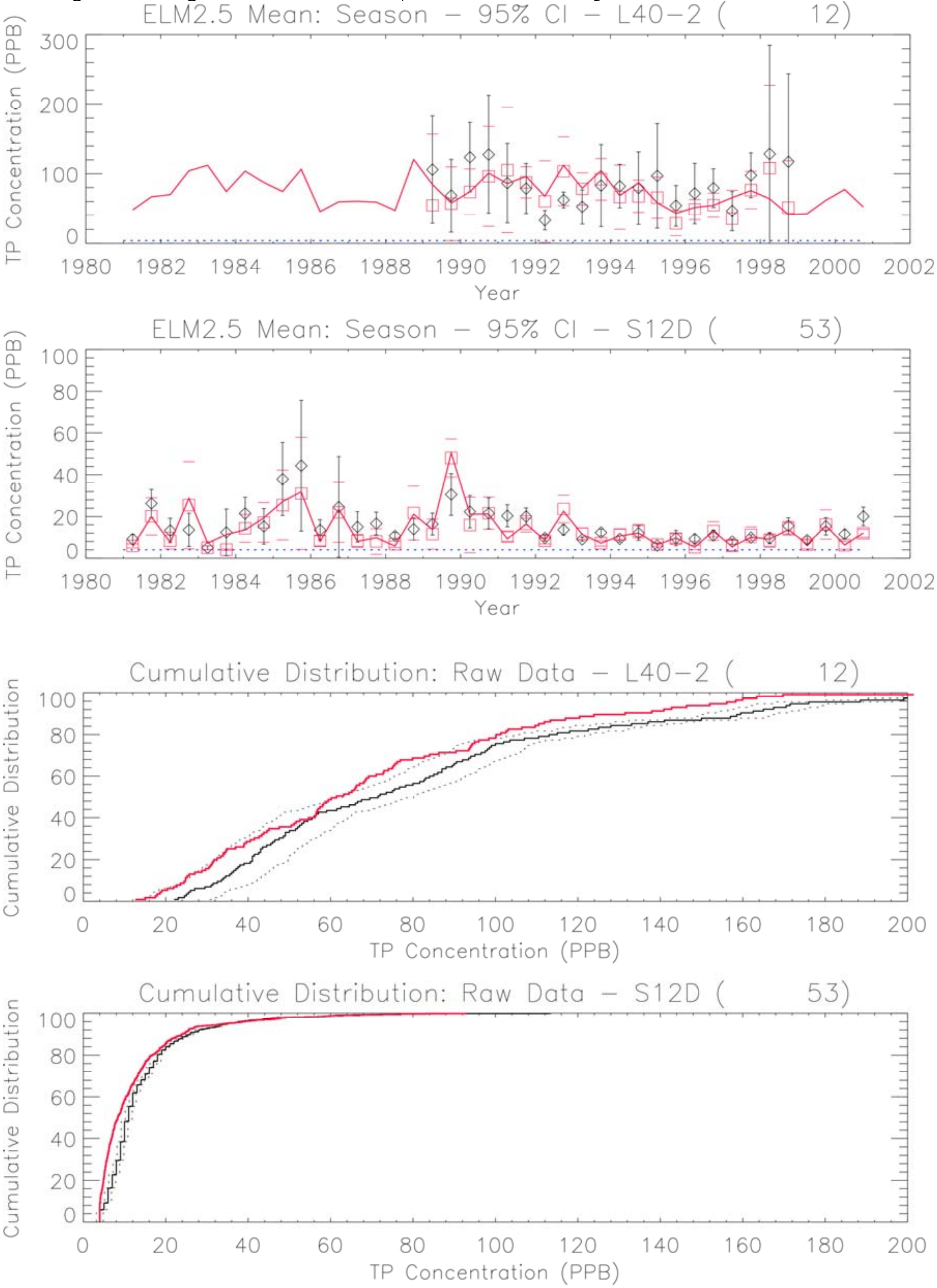
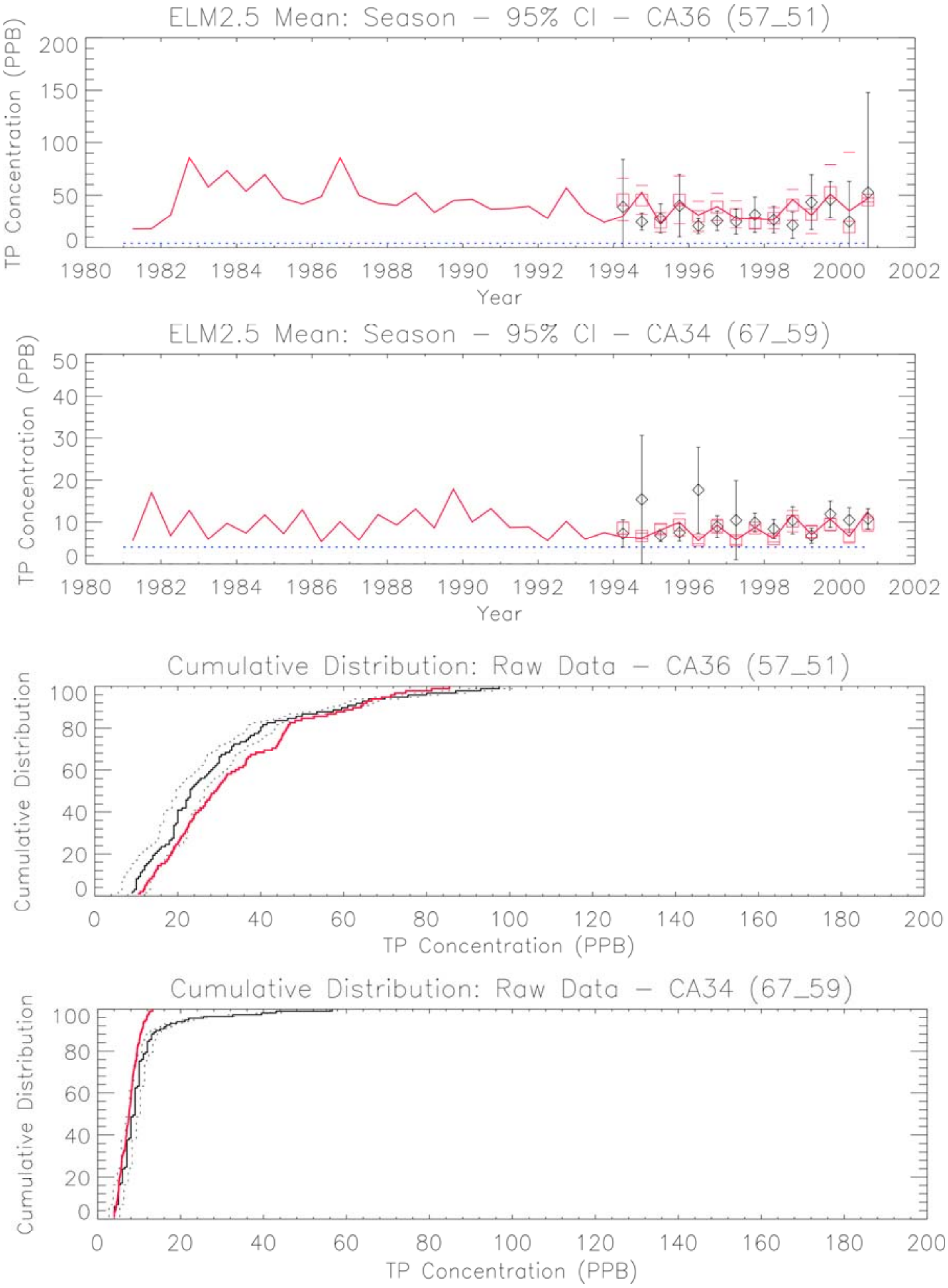


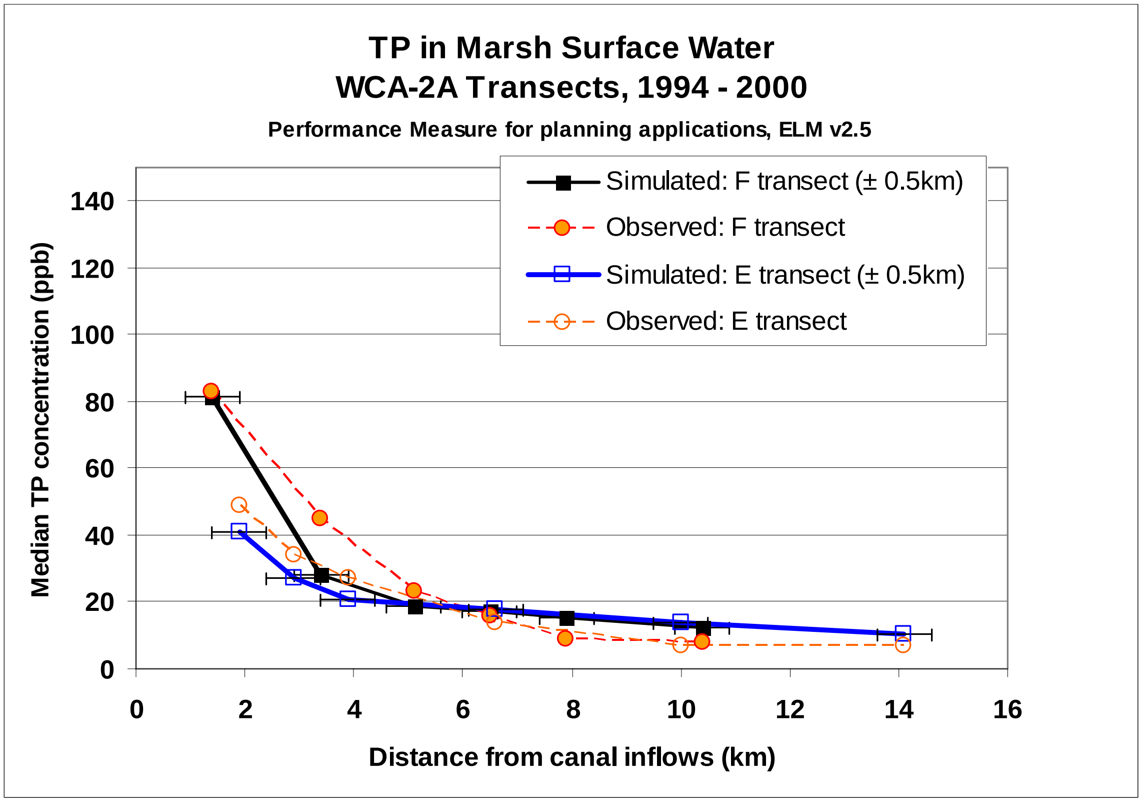
Figure 6.3a. Time series and CFDs of simulated and observed phosphorus concentrations for marsh monitoring sites with high mean concentrations (CA-36, WCA-3A) and low mean concentrations (CA-34, WCA-3A). The time series plots have different scales.

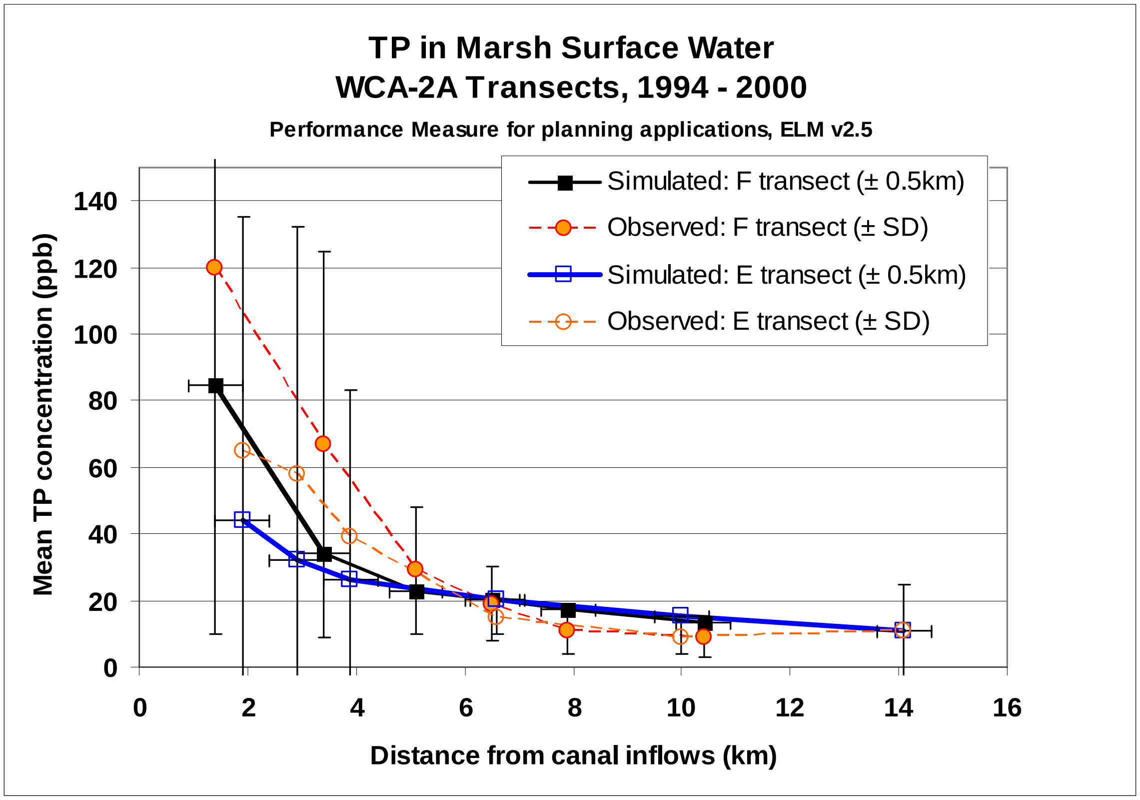


6.6.1.3 Surface water P concentration: transect evaluations

A subset of the monitoring locations analyzed above are actually sites that were established along specific eutrophication gradients in Water Conservation Area 2A. Each of these “E” and the “F” transects were monitored at six sites, from near the inflow “points” adjacent to canal inflows, into interior points 10-15 km downstream. At high ambient P concentrations near the inflows, there was high variability as evidenced in large standard deviations about the mean. The median values of modeled and observed concentrations were very closely matched along the gradient that ranged from approximately 80 to approximately 10 ppb concentrations.

Figure 6.4 Surface water phosphorus concentration along the “E” and the “F” transects in the WCA-2A eutrophication gradient. Sampling started in 1994.

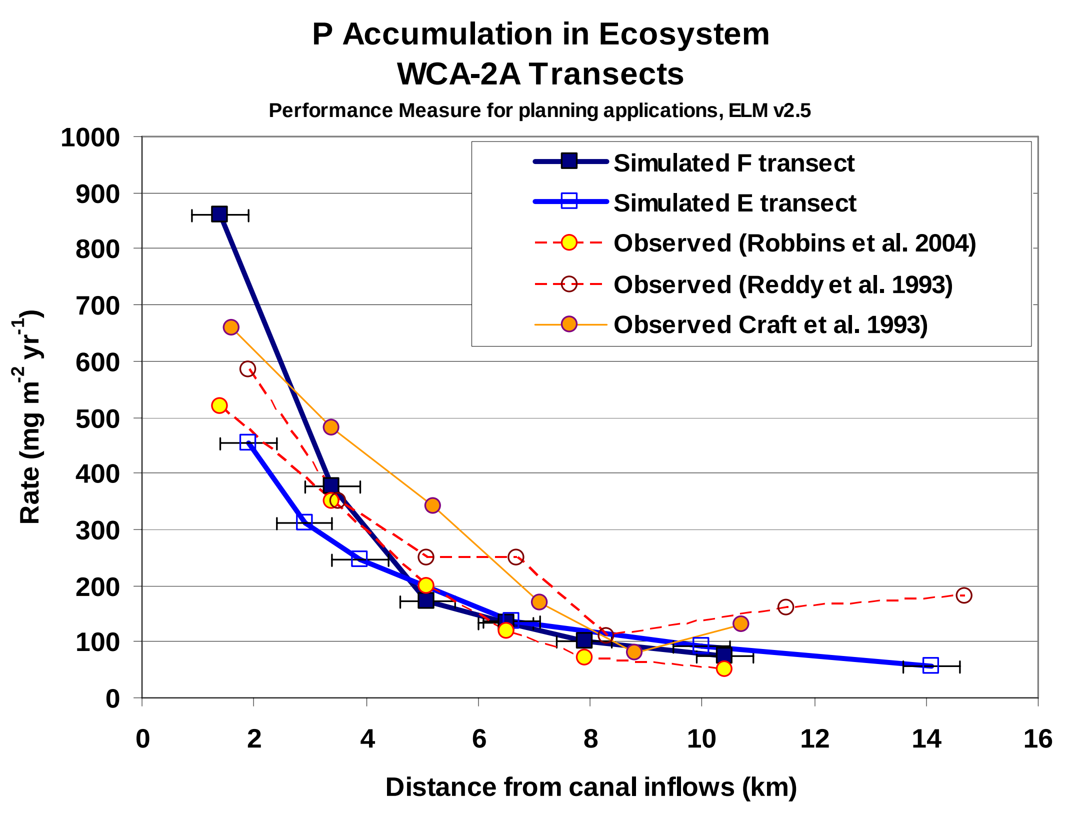




6.6.1.4 Phosphorus accumulation rate: transect evaluations

The accumulation rates of phosphorus are an integrated measure of the actual net nutrient load to which the ecosystem is responding. There was variability among studies and locations in estimated long term P accumulation from radionuclide tracers, but simulated data generally had strong concordance to the spatial trends in observed data.

Figure 6.5 Net phosphorus accumulation along the WCA-2A gradient. Observed data were summarized from Craft et al. (1993), Reddy et al. (1993) and Robbins et al. (2004).



6.6.2 Hydrologic performance

6.6.2.1 Stage: statistical metrics

The marsh stage monitoring locations used in evaluating the model performance are mapped in Figure 6.6. Table 6.2 shows the statistical performance metrics for the simulated vs. observed stage data at each location during the 1981-2000 historical simulation period. The median bias of predicted stages was -1 cm. The median Nash-Sutcliffe Efficiency statistic was 0.56 for the simulation. The spatial distribution of the annual hydroperiod (Figure 6.7) indicates relatively lengthy inundation periods in Water Conservation Areas and large slough features draining to the southwest and south in Everglades National Park. Biases do not appear in any spatial trend, but boundary conditions along the model periphery resulted in higher biases in and immediately adjacent to canals and estuarine regions.

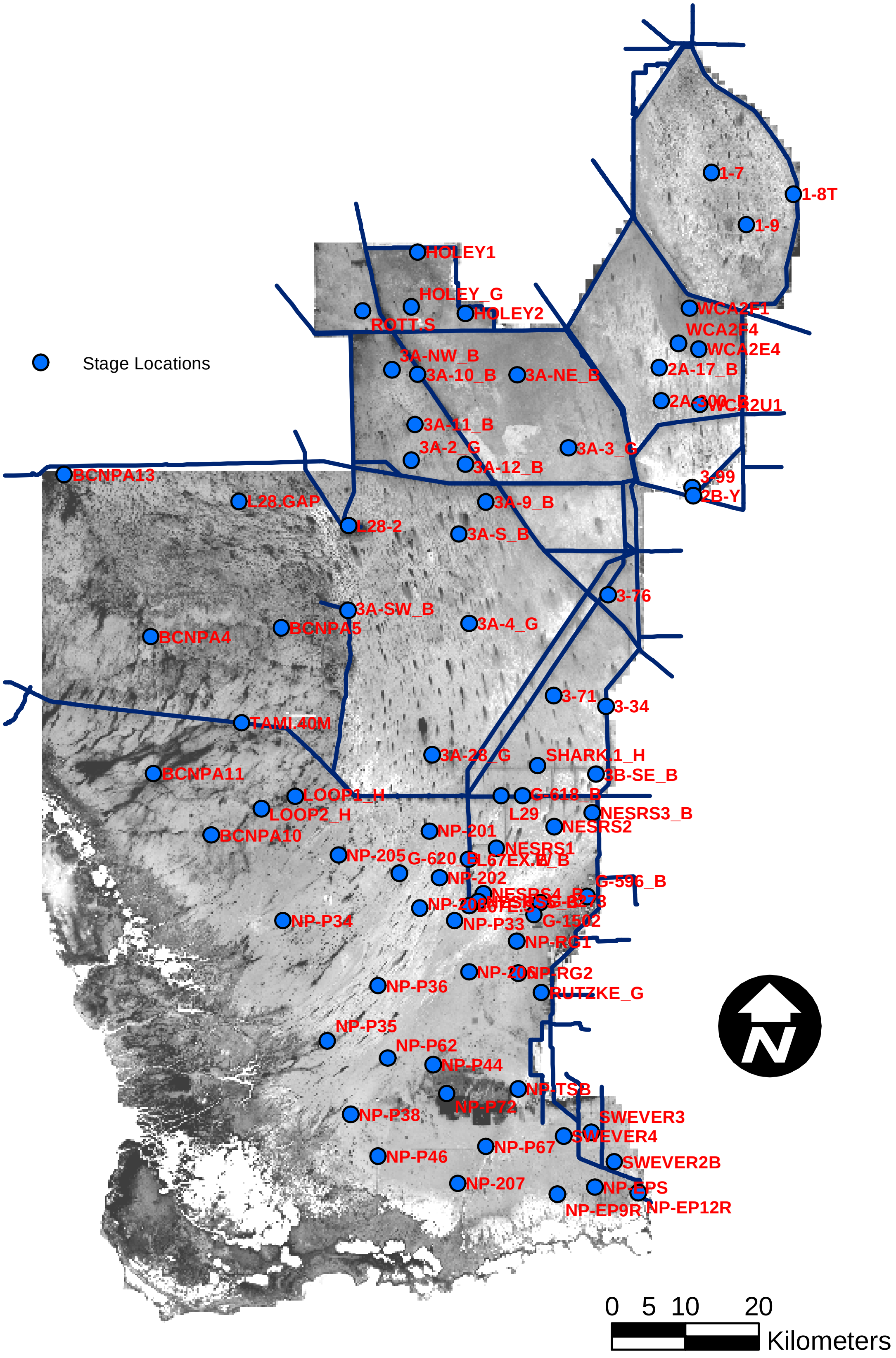


Figure 6.6. Map of stage monitoring site locations..

Figure 6.7 Map of statistical bias in model predictions of observed water stage elevations in marsh locations. Background map is the simulated mean annual hydroperiod during 1981-2000. Statistics are detailed in Table 6.2.

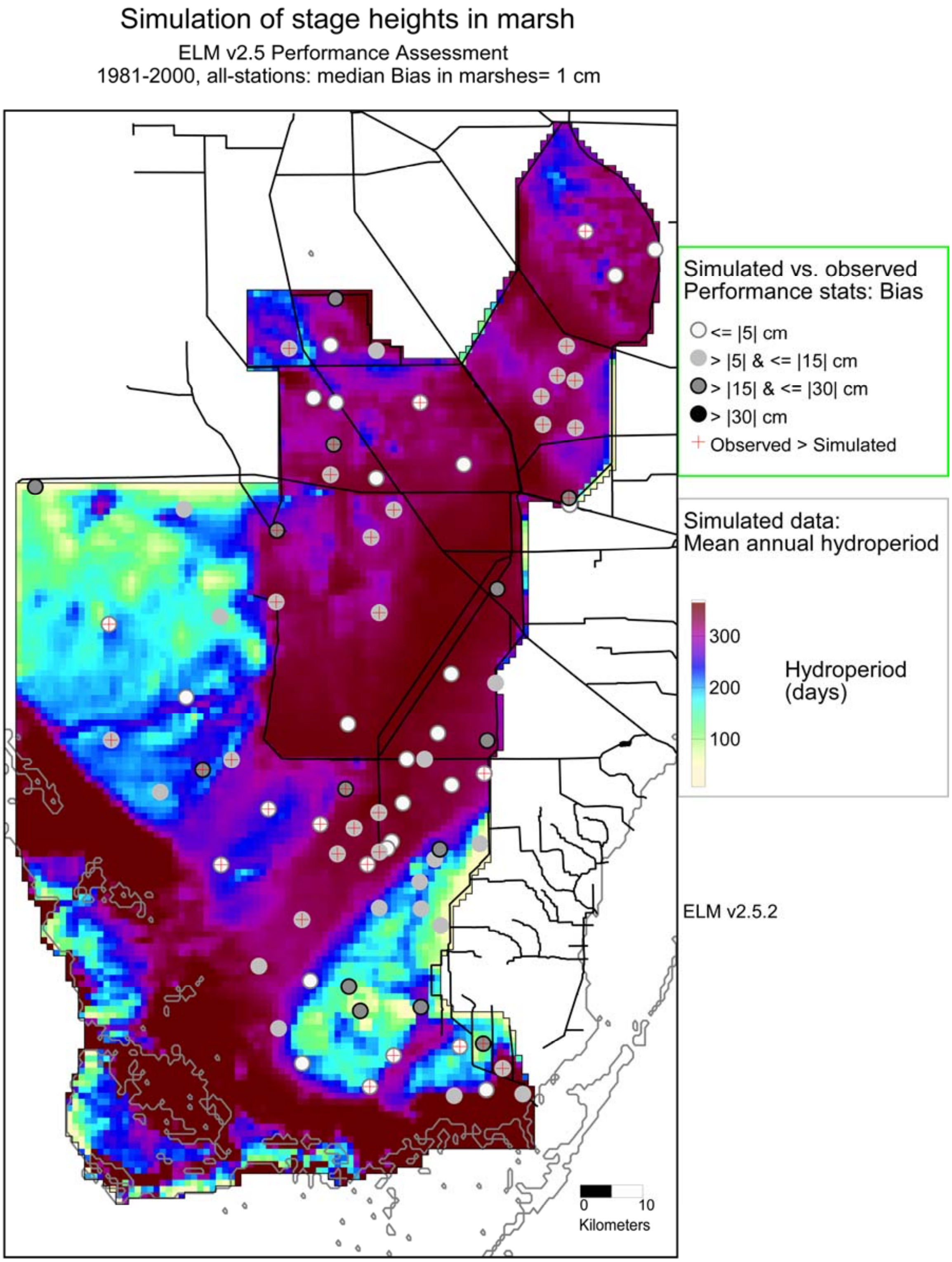


Table 6.2. Statistical evaluation of simulated vs. observed stage, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are meters.

		Stage 1981-2000				
Site	Basin	N	Bias (m)	RMSE (m)	R2	NS Eff.
_1-7	WCA1	7046	0.05	0.15	0.72	0.27
1-8T	WCA1	6869	-0.05	0.15	0.76	0.55
_1-9	WCA1	6879	-0.03	0.14	0.74	0.46
WCA2F1	WCA2A	2259	0.11	0.18	0.82	0.57
WCA2F4	WCA2A	1941	0.08	0.15	0.77	0.64
WCA2E4	WCA2A	2260	0.09	0.18	0.77	0.56
2A-17_B	WCA2A	7305	0.05	0.16	0.75	0.65
2A-300_B	WCA2A	7278	0.06	0.19	0.69	0.64
WCA2U1	WCA2A	2150	0.13	0.25	0.69	0.37
3A-NW_B	WCA3A	7035	-0.02	0.14	0.73	0.72
3A-10_B	WCA3A	6445	-0.03	0.13	0.75	0.58
3A-NE_B	WCA3A	6813	0.02	0.21	0.70	0.69
3A-11_B	WCA3A	6487	0.23	0.25	0.85	-0.56
3A-3_G	WCA3A	7305	-0.02	0.15	0.86	0.86
3A-2_G	WCA3A	7145	0.05	0.12	0.87	0.83
3A-12_B	WCA3A	6738	-0.02	0.16	0.65	0.56
3A-9_B	WCA3A	6969	0.15	0.18	0.86	0.59
L28-2	WCA3A	4007	0.18	0.21	0.84	0.06
3A-S_B	WCA3A	6871	0.12	0.16	0.86	0.61
3A-4_G	WCA3A	7305	0.12	0.18	0.85	0.68
3A-28_G	WCA3A	7295	-0.02	0.13	0.82	0.82
_3-99	WCA2B	3338	0.23	0.32	0.55	0.04
2B-Y	WCA2B	5515	-0.01	0.32	0.77	0.73
_3-76	WCA3B	3390	-0.16	0.22	0.61	-1.27
_3-71	WCA3B	3454	-0.02	0.12	0.63	0.50
_3-34	WCA3B	1633	-0.11	0.14	0.81	0.48
SHARK.1_H	WCA3B	6684	-0.04	0.12	0.84	0.78
3B-SE_B	WCA3B	6029	-0.15	0.23	0.83	0.50
HOLEY1	Holey L.	4041	-0.16	0.21	0.63	0.11
HOLEY_G	Holey L.	5599	-0.02	0.22	0.49	-0.49
HOLEY2	Holey L.	4046	-0.12	0.20	0.56	0.30
ROTT.S	Roten. T.	5208	0.12	0.17	0.60	0.24
BCNPA13	BCNP	1923	-0.18	0.26	0.37	-0.16
L28.GAP	BCNP	6393	-0.09	0.18	0.53	0.31
3A-SW_B	BCNP/3A	6641	0.08	0.13	0.86	0.68
BCNPA5	BCNP	3636	-0.13	0.21	0.42	0.02
BCNPA4	BCNP	3601	0.03	0.20	0.53	0.38
TAMI.40M	BCNP	7305	-0.01	0.18	0.72	0.66
BCNPA11	BCNP	3549	0.15	0.27	0.33	-0.01

Table continued on next page...

Table 6.2 continued. Statistical evaluation of simulated vs. observed stage, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are meters.

		Stage 1981-2000 (continued)				
Site	Basin	N	Bias (m)	RMSE (m)	R2	NS Eff.
G-618_B	ENP	7124	-0.05	0.14	0.72	0.66
L29	ENP	7305	0.00	0.13	0.69	0.67
LOOP1_H	ENP	5938	0.12	0.17	0.68	0.32
LOOP2_H	ENP	5972	0.17	0.23	0.70	0.24
NESRS3_B	ENP	5579	0.02	0.14	0.67	0.65
NESRS2	ENP	6228	-0.03	0.09	0.76	0.74
NP-201	ENP	5723	0.16	0.19	0.82	0.50
BCNPA10	ENP	3637	-0.10	0.17	0.53	0.24
NESRS1	ENP	6536	-0.02	0.09	0.74	0.72
NP-205	ENP	7149	0.04	0.14	0.80	0.78
L67EX.W	ENP	6319	0.05	0.18	0.74	0.59
L67EX.E_B	ENP	6187	-0.03	0.11	0.74	0.70
G-620_B	ENP	6264	0.01	0.11	0.79	0.79
NP-202	ENP	7069	0.08	0.15	0.74	0.61
NESRS4_B	ENP	4854	-0.03	0.10	0.71	0.63
G-596_B	ENP	7282	-0.13	0.23	0.60	0.16
NESRS5_B	ENP	4953	-0.01	0.08	0.76	0.70
G-3273	ENP	6137	-0.18	0.25	0.75	0.44
L67E.S	ENP	3631	0.10	0.19	0.55	0.34
NP-203	ENP	7049	0.05	0.13	0.74	0.68
G-1502	ENP	7305	-0.13	0.22	0.75	0.61
NP-P33	ENP	7147	0.02	0.13	0.60	0.57
NP-P34	ENP	6971	0.03	0.16	0.82	0.64
NP-RG1	ENP	1570	-0.09	0.14	0.85	0.67
NP-206	ENP	6641	-0.08	0.21	0.76	0.69
NP-RG2	ENP	1502	-0.11	0.16	0.85	0.63
NP-P36	ENP	6952	0.07	0.13	0.71	0.55
RUTZKE_G	ENP	2369	-0.05	0.20	0.79	0.21
NP-P35	ENP	6851	-0.14	0.20	0.79	-0.11
NP-P62	ENP	6851	-0.03	0.13	0.80	0.79
NP-P44	ENP	6440	-0.21	0.30	0.80	0.51
NP-TSB	ENP	7299	-0.16	0.22	0.79	0.56
NP-P72	ENP	7186	-0.20	0.29	0.75	0.47
NP-P38	ENP	6896	-0.09	0.14	0.87	0.44
SWEVER3	ENP	5330	0.20	0.25	0.68	-2.47
SWEVER4	ENP	5582	0.04	0.19	0.75	-0.58
NP-P67	ENP	7107	0.04	0.11	0.78	0.72
NP-P46	ENP	6680	-0.02	0.13	0.71	0.42
SWEVER2B	ENP	5488	0.14	0.17	0.58	-0.33
NP-207	ENP	6755	0.05	0.10	0.86	0.71
NP-EPS	ENP	5240	-0.02	0.06	0.70	0.67
NP-EP12R	ENP	2828	-0.07	0.09	0.76	0.22
NP-EP9R	ENP	2608	-0.12	0.13	0.75	-0.09
	Median:	6356	-0.01	0.17	0.75	0.56

6.6.2.2 Stage: graphical indicators

These visualizations of the temporal trends in simulated and observed data are an important component of understanding the model performance, particularly with respect to recognizing any unique aspects of the data dynamics at a particular site. Figure 6.8 shows an example of the time series of stage hydrographs in long and in short hydroperiod areas. The model effectively captured the spatial differences between southern Everglades marl prairie region that is periodically flooded, and a Water Conservation Area 3A location that is virtually always inundated with relatively deep surface water.

Figure 6.8 (following page). Example plots of time series and Cumulative Frequency Distributions (CFD) of simulated and observed stage in short hydroperiod (NP-206, Everglades National Park) and long hydroperiod (3A-28, WCA-3A) sites.

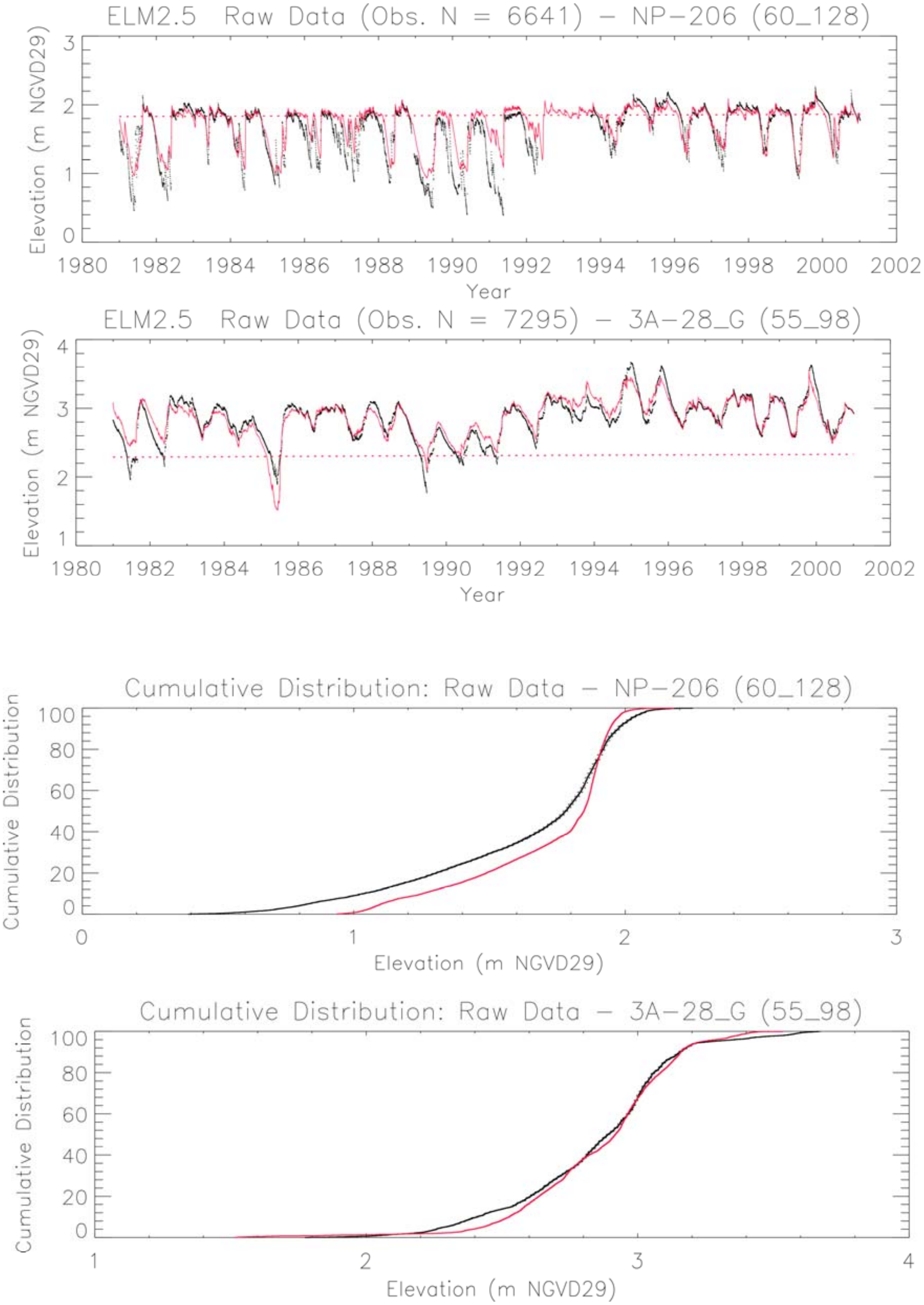
The red dashed line in the stage hydrographs is the model grid cell's land surface elevation, which is a time-varying output variable of the model. The model grid cell column and row locations are shown in parentheses (col_row) of each plot's title.

Time series plots: All data, with no temporal aggregation, of daily observations (black dots) and model results (red line).

Cumulative Frequency Distributions: The CFDs of the simulated and observed (raw, un-aggregated) data; the 95% confidence interval for observed data is shown in the dashed black lines. Note that only paired simulated and observed data points are used.

Appendix C. The complete set of graphics for all monitoring sites in the greater Everglades is provided in Appendix C.

Figure 6.8. Time series and Cumulative Frequency Distributions of simulated and observed stages for long and short hydroperiod sites. See full Figure legend above.



6.6.2.3 Consistency: inter-model water budget indicators

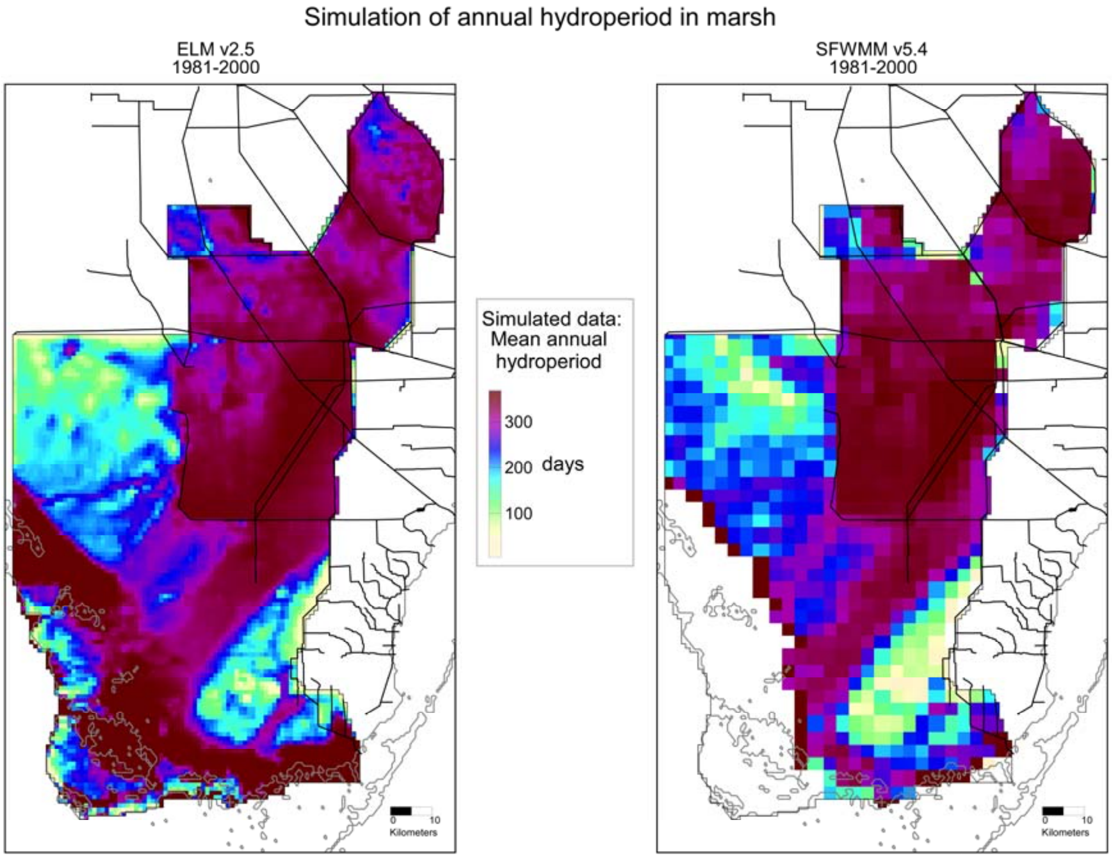
The water budgets of the ELM were generally similar to those of the SFWMM. For each of the major hydrologic basins, we compared the annual flows into and out of each Water Conservation Area. Figure 6.9 shows an example of such a comparison. Very minor differences in rainfall are due to the different spatial scales and discretization of grid cells. Other differences are observable in some years for other flows, but do not represent significant volumes (relative to the size of the basin). For each Water Conservation Area, Appendix D provides the actual hydrologic budgets for ELM, and the differences between the SFWMM and ELM.

Figure 6.9. Insert 3A budget comparison

6.6.2.4 Consistency: inter-model hydroperiod indicators

Another indicator of consistency between the ELM and the SFWMM is a comparison of the maps of the mean annual hydroperiod that is simulated by each model. Figure 6.10 indicates that the ELM generally mimics the distribution of hydroperiods, with some differences in the ELM capturing finer scaled features (largely due to finer scaled land surface elevation input data).

Figure 6.10. Mean annual hydroperiod simulated by the ELM and by the SFWMM, displaying only the portion of the SFWMM domain that overlaps with that of the ELM. The SFWMM grid cells are approximately 10.4 km^2, compared to the 1 km^2 grid resolution of the ELM. (As indicated, the SFWMM domain does not extend to the southwestern mangrove-dominated region along the Gulf of Mexico).



6.6.2.5 Consistency: Flow tracer (chloride) indicators

The distribution of chloride (CL) concentrations throughout the freshwater Everglades showed patterns of long-term flow regimes that were consistent with our understanding of major flow paths (Figure 6.11), most notably the "ring" of higher CL encircling WCA-1, and large inputs into WCA-2A. Other canal inputs within WCA-3A transported the tracer into Everglades National Park[9]. The relative bias metric indicated a distribution of relative errors that tended to be higher in close proximity to higher concentrations in canals, similar to the trends of phosphorus concentrations. The median relative error of all stations was -12% in the marshes, and 13% in canals (Table 3).

Appendix E: Figures E.1 – E.78 show the sets of 1981-2000 time series of chloride concentrations at varying temporal aggregations, including each site's cumulative frequency distribution. These visualizations of the temporal trends in simulated and observed data can be an important component of understanding the model performance, particularly with respect to recognizing any unique aspects of the data dynamics at a particular site.

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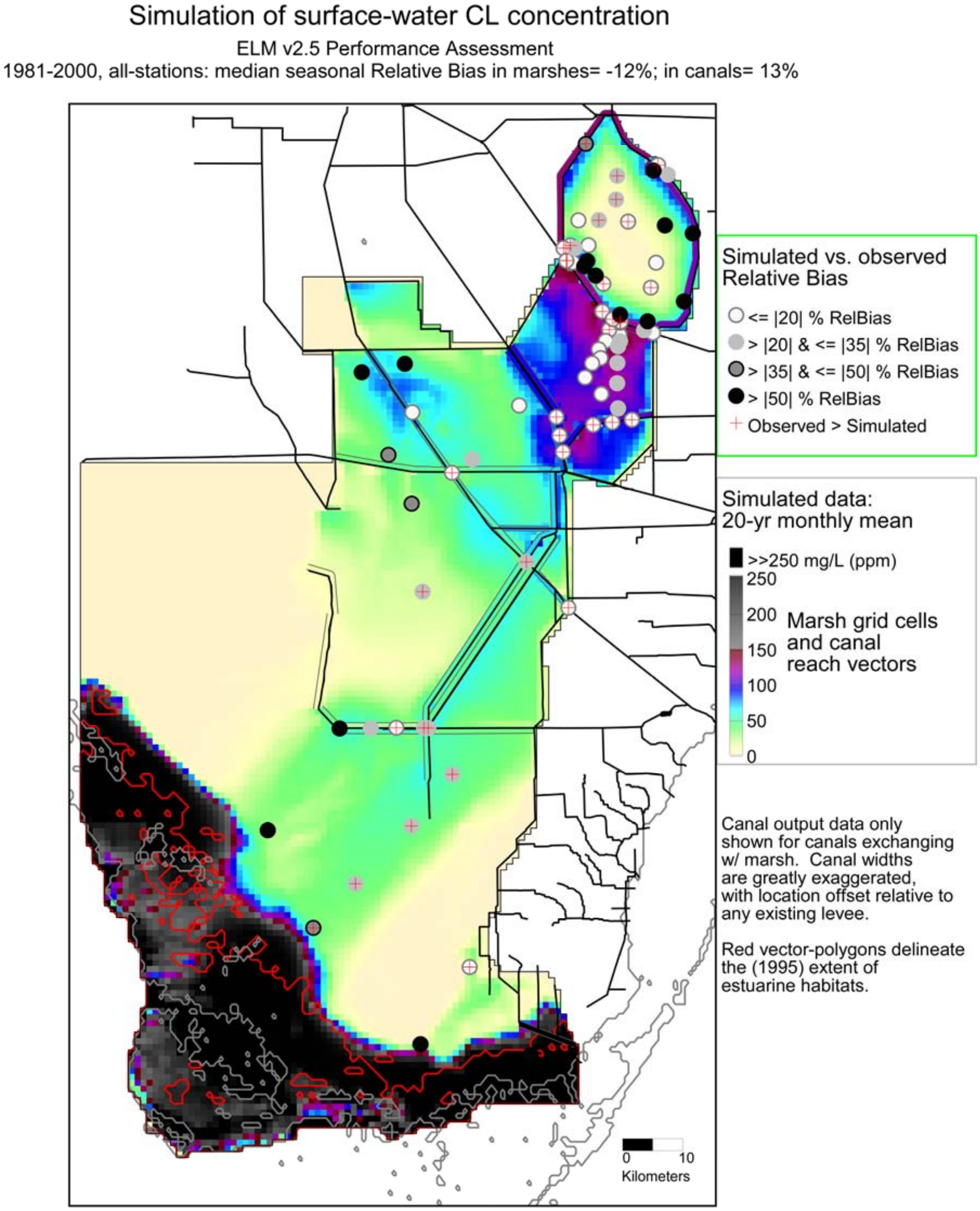
[9] The distribution of CL concentrations go "off-the-freshwater-scale" in the estuarine southern Everglades, with CL concentrations that were << 1 parts per thousand roughly corresponding to the extent of mangrove and other estuarine habitat types.

Figure 6.11 Map of statistical relative bias in model predictions of observed chloride (CL) concentrations in marsh and canal locations. Background map is the simulated mean monthly CL concentration during 1981-2000. Statistics are detailed in Table 6.3.



Canal output data only shown for canals exchanging w/ marsh. Canal widths are greatly exaggerated, with location offset relative to any existing levee.

Red vector-polygons delineate the (1995) extent of estuarine habitats.

Table 6.3. Statistical evaluation of simulated vs. observed surface water chloride concentration, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are mg l^{-1} (ppm).

					1981-2000		
Site	Basin	Site type	N	ObsMean	RelBias	Bias	RMSE
LOX4	WCA1	Marsh	25	68	-0.83	-57	77
LOX3	WCA1	Marsh	24	37	0.34	12	38
LOX5	WCA1	Marsh	26	18	0.34	6	12
LOX9	WCA1	Marsh	26	14	0.33	4	7
LOX10	WCA1	Marsh	24	28	-0.12	-3	29
LOX8	WCA1	Marsh	30	15	0.07	1	8
LOX7	WCA1	Marsh	30	29	-0.89	-26	35
LOX6	WCA1	Marsh	30	44	-1.20	-52	63
LOX11	WCA1	Marsh	29	13	-0.05	-1	7
LOX12	WCA1	Marsh	28	28	0.02	1	15
LOX13	WCA1	Marsh	29	12	0.01	0	6
LOX14	WCA1	Marsh	29	21	-2.97	-61	67
LOX15	WCA1	Marsh	29	48	-0.57	-28	42
LOX16	WCA1	Marsh	28	14	-3.60	-51	56
CA33	WCA3A	Marsh	38	53	-0.81	-43	56
CA35	WCA3A	Marsh	35	33	-0.79	-26	38
CA32	WCA3A	Marsh	46	50	-0.14	-7	43
CA36	WCA3A	Marsh	36	70	-0.10	-7	26
CA38	WCA3A	Marsh	51	31	-0.49	-16	28
CA34	WCA3A	Marsh	53	58	-0.29	-17	42
CA311	WCA3A	Marsh	45	29	-0.37	-11	26
CA315	WCA3A	Marsh	51	34	0.25	9	20
NE1	ENP	Marsh	107	78	0.25	20	32
P33	ENP	Marsh	113	71	0.21	15	29
P34	ENP	Marsh	69	22	-1.15	-26	39
P36	ENP	Marsh	108	72	0.26	19	34
P35	ENP	Marsh	103	131	0.48	63	223
TSB	ENP	Marsh	98	39	0.01	1	24
P37	ENP	Marsh	79	30	-1.59	-48	105
EP	ENP	Marsh	82	206	-64.21	-13229	17364
X1	WCA1	Mar. Trans.	55	122	0.12	15	29
X2	WCA1	Mar. Trans.	55	102	0.05	5	44
X3	WCA1	Mar. Trans.	55	86	-0.30	-26	55
X4	WCA1	Mar. Trans.	54	50	-0.19	-10	50
Y4	WCA1	Mar. Trans.	55	51	-0.86	-44	67
Z1	WCA1	Mar. Trans.	57	125	0.12	15	31
Z2	WCA1	Mar. Trans.	54	108	-0.09	-10	32
Z3	WCA1	Mar. Trans.	59	67	-0.55	-37	63
Z4	WCA1	Mar. Trans.	57	36	-0.92	-33	50
E1	WCA2A	Mar. Trans.	83	149	-0.01	-1	94
E2	WCA2A	Mar. Trans.	78	125	-0.24	-30	55
E3	WCA2A	Mar. Trans.	75	124	-0.23	-28	56
E4	WCA2A	Mar. Trans.	90	121	-0.26	-31	59
E5	WCA2A	Mar. Trans.	91	114	-0.32	-36	67
F1	WCA2A	Mar. Trans.	82	162	0.05	8	61
F2	WCA2A	Mar. Trans.	101	151	-0.11	-16	58
F3	WCA2A	Mar. Trans.	97	143	-0.12	-18	62
F4	WCA2A	Mar. Trans.	85	137	-0.12	-16	61
F5	WCA2A	Mar. Trans.	92	143	-0.08	-11	62
U1	WCA2A	Mar. Trans.	99	102	-0.28	-28	60
U2	WCA2A	Mar. Trans.	97	129	-0.05	-6	51
U3	WCA2A	Mar. Trans.	96	133	-0.10	-14	58

Table continued on next page...

Table 6.3 continued. Statistical evaluation of simulated vs. observed surface water chloride concentration, 1981 – 2000. Units of Bias (observed minus simulated) and RMSE are mg l^{-1} (ppm).

			1981-2000 (continued)				
Site	Basin	Site type	N	ObsMean	RelBias	Bias	RMSE
L7	WCA1	Canal	53	228	0.45	103	167
L40-1	WCA1	Canal	119	132	0.20	26	54
L40-2	WCA1	Canal	118	80	-0.33	-26	59
S10A	WCA1	Canal	94	95	-0.22	-21	56
S10C	WCA1	Canal	100	131	0.11	14	53
S10D	WCA1	Canal	198	145	0.17	24	56
S39	WCA1	Canal	251	106	-0.17	-18	56
S10E	WCA1	Canal	80	141	0.17	24	50
X0	WCA1	Can. Trans	60	131	0.18	24	38
Z0	WCA1	Can. Trans	59	133	0.19	25	40
E0	WCA2A	Can. Trans	108	128	0.01	1	37
F0	WCA2A	Can. Trans	110	132	0.04	5	41
S144	WCA2A	Canal	165	127	0.08	11	45
S145	WCA2A	Canal	206	121	0.07	8	44
S146	WCA2A	Canal	164	117	0.02	2	45
S11A	WCA2A	Canal	171	118	0.16	19	43
S11B	WCA2A	Canal	192	122	0.18	22	44
S11C	WCA2A	Canal	258	117	0.15	18	41
C123SR84	WCA3A	Canal	97	75	0.19	14	24
S151	WCA3A	Canal	229	98	0.25	24	39
S12A	WCA3A	Canal	320	29	-0.81	-24	33
S12B	WCA3A	Canal	345	39	-0.33	-13	28
S12C	WCA3A	Canal	350	54	0.04	2	33
S12D	WCA3A	Canal	367	69	0.24	16	37
S333	WCA3A	Canal	319	77	0.31	24	40
S31	WCA3B	Canal	109	89	0.01	1	60
		Median All:	80	80	-0.05	-3	44
		Median Canal:	165	118	0.13	14	43
		Median Marsh:	55	62	-0.12	-12	47

6.6.3 Ecological consistency

Beyond the above model application "water quality" Performance Measures, and the indicators of hydrologic consistency, below we provide some further indicators that the model adequately captures ecosystem dynamics in the regional landscape.

6.6.3.1 Consistency: Integrated ecosystem responses

The rate of peat accretion is a central integrator of the biological responses to water quality and hydrology. Using data from the "E" and "F" transects in WCA-2A, Figure 6.12 shows a strong correspondence of simulated and observed peat accretion, indicating a useful degree of balance between soil oxidation, plant mortality, and their hydrologic and nutrient drivers.

Macrophyte growth (and biomass) responds directly to porewater phosphorus availability, along with hydrologic variations. Simulated patterns of total macrophyte biomass were consistent with expected trends, particularly along nutrient gradients (Figure 6.13). Generally on longer time scales than those of macrophyte biomass changes, (and the even more transient porewater nutrients), phosphorus concentration in the soils[10] is a commonly used indicator of the eutrophication status of the Everglades wetlands. The simulated spatial pattern of the soil phosphorus concentrations (Figure 6.13) are consistent with our understanding of the trends in the Everglades, particularly downstream of known nutrient inflows such as those in WCA-2A. Also shown in that Figure, cattail succession as a result of (water levels and) eutrophication gradient in WCA-2A is generally consistent with the observed cattail distribution in 1995.

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[10] While the upper 10 cm, and especially the surficial floc layer, of the soil is usually used in describing (recent) soil phosphorus status, the ELM does not stratify the soils beyond separating the floc and the 0-30 cm layers. There are often significant differences among soil layers (often with lower concentration in deeper 10-20 or 20-30 cm layers).

Figure 6.12 Simulated and observed rates of peat accretion along the WCA-2A eutrophication gradient. Data are summarized from Craft et al. (1993), Reddy et al. (1993).

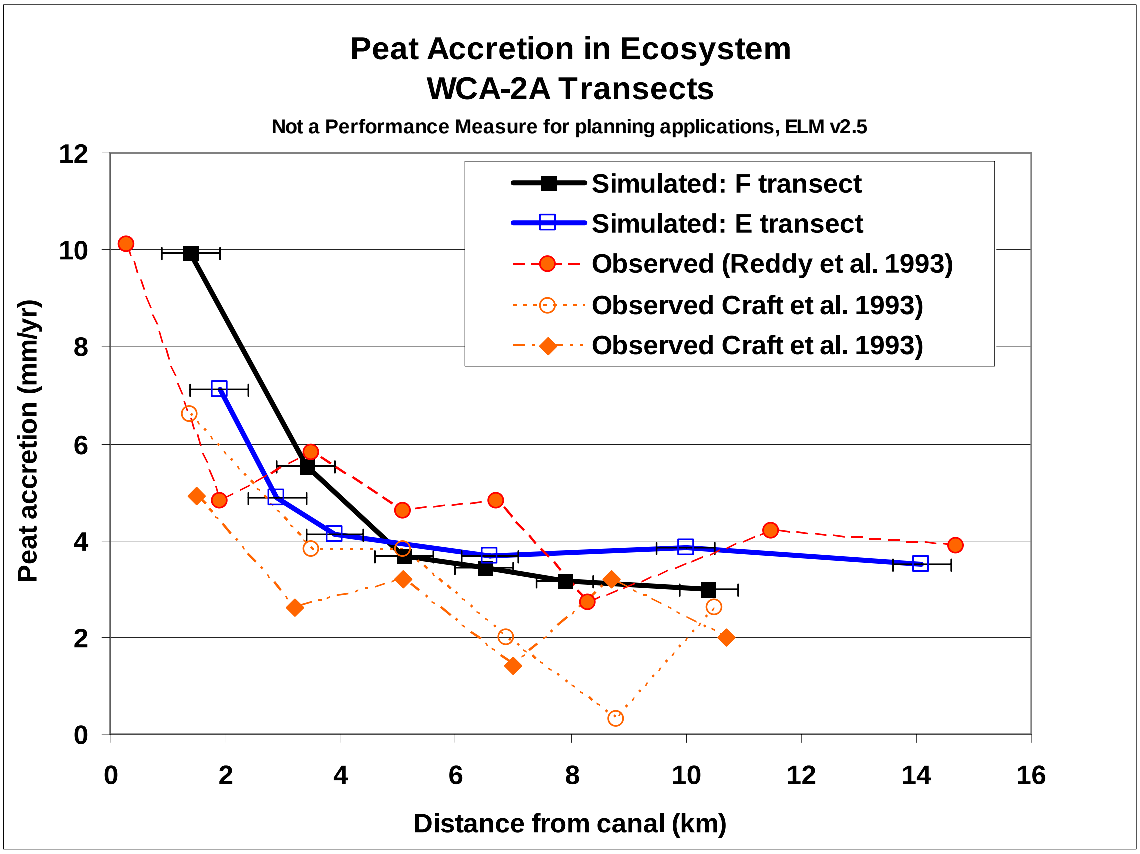
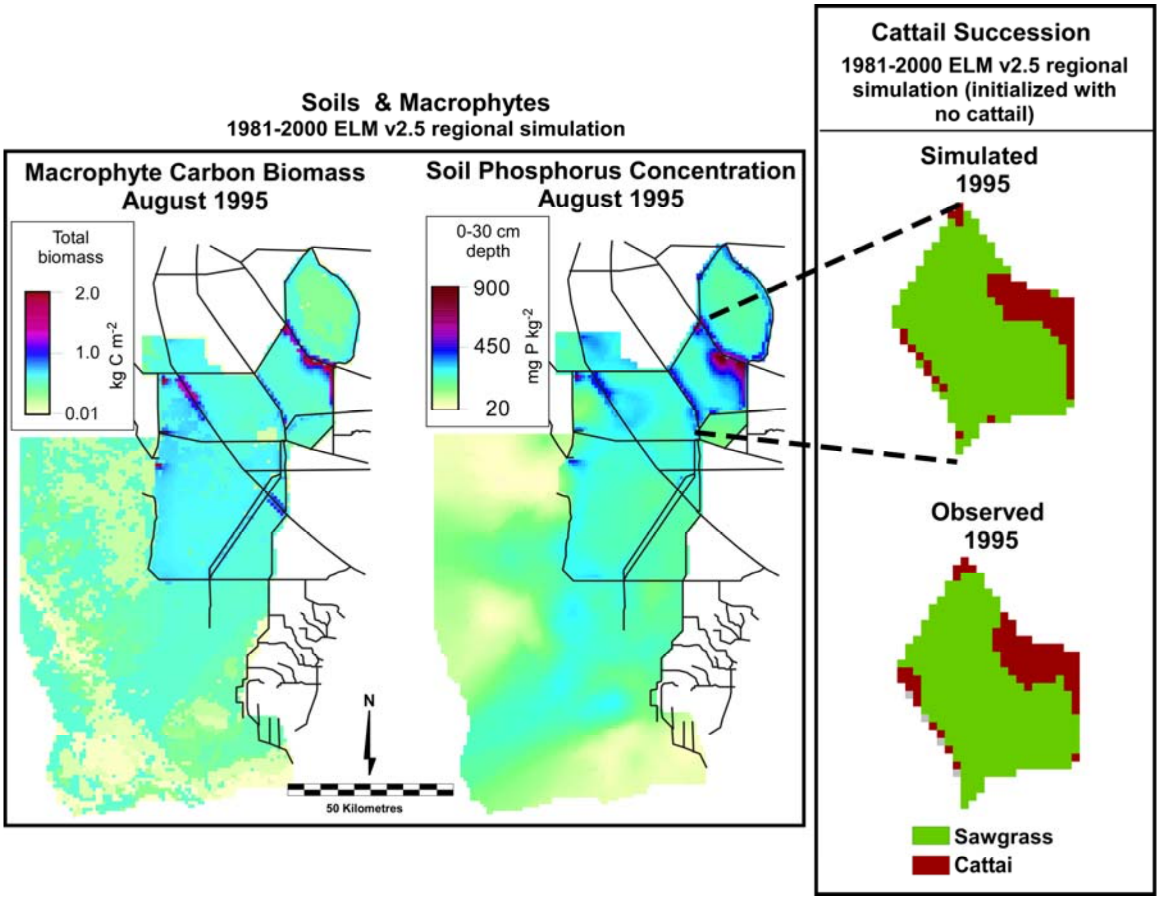


Figure 6.13 Simulated distribution of macrophyte biomass (left), in a snapshot of the mean during the month of August 1995. Soil phosphorus concentration during the same period, with the simulated cattail distribution at that time, compared to the observed distribution of that habitat (data summarized from (Rutchey and Vilchek 1999)).



6.6.4 Validation

With an extension to the period of simulation (to include 1996-2000), the interim ELM v2.2 results demonstrated a “classical validation” of the hydrologic algorithms and data used in ELM. Table 6.4 shows that the median of all (four) statistics comparing simulated to observed stages were similar during the (1981-1995) calibration and (1996-2000) validation periods. Moreover, the (theoretically) improved boundary condition data used to drive ELM v2.2 appeared to somewhat improve the model’s performance during the calibration period, as evidenced in the improved median statistics for the calibration of ELM v2.2 relative to v2.1 (Table 6.4).

As with the “classical” validation of stage predictions, the water column phosphorus predictions were “classically” validated in ELM v2.2. Table 6.5 shows that the median of both statistics comparing simulated to observed surface water phosphorus concentrations were similar during the (1981-1995) calibration and (1996-2000) validation periods. In updating the boundary condition data from ELM v2.1 to v2.2, there was generally little difference in the overall summary of the model’s performance, as evidenced in the similar median statistics for the calibration of ELM v2.2 relative to v2.1 (Table 6.5).

Table 6.4. Statistical evaluation of simulated vs. observed stages during the calibration period of ELM v2.1 and ELM v2.2, and during the validation period of ELM v2.2.

	ELM v2.1 stage calibration				ELM v2.2 stage calibration				ELM v2.2 stage validation			
Site	Bias	RMSE	R2	EFF	Bias	RMSE	R2	Eff	Bias	RMSE	R2	Eff
1-7	0.06	0.16	0.73	0.33	0.05	0.15	0.70	0.30	0.01	0.15	0.72	0.30
1-8T	0.04	0.23	0.67	0.06	0.07	0.19	0.72	0.28	0.02	0.18	0.75	0.39
1-9	0.00	0.15	0.72	0.50	0.02	0.14	0.68	0.42	-0.01	0.14	0.74	0.44
2A-17_B	-0.04	0.24	0.65	0.43	-0.14	0.24	0.69	0.22	-0.16	0.25	0.67	0.12
2A-300_B	-0.05	0.23	0.56	0.46	-0.14	0.25	0.69	0.42	-0.15	0.25	0.67	0.38
3-34	-0.09	0.16	0.84	-1.70	0.18	0.23	0.69	-0.18	0.18	0.22	0.72	-0.20
3-71	-0.09	0.14	0.68	0.35	0.16	0.20	0.60	-0.26	0.22	0.25	0.53	-1.31
3-76	-0.07	0.12	0.66	0.46	0.12	0.16	0.63	0.04	0.15	0.17	0.66	-0.36
3A-10_B	0.06	0.34	0.64	0.51	-0.05	0.14	0.76	0.53	-0.03	0.13	0.76	0.60
3A-11_B	-0.24	0.34	0.78	-1.25	0.21	0.24	0.85	-0.34	0.22	0.25	0.85	-0.46
3A-12_B	0.10	0.25	0.66	0.25	-0.03	0.19	0.59	0.46	-0.04	0.17	0.64	0.51
3A-2_G	0.06	0.26	0.59	0.53	0.02	0.12	0.87	0.85	0.04	0.12	0.87	0.84
3A-28_G	0.29	0.31	0.83	-0.19	-0.14	0.19	0.87	0.65	-0.13	0.17	0.88	0.69
3A-3_G	0.16	0.22	0.87	0.68	-0.07	0.16	0.88	0.85	-0.04	0.15	0.87	0.86
3A-4_G	0.10	0.17	0.84	0.75	0.07	0.14	0.86	0.80	0.08	0.14	0.87	0.80
3A-9_B	-0.02	0.16	0.83	0.82	0.09	0.16	0.86	0.74	0.10	0.15	0.86	0.72
3A-NE_B	0.07	0.25	0.68	0.59	0.00	0.23	0.68	0.67	0.01	0.21	0.71	0.70
3A-NW_B	-0.07	0.25	0.63	0.38	-0.04	0.15	0.75	0.70	-0.03	0.14	0.75	0.72
3A-S_B	0.01	0.20	0.85	0.44	0.07	0.15	0.86	0.71	0.09	0.15	0.86	0.69
3A-SW_B	0.11	0.17	0.82	0.49	0.03	0.11	0.86	0.75	0.04	0.11	0.87	0.79
3B-SE_B	0.03	0.31	0.56	0.46	0.07	0.26	0.71	0.46	0.07	0.23	0.70	0.52
G-1502	0.11	0.28	0.57	0.39	-0.16	0.25	0.74	0.54	-0.10	0.23	0.65	0.55
G-3273	0.15	0.26	0.67	0.39	-0.23	0.30	0.71	0.28	-0.16	0.26	0.64	0.38
G-618_B	0.10	0.18	0.60	0.02	-0.10	0.17	0.71	0.54	-0.07	0.15	0.69	0.61
G-620_B	0.11	0.16	0.80	0.57	-0.07	0.13	0.83	0.73	-0.05	0.11	0.84	0.79
HOLEY_G	0.24	0.29	0.55	-1.48	0.04	0.24	0.63	-0.48	-0.04	0.24	0.46	-0.74
HOLEY1	0.23	0.26	0.64	-0.53	-0.13	0.19	0.75	0.43	-0.20	0.24	0.59	-0.24
HOLEY2	0.19	0.23	0.67	-0.11	-0.12	0.19	0.69	0.48	-0.18	0.24	0.55	0.01
NESRS1	0.02	0.15	0.48	0.43	-0.06	0.12	0.67	0.56	-0.03	0.11	0.63	0.60
NESRS2	0.09	0.18	0.63	0.39	-0.07	0.13	0.70	0.53	-0.05	0.11	0.67	0.59
NESRS3_B	0.07	0.26	0.60	0.29	-0.03	0.21	0.62	0.39	0.01	0.18	0.59	0.45
NP-202	-0.06	0.12	0.81	0.71	-0.01	0.10	0.83	0.83	0.01	0.09	0.85	0.85
NP-203	0.00	0.10	0.79	0.77	-0.04	0.10	0.84	0.80	-0.02	0.09	0.85	0.84
NP-205	0.05	0.19	0.67	0.64	0.02	0.14	0.81	0.80	0.02	0.14	0.80	0.79
NP-206	0.14	0.29	0.57	0.45	-0.15	0.27	0.71	0.54	-0.11	0.23	0.71	0.60
NP-207	-0.05	0.14	0.79	-0.35	0.04	0.10	0.86	0.74	0.04	0.10	0.85	0.71
NP-P33	0.04	0.16	0.55	0.42	-0.06	0.14	0.69	0.57	-0.04	0.12	0.71	0.66
NP-P34	0.10	0.23	0.70	0.29	-0.05	0.17	0.85	0.60	-0.05	0.16	0.85	0.64
NP-P35	0.19	0.25	0.69	-0.95	-0.15	0.22	0.74	-0.36	-0.17	0.23	0.75	-0.59
NP-P36	0.04	0.18	0.47	0.38	0.01	0.11	0.76	0.72	0.03	0.10	0.78	0.74
NP-P38	0.08	0.19	0.70	-0.03	-0.10	0.16	0.84	0.35	-0.11	0.16	0.85	0.29
NP-P44	0.34	0.42	0.68	0.07	-0.37	0.43	0.77	0.02	-0.34	0.41	0.76	0.07
NP-P46	-0.06	0.17	0.63	0.59	-0.03	0.14	0.66	0.34	-0.05	0.14	0.66	0.31
NP-P62	0.12	0.20	0.72	0.32	-0.09	0.16	0.81	0.69	-0.08	0.15	0.80	0.72
NP-P67	0.03	0.13	0.71	0.63	0.02	0.10	0.79	0.77	0.02	0.10	0.80	0.79
NP-P72	0.37	0.44	0.66	-0.67	-0.42	0.47	0.79	-0.34	-0.40	0.44	0.78	-0.28
ROTT.S	0.03	0.15	0.62	0.25	0.18	0.21	0.71	-0.53	0.15	0.20	0.66	0.01
RUTZKE_G	-0.12	0.35	0.48	-1.36	-0.10	0.23	0.73	-0.42	0.00	0.27	0.73	-0.44
SHARK.1_H	-0.02	0.15	0.68	0.64	0.10	0.16	0.76	0.62	0.13	0.18	0.76	0.49
TAMI.40M	0.11	0.29	0.55	-14.55	-0.05	0.22	0.74	0.56	-0.03	0.20	0.75	0.57
Median:	0.06	0.21	0.67	0.39	-0.04	0.17	0.74	0.54	-0.03	0.17	0.75	0.56

Table 6.5. Statistical evaluation of simulated vs. observed phosphorus concentrations in surface waters during the calibration period of ELM v2.1 and ELM v2.2, and during the validation period of ELM v2.2.

		V2.1 Calibration		V2.2 Calibration		V2.2 Validation	
Site	Site type	Bias	RMSE	Bias	RMSE	Bias	RMSE
CA311	Marsh	-0.002	0.009	-0.001	0.001	-0.002	0.003
CA315	Marsh	0.002	0.007	0.002	0.002	0.001	0.001
CA32	Marsh	-0.001	0.008	0.002	0.002	0.003	0.003
CA33	Marsh	-0.017	0.011	-0.012	0.014	-0.005	0.008
CA34	Marsh	0.000	0.003	0.002	0.005	0.004	0.005
CA35	Marsh	-0.020	0.012	-0.031	0.032	-0.019	0.021
CA36	Marsh	-0.023	0.022	-0.021	0.024	-0.008	0.012
CA38	Marsh	-0.002	0.011	0.000	0.002	-0.001	0.005
EP	Marsh	-0.002	0.010	-0.004	0.006	-0.007	0.008
LOX10	Marsh	-0.001	0.008	0.006	0.007	0.005	0.006
LOX11	Marsh	0.004	0.004	0.000	0.001	0.001	0.002
LOX12	Marsh	-0.012	0.002	-0.021	0.021	-0.023	0.024
LOX13	Marsh	0.003	0.003	-0.003	0.004	-0.002	0.003
LOX14	Marsh	-0.014	0.005	0.001	0.002	0.002	0.002
LOX15	Marsh	-0.018	0.007	-0.015	0.015	-0.017	0.017
LOX16	Marsh	-0.016	0.007	-0.006	0.007	-0.008	0.008
LOX3	Marsh	0.000	0.011	0.001	0.005	-0.003	0.004
LOX4	Marsh	-0.022	0.004	-0.001	0.002	0.001	0.004
LOX5	Marsh	0.004	0.006	0.005	0.005	0.003	0.004
LOX6	Marsh	-0.004	0.006	-0.004	0.007	-0.007	0.008
LOX7	Marsh	-0.001	0.006	0.003	0.003	0.004	0.004
LOX8	Marsh	0.002	0.005	0.002	0.003	0.003	0.004
LOX9	Marsh	0.005	0.007	0.006	0.007	0.004	0.004
NE1	Marsh	0.006	0.009	0.007	0.009	0.004	0.004
P33	Marsh	0.002	0.009	0.002	0.005	0.000	0.002
P34	Marsh	-0.008	0.008	-0.004	0.005	-0.006	0.006
P35	Marsh	0.008	0.016	0.011	0.019	0.006	0.009
P36	Marsh	0.028	0.030	0.025	0.041	0.003	0.005
P37	Marsh	-0.012	0.009	-0.002	0.003	-0.004	0.005
TSB	Marsh	-0.002	0.017	-0.002	0.005	-0.004	0.005
C123SR84	Canal	0.004	0.038	0.024	0.028	0.026	0.028
COOPERTN	Canal	0.001	0.006	0.004	0.004	0.005	0.006
L40-1	Canal	-0.001	0.033	0.011	0.029	0.051	0.055
L40-2	Canal	0.017	0.049	0.039	0.050	0.063	0.066
L7	Canal	-0.023	0.047	0.054	0.072	0.000	0.000
S10A	Canal	0.002	0.033	-0.004	0.032	-0.003	0.015
S10C	Canal	0.037	0.064	0.026	0.044	0.021	0.026
S10D	Canal	0.060	0.072	0.061	0.071	0.041	0.045
S10E	Canal	0.050	0.101	0.068	0.078	0.042	0.046
S11A	Canal	-0.013	0.010	-0.013	0.027	0.005	0.012
S11B	Canal	0.008	0.014	0.011	0.028	0.010	0.016
S11C	Canal	0.018	0.034	0.030	0.039	0.028	0.029
S12A	Canal	0.006	0.009	0.009	0.024	0.006	0.009
S12B	Canal	0.005	0.008	0.005	0.017	0.005	0.009
S12C	Canal	0.004	0.005	0.004	0.008	0.003	0.004
S12D	Canal	0.004	0.005	0.005	0.008	0.003	0.004
S144	Canal	0.003	0.009	0.008	0.015	0.008	0.011
S145	Canal	0.000	0.006	0.007	0.012	0.006	0.008
S146	Canal	0.001	0.008	0.007	0.013	0.004	0.007
S151	Canal	0.009	0.016	0.020	0.026	0.013	0.015
S31	Canal	0.010	0.021	0.013	0.019	0.015	0.019
S333	Canal	0.006	0.006	0.006	0.010	0.005	0.006
Median:		0.001	0.009	0.003	0.010	0.003	0.006

Nevertheless, the strict, “classical validation” of a model is ephemeral. As soon as any improvement to the model is made based on scientific advances, the model is no longer truly validated in the classical sense. Classically, a new independent data set must be used to validate the model again. Perhaps more importantly, extending a model simulation period by another year (or 6 months, or 5 years) with an “independent” data set may or may not increase the confidence that users place in the model. As discussed elsewhere, any increased confidence in the model capabilities is largely dependent on how different the new boundary condition forcing data are from those previously input to the model. Instead of attempting to classically validate models, we argue that the most important criteria for user-confidence involves the demonstration of sufficient model performance under an extreme range of conditions – relative to the objectives of the model. Regardless of this debate (see Uncertainty Chapter for discussion of the utility of classical model validation), the ELM performance was enhanced under improved boundary conditions, and the overall performance of the ELM was comparable (if not improved) during the validation period that was driven by input data that were independent of the calibration period.

6.7 Discussion

6.7.1 Model performance summary

Multiple methods were used to evaluate the performance characteristics of this model of greater Everglades ecology. The following summarizes those performance evaluations:

6.7.1.1 Model Objectives – Phosphorus Performance Measures

- P concentration: median bias in predicting surface water TP concentrations was 2 ug l^{-1} for 78 marsh and canal locations in the greater Everglades, whose mean concentrations ranged from less than 10 to more than 100 ug l^{-1}
- P accumulation: along extreme eutrophication gradients, predicted rates of P accumulation in the ecosystems corresponded to field measurements

6.7.1.2 Model Consistency - Hydrology

- Water stage: median bias in predicting stage elevations was -1 cm for 82 marsh locations in the greater Everglades, whose hydroperiod ranged from continuously flooded to rarely flooded; other statistical metrics were comparable to the SFWMM
- Water flows: basin-wide flow budgets were in concordance with those of the SFWMM;
- Water flows: distribution of chloride (CL) concentrations throughout the freshwater Everglades showed patterns of long-term flow regimes that were consistent with our understanding of major flow paths, with a median relative error of -12% in marshes.

6.7.1.3 Model Consistency – Other Ecological Dynamics

- Peat accretion: along extreme eutrophication gradients, predicted rates of peat soil accretion in the ecosystems corresponded to field measurements
- Landscape patterns: regional patterns of macrophyte biomass, soil P concentrations, and (at least subregional) cattail succession corresponded to patterns of observed data

We note here that we have not evaluated the model performance within the mangrove-dominated region (that is delineated in the results map of the CL tracer regional). Thus, application of these ELM Performance Measures within that specific region have an undocumented level of accuracy.

6.7.2 Uncertainty & expectations

As discussed in more detail in the Uncertainty Chapter of this document, there are many factors that result in imperfect agreement of "point-to-point" comparisons between simulated and observed data. Particularly for "water quality" modeling, a critical consideration is the spatial and temporal quality of the inflow boundary nutrient loads, particularly in this managed system that is largely driven by such point sources. The frequency of observed data used to determine nutrient loading to the Everglades system is very sparse relative to the actual water flows; this imposes limits on the ability to simulate short term fluctuations in nutrient dynamics within the system.

At regional scales, it is possible for an improperly structured model to introduce spatial trends in predictive errors. However, such systematic spatial (or temporal) patterns of error were not observed during our extensive calibration process. Moreover, while a simulated value of phosphorus concentration is actually a mean concentration in one square kilometer (of the model grid), the measured phosphorus concentration is an instantaneous observation at a point location, and may not represent the average condition in a heterogeneous area that is subjected to a variety of random processes.

Because of these random errors in data observations, an exact match between simulated and observed "point" monitoring of phosphorus is difficult, and indeed is inappropriate when considering the data quality and expectations. When the number of observation is large, random samples do not increase bias, and thus random errors can be canceled out by aggregation. We thus used temporal aggregation to reduce the effects of random errors in observed data, in order to make the most effective use of the data in understanding long term dynamics: with available data, seasonal to annual (or coarser) temporal scales appear to be the most appropriate scale of aggregation for Everglades water quality dynamics. Decadal responses of the ecosystem are ultimately what we seek to understand and predict in planning for regional Everglades restoration.

6.7.3 Performance refinements

There are limits to model performance that are supported by input data that drive the model, as discussed in the Uncertainty Chapter. However, we also acknowledge that the current version can (and will) be improved within this boundary of expectations. In the Model Refinement Chapter, the near-term and long-term steps in model refinement are presented. We know of a number of relatively straightforward steps that can and will be taken to improve the model performance in the near term.

The overall statistical summaries presented were influenced by a small number of locations where stage or water quality performance is significantly lower than other, even adjacent, locations. In this version, we did not take the time to correct isolated performance “problems” at a handful of locations.

- Big Cypress region: Stage predictions in a number of sites in the Big Cypress National Preserve were generally not simulated as well as other regions in the model domain, likely due to our use of untested land topography data (that was different from that used in the SFWMM).
- WCA-1: While the topography in the marsh of this region is well sampled, we do not know of data that quantifies the magnitude of the topographic berms and associated dense brush vegetation along the edge of this canal; canal-marsh exchanges are significantly effected by these features, which we hope to better quantify. The unique hydraulics associated with this uninterrupted canal encircling the basin are sensitive to relative topographic differences along this feature.
- Mangrove region in south and southwest: Tidal boundary conditions are extremely aggregated in both space and time. Spatial distributions of tidal amplitude are not accounted for in our implementation, nor does the monthly-mean tide, repeating every year, accommodate the observed fluctuations at both fine temporal scales, nor among years.

Importantly, we have not completed our efforts to improve upon the parameter estimates used in the model (see the Uncertainty Chapter, which includes an evaluation of model sensitivity to parameter modifications). Nevertheless, the existing code and data support sufficient model performance to enable users to have reasonable confidence in applying model results to long term planning under new managed conditions.

6.7.4 Conclusions

The ELM performance was rigorously quantified in the greater Everglades system for a multi-decadal period of record (1981 through 2000). The primary Performance Measures intended for ELM v2.5 applications involve those of water quality: phosphorous concentrations and net accumulation throughout the greater Everglades region. Quantitative performance assessments provided strong, cumulative evidence that ELM could be effectively used to evaluate relative differences in those Performance Measures within the regional system. With other predicted ecological attributes and rates being consistent with available observations, there is cumulative, strong evidence of model skill in predicting phosphorus trends in the regional Everglades landscape at the relevant decadal time scales.

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6.9 Appendix A: Computational methods for statistics

Although numerous methods exist for analyzing and summarizing model performance, there is no consensus in the modeling community on a standard analytical suite for hydrology and ecological (incl. water quality) models. It appears most useful to use a variety of methods to evaluate model performance, as no single statistic can fully capture all of the important characteristics of a comparison between the simulated and observed data. We employed the below methods to estimate Bias, RMSE, R^2, and NS Efficiency in assessing some aspects of the model performance relative to observed data.

Bias:

$$\text{Bias} = \frac{\sum (x - y)}{n}$$

Where x is the field-observation values, y is the model-prediction values, and n is the number of observations.

Bias is calculated as the mean differences between paired modeled and observed values. It is a measure of how biased the overall values simulated by the model from the observed values. The bias should be as close to zero as possible.

Root Mean Square Error (RMSE):

$$\text{RMSE} = \sqrt{\frac{\sum (y - x)^2}{n}}$$

Where x is the field-observation values and y is the model-prediction values.

RMSE is the square root of the average values of the prediction errors squared. RMSE measures the discrepancy between modeled and observed values on an individual level to indicate accuracy of model predictions. Because of the quadratic term, RMSE gives greater weight to larger discrepancies than smaller ones. The RMSE should be as close to zero as possible.

Pearson product-moment correlation coefficient (R^2):

$$R^2 = \left(\frac{\sum (y - y_m)(x - x_m)}{\sqrt{\sum (y - y_m)^2 \sum (x - x_m)^2}} \right)^2$$

Where x_m is the observed mean of x (calculated as Σx/n), and y_m is the model-predicted mean of observed y (calculated as Σy/n).

The R^2 measure the degree of linear association between x and y (i.e., field observation and model predictions). It represents the amount of variability of one variable that is explained by correlating it with another variable. Depending on the strength of the linear relationships, the R^2 varies from 0.0 to 1.0, with 1.0 indicating a perfect fit.

Nash-Sutcliffe Efficiency (Eff):

$$\text{Eff} = 1 - \frac{\sum (y - x)^2}{\sum (x - x_m)^2},$$

Where x_m is the mean of the observed x, and y is the model prediction.

Like correlation coefficient, model efficiency is another overall indication of goodness of fit (Mayer and Butler 1993, Janssen and Heuberger 1995). Efficiency is equal to one minus the sum of squared prediction errors divided by the sum of squared deviation of observed values from the mean. It represents the amount of variability of one variable that is explained by modeled values. A model efficiency of 1.0 indicates a perfect fit between modeled and observed values, and a efficiency of 0.0 indicates the fit to $y = x$ is no better than $x = x_m$.

6.10 Appendix B: Time series & CFDs: TP (separate pdf)

Figures B.1 – B.78. Time series plots of water column total phosphorus (TP) concentration and their associated Cumulative Frequency Distributions (CFD) for the period of record 1981-2000 at each monitoring location. The sequence of the figures is based on geographic location of marsh sites, starting in northwest, moving towards the southeast; following the set of plots of all marsh sites, the canal monitoring sites are similarly sequenced. A map of all sites is provided in the Model Performance Chapter.

The constant dashed line indicates the TP field sampling Detection Limit (DL = 4 ug l^{-1} *for the model period of record), which was the minimum value used for observed data in plots and statistics. To enable equivalent comparisons, any simulated value which was below the DL was set equal to the DL. The model grid cell column and row locations (col_row) or canal reach identifier (single integer) are shown in parentheses of each plot's title.*

a) All data were aggregated into arithmetic mean values by wet and dry seasons within water years; the continuous lines pass through mean of all daily data points for each season; the mean of paired simulated and observed values are shown in red boxes and black diamonds, respectively; the 95% Confidence Interval (CI) of the paired means are shown by the "__" symbols in the red for the model and black for the observed data.

b) All data aggregated into arithmetic mean values by water year, with the same treatment as in plot a).

c) The CFDs of the simulated and observed (raw, un-aggregated) data; the 95% confidence interval for observed data is shown in the dashed black lines. Note that only paired simulated and observed data points are used.

6.11 Appendix C: Time series & CFDs: stage (separate pdf)

Figures C.1 – C.82. Plots of stage hydrographs and their associated Cumulative Frequency Distributions (CFD) for the period of record 1981-2000 at each monitoring location. The sequence of the figures is based on geographic location, starting in the northwest, moving towards the southeast. A map of all sites is provided in the Model Performance Chapter.

> *The red dashed line in the stage hydrographs is the model grid cell's land surface elevation, which is a time-varying output variable of the model. The model grid cell column and row locations are shown in parentheses (col_row) of each plot's title.*
>
> a) All data, with no temporal aggregation, of daily observations (black dots) and model results (red line).
>
> b) All data were aggregated into arithmetic mean values by wet and dry seasons within water years; the continuous lines pass through mean of all daily data points for each season; the mean of paired simulated & observed values are shown in red boxes and black diamonds, respectively; the 95% Confidence Interval (CI) of the paired means are shown by the "__" symbols in the red for the model and black for the observed data.
>
> c) All data aggregated into arithmetic mean values by water year, with the same treatment as in plot b).
>
> d) The cumulative frequency distributions of the simulated and observed (raw, un-aggregated) data; the 95% confidence interval for observed data is shown in the dashed black lines. Note that only paired simulated and observed data points are used.

6.12 Appendix D: Water budgets, ELM & SFWMM

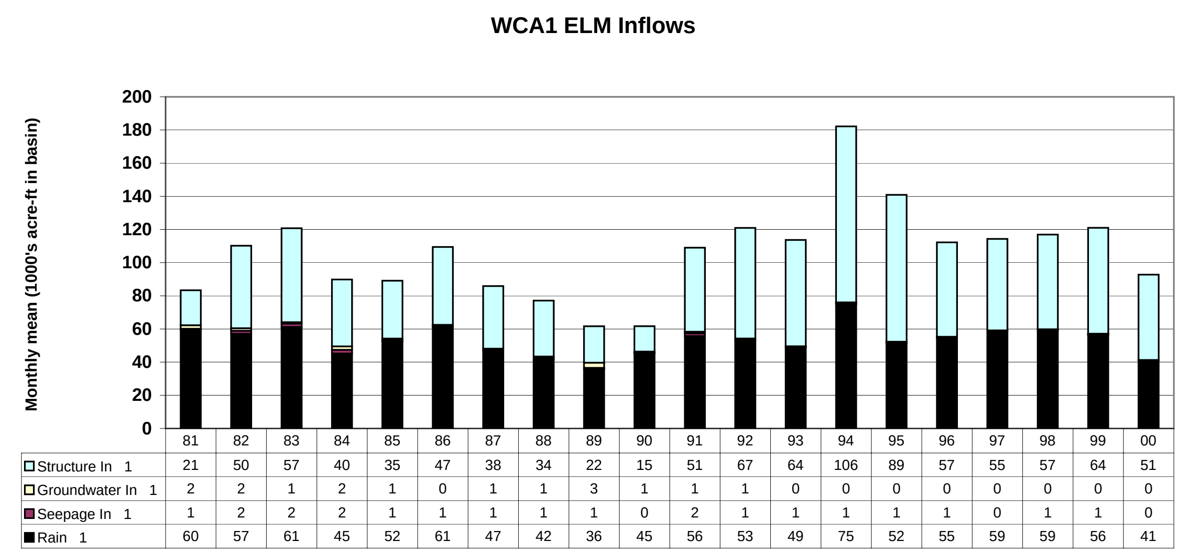
Figures D.1 – D.5. Budget comparisons between ELM and SFWMM for the following basins: WCA-1, WCA-2A, WCA-2B, WCA-3A, and WCA-3B. Each numbered figure contains four graphs:

a) ELM inflows

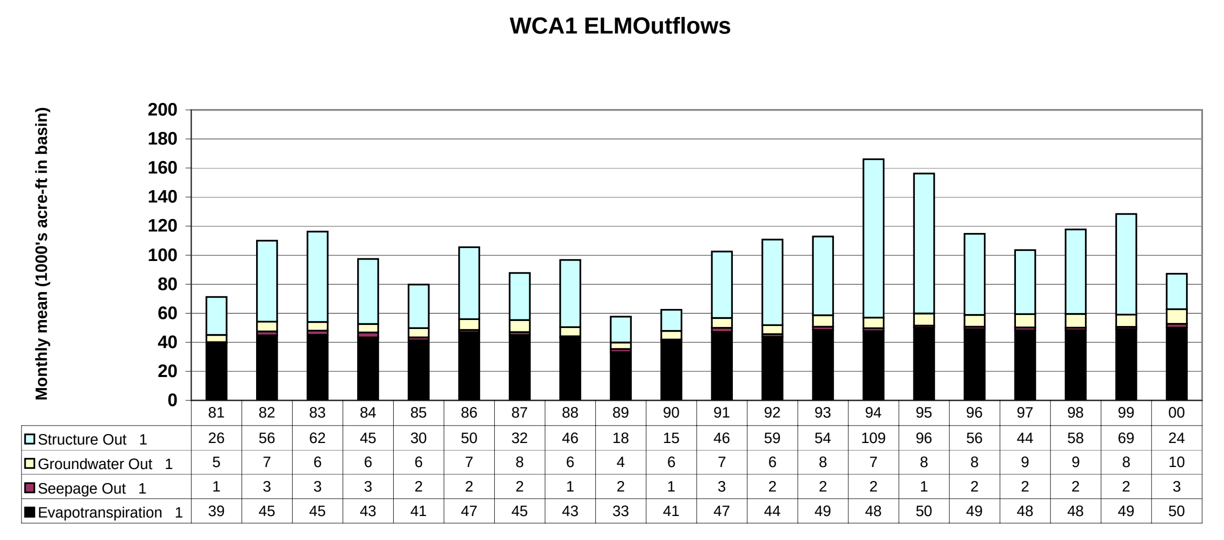
b) ELM outflows.

c) Differences, inflows to SFWMM & ELM

d) Differences, outflows from SFWMM & ELM

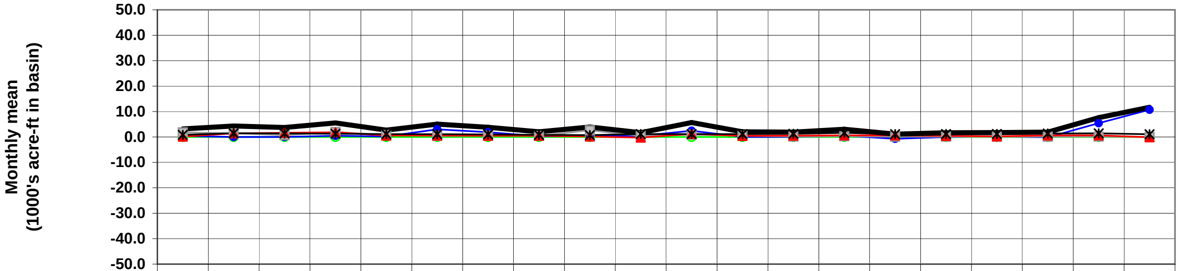


	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟦 Structure In 1	21	50	57	40	35	47	38	34	22	15	51	67	64	106	89	57	55	57	64	51
🟨 Groundwater In 1	2	2	1	2	1	0	1	1	3	1	1	1	0	0	0	0	0	0	0	0
🟪 Seepage In 1	1	2	2	2	1	1	1	1	1	0	2	1	1	1	1	1	0	1	1	0
■ Rain 1	60	57	61	45	52	61	47	42	36	45	56	53	49	75	52	55	59	59	56	41



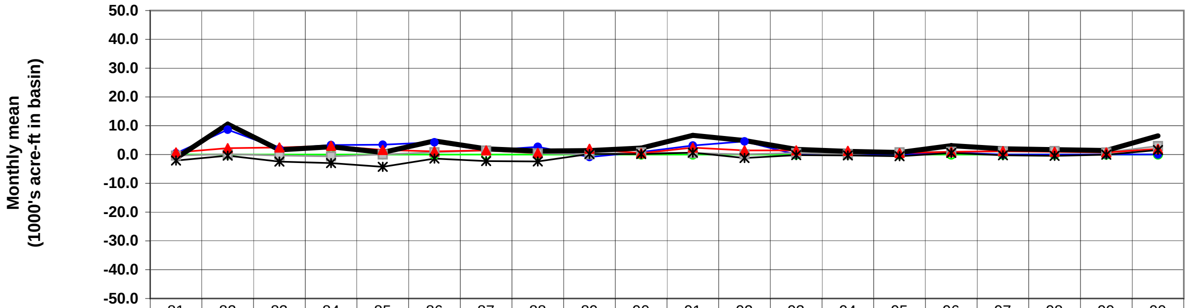
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟦 Structure Out 1	26	56	62	45	30	50	32	46	18	15	46	59	54	109	96	56	44	58	69	24
🟨 Groundwater Out 1	5	7	6	6	6	7	8	6	4	6	7	6	8	7	8	8	9	9	8	10
🟪 Seepage Out 1	1	3	3	3	2	2	2	1	2	1	3	2	2	2	1	2	2	2	2	3
■ Evapotranspiration 1	39	45	45	43	41	47	45	43	33	41	47	44	49	48	50	49	48	48	49	50

WCA1 ELM-SFWMM Inflow Differences



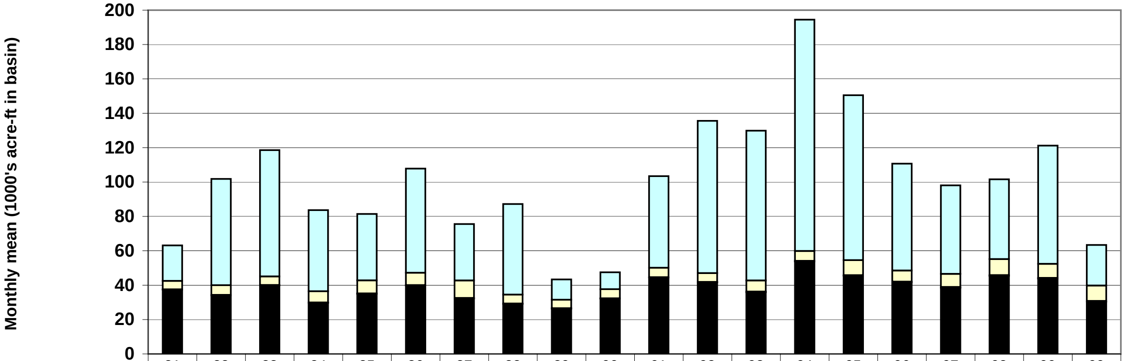
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
○ Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
● Structure	0.4	0.0	0.0	0.5	0.2	3.0	1.9	0.3	0.4	0.4	2.4	0.0	0.0	0.5	-0.7	0.0	0.2	-0.1	5.4	10.7
■ Groundwater	1.8	1.4	0.7	2.0	0.8	0.4	0.5	0.4	2.6	0.4	0.9	0.5	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.0
▲ Seepage	0.1	1.4	1.6	1.8	0.5	0.6	0.5	0.5	0.2	-0.2	1.2	0.4	0.5	0.6	0.6	0.4	0.2	0.6	0.6	-0.1
✳ Rain	0.8	1.5	1.4	1.3	1.1	1.1	1.0	0.8	0.7	1.1	1.1	1.1	1.2	1.6	1.1	1.1	1.2	1.3	1.4	1.1
━ Sum	3.2	4.3	3.7	5.5	2.7	5.1	3.8	2.0	3.9	1.7	5.7	2.0	1.9	3.0	1.1	1.7	1.7	1.9	7.6	11.7

WCA1 ELM-SFWMM Outflow Differences



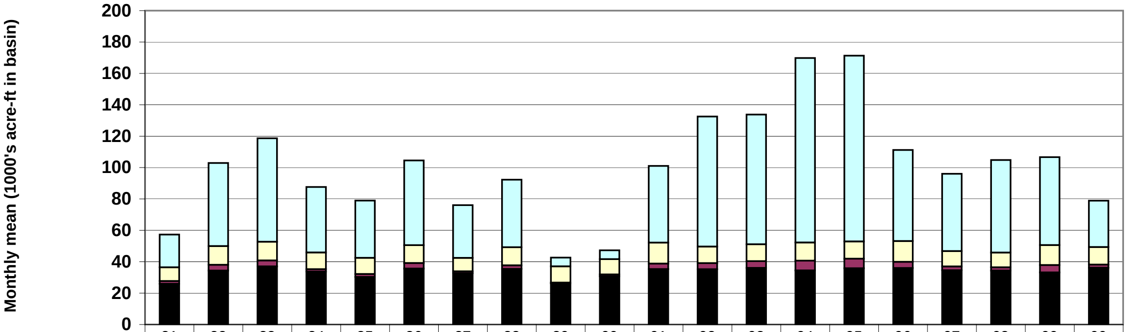
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
○ Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
● Structure	0.4	8.6	2.0	3.3	3.4	4.2	1.4	2.7	-0.9	0.9	3.1	4.6	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
■ Groundwater	-0.4	0.1	-0.3	-0.6	0.0	0.8	1.4	0.4	0.1	0.8	0.5	0.1	0.5	0.1	0.8	1.0	1.0	1.2	0.7	2.9
▲ Seepage	0.7	2.2	2.5	3.0	1.6	1.1	1.4	0.5	2.0	0.5	2.4	1.4	1.4	1.3	0.5	0.9	1.2	0.9	0.7	2.0
✳ ET	-2.1	-0.4	-2.5	-3.0	-4.3	-1.4	-2.3	-2.4	0.2	0.2	0.7	-1.2	-0.2	-0.3	-0.6	0.5	-0.3	-0.5	-0.1	1.6
━ Sum	-1.3	10.6	1.6	2.7	0.7	4.7	2.0	1.2	1.4	2.2	6.7	4.9	1.8	1.1	0.7	3.1	2.0	1.7	1.4	6.5

WCA2A ELM Inflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
☐ Structure In 2	21	62	73	47	39	61	33	53	12	10	53	89	87	135	96	62	52	46	69	24
☐ Groundwater In 2	5	6	5	7	8	7	10	5	5	5	5	5	6	6	9	6	8	9	8	9
■ Seepage In 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
■ Rain 2	37	34	40	30	35	40	32	29	26	32	44	42	36	54	45	42	38	45	44	30

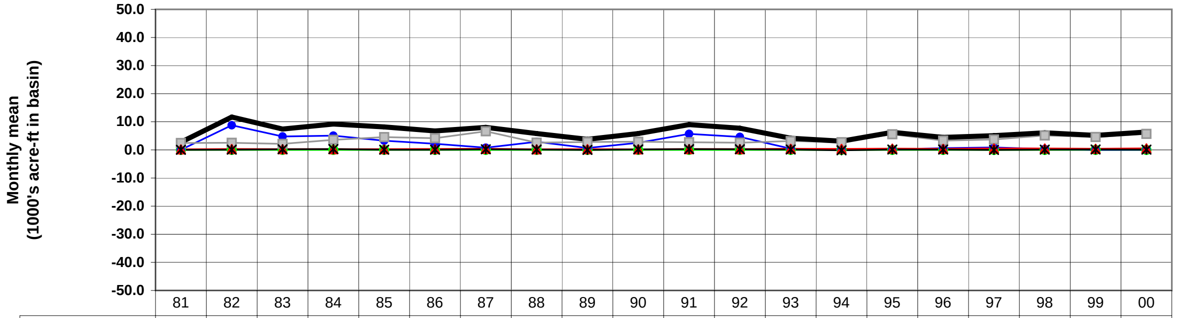
WCA2A ELMOutflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
☐ Structure Out 2	21	53	66	42	36	54	34	43	6	6	49	83	83	118	118	58	49	59	56	30
☐ Groundwater Out 2	9	12	12	11	10	11	9	12	10	10	13	11	11	12	11	13	10	9	13	11
■ Seepage Out 2	2	4	4	1	2	4	1	2	0	1	3	4	4	6	6	4	2	2	5	2
■ Evapotranspiration 2	26	34	37	34	30	36	33	35	26	31	35	35	36	34	36	36	35	34	33	36

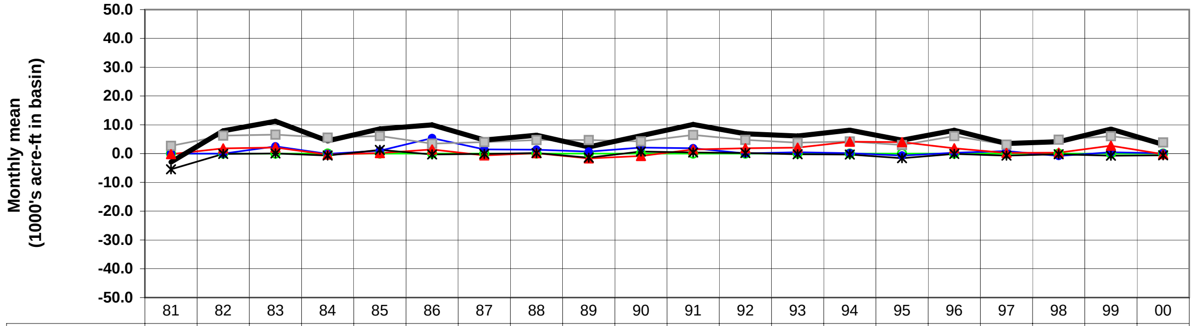
WCA2A ELM-SFWMM Inflow Differences

WCA2A ELM-SFWMM Inflow Differences

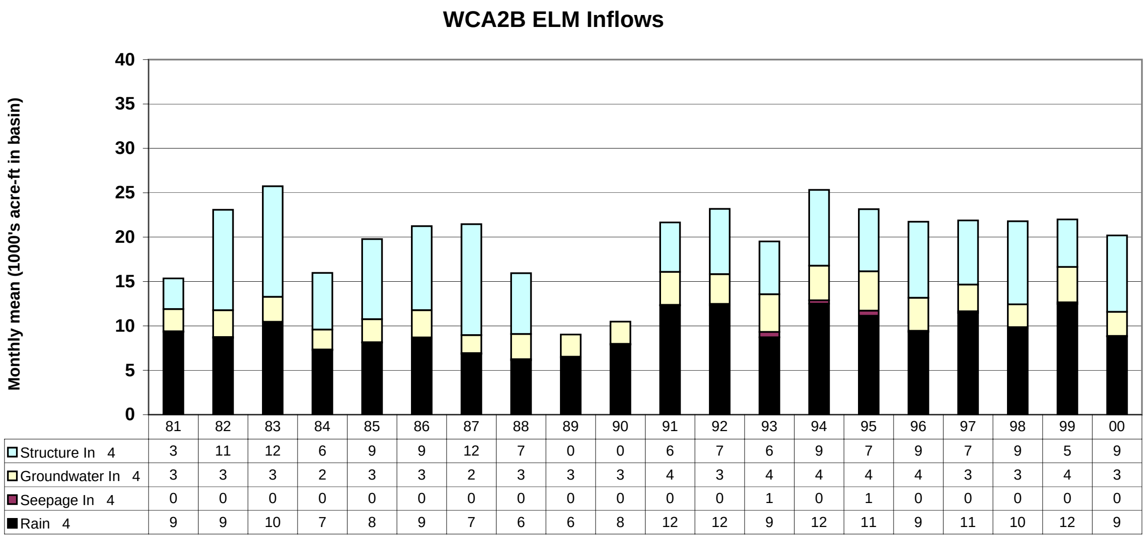


	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	0.0	8.8	4.8	5.1	3.3	2.2	0.8	2.9	0.7	2.5	5.7	4.6	0.4	0.1	0.1	0.6	0.9	0.3	0.0	0.0
Groundwater	2.5	2.5	2.2	3.6	4.6	4.2	6.6	2.6	2.8	2.9	2.7	2.6	3.2	2.7	5.6	3.3	3.7	5.1	4.6	5.7
Seepage	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.2	0.3	0.2	0.3	0.3	0.4	0.4	0.5	0.4	0.5	0.5	0.4	0.5
Rain	0.0	0.1	0.2	0.3	0.1	0.1	0.2	0.1	0.0	0.2	0.3	0.2	0.1	-0.1	0.1	0.1	0.0	0.1	0.2	0.1
Sum	2.7	11.7	7.4	9.2	8.2	6.7	8.0	5.8	3.8	5.8	9.0	7.7	4.2	3.1	6.3	4.5	5.1	6.1	5.2	6.4

WCA2A ELM-SFWMM Outflow Differences

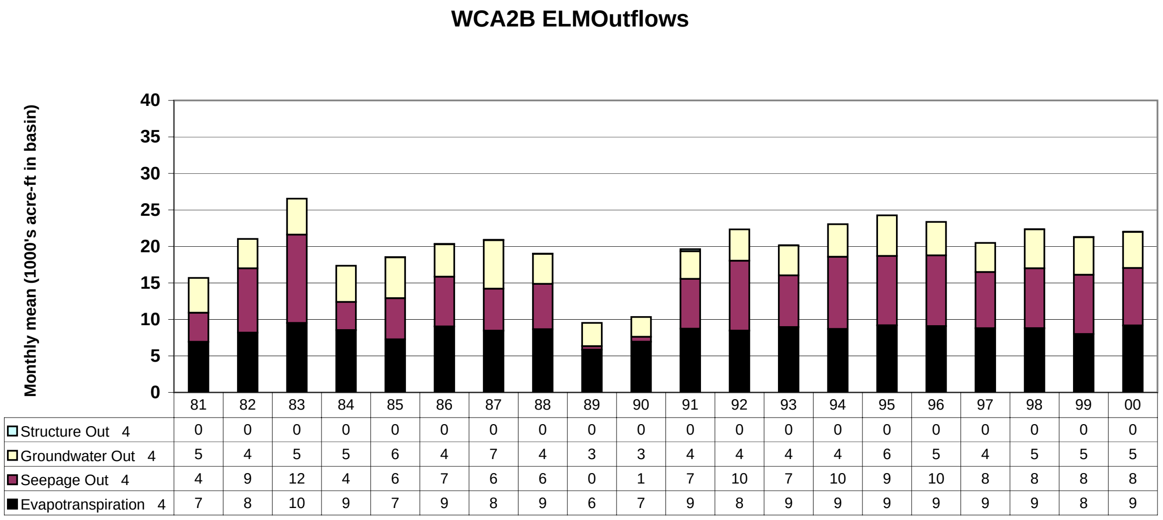


	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	0.0	0.0	2.5	-0.1	1.0	5.4	1.5	1.4	0.7	2.1	1.9	0.1	0.5	0.1	-0.7	0.3	0.9	-0.8	0.5	0.1
Groundwater	2.7	6.2	6.6	5.5	6.1	3.5	4.0	4.7	4.7	4.2	6.5	4.8	3.8	4.2	3.0	6.1	3.1	4.8	6.0	3.9
Seepage	-0.2	1.8	2.1	-0.3	0.2	1.4	-0.6	0.1	-1.7	-0.8	1.4	1.9	2.1	4.1	4.0	1.8	0.2	0.3	2.7	-0.2
ET	-5.5	-0.1	0.0	-0.7	1.3	-0.3	-0.1	0.2	-1.4	0.7	0.4	0.2	-0.2	-0.3	-1.6	-0.1	-0.7	-0.2	-0.7	-0.6
Sum	-3.0	7.9	11.2	4.4	8.6	10.0	4.7	6.4	2.3	6.2	10.1	6.9	6.1	8.1	4.7	8.1	3.5	4.1	8.5	3.2



WCA2B ELM Inflows

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
□ Structure In 4	3	11	12	6	9	9	12	7	0	0	6	7	6	9	7	9	7	9	5	9
□ Groundwater In 4	3	3	3	2	3	3	2	3	3	3	4	3	4	4	4	4	3	3	4	3
■ Seepage In 4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
■ Rain 4	9	9	10	7	8	9	7	6	6	8	12	12	9	12	11	9	11	10	12	9

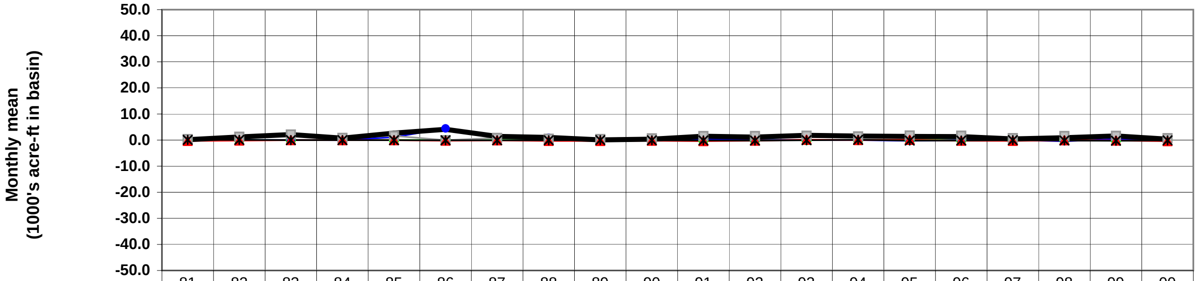


WCA2B ELMOutflows

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
□ Structure Out 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
□ Groundwater Out 4	5	4	5	5	6	4	7	4	3	3	4	4	4	4	6	5	4	5	5	5
■ Seepage Out 4	4	9	12	4	6	7	6	6	0	1	7	10	7	10	9	10	8	8	8	8
■ Evapotranspiration 4	7	8	10	9	7	9	8	9	6	7	9	8	9	9	9	9	9	9	8	9

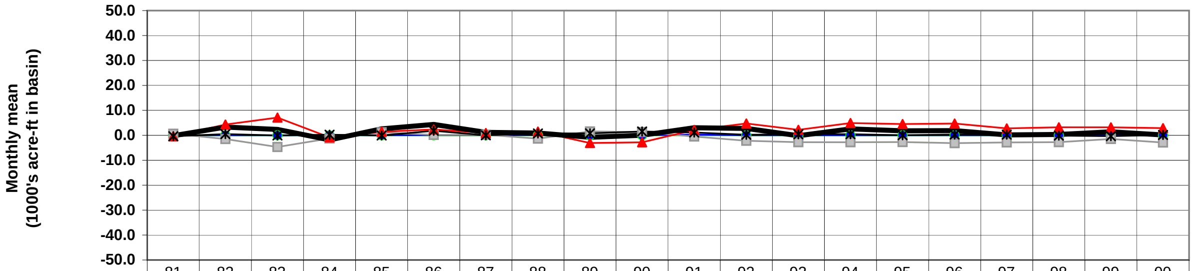
WCA2B ELM-SFWMM Inflow Differences

WCA2B ELM-SFWMM Inflow Differences



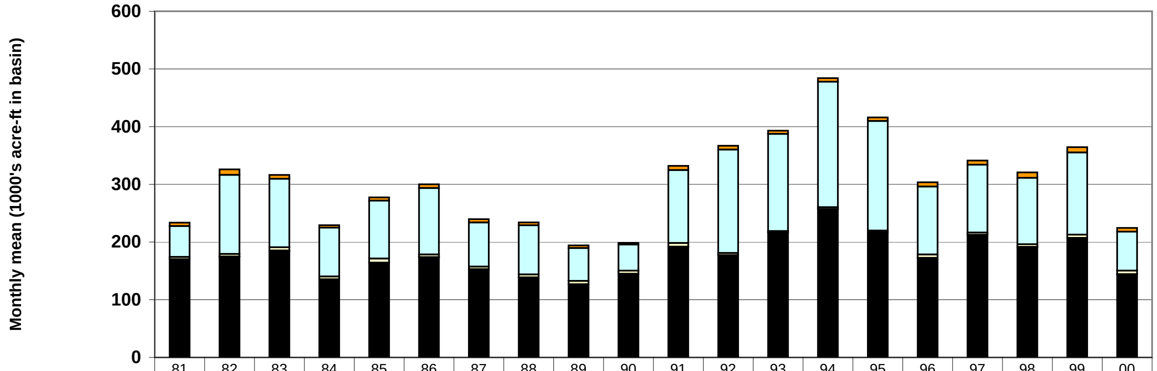
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	0.0	0.0	0.0	-0.1	1.1	4.5	0.7	0.9	0.0	0.0	0.4	0.0	0.0	0.0	-0.3	0.0	0.0	-0.4	0.4	0.1
Groundwater	0.4	1.3	2.1	0.8	1.6	0.0	0.8	0.5	0.4	0.7	1.6	1.6	1.7	1.4	1.8	1.7	0.8	1.6	1.6	0.7
Seepage	-0.3	-0.2	0.0	0.0	0.0	-0.2	-0.1	-0.3	-0.3	-0.2	-0.4	-0.2	0.1	0.0	0.1	-0.2	-0.3	-0.1	-0.2	-0.4
Rain	0.1	0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0	-0.1	-0.1	-0.2	0.0	0.1	-0.2	-0.2	0.0	-0.2	-0.3	-0.1
Sum	0.1	1.2	2.1	0.7	2.7	4.1	1.4	1.0	0.1	0.3	1.5	1.1	1.8	1.5	1.4	1.3	0.4	0.9	1.6	0.4

WCA2B ELM-SFWMM Outflow Differences



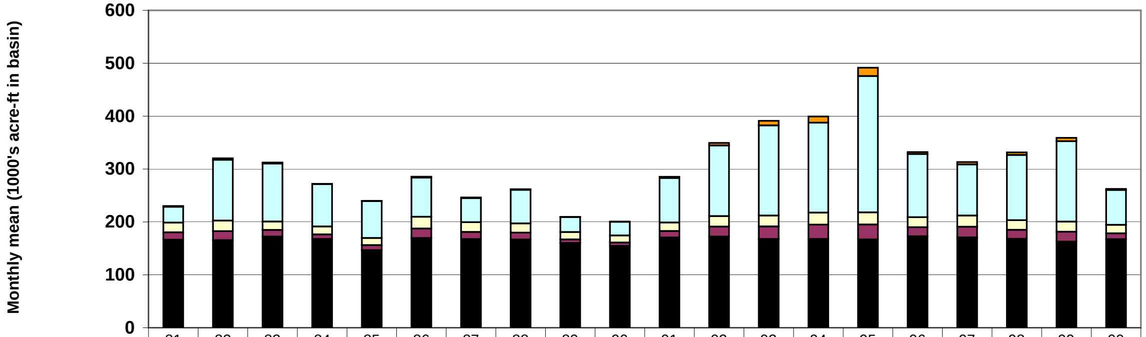
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater	0.6	-1.5	-4.7	-1.3	1.2	0.2	0.2	-1.3	1.5	1.3	-0.5	-2.2	-2.8	-2.8	-2.7	-3.2	-2.9	-2.7	-1.5	-2.9
Seepage	-0.4	4.3	7.1	-0.8	1.4	2.3	0.9	1.5	-3.1	-2.8	2.1	4.7	2.2	4.9	4.5	4.7	2.8	3.2	3.2	2.9
ET	-0.4	0.5	-0.1	0.2	-0.1	1.8	0.0	0.7	0.8	1.5	1.1	0.2	0.4	0.4	0.0	0.3	0.3	-0.1	-0.3	0.1
Sum	-0.2	3.3	2.3	-1.9	2.6	4.4	1.2	0.9	-0.8	0.0	3.0	2.8	-0.2	2.6	1.8	1.9	0.2	0.3	1.4	0.1

WCA3A ELM Inflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟧 Overland In 3	6	9	7	4	6	6	6	5	4	3	7	7	6	6	6	7	7	9	9	6
□ Structure In 3	53	137	119	85	100	115	77	85	57	45	126	179	168	217	190	118	118	115	143	67
□ Groundwater In 3	4	4	6	5	7	5	4	5	6	5	6	4	3	3	3	6	4	5	6	6
■ Seepage In 3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
■ Rain 3	170	175	185	135	164	174	153	139	127	145	192	177	216	257	217	173	212	192	207	144

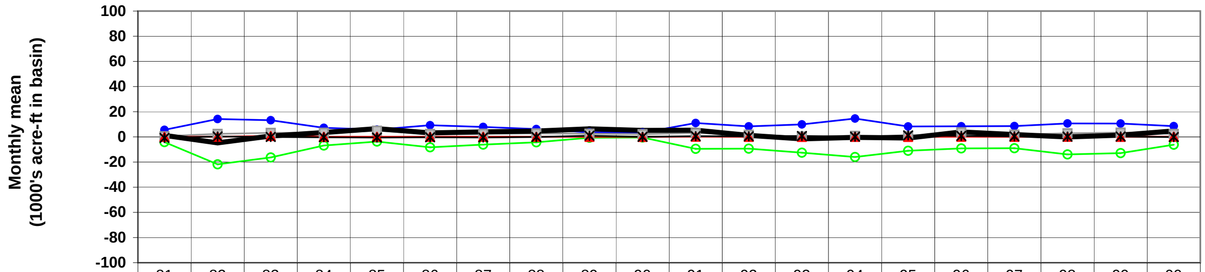
WCA3A ELMOutflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟧 Overland Out 3	1	3	2	1	1	2	1	1	0	0	2	5	9	12	16	4	4	5	6	2
□ Structure Out 3	30	115	110	80	70	74	45	63	28	26	84	134	170	170	258	120	97	123	152	66
□ Groundwater Out 3	18	20	16	15	13	22	18	17	14	13	16	20	21	23	23	19	21	18	19	16
■ Seepage Out 3	14	17	13	9	10	18	14	13	7	6	12	19	24	27	28	17	20	17	19	11
■ Evapotranspiration 3	166	166	172	168	147	170	168	167	160	155	171	172	168	168	167	173	171	168	163	167

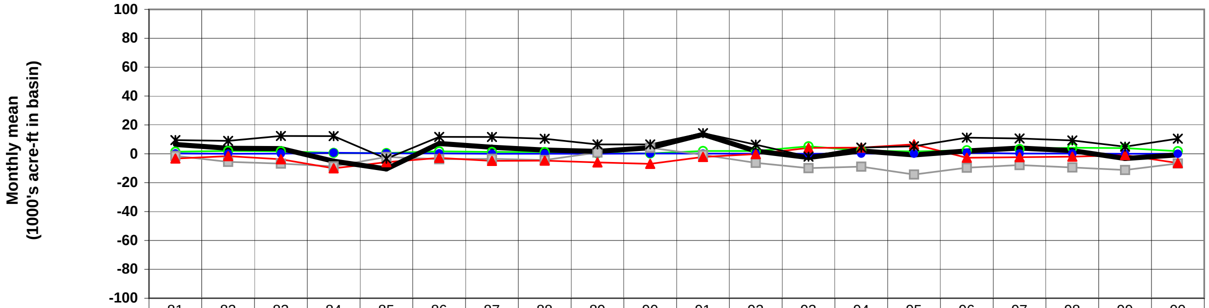
WCA3A ELM-SFWMM Inflow Differences

WCA3A ELM-SFWMM Inflow Differences



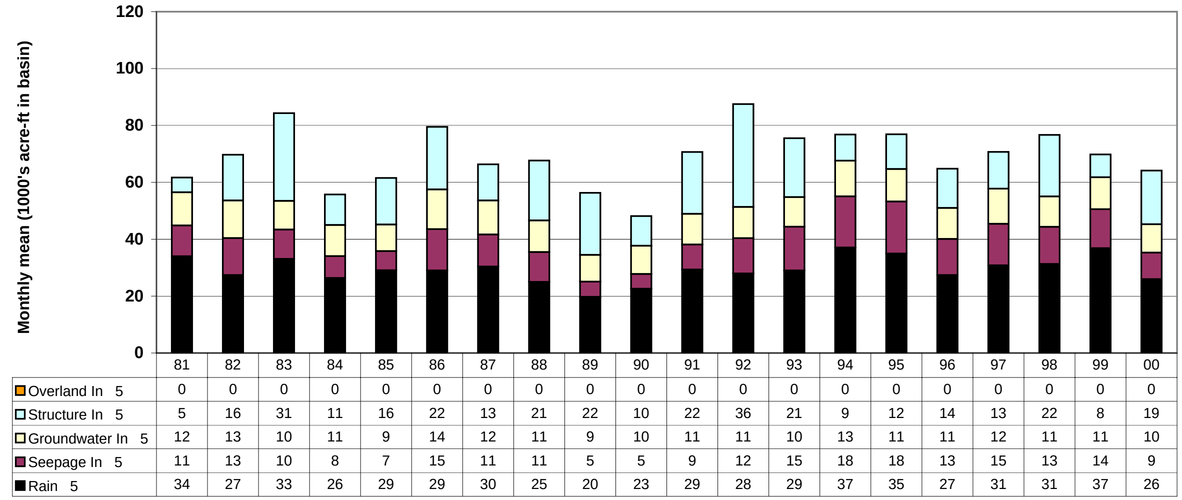
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	-4	-22	-16	-7	-4	-8	-6	-4	-1	0	-9	-9	-13	-16	-11	-9	-9	-14	-13	-6
Structure	6	14	13	7	6	9	8	6	4	3	11	8	10	15	8	8	9	11	11	9
Groundwater	1	2	3	3	5	2	3	3	3	2	3	2	0	1	1	4	2	3	3	2
Seepage	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rain	-1	0	0	0	-1	0	0	0	1	0	1	0	1	0	1	1	0	0	0	0
Sum	1	-5	1	3	7	3	4	5	6	5	5	1	-2	0	-1	4	2	0	1	5

WCA3A ELM-SFWMM Outflow Differences



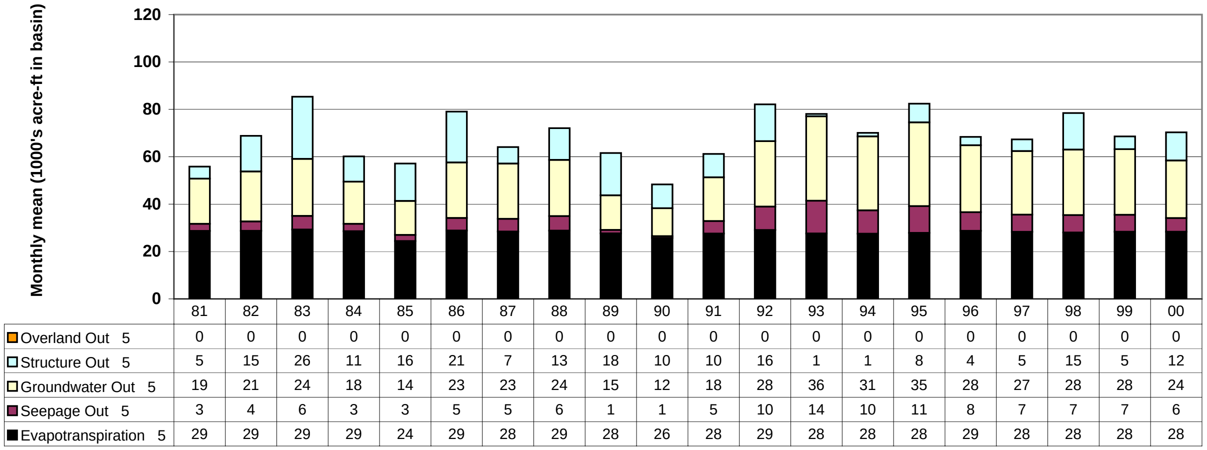
	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	1	2	2	1	1	2	1	1	0	0	2	2	5	2	2	2	3	4	4	2
Structure	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Groundwater	-1	-6	-7	-9	-2	-4	-3	-4	1	4	-1	-6	-10	-9	-14	-10	-8	-9	-11	-7
Seepage	-3	-2	-4	-10	-6	-3	-5	-5	-6	-7	-2	0	4	4	7	-3	-2	-2	-1	-6
ET	9	9	12	12	-3	12	12	10	7	7	14	6	-2	4	5	11	11	9	5	10
Sum	6	4	4	-5	-10	7	5	3	2	4	13	2	-3	2	-1	2	4	2	-3	-1

WCA3B ELM Inflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟧 Overland In 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
🟦 Structure In 5	5	16	31	11	16	22	13	21	22	10	22	36	21	9	12	14	13	22	8	19
🟨 Groundwater In 5	12	13	10	11	9	14	12	11	9	10	11	11	10	13	11	11	12	11	11	10
🟪 Seepage In 5	11	13	10	8	7	15	11	11	5	5	9	12	15	18	18	13	15	13	14	9
⬛ Rain 5	34	27	33	26	29	29	30	25	20	23	29	28	29	37	35	27	31	31	37	26

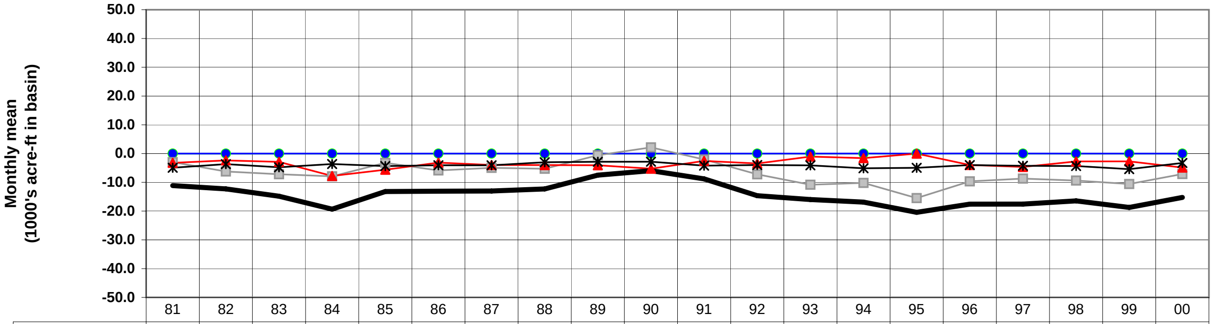
WCA3B ELMOutflows



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
🟧 Overland Out 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
🟦 Structure Out 5	5	15	26	11	16	21	7	13	18	10	10	16	1	1	8	4	5	15	5	12
🟨 Groundwater Out 5	19	21	24	18	14	23	23	24	15	12	18	28	36	31	35	28	27	28	28	24
🟪 Seepage Out 5	3	4	6	3	3	5	5	6	1	1	5	10	14	10	11	8	7	7	7	6
⬛ Evapotranspiration 5	29	29	29	29	24	29	28	29	28	26	28	29	28	28	28	29	28	28	28	28

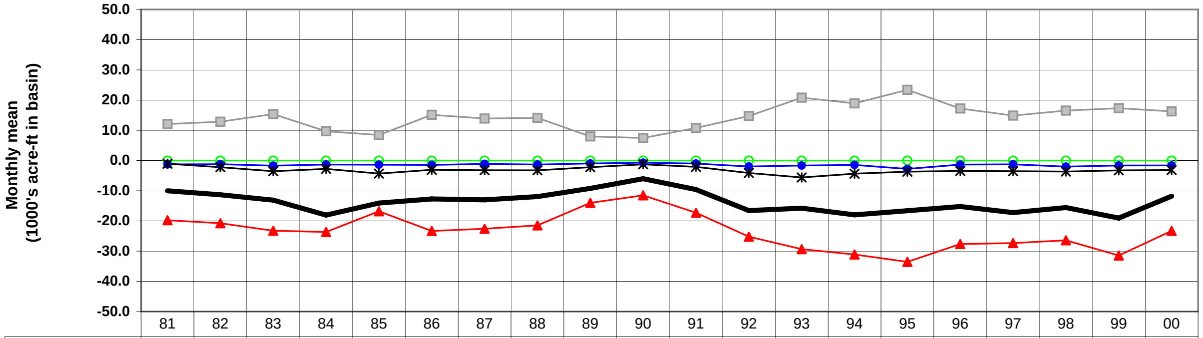
WCA3B ELM-SFWMM Inflow Differences

WCA3B ELM-SFWMM Inflow Differences



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundwater	-3.0	-6.2	-7.2	-7.9	-3.2	-5.9	-5.0	-5.3	-0.6	2.1	-2.1	-7.2	-10.8	-10.2	-15.5	-9.7	-8.7	-9.4	-10.6	-7.1
Seepage	-3.2	-2.4	-2.9	-7.8	-5.6	-3.1	-4.0	-4.0	-4.1	-5.3	-2.5	-3.5	-1.1	-1.6	0.0	-4.0	-4.6	-2.7	-2.7	-4.9
Rain	-4.9	-3.7	-4.8	-3.6	-4.4	-4.1	-4.1	-3.0	-2.8	-2.8	-4.2	-4.0	-4.1	-5.1	-4.9	-4.0	-4.2	-4.3	-5.4	-3.3
Sum	-11.1	-12.3	-14.8	-19.3	-13.2	-13.1	-13.0	-12.3	-7.5	-5.9	-8.8	-14.6	-16.0	-16.9	-20.4	-17.6	-17.6	-16.4	-18.7	-15.2

WCA3B ELM-SFWMM Outflow Differences



	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Overland	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Structure	-1.3	-1.2	-1.7	-1.3	-1.4	-1.4	-1.1	-1.3	-1.0	-0.7	-1.0	-2.0	-1.7	-1.4	-2.8	-1.3	-1.3	-2.0	-1.6	-1.6
Groundwater	12.1	12.8	15.4	9.7	8.4	15.1	13.9	14.1	8.0	7.5	10.8	14.7	20.8	18.9	23.4	17.2	14.9	16.5	17.3	16.3
Seepage	-19.8	-20.8	-23.2	-23.6	-16.8	-23.3	-22.6	-21.5	-14.0	-11.5	-17.3	-25.2	-29.3	-31.1	-33.5	-27.6	-27.3	-26.4	-31.4	-23.3
ET	-1.1	-2.2	-3.5	-2.8	-4.3	-3.1	-3.2	-3.2	-2.2	-1.3	-2.1	-4.1	-5.6	-4.4	-3.7	-3.5	-3.5	-3.7	-3.3	-3.2
Sum	-10.0	-11.3	-13.1	-18.1	-14.1	-12.7	-13.0	-11.9	-9.2	-6.0	-9.6	-16.6	-15.8	-18.0	-16.6	-15.2	-17.2	-15.6	-19.0	-11.8

6.13 Appendix E: Time series & CFDs: CL (separate pdf)

Figures E.1 – E.78. Time series plots of water column chloride (CL) concentration and their associated Cumulative Frequency Distributions (CFD) for the period of record 1981-2000 at each monitoring location. The sequence of the figures is based on geographic location of marsh sites, starting in northwest, moving towards the southeast; following the set of plots of all marsh sites, the canal monitoring sites are similarly sequenced. A map of all sites is provided in the Model Performance Chapter.

The model grid cell column and row locations (col_row) or canal reach identifier (single integer) are shown in parentheses of each plot's title.

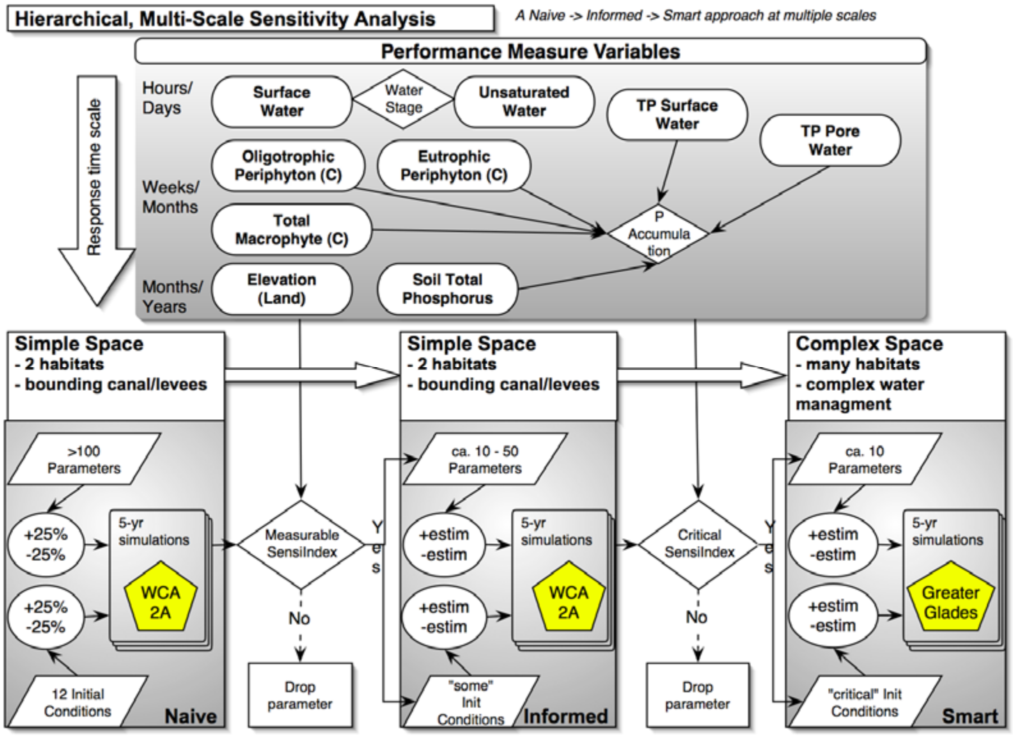
a) All data were aggregated into arithmetic mean values by wet and dry seasons within water years; the continuous lines pass through mean of all daily data points for each season; the mean of paired simulated & observed values are shown in red boxes and black diamonds, respectively; the 95% Confidence Interval (CI) of the paired means are shown by the "__" symbols in the red for the model and black for the observed data.

b) All data aggregated into arithmetic mean values by water year, with the same treatment as in plot a).

c) The cumulative frequency distributions of the simulated and observed (raw, un-aggregated) data; the 95% confidence interval for observed data is shown in the dashed black lines. Note that only paired simulated and observed data points are used.

Documentation of the
Everglades Landscape Model:
ELM v2.5

Chapter 7: Uncertainty



http://my.sfwmd.gov/elm

July 10, 2006

Chapter 7: Uncertainty

7.1 Overview

As we noted in the Introduction, Goals & Objectives Chapter, models are simple abstractions of reality, and may be used to guide our thinking. Towards this end, it is vital that modelers and model users acknowledge and understand the uncertainties inherent in any model. The topic of "Uncertainty" is broad, and a thorough treatment of it is well-beyond the scope of this documentation. Instead, we refer the reader to the report of the "Comprehensive Everglades Restoration Plan's Model Uncertainty Workshop" held in January 2002 (Lall et al. 2002).

In the Uncertainty Workshop technical report, Lall et al. (2002) specifically recommended that the Everglades Landscape Model (ELM) developers repeat the methods of prior sensitivity analyses on the current ELM version. In this chapter, we report on those results, and discuss their implications relative to model complexity.

Hydrology and water quality are primary drivers of the Everglades ecology, and are likewise an important component of the ELM ecological dynamics. Beyond the analysis of model sensitivity to parameter choices, we quantify the statistical expectations of the water quality performance metrics, which are highly dependent on the forces that drive the "boundaries" of the model. Another important concern in water quality modeling is that of "numerical dispersion", which is explicitly simulated in ELM (see Model Structure Chapter), and discussed here relative to model and data uncertainty.

Finally, we touch upon another common topic in modeling: what is validation, and can modelers truly validate the model output? The basic answer is "No". However, these model abstractions of reality have served useful purposes in better understanding system dynamics, and will continue to be important tools in aiding our decision-making process for uncertain topics such as understanding and restoring the Everglades.

7.2 Data uncertainty

Uncertainty in the data used to parameterize a model, to “drive” a model, and to compare to model output (i.e., calibrate), is a major source of uncertainty in simulation modeling. This topic of data uncertainty in modeling is a broad one, and the reader is referred to the recent synthesis of uncertainty in Everglades modeling (Lall et al. 2002). For this documentation Chapter, we present some important, specific considerations of the data uncertainty in water quality boundary conditions that drive much of the model dynamics.

7.2.1 Boundary inflows

As with any model, ELM simulations depend heavily on the forcing functions that drive the model. The major forcing functions are rainfall, potential evapotranspiration, inflows/outflows at water control structures, and other data described in the Data Chapter. Much of the effort in building a model application is the collection and synthesis of data to accurately represent these processes.

7.2.1.1 Nutrient sampling frequency

Water control structures that input water and constituents into the model domain were usually located along the model domain boundary (see Data Chapter). For water control structures at domain inflows, the intended historical sampling frequencies for water quality parameters ranged from one week to one month. However, at numerous of these locations, the time period between two consecutive samples often exceeded three months. Furthermore, at some stations (e.g., ACME1DS, with relatively minor inflow volumes) there were no observations of surface water TP concentration for the entire calibration period (1981-95). As described in the Data Chapter, missing values of flow and concentrations were filled in using several techniques, with linear interpolation between successive point samples. The use of linear interpolation between sampling events introduces additional error in prescribing model boundary conditions. This additional error propagates throughout the model domain and impacts any model’s ability to replicate observed field conditions. Considering all available water quality sampling stations used in domain inflows, the mean TP sampling frequency for the period of record - *when data were available* - was 16 days.

7.2.1.2 Model performance expectations

The goodness of fit of these interpolated daily TP concentrations from the unknown true daily TP concentrations depends on how well the measured TP concentrations were linearly autocorrelated at each site. Ideally, we should use statistical validation to evaluate uncertainty introduced by the interpolation, by splitting the entire dataset into two subsets, and then calculate the uncertainty between measured and interpolated data from the first subset and measured data from the second data set. This was not an option because TP concentrations were infrequently sampled at numerous stations. However, we can still use autocorrelation and cross-validation to assess the relative uncertainty introduced by linear interpolation. For example, the autocorrelation assesses how much correlation is present between successive measurements (assuming equi-spaced intervals between sampling events). Given N measurements, Y_i at time X_i, the lag k autocorrelation function is defined as:

$$r_k = \frac{\sum_{i=1}^{N-k}(Y_i - \bar{Y})(Y_{i+k} - \bar{Y})}{\sum_{i=1}^{N-k}(Y_i - \bar{Y})^2}$$

This autocorrelation function is a correlation coefficient between two values (i.e., Y_i and Y_{i+k}) of the same variable at times X_i and X_{i+k}. The first autocorrelation coefficient (lag 1) equals 1.0 if the data are not random and totally autocorrelated. If the data set has no autocorrelation and is totally random, the resulting coefficient would equal zero. Interpolated daily TP concentrations from a non-autocorrelated (e.g., random) data set will not correlate with the unknown true TP concentrations on dates not sampled.

Cross-validation removes each data point, one at a time, and interpolates the associated total phosphorus value with the rest of the data points. The interpolated and the actual measured values (at the locations of each omitted data point) are then compared.

The calculated statistics from autocorrelation and cross-validation are presented in Table 7.2.1 for all stations that have inflows into the model domain; i.e., those that are important drivers of surface water quality. These statistics can be used as diagnostics to indicate the relative degree of uncertainty in model input data for total phosphorus loadings, and to help set appropriate expectations for model predictions using available input data. For TP concentrations used in ELM for domain inflow loads, the autocorrelation coefficients ranged from 0.04 to 0.56, with a mean of 0.32. The correlation coefficients from cross-validation are even lower, ranging from 0.001 to 0.45, with a mean of 0.20. Therefore, for any model that uses these input data, it is reasonable to expect that the goodness of fit between observed TP concentrations and model-predicted daily values would not likely exceed the statistics calculated from autocorrelation and cross-validation of input data: the expectation of any model should not exceed a mean $R^2 = 0.20$ and maximum $R^2 \leq 0.45$.

While the cross-validation analysis indicates that the interpolated daily TP concentrations (using the best, state-approved method available) may not well-resemble the dynamic of the true unknown TP concentrations, but the biases estimated from cross-validation are all within the range of 1 ppb (ug L^{-1}). This suggests that the interpolated daily TP concentrations can be used in developing unbiased estimates of the true (unknown) long term mean TP concentrations. Thus, for models that simulate TP dynamics from interpolated daily TP concentrations, calibration of simulated TP concentrations should seek to compare the aggregated mean of TP concentrations over a prolonged period, rather than point to point comparisons based on instantaneous observations of water column concentrations. Given these temporal constraints imposed by the input forcing data, measures of temporally-aggregated statistical bias and root mean square error of model predictions can be used to demonstrate the degree to which the model captures the long term eutrophication in locations distributed across space.

7.2.2 Tables: data uncertainty

Table 7.2.1. Results of autocorrelation and cross-validation of input data for TP concentrations at water control structures that have inflows into the model domain. The text explains the methods used in the analyses; Bias and RMSE are in units of ug/L (ppb) of TP concentration.

Station	Sample Date		Number of Days Sampled	Mean Sample Frequency (Day)	Cross Validation				Autocorrelation function (lag 1)
	Start	End			**Bias**	**R^2**	**RMSE**	**EFF**	
ACME1DS	2/5/1997	12/18/2000	48	29	0.7	0.04	59	0.20	0.18
ENR012	12/16/1993	12/28/2000	393	7	0.1	0.09	34	0.29	0.22
G200	7/26/1989	12/27/2000	285	15	-0.7	0.26	42	0.49	0.31
G310	6/1/2000	12/28/2000	30	7	0.3	0.45	14	0.66	0.52
G94D	2/5/1997	12/18/2000	54	26	0.3	0.001	67	-0.03	0.04
L28I	1/3/1979	10/16/2000	277	29	1.0	0.29	51	0.54	0.40
L3BRS	10/30/1984	12/27/2000	217	27	0.2	0.45	65	0.66	0.56
S140	1/3/1979	12/28/2000	431	19	0.4	0.36	57	0.59	0.46
S150	1/2/1979	12/26/2000	359	22	0.9	0.04	57	0.21	0.18
S175	5/2/1995	12/20/2000	150	14	0.0	0.10	3	0.31	0.26
S18C	10/5/1983	12/20/2000	368	17	0.0	0.02	7	0.13	0.10
S332	10/5/1983	12/20/2000	454	14	0.1	0.27	6	0.51	0.44
S332D	6/16/1999	12/28/2000	94	6	0.0	0.21	4	0.44	0.37
S5A	1/2/1979	12/28/2000	682	12	1.3	0.27	76	0.51	0.41
S6	1/2/1979	12/28/2000	729	11	-0.4	0.22	73	0.45	0.34
S7	1/2/1979	12/26/2000	674	12	1.3	0.14	66	0.37	0.30
S8	1/2/1979	12/27/2000	782	10	1.3	0.33	81	0.57	0.48
S9	1/3/1979	12/26/2000	518	15	0.0	0.07	15	0.25	0.18
Mean			364	16	**0.4**	**0.20**	**43**	**0.40**	0.32
Min			30	6	**-0.7**	**0.001**	**3**	**-0.03**	0.04
Max			782	29	**1.3**	**0.45**	**81**	**0.66**	0.56
STD DEV			243	8	0.6	0.14	28	0.19	0.15

7.3 Model sensitivity analyses

7.3.1 Sensitivity analysis overview

Simulation models are potentially powerful tools for ecological research and management, but their inherent uncertainties need to be properly evaluated for effective model utility. A wide number of efforts using procedures of varying rigor have been undertaken to evaluate model performance for different objectives. For process based models which employ numerous parameters in their equations, the accuracy of the parameter estimates can be a critical component of the model development. Parameter estimation is a significant concern in determining the degree of certainty of the model output for use in understanding the system dynamics and making any useful predictions or forecasting.

The ELM was developed in a hierarchical fashion, with a unit model at the ecosystem level that is coupled to spatial model drivers to flux water and constituents through canal vectors and raster cells in a landscape whose pattern may vary over time. The unit model is replicated in each grid cell of the landscape and incorporates the fundamental hydrologic and ecological processes that dictate much of the model behavior. With numerous parameters that are input to the model, the user needs to understand the relative influence of parameter variations on the model results. The parameters range from rate coefficients to nutrient stoichiometric ratios and initial conditions (see Data Chapter). Some parameters are known with relatively high accuracy, while others are less understood and are the subject of ongoing research. To understand how parameter uncertainties may affect the ELM dynamics and its interpretation, we performed the first of a suite of sensitivity analyses on the updated version of ELM.

While the ELM has very fast run times[1] for a model of its spatial and computational complexity, there is nevertheless a need to simplify the problem in order to undertake the hundreds of runs that are required to fully evaluate the model sensitivity. The approach is an extension of our sensitivity analyses (Fitz et al. 1995) on an early development version of ELM. Indeed, repeating our prior methods on the current version of ELM was a specific recommendation by Lall et al. (2002), who detailed the technical considerations of uncertainty in Everglades modeling for the Comprehensive Everglades Restoration Plan (CERP). We continue to approach the task of evaluating the model sensitivity and communicating those results in a stepwise, hierarchical fashion in keeping with the model structure (described in the Model Structure Chapter).

The conceptual model that underlies our method is shown in Figure 7.3.1. We consider several phases to fully evaluate model sensitivity to the parameters (including those that modify initial conditions): “Naive”, “Informed”, and “Smart”.

Naive: In the “Naive” phase, we evaluate parameter perturbations to an implementation of the model that is as simple as possible/desirable, assuming no *a priori* knowledge of

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[1] The regional ELM application (10,364 1km2 grid cells) takes slightly more than 3 minutes of real-time per year of simulation time (on a 2.66 GHz Intel-based laptop).

the model or data. Each of the (entire set of) input parameters is adjusted by the same fixed percentage (one at a time), and the relative response of the Performance Measures are evaluated. Any parameter that has an observable effect on the Performance Measures is identified as a potentially important parameter.

Informed: Subsequently, the "Informed" phase is more knowledge-based, wherein *a priori* knowledge of parameter values is considered. For this phase, the subset of potentially important parameters that were identified in the Naive phase are more fully evaluated. Instead of using arbitrary values, we make sensitivity runs using realistic ranges of parameter values, in order to more accurately quantify the relative uncertainty of model outcomes based upon available data. This "Informed" phase is conducted on the same, simple model implementation that was used previously. As a result of the Informed phase, we identify the set of parameters that have significant (ecologically-meaningful) effects on the Performance Measure outputs; these parameters are (likely to be) a subset of those identified in the first "Naive" phase.

Smart: Finally, the "Smart" phase uses the ecologically significant parameters identified in the Informed phase, but extends the evaluation into the full complexity of the regional model implementation, with the regional-Everglades water management infrastructure and heterogeneity of habitats. Results of this phase may be used to better characterize the relative uncertainty of Performance Measures in model applications.

The primary considerations are 1) the *response time scales* of the model output Performance Measures, 2) the *spatial complexity* of the simulation, and 3) the *a priori knowledge of the parameter sensitivity*. We initiated the analyses using a relatively simple spatial implementation of ELM, and assume that we know nothing of the relative importance of any parameter. The objective of the sensitivity analysis is to develop an advanced understanding of the model parameters that are most influential on the model Performance Measure(s) output of interest. We seek to determine which parameters are most "important", on which we should focus our efforts in data acquisition and synthesis. Alternatively, evaluation of the sensitivity results may indicate the need to better refine future model algorithms. Regardless of the outcome for developers, the users of the model Performance Measures should be able to better understand and interpret results if we successfully summarize and communicate the results of the sensitivity analyses.

7.3.1.1 Response time scales

The most fundamental component of a sensitivity analysis is that of the objective function: what is the output that is of interest, and how is its response to perturbation (parameter change) measured? The goals of ELM (Introduction and Objectives Chapter) involve the understanding and assessment of the principal ecological dynamics that collectively determine the landscape or habitat characteristics. Ecosystems, and their depiction in ELM, encompass a rather wide range of time scales of response (Figure 7.3.1). Most hydrologic and surface water Performance Measures respond at scales on the order of hours to days. The biological responses of periphyton and macrophyte communities generally exhibit dynamic change at scales ranging from weeks to months. Integrators of these Performances Measures are the soil dynamic responses (and habitat succession), whose dynamic changes are generally considered over multiple seasons or years. An evaluation of the response of these Performance Measures to model perturbations necessarily needs to consider not only the magnitude of the change, but also its relationship to the variability within the appropriate response time scale.

For the current set of sensitivity analyses, we focused on the shorter time scales of hydrology and of water quality in surface and soil pore waters, which relate to the Performance Measures we support for ELM v2.5. At different locations along hydro-ecological gradients, the inherent variability of both of these hydrologic and water quality Performance Measures is large at relatively short time scales. Very small changes in water depths and phosphorus concentrations are of interest in this analysis, while these dynamic attributes can easily span an order of magnitude of change at the spatial and temporal scales under consideration.

7.3.1.2 Spatial complexity

In our early sensitivity analyses (Fitz et al. 1995), we were able to isolate the "unit" model from its spatial framework for the first step in sensitivity analyses. Because of subsequent changes to the model, we no longer can easily implement a non-spatial implementation of ELM that is identical to the algorithms and input forcing data within the spatial implementation. However, the ELM is easily "scalable", and thus we implemented a small subregional spatial version of ELM, with a total of only 449 active grid cells (vs. more than 10,000 in the regional implementation). This subregional implementation encompassed the hydrologic basin of Water Conservation Area 2A (WCA-2A) at a 1 km^2 grid scale. This basin contains no internal canals or levees other than those along its boundaries. Moreover, this implementation considered only the two habitat types of sawgrass and cattail, without the myriad of other habitats found in other portions of the greater Everglades (Figure 7.3.1).

An important characteristic of Water Conservation Area 2A is the extreme eutrophication (and lesser hydrologic) gradient that extends along a ~10 km transect downstream of major water control structure (point) inflows in the northeast quadrant. In order to evaluate the model sensitivity along this gradient, we considered seven Indicator Regions spanning its length. Within each Indicator Region, the Performance Measure outputs characterize the ecological (including hydrologic and water quality) responses to changing conditions – such as those associated with parameter perturbations. The aggregated whole-system (i.e., basin) response is part of this spatially explicit evaluation.

For the current set of sensitivity analyses, we did not consider the regional ELM. The latter implementation is the final component of the full sensitivity analysis suite, wherein we will consider the model sensitivity to the complex water management network and broader habitat mosaic (Figure 7.3.1).

7.3.1.3 A priori knowledge of parameters

Our approach was to initially assume that all parameters are important, i.e., that we have no *a priori* knowledge of the relative importance or sensitivity of any of the parameters. In this "Naive" phase of the analysis (Figure 7.3.1), we considered all parameters that are input to (and used by) the model from the parameter databases (see the Data Chapter for parameter descriptions). In each sensitivity simulation, a single parameter was modified by a fixed percentage from its nominal value (i.e., that used in current calibration). All other parameters were held at their nominal values. An index of sensitivity of the targeted Performance Measure was evaluated to determine if the parameter has any potential, large or small, to effect the model outcome at different spatial locations. The goal of the Naive phase was to "weed out" the parameters that have virtually no effect on the Performance Measure(s). This is an important component of the sensitivity analysis, as the foundation of the ELM is a generalized model of ecosystem dynamics, the General Ecosystem Model (Fitz et al. 1996). Partly due to this generality, there are parameters that may not have an effect on the Everglades landscape implementation. Moreover, some parameters may be somewhat important to macrophyte growth or habitat succession, but not affect hydrology or surface water quality to a measurable extent.

The Naive phase of the analysis serves to identify the subset of the total parameter set that has some non-trivial effect on dynamics of the targeted Performance Measures. This phase has the potential to be highly informative to both users who want to become familiar with the model, and to developers who need some further guidance in which "coarse" adjustments of parameters may be useful in refining model performance. Because it significantly reduces the number of parameters under consideration, this component of the sensitivity analysis can be valuable for that purpose alone. Moreover, the results from the Naive parameter-value perturbations can be used to ascertain the relative contributions of each parameter to model uncertainty, albeit potentially limited due to the naive choice of parameter changes (irrespective of the range that they may be known to take from field observations/experiments).

In further phases, that were not completed for these sensitivity analyses, we use more realistic ranges of parameter values, as opposed to arbitrary increments. Results from these phases provide more informed recommendations on the priorities for further data acquisition and synthesis, while also providing more quantitative evidence of the relative uncertainties associated with parameterization of the model.

7.3.2 Model configuration

The model was configured to simulate historical conditions inclusive of the years 1981 – 1985. The domain was that of the subregional ELM application in Water Conservation Area 2A, employing a 1 km^2 grid mesh encompassing all of that Water Conservation Area. The Indicator Regions used in model post-processing are shown in Figure 7.3.2. The vector topology of the canal/levee network and the point locations of water control structures were constant during the simulation period. Habitat succession was "turned off", while still having dynamic feedbacks associated with macrophyte growth/mortality within a constant habitat type. Dynamic boundary conditions included data on rainfall, potential evapotranspiration, managed water control structure flows with associated constituent concentrations, and stage (along the borders of the domain).

Full descriptions of the requisite data and the functionality of the source code is provided in Data and the Model Structure Chapters, respectively. The Data Chapter includes the full documentation of the parameters, including definitions and units. The User's Guide Chapter describes the simple steps to invoke the automated suite of model sensitivity runs, with each run acquiring the appropriate (low, nominal, or high) value of the parameter from one of the three parameter files generated by both the HabParms and GlobalParms databases. In the case of the database containing habitat-specific parameters (that may have unique values for each habitat), the parameter change was maintained at

25% for each parameter in each habitat, with two habitats (sawgrass habitat #2 and cattail habitat #11) simulated in this implementation. Each simulation was run for the 5-year period, and summarized for analysis by the mean daily value of each Performance Measure during entire simulation period. For one invocation of a suite (e.g., hundreds) of sensitivity runs, a single output file summarizes all of the Performance Measures for all of the runs.

7.3.3 Results

7.3.3.1 Hydrology

Table 7.3.1 lists all of the parameters that were evaluated, indicating whether a non-trivial (≥ 1%) hydrologic Performance Measure response was obtained for the ±25% parameter change. Depending on the Indicator Region's location along the gradient, changes to approximately 10 to 20 parameters[2] showed at least a 1% change to the 5-year mean surface water depth Performance Measure, relative to the NOMINAL parameter set (Table 7.3.1). Figure 7.3.3 shows the magnitude of the Performance Measure response for the twenty most-sensitive parameters, indicating that a many of these "top-20" consistently had relatively low effects across the spatial gradient.

7.3.3.2 Surface water nutrients

Table 7.3.2 lists all of the parameters that were evaluated, indicating whether a non-trivial (≥ 1%) surface water quality Performance Measure response was obtained for the ±25% parameter change. Depending on the Indicator Region's location along the gradient, changes to approximately 10 to 25 parameters[3] showed at least a 1% change to the 5-year mean surface water phosphorus concentration Performance Measure, relative to the NOMINAL parameter set (Table 7.3.2). Figure 7.3.4 shows the magnitude of the Performance Measure response for the twenty most-sensitive parameters, indicating that a many of these "top-20" consistently had relatively low effects across the spatial gradient. Note that the lowest value output by the model is 0.001 mg $TP \bullet L^{-1}$ (1 ppb), which is well under the detection limit of field sampling.

7.3.3.3 Soil nutrients

Table 7.3.3 lists all of the parameters that were evaluated, indicating whether a non-trivial (≥ 1%) soil pore water quality Performance Measure response was obtained for the ±25% parameter change. Depending on the Indicator Region's location along the gradient, changes to approximately 30 to 60 parameters[4] showed at least a 1% change to the 5-year mean soil pore water phosphorus concentration Performance Measure, relative to the NOMINAL parameter set (Table 7.3.3). Figure 7.3.5 shows the magnitude of the Performance Measure response for the twenty most-sensitive parameters, indicating that even though a relatively large number of parameter changes produced a non-negligible

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[2] Note that the total count summary shown on the final row of each Table usually includes Performance Measure threshold responses to both high and low values of a particular parameter.

[3] Note that the total count summary shown on the final row of each Table usually includes Performance Measure threshold responses to both high and low values of a particular parameter.

[4] Note that the total count summary shown on the final row of each Table usually includes Performance Measure threshold responses to both high and low values of a particular parameter.

response, perhaps only the “top-10” of this group had potentially significant effects across the spatial gradient.

7.3.4 Discussion

In this “Naive” phase of a three-part analysis, the sensitivity of the hydrologic and water quality Performance Measures varied spatially, and some parameters had relatively specific effects on specific Performance Measures, as expected. The parameter requirements increased, along with the sensitivity of the model to those parameters, as we considered physical hydrology, then surface water quality, and finally soil pore water quality. Each of these ecological dynamics are critical to understanding the system, and they respectively increase in process complexity due to their increased integration of more complete ecosystem properties.

Of particular interest in this analysis is the prioritization of data needs: from this initial perspective, which parameters were most “important”, and thus should be focused on in better parameterizing the model? Table 7.3.4 summarizes the answer at this point. The results in the table include the parameters which appeared in the “top 20” of any Performance Measure, and show which of the parameters had effects across more than one Performance Measure. While the associated “State of our knowledge” of the data behind each parameter varies in quality, all are supported by existing studies or supportable by aggregations of our understanding of Everglades ecosystem dynamics. This is not meant to imply that the data are constrained to anything close to an “ideal” state of knowledge. It does represent a useful perspective of our current understanding, and where we should put our resources to “do better”.

For the next phase of the full sensitivity analysis, we will further evaluate the model-influence of the subset of parameters that were identified here as potentially (or certainly) important. In this next “Informed” Phase, we will assign parameter values within a realistic range that is supported by observations, scaled/aggregated as best as possible using either quantitative methods or science-based inference if necessary. In advancing in this straightforward process, we will better constrain the input data to match our true knowledge of the system, and use the results to communicate a better understanding of the model performance.

The ELM has a “large” number of parameters due to its objectives of simulating integrated ecosystem dynamics across a spatially distributed, heterogeneous landscape. Furthermore, an early and fundamental objective of the modeling project was that of generality: a) the ecological dynamics were designed to be applicable across ecosystems in other regions, and b) code and parameters were generated to allow flexibility in implementation and analysis. These latter attributes of the ELM modeling system increase the “apparent” parameter complexity: a naive, simple count of the number of parameters contained in databases is not reflective of the number that are used in critical algorithm calculations, and thus represent critical data needs. As indicated in the results of this Naive phase of the ELM sensitivity analysis, the actual complexity induced by parameterization (i.e., data) needs is reasonable, and reflective of the basic properties of the integrated ecosystems - meaning that it is generally supported by available data and ongoing research. An important part of our future work is continued synthesis of research data, including the collaboration in design of field and lab experiments to help better understand these basic ecosystem properties within the Everglades landscape.

7.3.5 Tables: sensitivity analyses

Four tables follow on the next 7 pages.

Table 7.3.1. Hydrology. Naive case: +/-25% change in parameter. Compared to the 5-yr mean of the NOMINAL run output, if a simulation with a changed parameter resulted in at least a 1% change in the surface water depth Performance Measure in an Indicator Region (IR), the (ParmChangeRun - NominalRun) difference (meters) is shown for that simulation & IR. Parameters are grouped by ecological module (as found in databases).

	SfWat_9	SfWat_8	SfWat_7	SfWat_6	SfWat_5	SfWat_4	SfWat_3	SfWat_2	SfWat_0
NOMINAL	0.22	0.217	0.19	0.196	0.191	0.199	0.207	0.191	0.191
GP_SOLOMEGA_LO									
GP_SOLOMEGA_HI									
GP_ALTIT_LO									
GP_ALTIT_HI									
GP_LATDEG_LO									
GP_LATDEG_HI									
GP_mannDepthPow_LO	-0.003	-0.005	-0.009	-0.013	-0.016	-0.018	-0.023	-0.003	-0.003
GP_mannDepthPow_HI	0.007	0.009	0.015	0.019	0.021	0.021	0.026	0.007	0.007
GP_mannHeadPow_LO			-0.004	-0.007	-0.010	-0.012	-0.016	-0.002	-0.002
GP_mannHeadPow_HI	0.004	0.005	0.009	0.013	0.015	0.016	0.019	0.004	0.004
GP_calibGWat_LO	0.021	0.020	0.016	0.013	0.011	0.010	0.006	0.016	0.016
GP_calibGWat_HI	-0.014	-0.013	-0.010	-0.008	-0.007	-0.007	-0.003	-0.010	-0.010
GP_IDW_pow_LO									
GP_IDW_pow_HI									
GP_calibET_LO	0.223	0.216	0.193	0.177	0.162	0.151	0.119	0.192	0.192
GP_calibET_HI	-0.077	-0.071	-0.055	-0.048	-0.043	-0.042	-0.034	-0.065	-0.065
GP_HYD_IC_SFWAT_ADD_LO									
GP_HYD_IC_SFWAT_ADD_HI									
GP_HYD_IC_UNSAT_ADD_LO									
GP_HYD_IC_UNSAT_ADD_HI									
GP_HYD_ICUNSATMOIST_LO									
GP_HYD_ICUNSATMOIST_HI									
GP_DetentZ_LO									
GP_DetentZ_HI									
GP_MinCheck_LO									
GP_MinCheck_HI									
GP_dispLenRef_LO									
GP_dispLenRef_HI									
GP_dispParm_LO									
GP_dispParm_HI									
GP_SLRise_LO									
GP_SLRise_HI									
GP_ALG_IC_MULT_LO									
GP_ALG_IC_MULT_HI									
GP_alg_uptake_coef_LO									
GP_alg_uptake_coef_HI									
GP_ALG_SHADE_FACTOR_LO									
GP_ALG_SHADE_FACTOR_HI									
GP_algMortDepth_LO									
GP_algMortDepth_HI									
GP_ALG_RC_MORT_DRY_LO									
GP_ALG_RC_MORT_DRY_HI									
GP_ALG_RC_MORT_LO						0.002			
GP_ALG_RC_MORT_HI						-0.002			
GP_ALG_RC_PROD_LO									
GP_ALG_RC_PROD_HI									
GP_ALG_RC_RESP_LO									
GP_ALG_RC_RESP_HI									
GP_alg_R_accel_LO						0.003			
GP_alg_R_accel_HI						-0.003			
GP_AlgComp_LO									
GP_AlgComp_HI									
GP_ALG_REF_MULT_LO									
GP_ALG_REF_MULT_HI									
GP_NC_ALG_KS_P_LO									
GP_NC_ALG_KS_P_HI									
GP_alg_alkP_min_LO									
GP_alg_alkP_min_HI									
GP_C_ALG_KS_P_LO									
GP_C_ALG_KS_P_HI									
GP_ALG_TEMP_OPT_LO									
GP_ALG_TEMP_OPT_HI						0.002	0.003		
GP_C_ALG_threshTP_LO					-0.003	-0.005	-0.003		
GP_C_ALG_threshTP_HI						0.004			
GP_ALG_C_TO_OM_LO						-0.004	-0.003		
GP_ALG_C_TO_OM_HI						0.002			
GP_alg_light_ext_coef_LO									
GP_alg_light_ext_coef_HI									
GP_ALG_LIGHT_SAT_LO									
GP_ALG_LIGHT_SAT_HI									
GP_ALG_PC_LO									
GP_ALG_PC_HI									
GP_DOM_RCDECOMP_LO									
GP_DOM_RCDECOMP_HI									
GP_DOM_DECOMPRED_LO									
GP_DOM_DECOMPRED_HI									
GP_calibDecomp_LO									
GP_calibDecomp_HI									
GP_DOM_decomp_coef_LO						0.004	0.007		
GP_DOM_decomp_coef_HI									
GP_DOM_DECOMP_POPT_LO						0.002	0.005		
GP_DOM_DECOMP_POPT_HI									
GP_sorbToTP_LO									
GP_sorbToTP_HI									
GP_IC_BATHY_MULT_LO									
GP_IC_BATHY_MULT_HI									
GP_IC_TPtoSOIL_MULT_LO									
GP_IC_TPtoSOIL_MULT_HI									
GP_IC_DOM_BD_MULT_LO					-0.002	-0.005	-0.003		
GP_IC_DOM_BD_MULT_HI						0.002			
GP_IC_BulkD_MULT_LO									
GP_IC_BulkD_MULT_HI									
GP_IC_ELEV_MULT_LO	0.011	0.015	0.020	0.018	0.018	0.014	0.014	0.007	0.007
GP_IC_ELEV_MULT_HI	-0.014	-0.018	-0.020	-0.017	-0.017	-0.014	-0.012	-0.007	-0.007
GP_MAC_IC_MULT_LO	0.004	0.004	0.003	0.003	0.002			0.004	0.004
GP_MAC_IC_MULT_HI	-0.004	-0.003	-0.002					-0.003	-0.003
GP_MAC_REFUG_MULT_LO									
GP_MAC_REFUG_MULT_HI									
GP_mac_uptake_coef_LO							0.003		
GP_mac_uptake_coef_HI								0.002	0.002
GP_mann_height_coef_LO			-0.003	-0.004	-0.005	-0.006	-0.008		
GP_mann_height_coef_HI		0.003	0.005	0.006	0.006	0.007	0.007		
GP_Floc_BD_LO									
GP_Floc_BD_HI									
GP_FlocMax_LO									
GP_FlocMax_HI									
GP_TP_P_OM_LO									
GP_TP_P_OM_HI									
GP_Floc_rcSoil_LO									

GP_Floc_rcSoil_HI									
GP_TP_DIFFCOEF_LO									
GP_TP_DIFFCOEF_HI									
GP_TP_K_INTER_LO									
GP_TP_K_INTER_HI									
GP_TP_K_SLOPE_LO									
GP_TP_K_SLOPE_HI									
GP_WQMthresh_LO									
GP_WQMthresh_HI									
GP_PO4toTP_LO						0.003			
GP_PO4toTP_HI					-0.002				
GP_TP_IN_RAIN_LO									
GP_TP_IN_RAIN_HI									
GP_PO4toTPint_LO									
GP_PO4toTPint_HI									
GP_TP_ICSFWAT_LO									
GP_TP_ICSFWAT_HI									
GP_TP_ICSEDWAT_LO									
GP_TP_ICSEDWAT_HI									
GP_TPpart_thresh_LO									
GP_TPpart_thresh_HI									
GP_TP_DIFFDEPTH_LO									
GP_TP_DIFFDEPTH_HI									
GP_settlVel_LO									
GP_settlVel_HI									
HP_ALG_MAX_LO						0.002			
HP_ALG_MAX_HI						-0.002			
HP_DOM_MAXDEPTH_LO									
HP_DOM_MAXDEPTH_HI									
HP_DOM_AEROBTHIN_LO									
HP_DOM_AEROBTHIN_HI									
HP_TP_CONC_GRAD_LO									
HP_TP_CONC_GRAD_HI									
HP_SALT_ICSEDWAT_LO									
HP_SALT_ICSEDWAT_HI									
HP_SALT_ICSFWAT_LO									
HP_SALT_ICSFWAT_HI									
HP_PHBIO_MAX_LO									
HP_PHBIO_MAX_HI									
HP_NPHBIO_MAX_LO									
HP_NPHBIO_MAX_HI									
HP_MAC_MAXHT_LO			-0.003	-0.004	-0.005	-0.006	-0.008		
HP_MAC_MAXHT_HI		0.003	0.005	0.006	0.006	0.007	0.007		
HP_NPHBIO_ROOTDEPTH_LO	0.003	0.004	0.003	0.003	0.002	0.002		0.003	0.003
HP_NPHBIO_ROOTDEPTH_HI	-0.004	-0.004	-0.003	-0.002	-0.003	-0.003		-0.003	-0.003
HP_MAC_MAXROUGH_LO				-0.002	-0.003	-0.004	-0.005		
HP_MAC_MAXROUGH_HI				0.002	0.002	0.003	0.004		
HP_MAC_MINROUGH_LO	-0.005	-0.004	-0.004	-0.005	-0.005	-0.005	-0.004	-0.002	-0.002
HP_MAC_MINROUGH_HI	0.004	0.004	0.005	0.006	0.005	0.005	0.005	0.002	0.002
HP_MAC_MAXLAI_LO	0.006	0.006	0.006	0.005	0.004	0.004	0.003	0.006	0.006
HP_MAC_MAXLAI_HI	-0.006	-0.005	-0.004	-0.004	-0.004	-0.003		-0.005	-0.005
HP_MAC_MAXCANOPCOND_LO									
HP_MAC_MAXCANOPCOND_HI									
HP_MAC_CANOPDECOUP_LO									
HP_MAC_CANOPDECOUP_HI									
HP_MAC_TEMPOPT_LO									
HP_MAC_TEMPOPT_HI									
HP_MAC_LIGHTSAT_LO									
HP_MAC_LIGHTSAT_HI									
HP_MAC_KSP_LO									
HP_MAC_KSP_HI									
HP_PHBIO_RCNPP_LO									
HP_PHBIO_RCNPP_HI									
HP_PHBIO_RCMORT_LO						0.002	0.003		
HP_PHBIO_RCMORT_HI						-0.002			
HP_MAC_WAT_TOLER_LO									
HP_MAC_WAT_TOLER_HI									
HP_MAC_SALIN_THRESH_LO									
HP_MAC_SALIN_THRESH_HI									
HP_PHBIO_IC_CTOOM_LO									
HP_PHBIO_IC_CTOOM_HI									
HP_NPHBIO_IC_CTOOM_LO									
HP_NPHBIO_IC_CTOOM_HI									
HP_PHBIO_IC_PC_LO									
HP_PHBIO_IC_PC_HI									
HP_NPHBIO_IC_PC_LO									
HP_NPHBIO_IC_PC_HI									
HP_MAC_TRANSLOC_RC_LO									
HP_MAC_TRANSLOC_RC_HI									
HP_HYD_RCINFILT_LO									
HP_HYD_RCINFILT_HI									
HP_HYD_SPEC_YIELD_LO	0.018	0.017	0.013	0.011	0.009	0.009	0.004	0.014	0.014
HP_HYD_SPEC_YIELD_HI	-0.016	-0.015	-0.012	-0.009	-0.008	-0.008	-0.004	-0.013	-0.013
HP_HYD_POROSITY_LO	0.006	0.006	0.005	0.005	0.004	0.003	0.003	0.005	0.005
HP_HYD_POROSITY_HI	-0.006	-0.006	-0.005	-0.004	-0.004	-0.004	-0.003	-0.005	-0.005
HP_FLOC_IC_LO									
HP_FLOC_IC_HI									
HP_FLOC_IC_CTOOM_LO									
HP_FLOC_IC_CTOOM_HI									
HP_FLOC_IC_PC_LO									
HP_FLOC_IC_PC_HI									
HP_SfDepthLo_LO									
HP_SfDepthLo_HI									
HP_SfDepthHi_LO									
HP_SfDepthHi_HI									
HP_SfDepthInt_LO									
HP_SfDepthInt_HI									
HP_PhosLo_LO									
HP_PhosLo_HI									
HP_PhosHi_LO									
HP_PhosHi_HI									
HP_PhosInt_LO									
HP_PhosInt_HI									
HP_FireInt_LO									
HP_FireInt_HI									
Count:	21	23	26	27	30	44	31	23	23

Table 7.3.2. Surface water TP. Naive case: +/-25% change in parameter. Compared to the 5-yr mean of the NOMINAL run output, if a simulation with a changed parameter resulted in at least a 1% change in the surface water TP concentration Performance Measure in an Indicator Region (IR), the (ParmChangeRun - NominalRun) difference (mg/L) is shown for that simulation & IR. Parameters are grouped by ecological module (as found in databases).

	TPsf_9	TPsf_8	TPsf_7	TPsf_6	TPsf_5	TPsf_4	TPsf_3	TPsf_2	TPsf_0
NOMINAL	0.005	0.007	0.009	0.012	0.014	0.019	0.019	0.008	0.008
GP_SOLOMEGA_LO									
GP_SOLOMEGA_HI									
GP_ALTIT_LO									
GP_ALTIT_HI									
GP_LATDEG_LO									
GP_LATDEG_HI									
GP_mannDepthPow_LO	0.001								
GP_mannDepthPow_HI				-0.001				-0.001	-0.001
GP_mannHeadPow_LO	0.001								
GP_mannHeadPow_HI									
GP_calibGWat_LO									
GP_calibGWat_HI									
GP_IDW_pow_LO									
GP_IDW_pow_HI									
GP_calibET_LO		-0.001	-0.001		0.001				
GP_calibET_HI				-0.001				-0.001	-0.001
GP_HYD_IC_SFWAT_ADD_LO									
GP_HYD_IC_SFWAT_ADD_HI									
GP_HYD_IC_UNSAT_ADD_LO									
GP_HYD_IC_UNSAT_ADD_HI									
GP_HYD_ICUNSATMOIST_LO									
GP_HYD_ICUNSATMOIST_HI									
GP_DetentZ_LO									
GP_DetentZ_HI									
GP_MinCheck_LO									
GP_MinCheck_HI									
GP_dispLenRef_LO						0.001	0.001		
GP_dispLenRef_HI	0.001						-0.001		
GP_dispParm_LO	0.001						-0.001		
GP_dispParm_HI						0.001	0.001		
GP_SLRise_LO									
GP_SLRise_HI									
GP_ALG_IC_MULT_LO									
GP_ALG_IC_MULT_HI									
GP_alg_uptake_coef_LO	-0.001	-0.002	-0.001	-0.002	-0.001	-0.002	-0.002	-0.002	-0.002
GP_alg_uptake_coef_HI	0.002	0.001	0.002	0.001	0.002	0.002	0.002	0.001	0.001
GP_ALG_SHADE_FACTOR_LO									
GP_ALG_SHADE_FACTOR_HI									
GP_algMortDepth_LO									
GP_algMortDepth_HI									
GP_ALG_RC_MORT_DRY_LO									
GP_ALG_RC_MORT_DRY_HI									
GP_ALG_RC_MORT_LO	0.001		0.001		0.001	0.001	0.001		
GP_ALG_RC_MORT_HI				-0.001		-0.001		-0.001	-0.001
GP_ALG_RC_PROD_LO	0.001				0.001	0.001	0.001		
GP_ALG_RC_PROD_HI									
GP_ALG_RC_RESP_LO									
GP_ALG_RC_RESP_HI									
GP_alg_R_accel_LO	0.001		0.001		0.001	0.002	0.001		
GP_alg_R_accel_HI				-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
GP_AlgComp_LO					0.001	0.001	0.001		
GP_AlgComp_HI									
GP_ALG_REF_MULT_LO									
GP_ALG_REF_MULT_HI									
GP_NC_ALG_KS_P_LO									
GP_NC_ALG_KS_P_HI									
GP_alg_alkP_min_LO					0.001				
GP_alg_alkP_min_HI									
GP_C_ALG_KS_P_LO			-0.001	-0.001		-0.001	-0.001	-0.001	-0.001
GP_C_ALG_KS_P_HI	0.001		0.001		0.001	0.001	0.001		
GP_ALG_TEMP_OPT_LO				-0.001				-0.001	-0.001
GP_ALG_TEMP_OPT_HI	0.001				0.001	0.001	0.002		
GP_C_ALG_threshTP_LO			-0.001	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001
GP_C_ALG_threshTP_HI	0.001		0.001		0.002	0.002	0.002		
GP_ALG_C_TO_OM_LO									
GP_ALG_C_TO_OM_HI									
GP_alg_light_ext_coef_LO									
GP_alg_light_ext_coef_HI									
GP_ALG_LIGHT_SAT_LO									
GP_ALG_LIGHT_SAT_HI									
GP_ALG_PC_LO	0.001	0.001	0.001	0.001	0.002	0.002	0.001		
GP_ALG_PC_HI		-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
GP_DOM_RCDECOMP_LO				-0.001		-0.001	-0.001		
GP_DOM_RCDECOMP_HI	0.001				0.001	0.002	0.003		
GP_DOM_DECOMPRED_LO									
GP_DOM_DECOMPRED_HI					0.001				
GP_calibDecomp_LO				-0.001		-0.001	-0.001		
GP_calibDecomp_HI	0.001				0.001	0.002	0.003		
GP_DOM_decomp_coef_LO	0.001	0.001	0.001	0.001	0.003	0.006	0.007	0.001	0.001
GP_DOM_decomp_coef_HI				-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
GP_DOM_DECOMP_POPT_LO	0.001				0.001	0.004	0.006		
GP_DOM_DECOMP_POPT_HI									
GP_sorbToTP_LO									
GP_sorbToTP_HI									
GP_IC_BATHY_MULT_LO									
GP_IC_BATHY_MULT_HI									
GP_IC_TPtoSOIL_MULT_LO				-0.001			-0.001		
GP_IC_TPtoSOIL_MULT_HI	0.001				0.001	0.001	0.001		
GP_IC_DOM_BD_MULT_LO									
GP_IC_DOM_BD_MULT_HI									
GP_IC_BulkD_MULT_LO				-0.001					
GP_IC_BulkD_MULT_HI	0.001				0.001		0.001		
GP_IC_ELEV_MULT_LO									
GP_IC_ELEV_MULT_HI	0.001								
GP_MAC_IC_MULT_LO	0.001				0.001				
GP_MAC_IC_MULT_HI									
GP_MAC_REFUG_MULT_LO									
GP_MAC_REFUG_MULT_HI									
GP_mac_uptake_coef_LO				-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
GP_mac_uptake_coef_HI	0.001		0.001		0.001	0.002	0.003		
GP_mann_height_coef_LO					0.001				
GP_mann_height_coef_HI									
GP_Floc_BD_LO									
GP_Floc_BD_HI									
GP_FlocMax_LO									
GP_FlocMax_HI									
GP_TP_P_OM_LO									

GP_TP_P_OM_HI									
GP_Floc_rcSoil_LO					0.001	0.001	0.001		
GP_Floc_rcSoil_HI									
GP_TP_DIFFCOEF_LO									
GP_TP_DIFFCOEF_HI					0.001				
GP_TP_K_INTER_LO					0.001	0.001	0.001		
GP_TP_K_INTER_HI									
GP_TP_K_SLOPE_LO									
GP_TP_K_SLOPE_HI									
GP_WQMthresh_LO									
GP_WQMthresh_HI									
GP_PO4toTP_LO	-0.001	-0.001	-0.001	-0.002	-0.001	-0.002	-0.002	-0.001	-0.001
GP_PO4toTP_HI	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.001	0.001
GP_TP_IN_RAIN_LO				-0.001				-0.001	-0.001
GP_TP_IN_RAIN_HI	0.001	0.001	0.001		0.001	0.001	0.001		
GP_PO4toTPint_LO	0.001				0.001	0.001			
GP_PO4toTPint_HI				-0.001					
GP_TP_ICSFWAT_LO									
GP_TP_ICSFWAT_HI									
GP_TP_ICSEDWAT_LO									
GP_TP_ICSEDWAT_HI									
GP_TPpart_thresh_LO	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001
GP_TPpart_thresh_HI	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
GP_TP_DIFFDEPTH_LO					0.001				
GP_TP_DIFFDEPTH_HI									
GP_settlVel_LO	0.001	0.001	0.001		0.001	0.001	0.001		
GP_settlVel_HI				-0.001				-0.001	-0.001
HP_ALG_MAX_LO	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001
HP_ALG_MAX_HI		-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
HP_DOM_MAXDEPTH_LO						0.001			
HP_DOM_MAXDEPTH_HI									
HP_DOM_AEROBTHIN_LO									
HP_DOM_AEROBTHIN_HI	0.001				0.001	0.001	0.001		
HP_TP_CONC_GRAD_LO									
HP_TP_CONC_GRAD_HI									
HP_SALT_ICSEDWAT_LO									
HP_SALT_ICSEDWAT_HI									
HP_SALT_ICSFWAT_LO									
HP_SALT_ICSFWAT_HI									
HP_PHBIO_MAX_LO	0.001				0.001	0.001	0.001		
HP_PHBIO_MAX_HI				-0.001			-0.001		
HP_NPHBIO_MAX_LO									
HP_NPHBIO_MAX_HI									
HP_MAC_MAXHT_LO	0.001				0.001				
HP_MAC_MAXHT_HI									
HP_NPHBIO_ROOTDEPTH_LO									
HP_NPHBIO_ROOTDEPTH_HI									
HP_MAC_MAXROUGH_LO					0.001				
HP_MAC_MAXROUGH_HI									
HP_MAC_MINROUGH_LO									
HP_MAC_MINROUGH_HI									
HP_MAC_MAXLAI_LO	0.001				0.001				
HP_MAC_MAXLAI_HI									
HP_MAC_MAXCANOPCOND_LO									
HP_MAC_MAXCANOPCOND_HI									
HP_MAC_CANOPDECOUP_LO									
HP_MAC_CANOPDECOUP_HI									
HP_MAC_TEMPOPT_LO				-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
HP_MAC_TEMPOPT_HI	0.001				0.001	0.001	0.002		
HP_MAC_LIGHTSAT_LO									
HP_MAC_LIGHTSAT_HI									
HP_MAC_KSP_LO									
HP_MAC_KSP_HI						0.001	0.001		
HP_PHBIO_RCNPP_LO	0.001				0.001	0.001	0.001		
HP_PHBIO_RCNPP_HI				-0.001			-0.001		
HP_PHBIO_RCMORT_LO									
HP_PHBIO_RCMORT_HI					0.001				
HP_MAC_WAT_TOLER_LO									
HP_MAC_WAT_TOLER_HI									
HP_MAC_SALIN_THRESH_LO									
HP_MAC_SALIN_THRESH_HI									
HP_PHBIO_IC_CTOOM_LO									
HP_PHBIO_IC_CTOOM_HI									
HP_NPHBIO_IC_CTOOM_LO									
HP_NPHBIO_IC_CTOOM_HI									
HP_PHBIO_IC_PC_LO	0.001				0.001	0.001	0.001		
HP_PHBIO_IC_PC_HI									
HP_NPHBIO_IC_PC_LO									
HP_NPHBIO_IC_PC_HI									
HP_MAC_TRANSLOC_RC_LO									
HP_MAC_TRANSLOC_RC_HI									
HP_HYD_RCINFILT_LO									
HP_HYD_RCINFILT_HI									
HP_HYD_SPEC_YIELD_LO									
HP_HYD_SPEC_YIELD_HI									
HP_HYD_POROSITY_LO									
HP_HYD_POROSITY_HI									
HP_FLOC_IC_LO									
HP_FLOC_IC_HI									
HP_FLOC_IC_CTOOM_LO									
HP_FLOC_IC_CTOOM_HI									
HP_FLOC_IC_PC_LO									
HP_FLOC_IC_PC_HI									
HP_SfDepthLo_LO									
HP_SfDepthLo_HI									
HP_SfDepthHi_LO									
HP_SfDepthHi_HI									
HP_SfDepthInt_LO									
HP_SfDepthInt_HI									
HP_PhosLo_LO									
HP_PhosLo_HI									
HP_PhosHi_LO									
HP_PhosHi_HI									
HP_PhosInt_LO									
HP_PhosInt_HI									
HP_FireInt_LO									
HP_FireInt_HI									
Count:	37	14	21	30	50	46	49	22	22

Table 7.3.3. Soils. Naive case: +/-25% change in parameter. Compared to the 5-yr mean of the NOMINAL run output, if a simulation with a changed parameter resulted in at least a 1% change in the soil porewater TP concentration Performance Measure in an Indicator Region (IR), the (ParmChangeRun - NominalRun) (mg/L) difference is shown for that simulation & IR. Parameters are grouped by ecological module (as found in databases).

	TPpore_9	TPpore_8	TPpore_7	TPpore_6	TPpore_5	TPpore_4	TPpore_3	TPpore_2	TPpore_0
NOMINAL	0.002	0.003	0.005	0.011	0.021	0.060	0.059	0.011	0.011
GP_SOLOMEGA_LO									
GP_SOLOMEGA_HI									
GP_ALTIT_LO									
GP_ALTIT_HI									
GP_LATDEG_LO									
GP_LATDEG_HI									
GP_mannDepthPow_LO		-0.001				-0.002	-0.001		
GP_mannDepthPow_HI	-0.001				-0.001		0.002		
GP_mannHeadPow_LO			0.001			0.001			
GP_mannHeadPow_HI		-0.001				-0.002	0.001		
GP_calibGWat_LO		-0.001				-0.005	-0.003	-0.001	-0.001
GP_calibGWat_HI						0.004	0.004	0.001	0.001
GP_IDW_pow_LO									
GP_IDW_pow_HI									
GP_calibET_LO	-0.001	-0.001	-0.001	-0.001	-0.002	-0.009	-0.002	-0.001	-0.001
GP_calibET_HI		0.001	0.002	0.002	0.002	0.006	0.005	0.002	0.002
GP_HYD_IC_SFWAT_ADD_LO									
GP_HYD_IC_SFWAT_ADD_HI									
GP_HYD_IC_UNSAT_ADD_LO									
GP_HYD_IC_UNSAT_ADD_HI									
GP_HYD_ICUNSATMOIST_LO									
GP_HYD_ICUNSATMOIST_HI									
GP_DetentZ_LO						-0.001			
GP_DetentZ_HI									
GP_MinCheck_LO									
GP_MinCheck_HI									
GP_dispLenRef_LO	-0.001	-0.001				0.003	0.006		
GP_dispLenRef_HI			0.001			-0.003	-0.004		
GP_dispParm_LO			0.001			-0.003	-0.004		
GP_dispParm_HI	-0.001	-0.001				0.003	0.006		
GP_SLRise_LO									
GP_SLRise_HI									
GP_ALG_IC_MULT_LO									
GP_ALG_IC_MULT_HI						-0.001			
GP_alg_uptake_coef_LO	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003	-0.002	-0.001	-0.001
GP_alg_uptake_coef_HI			0.001	0.001	0.001	0.002	0.002	0.001	0.001
GP_ALG_SHADE_FACTOR_LO									
GP_ALG_SHADE_FACTOR_HI							0.001		
GP_algMortDepth_LO									
GP_algMortDepth_HI									
GP_ALG_RC_MORT_DRY_LO									
GP_ALG_RC_MORT_DRY_HI						-0.001			
GP_ALG_RC_MORT_LO			0.001	0.001	0.001	0.003	0.003	0.001	0.001
GP_ALG_RC_MORT_HI	-0.001	-0.001			-0.001	-0.002	-0.001		
GP_ALG_RC_PROD_LO			0.001	0.001	0.001	0.001	0.003		
GP_ALG_RC_PROD_HI		-0.001			-0.001	-0.001	-0.001		
GP_ALG_RC_RESP_LO									
GP_ALG_RC_RESP_HI						-0.001			
GP_alg_R_accel_LO			0.001	0.001	0.002	0.004	0.004	0.001	0.001
GP_alg_R_accel_HI	-0.001	-0.001		-0.001	-0.002	-0.004	-0.003		
GP_AlgComp_LO						0.001	0.004		
GP_AlgComp_HI						-0.001			
GP_ALG_REF_MULT_LO						-0.001			
GP_ALG_REF_MULT_HI									
GP_NC_ALG_KS_P_LO							0.002		
GP_NC_ALG_KS_P_HI						-0.001			
GP_alg_alkP_min_LO							0.001		
GP_alg_alkP_min_HI						-0.001			
GP_C_ALG_KS_P_LO	-0.001	-0.001		-0.001	-0.001	-0.001			
GP_C_ALG_KS_P_HI			0.001	0.001		-0.001			
GP_ALG_TEMP_OPT_LO	-0.001	-0.001			-0.001	-0.001	-0.001		
GP_ALG_TEMP_OPT_HI			0.001	0.001	0.002	0.003	0.005	0.001	0.001
GP_C_ALG_threshTP_LO	-0.001	-0.001		-0.001	-0.003	-0.007	-0.005	-0.001	-0.001
GP_C_ALG_threshTP_HI			0.001	0.001	0.002	0.004	0.005	0.001	0.001
GP_ALG_C_TO_OM_LO		-0.001			-0.002	-0.006	-0.006	-0.001	-0.001
GP_ALG_C_TO_OM_HI			0.001	0.001	0.001	0.004	0.006	0.001	0.001
GP_alg_light_ext_coef_LO									
GP_alg_light_ext_coef_HI									
GP_ALG_LIGHT_SAT_LO									
GP_ALG_LIGHT_SAT_HI									
GP_ALG_PC_LO			0.001	0.001	0.001	-0.001	-0.001		
GP_ALG_PC_HI	-0.001	-0.001		-0.001	-0.001		0.002		
GP_DOM_RCDECOMP_LO	-0.001	-0.001	-0.002	-0.004	-0.007	-0.016	-0.017	-0.003	-0.003
GP_DOM_RCDECOMP_HI	0.001	0.001	0.003	0.005	0.008	0.029	0.04	0.005	0.005
GP_DOM_DECOMPRED_LO	-0.001	-0.001	-0.001	-0.001	-0.002	-0.004	-0.004	-0.001	-0.001
GP_DOM_DECOMPRED_HI			0.001	0.002	0.002	0.004	0.005	0.001	0.001
GP_calibDecomp_LO	-0.001	-0.001	-0.002	-0.004	-0.007	-0.016	-0.017	-0.003	-0.003
GP_calibDecomp_HI	0.001	0.001	0.003	0.005	0.008	0.029	0.04	0.005	0.005
GP_DOM_decomp_coef_LO	0.009	0.011	0.017	0.025	0.039	0.107	0.115	0.022	0.022
GP_DOM_decomp_coef_HI	-0.001	-0.002	-0.003	-0.007	-0.013	-0.028	-0.029	-0.005	-0.005
GP_DOM_DECOMP_POPT_LO			0.001	0.001	0.003	0.062	0.1	0.006	0.006
GP_DOM_DECOMP_POPT_HI					-0.001	-0.007	-0.008	-0.001	-0.001
GP_sorbToTP_LO	-0.001	-0.001	-0.001	-0.002	-0.003	-0.004	-0.003	-0.001	-0.001
GP_sorbToTP_HI		0.001	0.002	0.003	0.003	0.003	0.004	0.002	0.002
GP_IC_BATHY_MULT_LO									
GP_IC_BATHY_MULT_HI									
GP_IC_TPtoSOIL_MULT_LO	-0.001	-0.002	-0.002	-0.004	-0.006	-0.01	-0.01	-0.003	-0.003
GP_IC_TPtoSOIL_MULT_HI	0.002	0.002	0.004	0.005	0.007	0.012	0.013	0.004	0.004
GP_IC_DOM_BD_MULT_LO			0.001	0.002	0.003	0.006	0.006	0.001	0.001
GP_IC_DOM_BD_MULT_HI	-0.001	-0.001	-0.001	-0.002	-0.004	-0.01	-0.009	-0.002	-0.002
GP_IC_BulkD_MULT_LO	-0.001	-0.002	-0.002	-0.004	-0.006	-0.009	-0.008	-0.003	-0.003
GP_IC_BulkD_MULT_HI	0.001	0.002	0.003	0.004	0.004	0.003	0.004	0.003	0.003
GP_IC_ELEV_MULT_LO	-0.001	-0.001			-0.001	-0.002			
GP_IC_ELEV_MULT_HI			0.001			0.002			
GP_MAC_IC_MULT_LO		0.001	0.002	0.002	0.002	0.002	0.003	0.002	0.002
GP_MAC_IC_MULT_HI	-0.001	-0.001		-0.001	-0.001	-0.001		-0.001	-0.001
GP_MAC_REFUG_MULT_LO									
GP_MAC_REFUG_MULT_HI									
GP_mac_uptake_coef_LO	-0.001	-0.002	-0.004	-0.009	-0.018	-0.036	-0.036	-0.007	-0.007
GP_mac_uptake_coef_HI	0.009	0.01	0.012	0.015	0.018	0.035	0.043	0.013	0.013
GP_mann_height_coef_LO		-0.001				-0.002			
GP_mann_height_coef_HI			0.001			0.001	0.001		
GP_Floc_BD_LO	-0.001	-0.001			-0.002	-0.005	-0.005	-0.001	-0.001
GP_Floc_BD_HI			0.001	0.001	0.001	0.004	0.006	0.001	0.001
GP_FlocMax_LO	-0.001	-0.001			-0.002	-0.005	-0.005	-0.001	-0.001
GP_FlocMax_HI			0.001	0.001	0.001	0.004	0.006	0.001	0.001
GP_TP_P_OM_LO						-0.001			
GP_TP_P_OM_HI							0.001		
GP_Floc_rcSoil_LO			0.001	0.001	0.002	0.006	0.008	0.001	0.001

Table 7.3.3, p. 2 of 2

GP_Floc_rcSoil_HI	-0.001	-0.001			-0.001	-0.004	-0.004		
GP_TP_DIFFCOEF_LO						0.002	0.004		
GP_TP_DIFFCOEF_HI					-0.001	-0.003	-0.002		
GP_TP_K_INTER_LO			0.002	0.004	0.007	0.021	0.024	0.004	0.004
GP_TP_K_INTER_HI	-0.001	-0.001	-0.001	-0.002	-0.005	-0.013	-0.012	-0.002	-0.002
GP_TP_K_SLOPE_LO						-0.002	-0.001		
GP_TP_K_SLOPE_HI						0.001	0.002		
GP_WQMthresh_LO									
GP_WQMthresh_HI									
GP_PO4toTP_LO	-0.001	-0.001		0.001	0.001	0.001	0.004		
GP_PO4toTP_HI			0.001		0.001		-0.003		
GP_TP_IN_RAIN_LO	-0.001	-0.001		-0.001	-0.001	-0.002	-0.001	-0.001	-0.001
GP_TP_IN_RAIN_HI			0.001	0.001	0.001	0.001	0.001	0.001	0.001
GP_PO4toTPint_LO							0.001		
GP_PO4toTPint_HI	-0.001	-0.001				-0.001			
GP_TP_ICSFWAT_LO									
GP_TP_ICSFWAT_HI									
GP_TP_ICSEDWAT_LO	-0.001	-0.001			-0.001	-0.001	-0.001		
GP_TP_ICSEDWAT_HI						0.001	0.002		
GP_TPpart_thresh_LO	-0.001	-0.001			-0.001		0.002		
GP_TPpart_thresh_HI			0.001	0.001			-0.001		
GP_TP_DIFFDEPTH_LO					-0.001	-0.004	-0.003		
GP_TP_DIFFDEPTH_HI						0.002	0.003		
GP_settlVel_LO			0.001			-0.002	-0.002		
GP_settlVel_HI	-0.001	-0.001				0.001	0.003		
HP_ALG_MAX_LO			0.001	0.002	0.003	0.005	0.005	0.001	0.001
HP_ALG_MAX_HI	-0.001	-0.001		-0.001	-0.002	-0.004	-0.003	-0.001	-0.001
HP_DOM_MAXDEPTH_LO	-0.001	-0.001	-0.001	-0.002	-0.002	0.003	0.002	-0.001	-0.001
HP_DOM_MAXDEPTH_HI	0.001	0.001	0.002	0.002	0.001	-0.003	-0.002	0.001	0.001
HP_DOM_AEROBTHIN_LO	-0.001	-0.001			-0.001	-0.002	-0.001		
HP_DOM_AEROBTHIN_HI			0.001				0.001		
HP_TP_CONC_GRAD_LO						0.004	0.005	0.001	0.001
HP_TP_CONC_GRAD_HI	-0.001	-0.001			-0.001	-0.004	-0.003		
HP_SALT_ICSEDWAT_LO									
HP_SALT_ICSEDWAT_HI									
HP_SALT_ICSFWAT_LO									
HP_SALT_ICSFWAT_HI									
HP_PHBIO_MAX_LO	0.003	0.004	0.006	0.007	0.008	0.017	0.023	0.006	0.006
HP_PHBIO_MAX_HI	-0.001	-0.002	-0.003	-0.005	-0.007	-0.013	-0.013	-0.003	-0.003
HP_NPHBIO_MAX_LO	-0.001	-0.001					0.001		
HP_NPHBIO_MAX_HI						-0.001			
HP_MAC_MAXHT_LO	-0.001	-0.001			-0.001	-0.003	-0.001		
HP_MAC_MAXHT_HI			0.001	0.001		0.002	0.002		
HP_NPHBIO_ROOTDEPTH_LO			0.001				0.001		
HP_NPHBIO_ROOTDEPTH_HI	-0.001	-0.001				-0.001			
HP_MAC_MAXROUGH_LO						-0.001			
HP_MAC_MAXROUGH_HI							0.001		
HP_MAC_MINROUGH_LO						-0.001			
HP_MAC_MINROUGH_HI							0.001		
HP_MAC_MAXLAI_LO	-0.001	-0.001	-0.001	-0.001	-0.002	-0.004	-0.002	-0.001	-0.001
HP_MAC_MAXLAI_HI			0.001	0.001	0.001	0.002	0.003	0.001	0.001
HP_MAC_MAXCANOPCOND_LO									
HP_MAC_MAXCANOPCOND_HI									
HP_MAC_CANOPDECOUP_LO									
HP_MAC_CANOPDECOUP_HI									
HP_MAC_TEMPOPT_LO	-0.001	-0.002	-0.004	-0.008	-0.016	-0.033	-0.033	-0.006	-0.006
HP_MAC_TEMPOPT_HI	0.004	0.005	0.007	0.008	0.01	0.024	0.031	0.007	0.007
HP_MAC_LIGHTSAT_LO									
HP_MAC_LIGHTSAT_HI									
HP_MAC_KSP_LO		-0.001			-0.002	-0.008	-0.009	-0.001	-0.001
HP_MAC_KSP_HI				0.001	0.001	0.007	0.012	0.001	0.001
HP_PHBIO_RCNPP_LO	0.003	0.004	0.005	0.007	0.008	0.017	0.023	0.006	0.006
HP_PHBIO_RCNPP_HI	-0.001	-0.002	-0.002	-0.005	-0.007	-0.013	-0.013	-0.003	-0.003
HP_PHBIO_RCMORT_LO	-0.001	-0.001			-0.001		0.001		
HP_PHBIO_RCMORT_HI			0.001	0.001					
HP_MAC_WAT_TOLER_LO			0.001	0.002	0.001	0.001		0.001	0.001
HP_MAC_WAT_TOLER_HI	-0.001	-0.001			-0.001	-0.001			
HP_MAC_SALIN_THRESH_LO									
HP_MAC_SALIN_THRESH_HI									
HP_PHBIO_IC_CTOOM_LO					-0.001	-0.002	-0.001		
HP_PHBIO_IC_CTOOM_HI							0.001		
HP_NPHBIO_IC_CTOOM_LO						-0.001			
HP_NPHBIO_IC_CTOOM_HI							0.001		
HP_PHBIO_IC_PC_LO	0.003	0.004	0.005	0.007	0.008	0.015	0.021	0.006	0.006
HP_PHBIO_IC_PC_HI	-0.001	-0.002	-0.002	-0.005	-0.007	-0.012	-0.012	-0.003	-0.003
HP_NPHBIO_IC_PC_LO						-0.001			
HP_NPHBIO_IC_PC_HI									
HP_MAC_TRANSLOC_RC_LO						-0.001			
HP_MAC_TRANSLOC_RC_HI									
HP_HYD_RCINFILT_LO									
HP_HYD_RCINFILT_HI									
HP_HYD_SPEC_YIELD_LO				0.001		-0.003			
HP_HYD_SPEC_YIELD_HI	-0.001	-0.001			-0.001	0.001	0.001		
HP_HYD_POROSITY_LO	-0.001	-0.001		-0.001	-0.001	-0.004	-0.002	-0.001	-0.001
HP_HYD_POROSITY_HI	-0.001		0.001	0.001	0.001	0.002	0.003	0.001	0.001
HP_FLOC_IC_LO									
HP_FLOC_IC_HI									
HP_FLOC_IC_CTOOM_LO									
HP_FLOC_IC_CTOOM_HI									
HP_FLOC_IC_PC_LO									
HP_FLOC_IC_PC_HI									
HP_SfDepthLo_LO									
HP_SfDepthLo_HI									
HP_SfDepthHi_LO									
HP_SfDepthHi_HI									
HP_SfDepthInt_LO									
HP_SfDepthInt_HI									
HP_PhosLo_LO									
HP_PhosLo_HI									
HP_PhosHi_LO									
HP_PhosHi_HI									
HP_PhosInt_LO									
HP_PhosInt_HI									
HP_FireInt_LO									
HP_FireInt_HI									
Count:	60	68	65	67	85	121	112	64	64

Table 7.3.4. Most 'important' parameters for different ecological process modules as understood from the Naive case. Note that the Naive case does not employ "realistic" changes to parameters, nor does it consider the broader spatial characteristics of the entire greater Everglades. A larger number of parameters than shown in this table are evaluated in the "Informed" phase of the NIS multi-scale sensitivity analysis.

"Yes" = affects performance in potentially significant manner at various spatial locations/scales

"Potential" = in "top 20", w/ observable affect on performance at various spatial locations/scales

Parameter	Hydrology	Surface water quality	Soil water quality	State of knowledge
GP_calibET	**yes**	**potential**	**yes**	Evapotranspiration rates known to Level II - III
GP_calibGWat	**yes**		**potential**	Subsurface groundwater flows known to Level I - II
HP_HYD_SPEC_YIELD	yes			Horizontal and vertical distributions of surficial storage = Level I - III
GP_IC_ELEV_MULT	yes			Land surface elevations known to Level III, some Level II
HP_MAC_MAXLAI	yes			Maximum LAI is Level II - III, but actual LAI is Level I - II
HP_HYD_POROSITY	yes			Horizontal and vertical distributions of surficial storage = Level I - III
GP_MAC_IC_MULT	**yes**		**potential**	Initial macrophyte biomass known to Level I - III
HP_NPHBIO_ROOTDEPTH	yes			Depth of principal root mass known to Level II
HP_MAC_MINROUGH	yes			Minimum Manning's N known to Level I -II, actual roughness is closer to Level I
GP_PO4toTP		yes		Ratio of bio-available to total phosphorus Level II, model value is Level I
HP_ALG_MAX	**potential**	**yes**		Maximum periphyton biomass is Level II - III, actual biomass is Level I - II
GP_TPpart_thresh		yes		Settling physics Level III, actual particulate and microbial dynamics Level I
GP_DOM_DECOMP_POPT	**potential**	**yes**	**yes**	Laboratory constants known to Level III, scaled constants Level II
GP_DOM_RCDECOMP		**yes**	**yes**	Laboratory constants known to Level III, scaled constants Level II
GP_C_ALG_threshTP	**potential**	**yes**	**potential**	Laboratory and field experiments for periphyton TP threshold are Level III
GP_ALG_TEMP_OPT		yes		Periphyton temperature optimimum known to Level III, correlated to Level I - II growth rate
GP_alg_R_accel	**potential**	**yes**		Biochemical cause for periphyton loss at high TP unknown; proxy here is calibrated
GP_ALG_RC_MORT		yes		Maximum specific mortality rate known to Level II; field rates known to I - III
GP_ALG_PC		yes		Phosphorus:Carbon periphyton ratio known to Level II
GP_C_ALG_KS_P		**yes**	**potential**	Laboratory constants known to Level III, scaled constants Level II
HP_MAC_TEMPOPT		**potential**	**yes**	Macrophyte temperature optimimum known to Level III, correlated to Level I - II growth rate
HP_PHBIO_MAX			yes	Maximum macrophyte biomass is Level II - III, actual biomass is Level I - II
HP_PHBIO_RCNPP		**potential**	**yes**	Maximum rate of macrophyte net primary production known to Level II, actual is level I - III
HP_PHBIO_IC_PC			yes	Phosphorus:Carbon macrophytes ratio known to Level II
GP_TP_K_INTER			yes	Laboratory constants known to Level III, scaled constants Level II
GP_IC_TPtoSOIL_MULT			yes	Initial soil TP concentration known to level II - III
GP_IC_BulkD_MULT	**potential**		**yes**	Initial (constant) soil bulk density known to level II - III

7.3.6 Figures: sensitivity analyses

Five figures follow on the next five pages.

Figure 7.3.1. Conceptual model of approach to sensitivity analysis of complex system simulations.

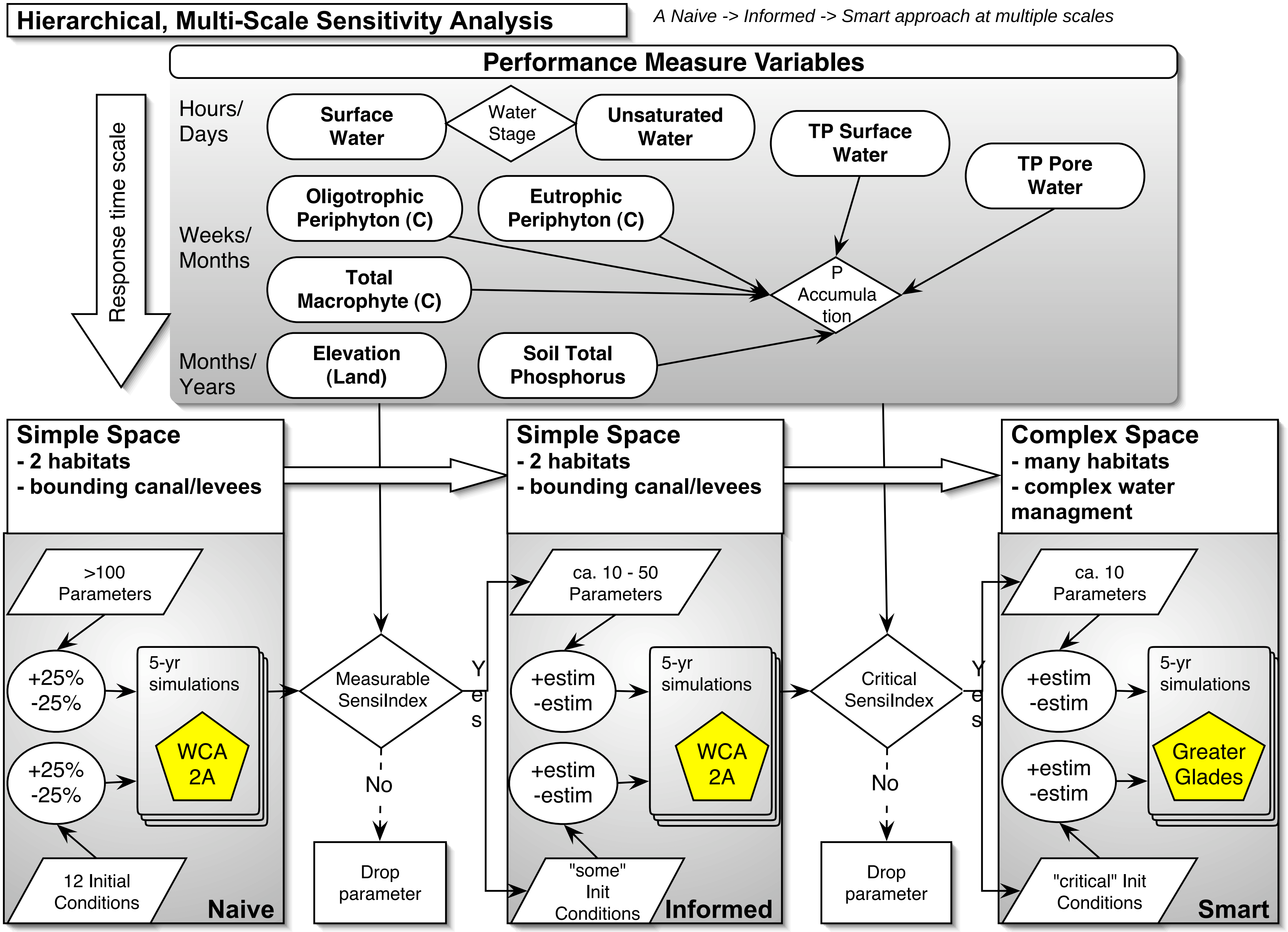


Fig.7.3.2.Basin/Indicator-Region configuration of model used in sensitivity analysis.

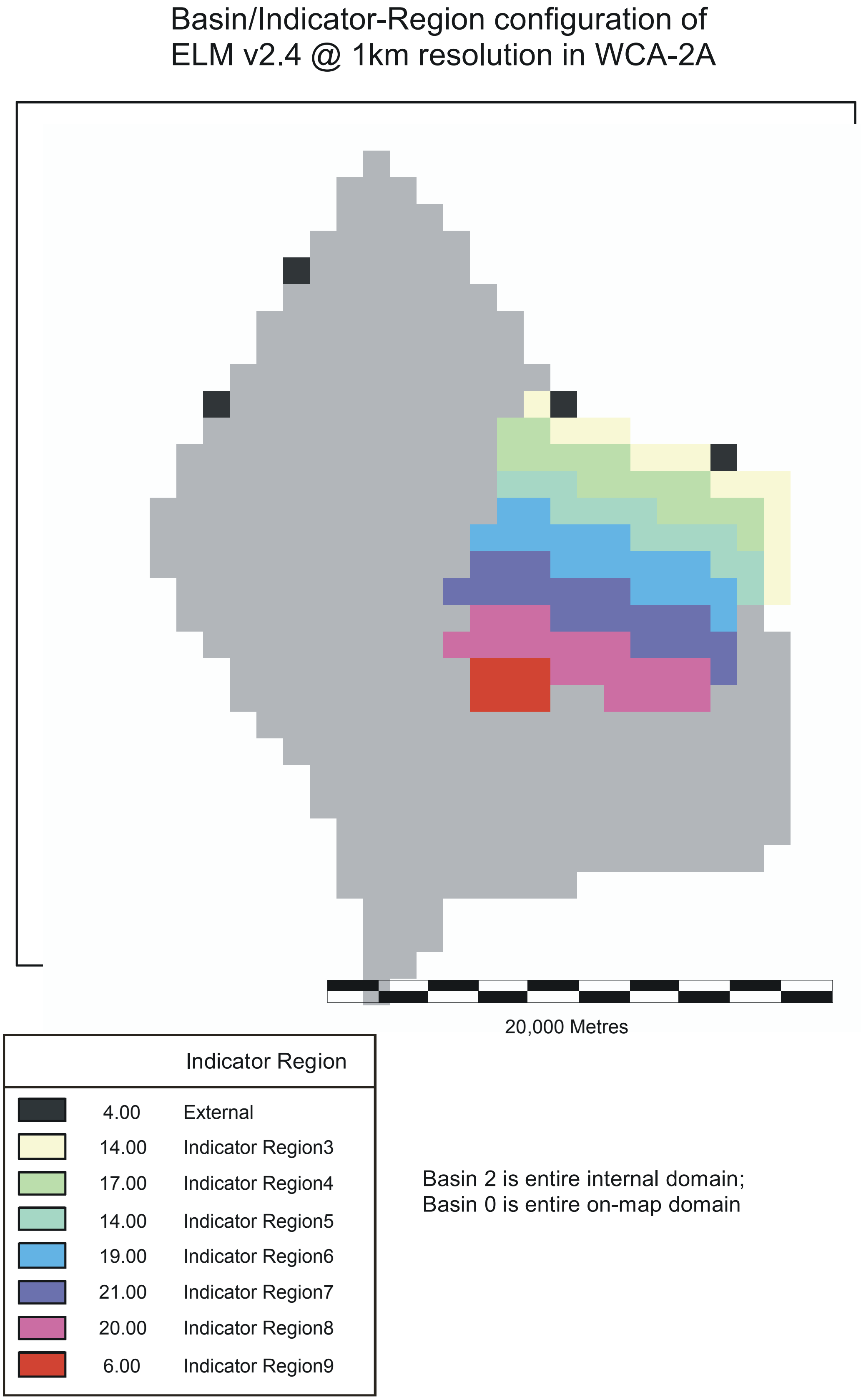


Figure 7.3.3a. Hydrology Naive case: +/- 25% change in parameter. Lowest (most negative) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).

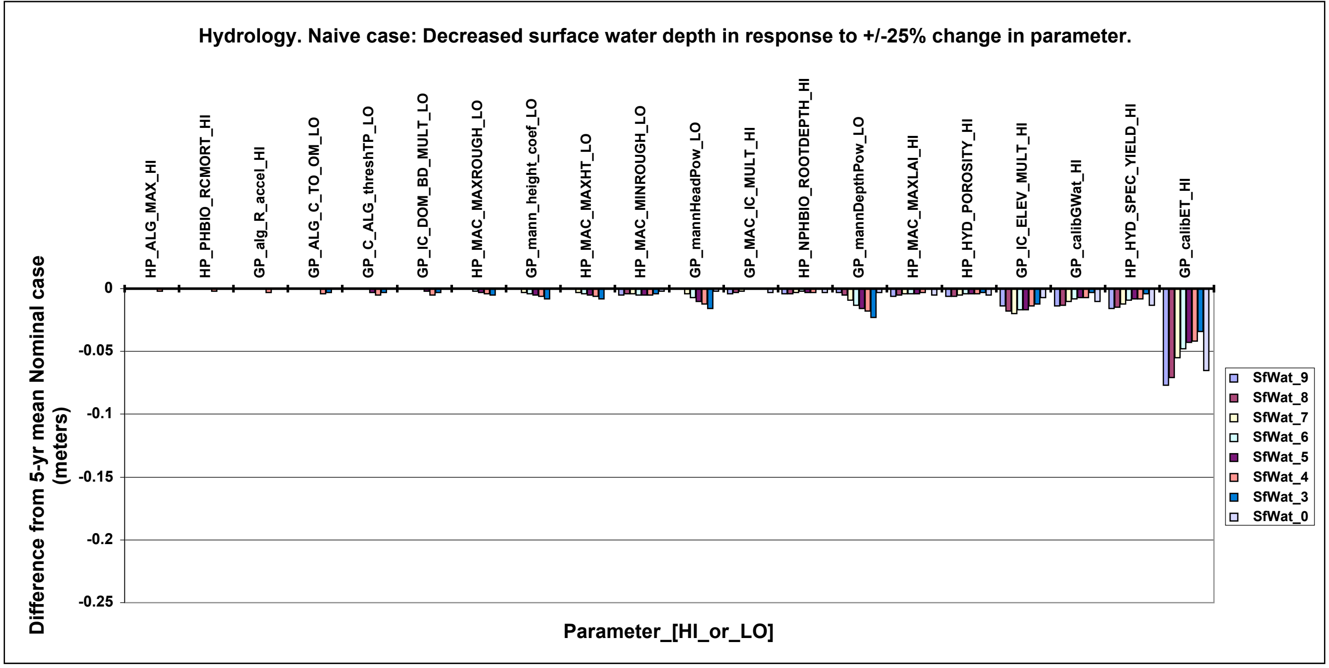


Figure 6.3.3b. Hydrology Naive case: +/- 25% change in parameter. Highest (most positive) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).

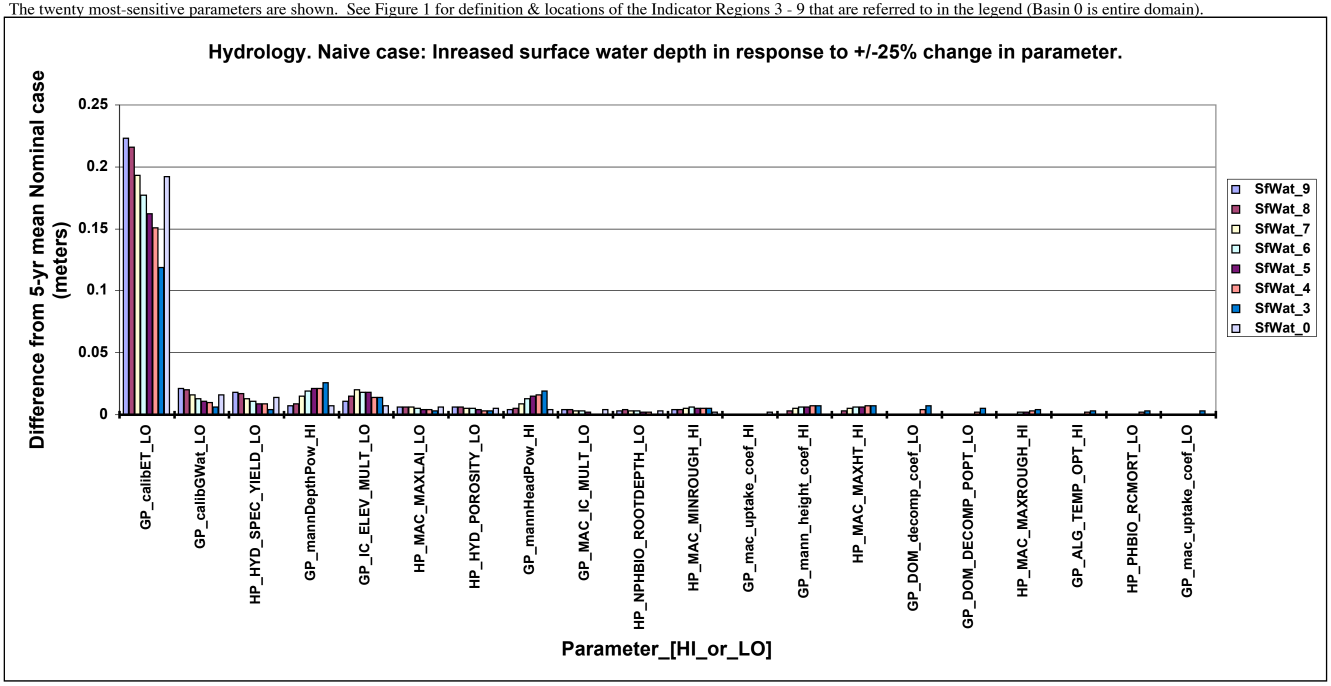


Figure 7.3.4a. Surface water TP Naive case: +/- 25% change in parameter. Lowest (most negative) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).

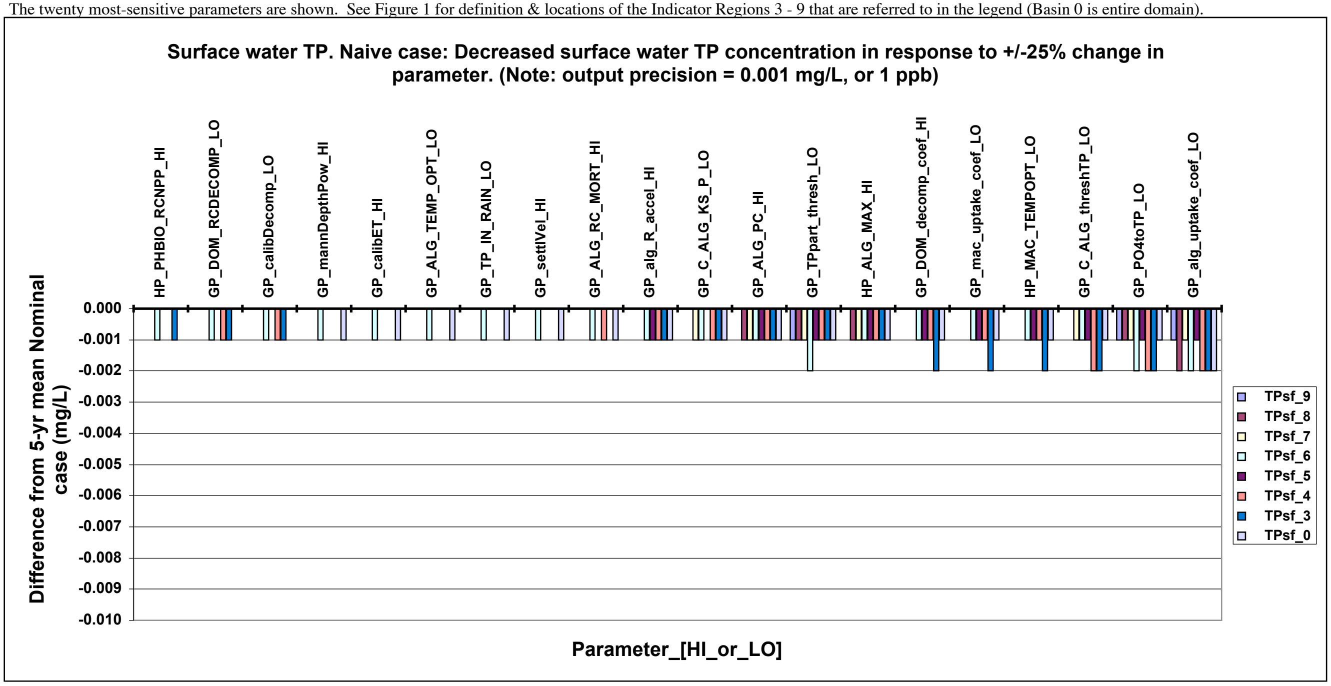


Figure 6.3.4b. Surface water TP Naive case: +/- 25% change in parameter. Highest (most positive) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).

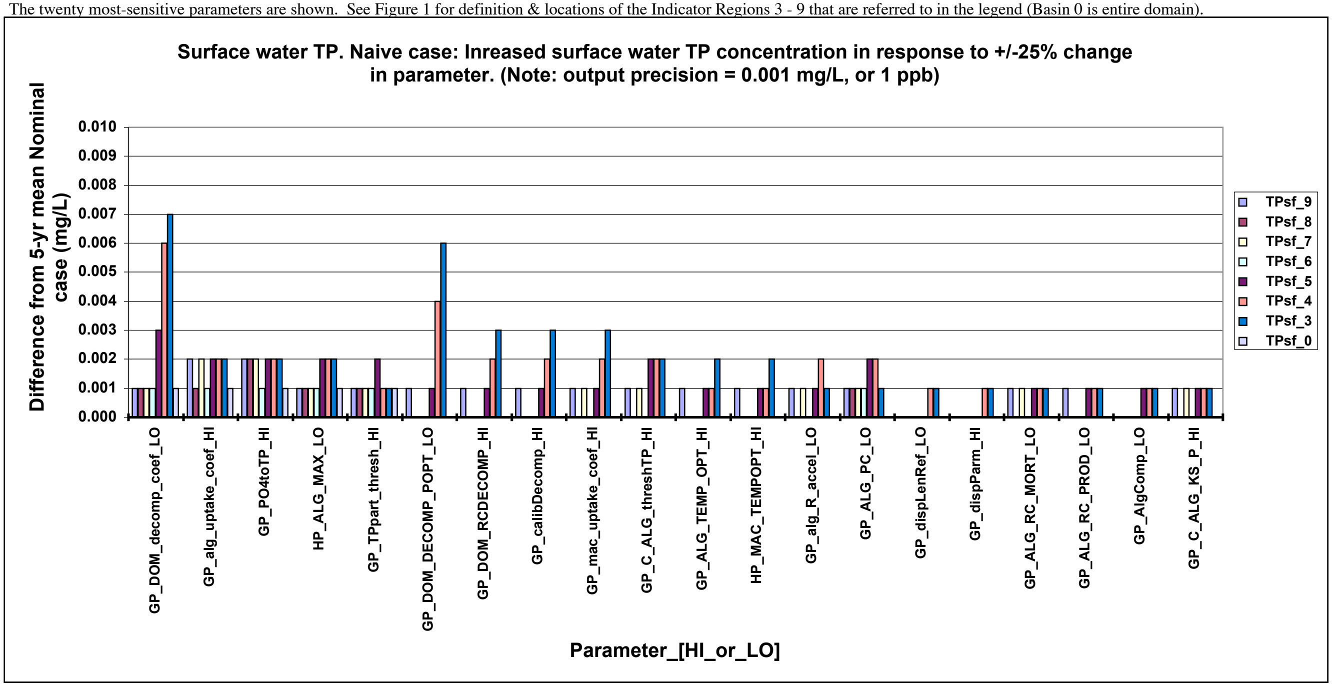


Figure 7.3.5a. Soils Naive case: +/- 25% change in parameter. Lowest (most negative) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).

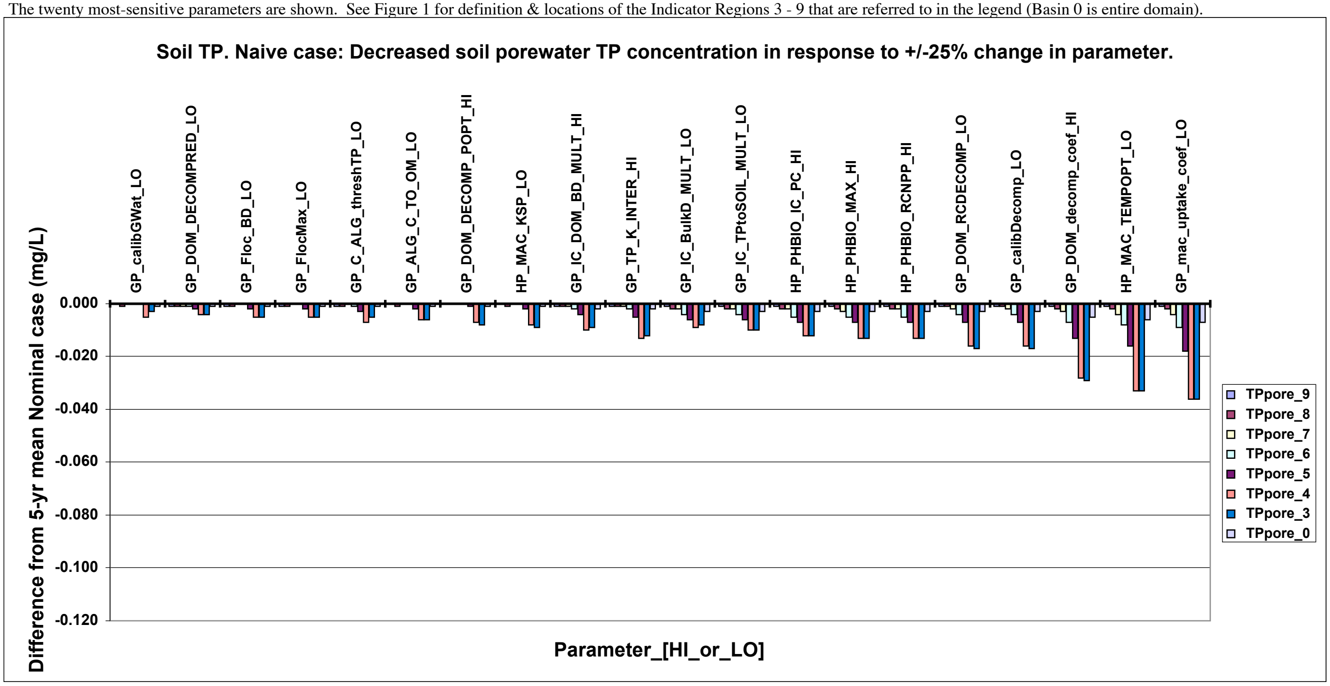
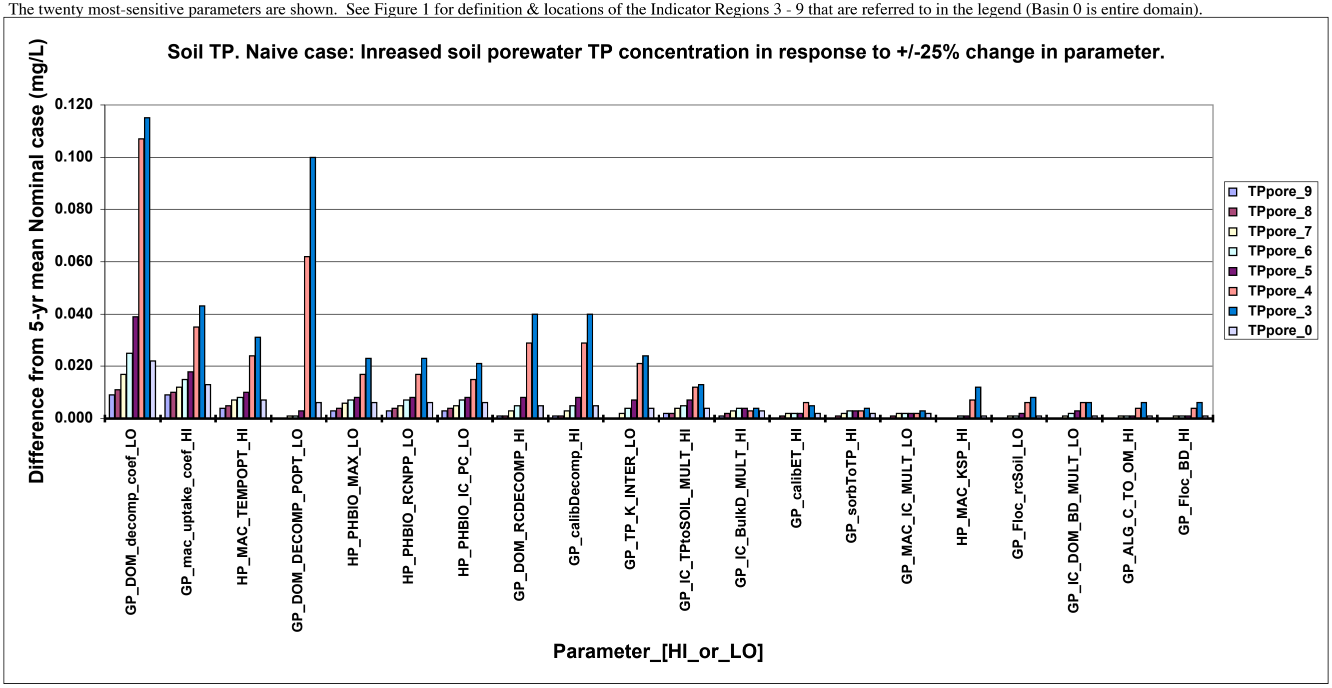


Figure 6.3.5b. Soils Naive case: +/- 25% change in parameter. Highest (most positive) output differences of Performance Measure compared to the 5-yr mean of the NOMINAL run output. The twenty most-sensitive parameters are shown. See Figure 1 for definition & locations of the Indicator Regions 3 - 9 that are referred to in the legend (Basin 0 is entire domain).



7.4 Model complexity

7.4.1 Parameters and complexity[5]

Because the ELM is a spatially distributed model of the fundamental ecosystem properties of a regional system, it necessarily uses a relatively large number of parameters to define rates, initial conditions, and various other system attributes. The parameters are not "hard-coded" into the model source code, but organized within user-friendly databases. The regional nature of this model encompasses a wide range of physical and biological characteristics. For example, a single parameter that is spatially distributed can take on a wide range of values – the important parameter of hydraulic conductivity varies over several orders of magnitude across the greater Everglades domain (see Data Chapter). To accurately communicate the data requirements of the model, the parameters should be classified according to their spatial distributions, according to their importance in influencing model results, and according to the degree to which they can be supported by available research.

Their spatial distribution is a fundamental component of these data. There are no more than approximately 40 individual parameters that are important to model results and that impose data acquisition needs. Some of these parameters are distributed in some spatial context. The spatial distributions involve those that are spatially-constant, those that are distributed among specific habitat types across the landscape, and parameters that are distributed among individual grid cells across the landscape.

While there are decades of monitoring and research activities in the greater Everglades, the past 5-10 years has dramatically increased our knowledge of system properties. Some of the parameters in use in the current ELM v2.5 have not been updated from ELM v2.1, and we anticipate that the next version of ELM (v3.0) will advance our synthesis of this base of knowledge of the Everglades.

7.4.1.1 Global parameters

As described in the Data Chapter, global parameters are those that apply uniformly throughout the spatial domain of the model. Of the 70 global parameters, 30 are unused or not intended to be modified except in model sensitivity experiments. The sensitivity analysis of this Chapter shows that a total of 23 of the 70 global parameters have the potential to affect, to at least a very small but observable extent, the hydrologic and water quality Performance Measures being considered[6]. Six of those 23 potentially- important parameters have significant effects on multiple Performance Measures.

7.4.1.2 Habitat-specific parameters

As described in the Data Chapter, habitat-specific parameters are those that apply only to the specified habitat type within spatial domain of the model. Of the 40 habitat-specific

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[5] Some of the text discussion here is also found in the Model Parameters section of the Data Chapter.

[6] Those performance measures are water depth, and TP concentration in surface and in pore water.

parameters, 5 are unused in this version of the model. The sensitivity analysis of this Chapter shows that a total of 13 of the 40 habitat-specific parameters have the potential to affect, to at least a very small but observable extent, the hydrologic and water quality Performance Measures being considered[7]. Of those 13 "important" parameters, one (1) has significant effects on multiple Performance Measures.

While each of the 40 habitat-specific parameters may have unique values for each of 28 habitats considered in the model (i.e., 1120 potentially unique values), such unique-by-each-habitat distributions do not exist for any of the parameters. The actual number of unique parameter values in the entire matrix is less than 140, with the most complex distribution of a single parameter across habitats having unique values for less than half of the habitats. When considering only the 13 "important" parameters, the actual number of unique values is 64, across all 28 habitats. Finally, only half (14) of the total number of habitats comprise >90% of the region of the ELM domain. Thus, in general, *there is, in total, on the order of several dozen unique-by-habitat values that may be important to quantify for model application*.

Of those parameters that we do assign unique values, basic field observations are used to support the parameter values. Generally, habitat-distributions of parameters are limited to differences among broadly defined ecosystem types involving *sedge, forest, savannah, and scrub* type habitats. Within an ecosystem type, any (usually limited) variation employs simple field-supported modifications of parameters according to the following: 1) slight modifications of maximum macrophyte biomass and related parameters along a gradient (e.g., the 3 cattail habitats of high, medium, and low density), 2) replication of data from one habitat type to values for a similar habitat, differing in one or two primary attributes (e.g., from a simplistic perspective, *Juncus* and *Cladium* could differ primarily in salt tolerance, with some limited structural parameter differences), and 3) specific field research and monitoring data that supports the use of distinctions among the attributes of different habitats.

Instead of supporting a parameter database that includes such a large number (28) of habitat types for 40 parameters (in a 2D array of parameters), we could obtain the same or similar model results in the current water-quality oriented version by simply not including all of the fundamental habitat types. This is attractive in terms of reducing the apparent complexity of the ELM via a smaller 2D array of parameters, but would do little to decrease the actual complexity in terms of the data that currently populates the 2D array of parameters. As discussed, the large majority of parameter values are the same for multiple habitat types, and thus the numerical complexity of such a large array is never realized. Moreover, a reduction of the number of habitat types would require increased maintenance of spatial and parameter databases, as future model updates include increased levels of differentiation among ecological dynamics of soils, periphyton, macrophytes, and habitat succession. Whereas we can currently simply improve the parameter values as data become available, the alternative is to incrementally modify both the habitat type map and the number of records supported in the database. The bottom line: from a model development and refinement perspective, it is attractive to

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[7] Ibid.

maintain the two-dozen habitat types currently defined as the minimum (that only begins) to represent the regional heterogeneity across the greater Everglades.

We have taken a *simple approach that generally assumes a high degree of similarity among most habitats, while providing a database mechanism to recognize differences in attributes where they are important,* either currently or in the future. Regardless of the database implementation of habitat-specific parameters, that assumption of broadly-based habitat-similarity will remain until increased knowledge supports more refined distinctions in the heterogeneity of the greater Everglades.

The ELM "history-matching" performance was documented (see Model Performance Chapter) by a variety of analyses of an historical simulation that used single-estimates of parameters. We recognize that it can be beneficial to express the relative performance uncertainty of the model by employing distributions of uncertain parameter estimates. We plan on future refinements that will explore methods of expressing the model results in probabilistic outcomes under a range of parameter estimates.

7.5 Model numerical dispersion

There are a variety of mechanisms that result in water movement and transport of dissolved/suspended matter in hydrologic systems, and they can be conceptualized in two basic forms: *advection* and *diffusion*. *Advection* results from a unidirectional flow, such as water coursing down a river. This action of an advected water mass does not change the concentration of a mass of a solute within the water parcel, and thus does not affect the gradient of the solute within the system as the water parcel moves downstream. *Diffusion* can generally be considered to be the movement of mass due to random water motion or mixing (Chapra 1997). Molecular diffusion results from the random movement of water molecules, while turbulent diffusion is a similar type of random movement that occurs at much larger scales such as eddies. The effect is to distribute mass of solutes in the system, smoothing the gradient of concentration. The process of dispersion is closely related to diffusion in that dispersion also results in the lateral spread of the mass or concentration of the solute in the system. One may consider dispersion to be a special class of diffusion, at least with respect to the results of the processes. Dispersion, however, is the result of velocity differences across space, as opposed to random motion of water. It may be apparent that the spatial and temporal scale of observing, or modeling, the system is a critical characteristic that must be considered when exploring the contributions of these flux processes.

In dynamic modeling of flowing, spatially distributed (e.g., gridded) systems, the numerical solution technique has an effect on the accuracy of the model prediction. Use of an explicit, finite difference technique (such as used in ELM), is known to result in numerical errors that have the effect of dispersing the concentration of a solute in the system (Chapra 1997), (many others). Note that numerical dispersion (errors) can be assumed to have the same effect on solute gradients that real diffusion/dispersion in the observed system.

This numerical dispersion (error) is very sensitive to scale: numerical dispersion is increased by increasing the size of the model grid, and/or by increasing the number of temporal iterations per unit of time (i.e., decreasing the model time step, *dt*).

Additionally, this spatio-temporal relationship is a non-linear function of the modeled system's water velocity. Figure 7.5.1 demonstrates this relationship for scales that are pertinent to the ELM, which uses a 2 hour time step when implemented with a 1 km square grid. There are two important points to note. 1) The Everglades operates at velocities that are likely well under 5 cm•sec^{-1}, with measured velocities (Lee and Carter 1999, Ball and Schaffranek 2000, Schaffranek and Ball 2000, DBEnvironmental 2002, Noe et al. in press) in northern and southern regions of the Everglades generally less than 1-2 cm•sec^{-1}, (though Ball and Schaffranek (2000) measured a peak of 4.7 cm•sec^{-1} downstream of outflows from the L-31W canal apparently due to a pump test of the S-332D structure and releases due to tropical storm Harvey (Schaffranek and Ball 2000). 2) At the 3000 m model grid scale (slightly smaller than that of the 2 mile SFWMM), numerical dispersion is very high at all velocities.

While these numerical diffusion estimates are useful to understand the magnitude of the *potential* effect on ELM results, we (previously) implemented the model (ELM v2.1) at three different spatial scales in order to evaluate the *actual* effect on ELM results (Fitz et al. 2002). Using model implementations at 100, 500, and 1000 m grid scales in Water Conservation Area 2A, we showed that the highest numerical dispersion, at a 1000 m grid scale length, is of the same order of magnitude as dispersion estimates for a wetland system such as this. DBEnvironmental (2002) provided estimates of various hydraulic parameters that were obtainable from tracer dye studies in the Cell 4 wetlands of STA-1W. One of the estimated parameters they provided was the dispersion number D_n, which is a function of the dispersion coefficient D(m^2•d^{-1}), the nominal water velocity u (m•d^{-1}), and the pathlength of flow l (m) as follows:

$$D = D_n \bullet u \bullet L$$

They reported D_n ranging from 1.25 – 2.75 (dimensionless) from the Cell 4 dye study. Using a mean measured velocity for (for a different period but similar hydraulic conditions) of 0.54 cm•sec^{-1}, a path length of about 3000 m, a dispersion coefficient D would be roughly 1.5 – 4 million m^2•d^{-1}. While these somewhat incomplete data could possibly represent an overestimate of dispersion, it was clear that the numerical dispersion in the regional 1km^2 ELM (ca. 200,000 m^2•d^{-1} for a similar velocity) did not introduce significant bias to predictions of gradient dynamics, as the actual dispersion is at least the same order of magnitude as numerical dispersion in the 1km^2 ELM applications.

Because of this uncertainty in the magnitude of dispersion, we expanded (from ELM v2.1) the model's purely advective equations of flow, including a dispersion component. The ELM v2.5 Anti-Numerical Dispersion (AND, see Model Structure Chapter) algorithm is based simply on the well-known equation describing the behavior of the explicit solution technique. The AND was expanded to include the true dispersion estimates based on the equation (Wool et al. in press):

$$\frac{dM_{i,k}}{dt} = \frac{E_{i,j}(t) \bullet A_{i,j}}{L_{i,j}} \left(C_{j,k} - C_{i,k}\right)$$

where:

$M_{i,k}$ = mass of nutrient "k" in cell "i", g

$C_{i,k}$, $C_{j,k}$ = concentration of nutrient "k" in cells "i" and "j", g/m^3 (mg/L)

$E_{i,j}$ = dispersion coefficient (time function) for exchange "i,j", m^2/day

$A_{i,j}$ = interfacial area shared by cells "i,j", m^2

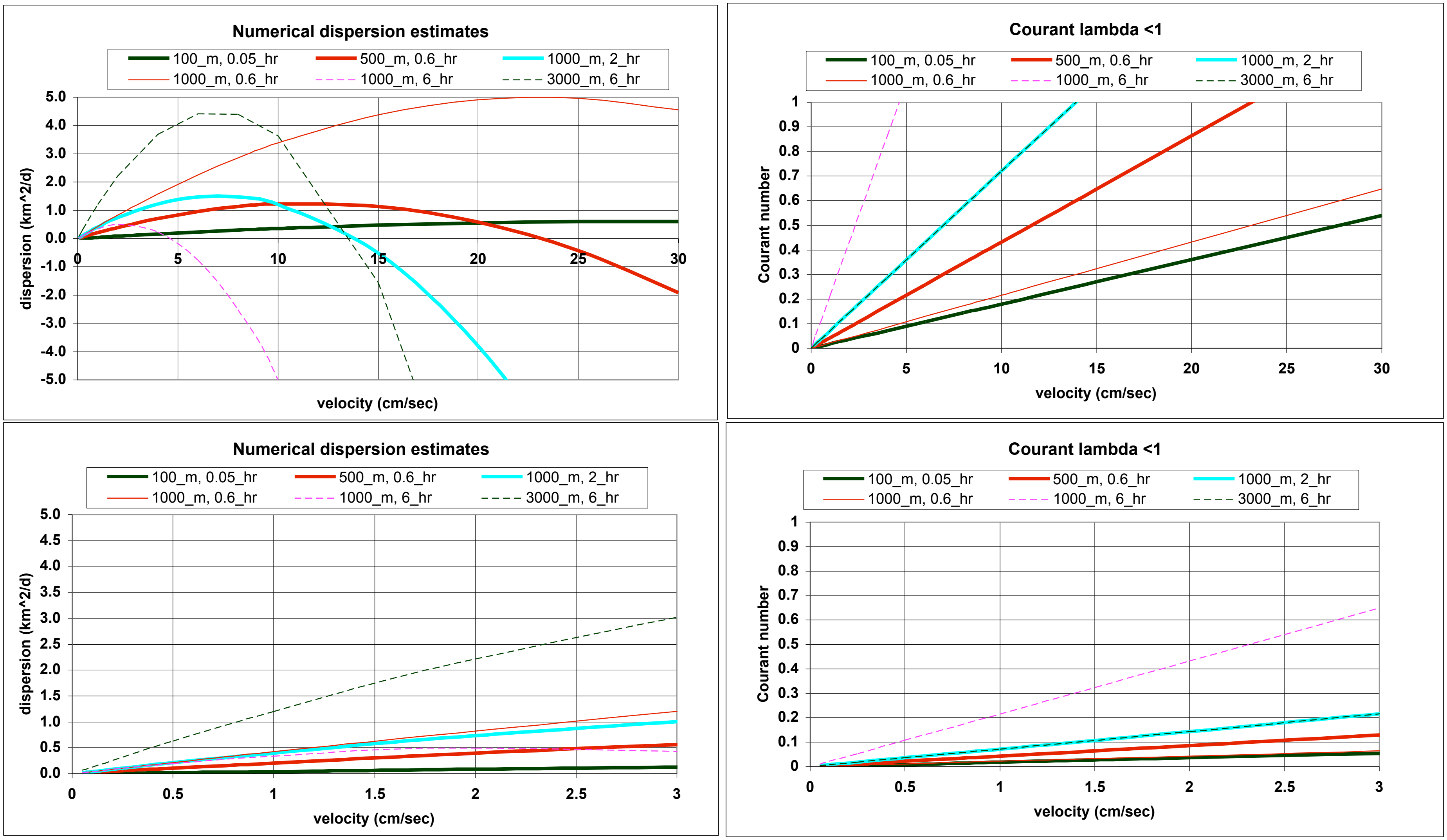
$L_{i,j}$ = mixing length between cells "i,j", m

With this simple algorithm, the degree of (numerical) dispersion in ELM can be maintained independent of model grid scales (using the length scale parameter), and the velocity-varying actual dispersion can be proscribed with the dispersion coefficient. However, this remains a relatively coarse “calibration knob”, as significantly more field-based evaluations are necessary to better estimate the true magnitude of dispersion under Everglades conditions.

7.5.1 Figures: dispersion

One Figure follows this page.

Figure 7.5.1. Calculated numerical dispersion and Courant lambda of finite difference models at different time steps and different (regular) grid scales. Courant numbers >1.0 have a tendency towards instability in the hydrologic flux solutions.



7.6 Model "validation"

It is uncertain that a classical "validation" process is required to demonstrate the utility of models. Validation is no longer considered the most credible way to evaluate model performance (Kleindorfer et al. 1998). "Verification and validation of numerical models of natural systems is impossible" (Oreskes et al. 1994). Logically, aka (Popper 1959), this appears to be true. Others (Konidow and Bredehoeft 1992, Beven 1993, Rastetter 1996) agree. However, it does not appear necessary to "validate" models. To build confidence in the models' utility, one needs to demonstrate that it performs in a manner consistent with objectives. A major utility of process-based models such as ELM is in synthesis of accumulated knowledge. Through this synthesis, we gain understanding of the system. And develop a self-consistent synthesis of the complex interactions in the bio-physical-chemical landscape (Rastetter 1996). With increasing knowledge of the system, and increasing confidence in the model performance for particular objectives, we can think about making projections of potential ecological (or hydrological) responses to external change. But models of complex systems – whether they are simple black-boxed numerical interpretations such as the DMSTA[8], or complex numerical interpretations such as ELM, SFWMM, ATLSS[9] models, Global Climate Models, – are not going to be "accurate" predictors of the future. These models still can be credible tools for evaluating potential scenarios of change. A credible, if imperfect, model is far better than reductionist "best guesses" when embarking on complex system changes – such as the restoring the Everglades, or ameliorating CO_2 increases in the atmosphere.

Very important for achieving credibility of a model is the demonstration of sufficiently high levels of performance under a wide range of conditions (external and internal). The longer the time scale over which observations are available for comparison, relative to the predictive time scales of the model, the more credible the model. The (previous version) ELM v2.1 simulated the historical period from 1979 – 1995, encompassing a wide range of drought and flooding conditions, with widely varying phosphorus inputs (ELM_Team 2002). As part of the update to ELM v2.5, we acquired new 1996-2000 data that can be used to "validate[10]" ELM (see Model Performance Chapter); however, we primarily offer those analyses as further demonstrations of the credibility of this model as a potential forecasting tool. In the Model Performance Chapter, we presented an evaluation of the performance of ELM under the new and extended forcing data, demonstrating that the model was validated in the "classical" sense. However, even though such an update indicated consistent -or better - levels of model performance in both periods of time, the process in itself did not sufficiently dictate "trust" in the model reliability. Most valuable for enhancing any model credibility would be the introduction of some suite of external inputs that are very different from those observed in prior years that have been used. However, the additional years appended onto the ELM simulation period did not appear to have any such dramatic change in external forcings, i.e. that extended beyond that of the past variability. In actuality, this '96-'00 extension to ELM v2.5 was merely a part

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[8] Dynamic Model of STAs, http://wwwalker.net/dmsta/index.htm

[9] Across Trophic Level System Simulation, http://atlss.org

[10] sensu the traditional or classical use of the term

of the process of refining a model: an extended synthesis of new data, and enhancing the model performance relative to objectives.

An important part of a model evaluation is how effective the code logic is, and how effectively it is parameterized to meet the performance goals. In past comments on ELM, a reviewer pointed out that there could be other combinations of parameters that could provide a good model fit for TP concentration in the surface water. Indeed, any model with a few parameters or more can possibly have more than one combination of parameters to achieve a same/similar statistical fit of the model to observed data for one particular target variable. Fine tuned parameter sets for model calibrations are never unique (Spear 1997). It is likely that another combination of parameters could be found that will result in comparable performance of ELM predictions of TP concentration in the water column. However, in our testing of the model performance to different parameters, we explicitly evaluate more than just a single target variable to ensure that other components of this complex, interactive system remain within targeted boundaries. Thus, it is important to evaluate whether the proper mechanisms are responsible for model predictions.

Recently there has been significant discourse on what is truly meant by “model validation”, and the means by which to communicate the level of trust in the application of a particular model. Model validations include both conceptual validity and operational validation (Rykiel 1996, Parker et al. 2002). Conceptual validation checks if the theories, hypothesis, assumptions, system structures and processes underlying the model are sound and justifiable. Operational validation tests how well the model mimics the system. It does not, however, guarantee that the mechanisms contained in the model are scientifically complete and correct (Rykiel 1996). To re-iterate, we argue that it is impossible to validate models because the natural system is open and constantly evolving (Oreskes et al. 1994, Rastetter 1996, Oreskes 1998, Haag and Kaupenjohann 2001). As previously indicated, a simple dictum is operative: Models can only be falsified; they cannot be validated (sensu Popper 1959).

Despite this discourse on the logic associated with traditional validation, we have previously shown the ELM to be validated in this traditional sense (Model Performance Chapter). However, after a single parameter or equation is modified (in order to expand Performance Measures beyond water quality, or to improve water quality performance), the model will no longer be “validated” in the strict sense of unchanged models tested against ever-increasing extents of boundary conditions. Instead, we need to evaluate how consistently the model performs under an increasing range of conditions; adding 6 months, one year, or five years to a model’s Period of Record does not necessarily enhance credibility. Most important to enhanced model credibility is a demonstration of consistent, unbiased performance under very new boundary condition forcings (such as the 1994-95 high water years, or 1990 drought and associated changes in flows and loads).

Models are used to provide synthesis, reveal system properties, and outline system behavioral possibilities (Joegensen et al 1995; Rastetter, 1996; Haag and Kaupenjohann, 2001). It is the communication with model stakeholders that is essential to effect model validation and conformance with its intended purpose and performance criteria (Korfmacher 1995, Kleindorfer et al. 1998, Parker et al. 2002). ELM will be constantly updated and evolve, but it will not be "validated" under all conditions. Nor will other models.

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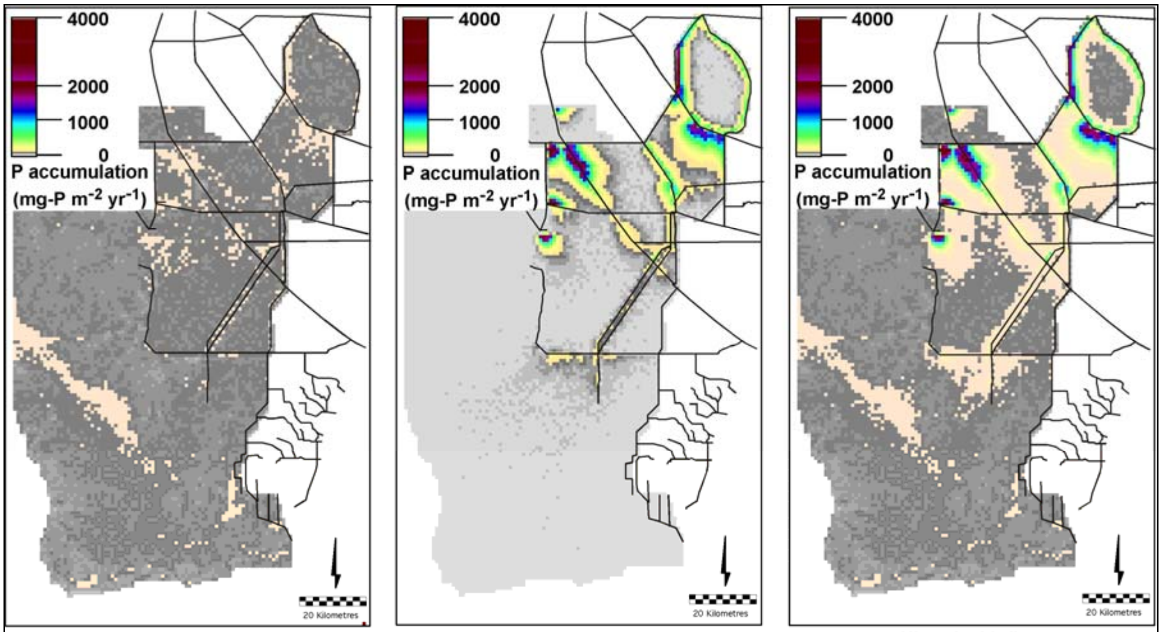
Chapter 8: Model Application



10 ppb inflows

Difference,
Historical minus 10ppb scenarios

Historical inflows

http://my.sfwmd.gov/elm

July 10, 2006

Chapter 8: Model Application

8.1 Overview

The Model Performance chapter of the ELM documentation provides strong evidence of model skill in predicting eutrophication trends across these scales that are of interest in Everglades landscape analysis. In its regional (~10,000 km^2) application at 1 km^2 grid resolution, the current ELM version 2.5 is available to assess relative differences in ecological performance of Everglades water management plans. Two water quality-oriented model Performance Measures may be used in this interim model version: phosphorus (P) concentration in the surface water, and P accumulation (net load) in the ecosystem. The latter is the more sensitive metric for evaluating ecosystem nutrient status. Consistent with the goals of water management planning for the regional system, the temporal scales of these Performance Measures are multi-decadal with seasonal or annual resolution. Likewise, the spatial scales capture multi-kilometer gradients at a 1-kilometer resolution, within a regional landscape of thousands of square kilometers.

Examples of application of the ELM to scenarios of alternative water management are shown. One example is from recent peer reviewed publication, while the other demonstrates a hypothetical scenario of reduced historical phosphorus inflows. In comparing relative benefits of different alternatives, graphs of trends along gradients and maps of regional differences are presented as examples of model application for planning purposes. Other applications of ELM include the ongoing use of the model in Everglades research programs, wherein the model can help identify information needs. Importantly, models such as ELM can be used to extrapolate and synthesize fine-scaled research results to the larger regional scales of the greater Everglades, across decadal time scales.

8.2 Background

The Performance Measures to be used in model applications are quantitative metrics that are used to evaluate the benefits of one simulation scenario relative to another. While models can potentially produce a very large suite of outputs, the intent of formalizing a small set of Performance Measures is to distill the model results into scientifically definitive summaries of the modeled scenarios. Generally, Performance Measures themselves are developed and reviewed by users of the model, preferably in collaboration with the model developers. There are currently[1] two dozen different Performance Measures that are intended for use by multiple models within the Greater Everglades; three of these are relevant to calibrated/validated output from the current version of ELM.

The ELM version 2.5 is available to evaluate relative differences in ecological performance of Everglades water management plans. As shown in the Model Performance chapter of this documentation, hydrologic performance of the ELM is comparable to the South Florida Water Management Model within the Everglades. While consistency with that primary tool for Everglades water management is important, the focus of ELM is on the associated ecological assessment. Two water quality- oriented Performance Measures may be used in this interim model version: phosphorus (P) concentration in the surface water, and P accumulation (net load) in the ecosystem. The Model Performance chapter showed that, during a 2-decade period, the ELM has a 2 ug/L median bias in predictions of surface water P concentration within the marshes. Predicted P accumulation along a multiple- decade eutrophication gradient shows a high degree of concordance with P accumulation estimates from radionuclide markers. With other predicted ecological attributes and rates being consistent with available observations, there is strong evidence of model skill in predicting eutrophication trends across the scales of interest in Everglades landscape analysis.

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[1] May 2006. See the Programs – RECOVER – Performance Measures section of http://www.evergladesplan.org. Note on syntax used by RECOVER: the term “evaluation” is used in a context specific to model predictions, and the term “assessment” is used in a context specific to field monitoring. The ELM documentation does not necessarily distinguish those terms.

8.3 Performance Measure: Phosphorus Accumulation (Net Load)

The text in this section describes the phosphorus accumulation (or net load) Performance Measure (GE-5[2]), in the draft form that was submitted to CERP REstoration COordination and VERification (RECOVER) group (August 2005). The general format follows that of formal Performance Measure documentation. Along with the other Greater Everglades water quality Performance Measures, this is under review by RECOVER (May 2006). While measures of phosphorus concentration in the surface water provide useful information (supported by a network of historical monitoring points), this P accumulation metric is the more definitive measure of eutrophication processes in wetlands of the Everglades.

8.3.1 Source of Performance Measure

- Everglades Ridge and Slough Conceptual Ecological Model stressor (RECOVER 2004)
- Total System Conceptual Ecological Model stressor (Ogden et al. submitted)

Ecological Premise: The pre-drainage Greater Everglades Wetlands system was characterized by hydrologic inputs (primarily from direct rainfall) and by extended hydroperiods. Natural conditions were characterized by oligotrophic conditions with low phosphorus concentrations in surface waters and the underlying ecosystems. An overriding expectation of CERP is that it will restore hydroperiods by increased freshwater inflows and restored hydropatterns to the Greater Everglades Wetlands. This will be accomplished without subjecting the system (particularly the more pristine areas) to harmful phosphorus inputs, in order to maintain or improve water quality throughout the wetland system.

CERP Hypothesis: The restoration of hydrology toward Natural Systems Model (NSM) conditions (a simulation of the pre-drainage Everglades) will result in the following:

- Maintenance or reduction of phosphorus loads from inflow structures, such that phosphorus concentrations within marsh ecosystems do not lead to expanded zones of eutrophication in Greater Everglades Wetlands. The combined hydrologic and water quality performance will halt the loss of Everglades landscape patterns (i.e., loss of periphyton mats and spread of cattail) and the breakdown in aquatic trophic relationships.

8.3.2 Justification

Measurements of phosphorus (P) concentration in the surface water column are available for numerous locations in the Everglades, with reasonably consistent data (with respect to methodology and quality assurance) since the late 1970’s (Bechtel et al. 1999, Walker 1999b). At the “point” source locations of water control structures that empty into Everglades basins, P concentrations encompass at least an order of magnitude of spatio-temporal variation: the above studies generally indicate that annual mean flow-weighted

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[2] See the Programs – RECOVER – Performance Measures section of http://www.evergladesplan.org.

P concentrations at structures ranged from <10 to >100-200 ug L^{-1}, depending on proximity to anthropogenic nutrient sources and water management operations. Spatio-temporal variation of P within receiving marshes of the Everglades exhibited a similarly wide range. In "interior" sites that are generally well-removed from effects of canal inputs, water column P concentration ranged from 4-10 ug L^{-1}, and increased by an order of magnitude or more in proximity to point source discharges of the water control structures (McCormick et al. 2002). These monitoring data have provided a useful perspective on spatial and temporal trends in water quality for parts of the greater Everglades.

However, water column concentrations of nutrients in vegetated marshes within this shallow, slow-flowing wetland are not usually indicative of the degree to which the marsh is receiving and assimilating nutrients. Particularly within the past decade, a suite of rigorous experiments and expanded monitoring programs have documented the importance of P loading (vs. instantaneous P concentration observations) on the relative degree of eutrophication in Everglades wetlands. This justification section of the P loading Performance Measure outlines those results and their implications for ecosystem monitoring and modeling for CERP RECOVER.

8.3.2.1 Water column concentration

With the significant exceptions of areas that have previously been loaded with anthropogenically-derived P, the freshwater Everglades is widely recognized to be naturally oligotrophic and severely P limited (many sources reviewed in Noe et al. (2001) and McCormick et al. (2002)). Largely due to this limitation, P is rapidly taken up by microbes, algae (periphyton assemblages), and macrophytic vegetation. With most areas of the Everglades periodically drying out, the water column generally lacks planktonic autotrophs, and comprehensive ecosystem studies have shown that periphyton and benthic microbial flora are the primary drivers of P loss from the shallow water column (McCormick et al. 2002, Noe et al. 2002, Noe et al. 2003).

These removal mechanisms operate at very fast time scales. For example, inorganic P, added in significant quantities to enclosed marsh mesocosms, was either completely or mostly removed within 24 h (McCormick and O'Dell 1996, Newman et al. 2001), starting from P concentrations as high as ca. 250-800 ug L^{-1}. Noe et al. (2003) introduced radioisotope-labeled P into enclosed mesocosms. Within one minute of introduction of the labeled-P in that study, 95% of it was incorporated into particulate form, and within 10 days only a very small fraction remained (in any form) within the water column. This loss from the water column over a very short time period was consistent with an earlier study of labeled-P (Davis 1982). Thus, P in the water column is not expected to be a representative indicator of the P that is being rapidly assimilated by the local ecosystem.

While water column P that is in inorganic form is lost extremely rapidly to the microbial and plant flora, particulate organic forms of P in the water column have the *potential* to be transported longer distances from their introduction into marshes via water control structures. However, again this P-limited ecosystem is known to have oligotrophic adaptations in order to more readily utilize organic P. When the ecosystem is more P-limited (i.e., low available inorganic forms of P), extra-cellular phosphatase enzymes of periphyton and microbial (and macrophyte) communities in the Everglades are more actively involved in hydrolyzing organic P into forms that are more available for biotic uptake (Reddy et al. 1999, Kuhn et al. 2002, Newman et al. 2003, Scinto and Reddy 2003). Along with physical settling of particulates from the water column in the low-velocity marshes, this activity also tends to rapidly remove P from the water column and assimilate it locally.

Phosphorus is held in a tight nutrient cycle in oligotrophic portions of the Everglades (Reddy et al. 1999), with low apparent availability of P in the water column. This nutrient cycle tends towards an autocatalytic system (Odum 1983) in which increased available P is taken up for plant growth, leading to higher turnover (growth minus mortality) in components of the ecosystem such as macrophytes (Daoust and Childers 2004). With the associated increase in detrital inputs to soils, along with phosphatase activity in the soil/microbial community, there is a tendency towards higher detrital decomposition and P mineralization. This is further accelerated with increases in P availability, such as those due to anthropogenically-derived P inflows (Amador and Jones 1993, Debusk and Reddy 1998, Newman et al. 2001, DeBusk and Reddy 2003). This positive feedback loop tends to become less efficient at higher levels of P availability, and thus "leaks" P to the water column, as reflected in higher water column P concentrations above marsh surfaces that have assimilated P loads over time.

For all of these reasons summarized above, observations of water column nutrient concentrations do not usually capture the degree to which the underlying marsh ecosystem is *currently* assimilating nutrients. This is further borne out by attempts to relate long term surface water quality to ecosystem eutrophication. In a multi-decadal statistical analysis of the intensively-studied marshes in Water Conservation Area-2A, Smith and McCormick (2001) were unable to find significantly elevated water column P in areas that were otherwise known to be P-impacted (except in very close proximity to canal water inputs). In other words, observations of elevated water column concentrations were not always apparent as a "causal mechanism" of the ecosystem degradation, although surface transport of P (in some form) necessarily existed along this gradient over decadal time scales. Similarly, Gaiser et al. (2004) did not find a relationship between (a 16 km transect) distance from a P-inflow point and water column P concentration, even though the periphyton community showed a eutrophication gradient along that same distance. Similar to other authors' proposals (McCormick and Stevenson 1998), Gaiser et al. (2004) strongly recommended against the primary use of surface water concentrations as an early-determinant of eutrophication problems in the Everglades.

Nevertheless, the metric of water column nutrient concentration has been useful in water quality assessments in the Everglades. This monitoring should continue to be particularly useful to 1) calculate the inputs of nutrients into specific regions via managed flows, and 2) understand spatial and temporal trends in the degree to which marshes have assimilated significant quantities of P.

8.3.2.2 Load and accumulation

The extent to which a particular mass of P is transported downstream in the Everglades depends largely on the water flow rate, the exposed marsh surface area, and the P-uptake affinity of the marsh ecosystem. In this shallow wetland with slow water velocities and high affinity for P uptake, water column P concentrations are often unrepresentative of the magnitude to which P loads are affecting the ecosystem (as indicated above). The mass of P that is accumulated within the ecosystem determines the degree of eutrophication, not the transient water column P concentration that is “left over” from the biogeochemical dynamics. The basic underlying processes associated with P load and accumulation, and their importance in understanding the long term nutrient dynamics, are summarized below.

Load

Wet and dry deposition of P from the atmosphere can be considered the background condition of P load to the ecosystems across the Everglades. There is spatial variation in atmospheric loads within the existing Everglades wetlands, related to proximity of urban and/or agricultural activities that can increase the local inputs of dust particles and aerosols (Redfield 2002). Using techniques to remove outlier data points of contaminated samples, rainfall at interior sites of the Everglades had median P concentrations of 4-7 ug L^{-1} (McCormick et al. 2002), or at maximum <10 ug L^{-1} (Ahn 1999) at sites along the periphery of the Everglades. In evaluating data sets specific to interior sites of the Everglades, and using the geometric mean or the median measure of central tendency (to avoid the common problem of contamination in rainfall and dry deposition estimates), we estimate that background total atmospheric P load ranges from 10-15 mg m^{-2} yr^{-1} in interior sites, increasing up to ca. 30 mg m^{-2} yr^{-1} along the periphery of the Everglades (data in Walker (1999a) and Ahn and James (2001)). Regardless of the actual deposition rates at different locations within the Everglades, this atmospheric source of P to the Everglades is not influenced by CERP projects.

Those estimates, however, can serve as a reference, or background, P load to which the Everglades has adapted. Atmospheric inputs are assumed to be broadly-distributed across regions. There do not appear to be significant natural gradients of P through the region within the water column, nor significant (non-anthropogenically derived) P loads from the Everglades into receiving waters of Florida Bay (Rudnick et al. 1999). Thus, it seems reasonable to assume that these atmospheric P loads are accumulated as a net load that is distributed throughout the landscape.

Another method of estimating the reference P load to the Everglades is through the use of radionuclides found in the soil layers. Early efforts to estimate the long-term P accumulation (or net load) rates indicated that areas that were distant from most anthropogenic inputs accumulated P at rates on the order of 60-100 mg m^{-2} yr^{-1}, increasing to 500-700 mg m^{-2} yr^{-1} near water control structure inputs (Craft and Richardson 1993a, 1993b, Reddy et al. 1993, Robbins et al. 2004), and possibly peaking at approximately 1,000 mg m^{-2} yr^{-1} in very close proximity to P inflow loading points (Reddy et al. 1993). Recently Robbins et al. (2004) developed an improved model-based analysis of radionuclide markers in soils. They estimated that background P accumulation rates were approximately 20, up to perhaps as much as 50, mg m^{-2} yr^{-1}. The lower end of this range is consistent with the atmospheric P deposition estimates (above) to the Everglades. Using the two lines of evidence, it appears that a baseline load for the oligotrophic Everglades is most likely in the range of 10 – 30 mg m^{-2} yr^{-1}.

Several comprehensive P-dosing experiments have been conducted in the Everglades, using either flumes under natural flow regimes that were continually dosed at low concentrations over time (Richardson et al. 1997, Childers et al. 2001), or mesocosms that had periodic dosing of P into temporarily enclosed ecosystems (Craft et al. 1995, McCormick and O'Dell 1996, Daoust and Childers 2004, Newman et al. 2004). While it is beyond the scope of this document to summarize most of the findings from those experiments, all demonstrated significant changes to Everglades ecosystems along gradients of increasing P loads over time.

Ecosystem changes have been observed at low levels of P additions relative to the background atmospheric loading. With input loads of 40 mg m^{-2} yr^{-1} above the background atmospheric input, Daoust and Childers (2004) found rapid loss of the periphyton mats, and within 2 years an increase in primary production and turnover of macrophytes in wet prairie habitats. Higher total P input loads were used in the other P loading experiments, even though concentrations in the inflow waters were as low as 5 ug L^{-1} above ambient levels (Childers et al. 2001). A central concept in these loading experiments is the degree to which P was ultimately assimilated within vs. exported from the measured area. Noe et al. (2002) and Craft et al. (1995) found that their experimental units (flumes and mesocosms, respectively) had a low and widely ranging assimilation of P over the short term, and Noe et al. (2002) hypothesized that some form of P export was occurring, but which was not measurable in P concentration in the water column.

Portions of the Everglades have received significant mass loads of P through managed flows originating from urban and agricultural sources. Walker (1999b) summarized many of these loads into Everglades basins. Historically, the Everglades Agricultural Area has been a significant source of P inputs to the Everglades. While P concentration in those source waters declined during 1992-1996 relative to the earlier 1979-1992 period, total load from the EAA into the Everglades increased (due to increased water flows). Similarly, inflows to WCA-2A decreased in concentration at the S-10 inflow structures, while load through those inputs increased. Piccone et al. (2004) summarized the total P load contributions of varying source waters to different basins of the greater Everglades, partitioning the source waters of Everglades inflows as best as possible in a complex water management network.

Flow is a central component of nutrient load, and thus of wetland water quality dynamics and ecosystem responses. Introduction of elevated P concentrations in point-source inflow waters has the potential to impact the oligotrophic dynamics of the Everglades wetlands. The flow paths and flow velocities of those water parcels within the wetlands are integral to estimating the potential impacts of those input loads. Flows within Everglades marshes appear to operate at depth-averaged velocities that are <<10 cm sec^{-1}: continuous measurements over several years in a marsh of Shark River Slough indicate "typical" flows of ca. 0.5 cm sec^{-1}, or about 400 m d^{-1} (Noe et al. 2002), while flows as high as approximately 5 cm sec^{-1} were measured downstream of a water control structure during a test of a water control pump and releases related to a tropical storm (Ball and Schaffranek 2000, Schaffranek and Ball 2000). Low flow velocities in the marshes, a high surface area exposed for P exchange (i.e., shallow depth), and rapid microbial/algal uptake rates, all combine into a system that will rapidly accumulate P that is input from upstream sources.

The managed canal network that is integral with some interior Everglades marshes has the capability of moving water at velocities of about an order of magnitude higher than those peak marsh flows. Thus, the managed flows in the network of water control structures and canals have the potential to short-circuit overland marsh flows, propagating P loads into interior locations of the greater Everglades. An example is the P loads through the S-12 structures in the southern-central Everglades (Walker 1999b), which have several distant managed-flow sources in addition to overland marsh flows. Unfortunately, the confluence of multiple sources of managed flows within and through the marshes tends to make P load predictions a complex problem of the interacting physics of the different flow sources.

The physical complexities of these managed flows, and the logistical difficulties of obtaining continuous measurements within a regional landscape, generally preclude monitoring-assessments of input load differences across time and space *within* the marshes. However, because the major inflow points into the Everglades and its sub-basins have continuously/routinely monitored flow and P concentrations, it is feasible to (continue to) calculate the total mass of P that enters into specific, relatively large basins.

Accumulation

While input and output P loads within marshes may be too difficult to comprehensively measure across the region, the net effect of (input minus output) loading is reflected in the accumulation of P in a local ecosystem. The concentration of P (that has accumulated) in consolidated soil has been well-associated with significant changes to ecosystems of the Everglades (Urban et al. 1993, Newman et al. 1996, Doren et al. 1997, Wu et al. 1997, Noe et al. 2001). However, this increased storage appears to occur well after other impacts to the ecosystem have occurred. The rates of P accumulation in different components of the ecosystem have been quantified using a variety of methods in the past ~decade. One of the common conclusions in these studies has been the importance of time, particularly relative to the ecosystem component being measured. Compared to soils, other components of the ecosystem respond to P loads at faster time scales: while microbially-dominated pathways of flux may respond with days to weeks, it is apparent that macrophytes respond over longer time scales, and the consolidated soils may not show significant impacts for several years or more (Craft et al. 1995, Newman et al. 2001, Newman et al. 2004, Gaiser et al. 2005).

Flocculent organic detritus (from periphyton and macrophyte mortality) appears to be an important regulator of Everglades biogeochemistry (Newman et al. 2001, Noe et al. 2002), and responds rapidly to P additions. However, the microbial/algal assemblage of periphyton appears to show the most rapid change in response to P additions (McCormick and O'Dell 1996, Noe et al. 2003, Newman et al. 2004). Most of the P uptake response is biological, as the abiotic adsorption is approximately 15% of the total uptake (Scinto and Reddy 2003). In the response time spectrum, periphyton is a very useful early indicator of ecosystem changes (McCormick and Stevenson 1998, Gaiser et al. 2004), and periphyton P concentration is an effective indicator of ongoing ecosystem change as P starts to accumulate within the system. Periphyton P concentrations above approximately 400-500 mg kg^{-1} appear to be indicative of the initiation of such change (McCormick and O'Dell 1996, McCormick and Scinto 1999, McCormick et al. 2001, Gaiser et al. 2004, Newman et al. 2004), particularly if the periphyton in the ecosystem continue to be exposed to elevated P loading.

As discussed in a prior section of this document, the baseline (background) P accumulation rates in the Everglades appear to be on the order of 10 – 30 mg m^{-2} yr^{-1}, and ecosystem changes can occur at net P loads of approximately 40 mg m^{-2} yr^{-1} over this baseline. However, higher accumulation rates (Richardson et al. 1997, Gaiser et al. 2005) have been suggested for parts of ecosystems that are experimentally loaded with low concentrations of P, but which show comparatively little change over the short term. To estimate total ecosystem P accumulation rates, it is somewhat difficult to extrapolate the relatively small spatial and temporal scales of the experiments to the longer temporal and broader spatial scales of ecosystems within the landscape. In particular, accurate measurements of *both* the input and the output loads are uncertain and difficult to measure experimentally.

However, the wide range of experiments and observations above have shown that P is assimilated and accumulated in rapid response to P loads associated with very low water column concentrations. In order to understand and protect the Everglades landscape, it appears to be imperative that we integrate the existing scientific understanding into Performance Measures that consider the load of P to which ecosystems are exposed, and not rely solely upon the more transient dynamics of water column P concentrations.

8.3.3 Statistical and Simulation Methods

8.3.3.1 Statistical assessments

Statistical models may provide some insight into relationships between phosphorus inputs and downstream concentrations (Smith and McCormick 2001), but the changing physical and biogeochemical mechanisms that are responsible for downstream effects tends to obscure their utility for predictive planning for CERP. Nevertheless, this approach can provide useful information under conditions where specific spatial and temporal assumptions are met. Most pertinent to this document on P loading, the statistical approach is perhaps most useful in characterizing input loads to specific hydrologic basins.

Calculations of these input loads are feasible when sufficient data are available on the relatively continuous input flows and P concentrations. At water control structures that introduce water into hydrologic basins of the Everglades, the time-varying concentration of P in the source waters provides an indicator of relative changes in nutrient inputs. Concentrations that are mathematically weighted by the associated water flow volumes provide a relative accounting for the associated inflow water volumes, whereas the flow volume multiplied by its P concentration more directly accounts for the total mass of P that is introduced (loaded) into a basin. Coupled with historical or model-predicted water inflows to specific basins, inflow P concentrations can be used to estimate total phosphorus mass loading to such relatively broad regions. A variety of summaries compare differences in loads into the greater Everglades among years (Walker 1999b, Goforth et al. 2003, Piccone et al. 2004, Payne et al. 2005), providing baseline understanding of the relative P inputs over time throughout the region.

Finally, it should be noted that statistical characterization of P concentrations within the marshes remains useful to characterize long term water quality trends of the ecosystems. Within the receiving marshes themselves, the observations of water column P concentration can provide an indication of relative change in eutrophication. Under relative high flow velocities and/or in close proximity to the inflow point(s), water column concentrations can potentially capture pulses of changed nutrient inputs. Even at sites relatively distant from inflow points, continued monitoring of water column concentrations in the marshes will build upon an existing long-term data set, and allow inferences of long-term improvements in marsh eutrophication.

8.3.3.2 Empirical simulation

One empirically-based simulation approach assumes high levels of system aggregation in a 1-D simulation framework. In this method (Walker and Kadlec 1996, Walker and Kadlec 2003), biological and biogeochemical mechanisms within the ecosystem are all combined ("black-boxed") into a single or several equation(s), using some form of a "net settling rate" of phosphorus loss from the water column. Such an approach (Walker and Kadlec 2003) appears to reasonably simulate long-term, historical phosphorus accumulations in cases where the flows are well-constrained, and the underlying mechanisms (assumptions) of phosphorus removal remain constant over long time periods. This fixed settling rate simulation method makes the critical assumption that the principal drivers of phosphorus loss (including vegetation and periphyton) remain constant during restoration.

While not specifically applied within the greater Everglades, the DMSTA model (Walker and Kadlec 2003) has been applied to predict future TP concentrations in the outflows from Stormwater Treatment Areas that flow into the Everglades. Coupled with water flow predictions from the South Florida Water Management Model (SFWMM), the DMSTA was used to predict and optimize the relative distribution of loads into Everglades basins as part of the Long Term Plan for Achieving Water Quality Goals (Burns&McDonnell 2003).

Within the greater Everglades region, the confluence of water and nutrient flows in an interconnected, highly managed canal network is a vital consideration of predictive planning for CERP projects. However, altered flow regimes due to changing managed flow distributions and/or magnitudes lead to altered assumptions from the simple, 1-D flows. To accommodate spatial considerations, the simple "net settling rate" method has been applied using 2-dimensional simulation models within portions of the greater Everglades (Raghunathan et al. 2001, Munson et al. 2002). The underlying methods of predicting flows with marshes and within the canal network were highly simplified in Munson et al. (2002), effectively ignoring the rapid canal transport within the system. Raghunathan et al. (2001) used (depth and flow) output from the SFWMM, which assumed homogeneity of P within canal reaches that extended for tens of kilometers and thus eliminated gradients within those canals. Nevertheless, Raghunathan et al. (2001) demonstrated reasonable predictive success (for P concentration and accumulation) in some selected basins within the model domain, and that Everglades Water Quality Model (EWQM) was used in evaluating water quality for the original CERP, or "Restudy" (USACE and SFWMD 1999).

The EWQM is no longer available, but the same algorithm and input data are incorporated as an option in the simulation environment of the Everglades Landscape Model (ELM, http://my.sfwmd.gov/elm). This specific settling rate approach, or that updated as in the DMSTA (Walker and Kadlec 2003), could also be incorporated into other 2-D hydrologic models such as the Regional Simulation Model (RSM, http://www.sfwmd.gov/site/index.php?id=342).

8.3.3.3 Mechanistic simulation

The Everglades Landscape Model (http://my.sfwmd.gov/elm) dynamically integrates simple modules of the primary ecosystem components: hydrology, water column & porewater P, floc, periphyton, macrophytes, and soils. The model demonstrated reasonable performance in capturing spatial and temporal trends in these ecosystem components (Fitz and Sklar 1999), and effectively captured regional trends in surface water P concentration across the greater Everglades over decadal time scales (Fitz et al. 2004, Villa et al. 2004). Fitz et al. (2004) showed that the model calculations of increased P accumulation along nutrient gradients was not always reflected in water column P concentrations, as observed in natural system experiments described previously. Recent review of the ELM version 2.1 by inter-agency staff (see Fitz et al. (2002)) resulted in a wide range of opinions on its suitability for application. The model is currently (August 2005) unavailable for CERP application, pending its update (to ELM v3.0) and review by a panel of independent modeling experts.

8.3.4 Restoration Expectation

In restoration of Everglades hydrology, CERP projects will maintain or reduce phosphorus loads from inflow structures, such that phosphorus concentrations within marsh ecosystems do not lead to expanded zones of eutrophication in Greater Everglades Wetlands. The combined hydrologic and water quality performance will halt the loss of Everglades landscape patterns (i.e., loss of periphyton mats and spread of cattail) and the breakdown in aquatic trophic relationships.

8.3.4.1 Predictive (modeling) metric and target

P accumulation (net load)

The target metric of net P loading, or accumulation, to Everglades wetlands should be consistent with objectives of restoring the system towards its oligotrophic status throughout as much of the region as possible. Net P accumulation is considered to be the net P loss from the water column that is incorporated either implicitly (empirical model) or explicitly (mechanistic model) into all of the components of an ecosystem within defined local areas. The spatial scale should be considered along regional gradients (aka Indicator Regions) at resolutions of approximately 1-2 km or less. The temporal scale should encompass at least a 5-10 year period, and preferably span several decades of varying climatic and operational environments.

The baseline (background) P accumulation due to atmospheric deposition is subtracted from the total P accumulation, in order to only consider the loads derived from flow of surface- and ground-water. There are two relative levels of P accumulation considered in the restoration target:

- Possible eutrophication impact: P accumulation of 30 – 50 mg m^{-2} yr^{-1} (independent of atmospheric loads)
- Probable eutrophication impact: P accumulation in excess of 50 – 100 mg m^{-2} yr^{-1} (independent of atmospheric loads)

Basin-specific P load

At much larger spatial scales, the total mass of P that is loaded into specific hydrologic basins (e.g., Water Conservation Areas, Everglades National Park) provides a relative indicator of the extent to which P inputs are changing. Using water flows output from the South Florida Water Management Model, the concentration in Everglades source waters (such as the Stormwater Treatment Areas) can be evaluated with models such as the DMSTA (Walker and Kadlec 2003), or even simpler regression-based models (N. Wang, in Fitz et al. (2002)). The approach based on the DMSTA was used in developing the Long Term Plan for Achieving Water Quality Goals (Burns&McDonnell 2003). The target flow-weighted concentration, and target number of metric tons of P input into each major basin within the greater Everglades should be consistent with the methods and results found in that study. Because of the broad spatial scale that does not consider subregional eutrophication gradients, targets associated with basin-specific loads are primarily useful as screening tools to understand regional trends.

8.3.4.2 Assessment (monitoring) metric and target

P accumulation (net load)

Lacking the ability to continuously measure flows within marshes across the region, it is not feasible to assess historical/ongoing nutrient loading within specific areas of the marshes. Likewise, it is impractical to measure the P that is accumulating in all ecosystem components throughout the Everglades region. However, as noted above, periphyton tissue concentration is a useful early-indicator of ongoing eutrophication and P accumulation is the marsh ecosystems. As in the predictive target, the assessment target considers two relative levels, but in this case considers P accumulation to be reflected in P concentration in periphyton:

- Possible eutrophication impact: P concentration of 400 – 600 mg kg^{-}1 in the tissues of periphyton assemblages
- Probable eutrophication impact: P concentration in excess of 600 – 900 mg kg^{-}1 in the tissues of periphyton assemblages

Basin-specific P load

In an approach analogous to that of the model-based evaluation of basin-specific P loads, the total mass load of P entering major hydrologic basins will be calculated from monitored flow and concentration data at inflow structures into the greater Everglades. The target flow-weighted concentration, and target number of metric tons of P input into each major basin within the greater Everglades should be consistent with the methods and results found in Burns&McDonnell (2003) and related summaries (Piccone et al. 2004, Payne et al. 2005). Because of the broad spatial scale that does not consider subregional eutrophication gradients, targets associated with basin-specific loads are primarily useful as screening tools to understand regional trends.

8.3.5 Projects expected to affect performance measure

All projects that affect flows within the greater Everglades region. In particular, projects that alter operations of Stormwater Treatment Areas (including STA-bypass events), and redistribute flows through the greater Everglades.

8.3.6 Evaluation Application

The methods used to apply a model or models for evaluation application are to be determined, pending selection of model(s) to simulate greater Everglades water quality/ecology. If ELM is available, see Fitz et al. (2004) for example Performance Measures of net P accumulation and water column concentrations.

8.4 Performance Measure: Phosphorus Concentration

The text in this section describes the surface water phosphorus concentration Performance Measure (GE-4) which is under review by the CERP REstoration COordination and VERification group (May 2006). The format and text were copied from the formal Performance Measure documentation (version dated July 7, 2005).

1.0 Performance Measure Title

GE-4 Greater Everglades Wetlands TP Concentrations in Surface Water

Last Date Revised: July 7, 2005

2.0 Justification

Elevated concentrations of organic and inorganic forms of TP in greater Everglades wetlands surface is a critical short-term measure of water quality, and is significantly correlated to habitat and periphyton community successional changes.

Elevated nutrients in the water column, attributed to anthropogenic activities, have resulted in significant shifts in the nutrient sensitive biological communities in the oligotrophic Everglades. Depending on location, season and hydrologic conditions, it is not unusual for total phosphorus (TP) in the water column of Greater Everglades Wetlands to range from 6 parts per billion (ppb) to 200 ppb and for total nitrogen (TN) to range from 1.25 parts per million (ppm) to 10 ppm. However, less than 10 pbb is a reasonable approximation of long-term average TP at interior marsh locations.

Extensive studies (Gleason and Sparkman 1974, Reddy et al. 1999, and Newman et al. 2000) have examined phosphorus concentrations in the water column and document the biological changes observed in the Greater Everglades Wetlands ecosystem caused by elevated concentrations. During the development of the numeric phosphorus criterion for the Everglades, the Florida Department of Environmental Protection, South Florida Water Management District and others conducted extensive analyses of the available biological, water quality and sediment quality data. The results of these analyses are presented in the Everglades Phosphorus Criterion Technical Support Documents (Payne et al. 1999, 2000, 2001a) and summarized by Payne et al. in the annual Everglades Consolidated Reports (Payne et al. 2001b, 2002, 2003). The analyses indicate that significant changes in the structure and function of the native biological communities occur as TP concentrations in the water column increase above 10 ppb. The average change point for all communities was determined based on transect data to be 10 micrograms per liter (µg/l) of TP. Based on analyses of the available data, the Florida Department of Environmental Protection has recommended a protective numeric phosphorus water quality criterion of 10 ppb (as a long-term geometric mean) (Rule 62-302.540, FAC). This is believed to adequately protect the native flora and fauna of the oligotrophic Everglades.

Most phosphorus control efforts in the Everglades region are outside CERP's purview and are not CERP's responsibility.

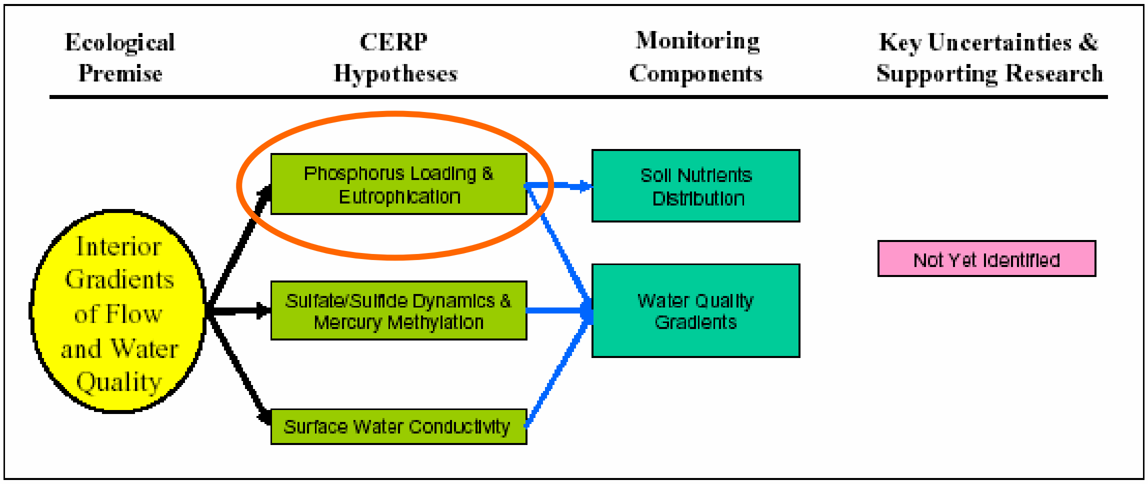
3.0 Relationship to CEMs and Adaptive Assessment Hypotheses

Everglades Ridge and Slough Conceptual Ecological Model stressor (RECOVER 2004b)

Ecological Premise: The pre-drainage Greater Everglades Wetlands system was characterized by hydrologic inputs (primarily from direct rainfall) and by extended hydroperiods. Natural conditions were characterized by oligotrophic conditions with low phosphorus and sulfur concentrations in surface waters having defined zones of low or high conductivity as compared to present conditions. An overriding expectation of CERP is that it will restore hydroperiods by providing freshwater inflows and restored hydropatterns to the Greater Everglades Wetlands without increasing nutrient loads or subjecting more of the system (particularly the more pristine areas) either to elevated concentrations of surface water phosphorus, nitrogen, and sulf ur or to constituents that alter the natural zones of conductivity in the freshwater regions, thereby improving overall water quality throughout the wetland system.

CERP Hypothesis: The restoration of hydrology toward Natural Systems Model (NSM) conditions (a simulation of the pre-drainage Everglades) will result in the following:

- Maintenance or reduction of nutrient (phosphorus and nitrogen) loads from inflow structures and phosphorus and nitrogen concentrations in surface water and soils in the open marsh at levels that do not expand zones of eutrophication in Greater Everglades Wetlands and halt the loss of Everglades landscape patterns (i.e., spread of cattail) and the breakdown in aquatic trophic relationships



4.0 Restoration Expectation

4.1 Predictive Metric and Target

The TP concentration is not to exceed 10 ppb for both the annual geometric mean concentration at surface water monitoring points and the flow-weighted annual geometric mean at water control structures, and should not exceed O.F.W. concentration levels.

4.2 Assessment Parameter and Target

The long-term TP requirement is 10 ppb for a location. If long-term TP is greater than 10 ppb, the annual trend must be flat or decreasing. If the trend is increasing, determine why, and whether a CERP activity is directly responsible for TP increasing.

5.0 Evaluation Application

5.1 Evaluation Protocol

There is no evaluation protocol at this time. The Everglades Landscape Model (ELM), which is undergoing peer-review, is a potential candidate to evaluate this performance measure. The ELM will not be considered for use in conducting evaluations until peer-review of the model is complete, and it is accepted by the IMC.

5.2 Normalized Performance Output

5.3 Model Output (example attached)

5.4 Uncertainty

6.0 Monitoring and Assessment Approach

See *CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Researc*h - Greater Everglades Wetlands Module section 3.1.3.1 (RECOVER 2004a)

See *The RECOVER Team's Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan* – Interim Goal 3.5 Everglades Wetlands Total Phosphorus (RECOVER 2005)

7.0 Future Tool Development to Support Performance Measure

7.1 Evaluation Tools Needed

7.2 Assessment Tools Needed

8.0 Notes

9.0 Working Group Members

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10.0 Acceptance Status

GE Working Group	July 7, 2005
ET	
AT	
Public Review	
Final Acceptance Date	

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8.5 Application Examples

8.5.1 Project evaluations

Applications of the ELM have been requested for evaluating a variety of projects associated with Everglades water management planning. Several of the principal project applications are:

- Modified Water Deliveries to Everglades National Park and C-111 Projects[3]
- CERP, Water Conservation Area 3 Decompartmentalization and Sheetflow Enhancement[4]
- CERP, Initial CERP Update[5]
- Long Term Plan for Achieving Water Quality Goals, Accelerated Recovery of Impacted Areas[6]

However, prior to ELM application for any project planning, independent experts must review the ELM to determine if it is suitable for such application. Thus, the example applications described in this document do not encompass those projects, but instead generically demonstrate how the ELM output Performance Measures may be used in project evaluations within the greater Everglades.

8.5.1.1 Assumptions of future scenario simulations

In simulating the response of the Everglades to scenarios of future managed flows of water, projections of those managed flows through water control structures are required. The South Florida Water Management Model (SFWMM) is currently (May 2006) the accepted tool for such planning. The assumptions that are involved in initializing and simulating water management for future project alternative plans (i.e., scenarios) are relatively complex, involving the entire south Florida regional system. Model developers and stakeholders collaborated on developing the assumptions concerning future climate, land use, water use, and many other factors. Documentation of the SFWMM and its primary assumptions is found at the South Florida Water Management District web site[7], and assumptions specific to particular planning projects are found in the respective project web site given above.

In simulating project planning alternatives, the SFWMM uses the climate record that was observed between 1965 and 2000. This 36-year period encompasses periods of both extreme rainfall and drought conditions. Relative differences in system behavior under different project alternatives reflect how the system would likely respond to the alternative management, given the same climate forcing data that has been observed in

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[3] Also referred to as the Combined Structural and Operational Plan (CSOP), see http://www.saj.usace.army.mil/dp/mwdenp-c111/index.htm and http://hpm.sfrestore.org/csopweb/sfwmm/

[4] Often referred to as the "Decomp" Project, see http://www.evergladesplan.org/pm/projects/proj_12_wca3_1.cfm

[5] See http://www.evergladesplan.org/pm/recover/icu.cfm

[6] See http://www.sfwmd.gov/org/erd/longtermplan/index.shtml

[7] SFWMM v5.5 documentation is currently (May 2006) found at http://www.sfwmd.gov/org/pld/sfwmm_doc/menu.htm

the past. The ELM uses databases of 1965-2000 rainfall and potential evapotranspiration that are identical to inputs to the SFWMM.

In applying the ELM to evaluate future conditions, a number of other assumptions are generally required for initializing and simulating ecological dynamics. As with the SFWMM, the specific assumptions for the ecological simulation must be determined for each project application. The following summarizes the nature of these assumptions that are in addition to those for simulating future managed flows in the SFWMM.

All equations and related algorithm assumptions (see Model Structure Chapter) remain unchanged from historical simulations (and thus no changes are made to source ELM code for future scenarios). Likewise, all habitat-specific parameters (HabParms, see Data Chapter) remain unchanged from historical simulations. With the possible exceptions of global parameters used to initialize the model, and/or the parameter of the rate of sea level rise, global parameters (GlobalParms, see Data Chapter) remain unchanged from historical simulations.

Changed parameters

- The topology and attributes of canals and levees (CanalData.chan, see Data Chapter) are modified as needed to describe the future water management infrastructure; these definitions are based on any Everglades-specific changes to the SFWMM
- The locations and attributes of water control structures (CanalData.struct, see Data Chapter) are modified as needed to describe the future water management infrastructure; these definitions are based on any Everglades-specific changes to the SFWMM

Changed initial conditions

- Maps of the initial surface and unsaturated water depths (see Data Chapter) are derived from the initial conditions of the SFWMM
- The map of the initial soil phosphorus concentration is modified from the historical initial condition (1981, see Data Chapter), interpolating the best available recent (1990's) observed point data.
- The map of the initial Habitat type is modified from the historical initial condition (1981, see Data Chapter). In the current v2.5, this is primarily done by adding cattail habitat types where they were found in the 1990's observed data.

Changed domain-boundary stages

- For grid cells along the ELM domain boundary, external water depths are daily output data from the SFWMM.

Changed managed flows

- Water flows through all managed water control structures in the model domain are daily output data from the SFWMM.

Changed water quality in managed flows

- Total phosphorus concentration is estimated for all managed water control structure flows whose source water is external to the ELM domain. Several options may be used for these estimates:

1) apply a temporally-constant concentration to water volumes in each such flow (which may be unique to each structure);
2) apply a time varying concentration to any Stormwater Treatment Area (STA) structure that is input to ELM, using output from the Dynamic Model of STAs (DMSTA) (Walker and Kadlec 1996, Walker and Kadlec 2003); and/or
3) lacking time-series output from the DMSTA, employ a simple mass-balance, net settling technique of estimating STA outflow concentration based on flow rates and STA-input concentrations.

- Chloride concentration is estimated for all managed water control structure flows whose source water is external to the ELM domain. Chloride does not affect any other dynamics in the current ELM v2.5, and is only used as a tracer. If the RECOVER GE-9 Performance Measure[8] is to be evaluated, a fixed concentration can be applied only to flows identified in the SFWMM output as flows that bypass the STAs.

8.5.1.2 Simulating downstream effects of STAs

Stormwater Treatment Areas (STAs) are intended to serve as natural filters in which macrophytic vegetation removes nutrients (primarily phosphorus) from waters flowing into the Everglades. The first constructed wetlands to be in operation appeared to be effective in reducing phosphorus concentrations well below the interim target of 50 ug·L^{-1} (Chimney et al. 2000, Nungesser et al. 2001), and will be supplemented with other phosphorus removal methods to reduce outflow concentrations to a target of approximately 10 ug·L^{-1}.

Using the previous release (version 2.1) of ELM, Fitz et al. (2004) provided examples of a model- comparison of “current” and “future” scenarios of water management. The following is excerpted from that publication:

> *In this application of ELM [v2.1], we evaluated landscape phosphorus dynamics with and without the STAs. The scenario simulations reflected the system responses had it been managed differently during the 1965-1995 climate years. [Managed flows through water control structures in all of the simulations were output data from the South Florida Water Management Model v3.5]. The 1995 base, assuming “current” operations, without treatment of inflow waters by STAs, demonstrated eutrophication in the Everglades that would have occurred in the absence of these biological filters for the [Everglades] inflow waters. The 2050 (future) base was driven by altered water management, with the STA’s in place in order to remove significant phosphorus mass from surface inflows to the Everglades. [...]*

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[8] Tracer of flows that bypass the STAs, for purposes of local flood control or distant water supply.

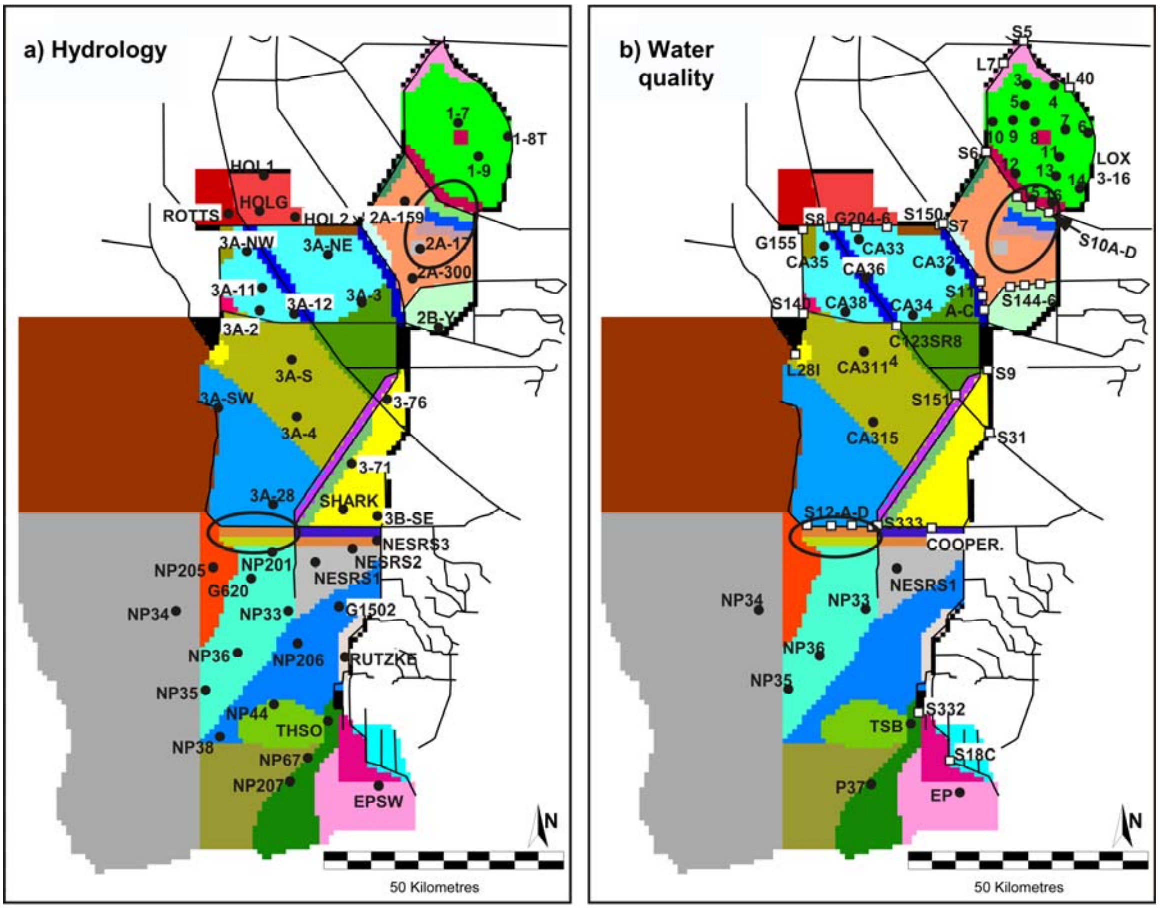


Figure [8.1]. Shaded polygons of indicator regions, and point locations in the Everglades for monitoring a) stage; b) water quality. Circled indicator regions are used in example analyses of model scenario runs. [Figure from Fitz et al. (2004)].

The response of the biological communities varied along nutrient gradients, depending on the nutrient loads in the simulations and on the proximity of the areas to the phosphorus inflows. We compared the 1995 base [using long-term mean historical inflow P concentrations] with two implementations of the 2050 base: one with 10 ug P·L^{-1} *and one with 50 ug P·L*$^{-1}$ *in the inflow waters. We analyzed two example gradient regions, circled in Figure [8.1]. The indicator regions in WCA-2A south of the S-10 structures are in relatively close proximity to anthropogenic nutrient loading [see Data Chapter of ELM documentation], while the indicator regions in Everglades National Park (ENP) south of the S-12 structures are more indirectly affected by P loading in the northern part of the system. The 31-yr mean and maximum P concentrations in the surface water declined steeply with distance from the inflows in the 1995 base simulation in the WCA-2A region, while there was less change down-gradient in ENP (Figure [8.2a]). Neither 2050 base case demonstrated a [ecologically] significant change in mean concentrations along either spatial gradient, although the maximum monthly mean concentrations declined along the gradient in the 2050, 50 ug·L*$^{-1}$ *case in WCA-2A. The magnitude of that difference was relatively small. In all of the cases, the 1995 base showed substantially higher P concentrations relative to the 2050 base cases. In these particular indicator regions, both 2050 base cases resulted in approximately background, oligotrophic, surface water concentrations on the order of 5 ug P·L*$^{-1}$*.*

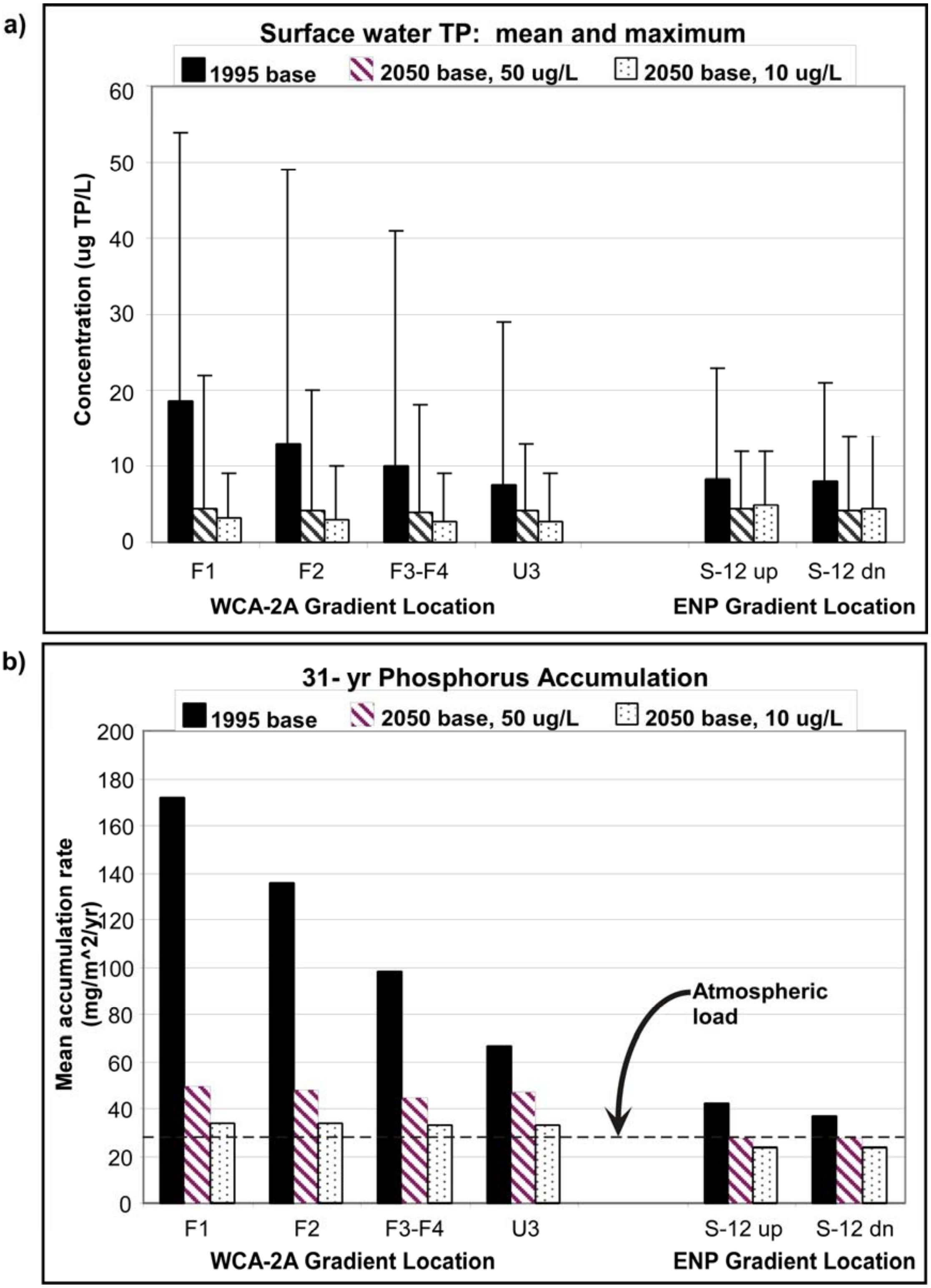


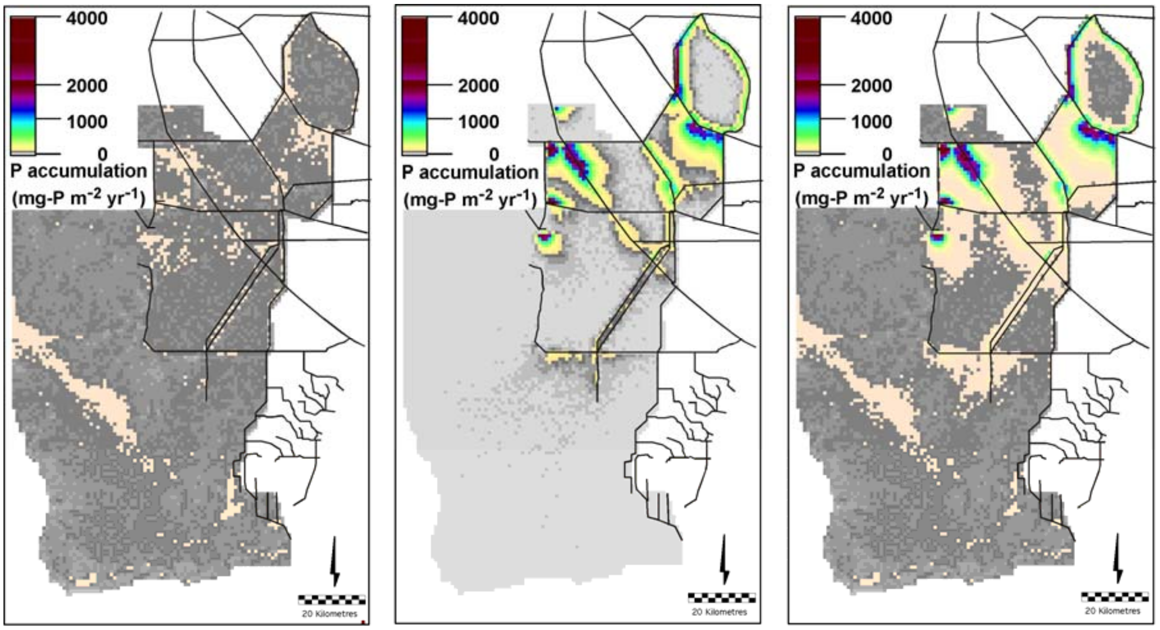
Figure [8.2]. Model (version 2.1) scenario results in the gradients of indicator regions in WCA-2A and in ENP: a) 31-yr mean and maximum concentration of Total Phosphorus (TP) in surface water; and b) 31-yr accumulation of TP in soils and biota (with atmospheric phosphorus loading indicated for comparison). [Figure from Fitz et al. (2004)].

> *Phosphorus accumulation in the soils and biota within the indicator regions generally reflected the pattern of surface water concentrations, showing similar trends along spatial gradients in the scenarios (Figure [8.2b]). However, the phosphorus accumulation (and loads) provided indications of eutrophication that were somewhat obscured in the long term mean surface water concentrations. The furthest downstream (U3) region in WCA-2A, considered by some to be relatively unimpacted from significant anthropogenic nutrients, accumulated more P than the gradient regions to the south in the ENP. Relative to the ~27 mg $P \cdot m^{-2} \cdot y^{-1}$ being input to the system from atmospheric sources, all of the indicator regions were impacted by overland P loads in the 1995 base. Only when inflow concentrations were reduced to 10 ug $P \cdot L^{-1}$ (2050 base, 10 ug $P \cdot L^{-1}$) did the total net accumulation in all indicator regions approximate that from atmospheric inputs alone.*

The most current ELM version (2.5) has enhanced model performance relative to the previous ELM v2.1 discussed in the above publication. However, the relative differences among scenarios and Performance Measures are consistent between model versions, providing a demonstration of Performance Measure evaluations in a model application.

8.5.1.3 Simulating a hypothetical scenario

For another application example, the ELM v2.5.0 (current release is v2.5.2) was applied in a hypothetical scenario comparison. The simple question was: relative to the historical, baseline conditions, how much reduction in phosphorus accumulation would have likely occurred if managed inflow waters to the Everglades had phosphorus concentrations of 10 $ug \cdot L^{-1}$ during the period from 1981 through 2000? In this comparison, the Base Condition was the historical (observed concentrations) simulation, while a hypothetical Low-P Alternative assumed all phosphorus (TP) inflows into the Everglades domain had been fixed at 10 $ug \cdot L^{-1}$. In both simulations, managed flows through water control structures were driven by observed, historical flow data (instead of output from the South Florida Water Management Model as in the case of future water management scenarios).



10 ppb inflows

**Difference,
Historical minus 10ppb scenarios**

Historical inflows

Figure 8.3. Phosphorus (P) accumulation rates during two scenarios of water and phosphorus inflows to the greater Everglades during 1981 - 2000. The left graphic shows the Low-P Alternative simulation of the accumulation that may have occurred if all inflow concentrations were fixed at 10 ug L^{-1} (ppb). The right graphic shows the Base Condition simulation of the accumulation that occurred under historical, observed inflow P concentrations. The difference map (center) indicates the relative degree of increased eutrophication under the Base Condition relative to the Low-P Alternative.

Figure 8.3 shows the relative differences in eutrophication between the two scenarios. The grey-scaled values of the difference map include those that are less than 100 mg m^{-2} yr^{-1}. Ecosystem eutrophication very likely occurs in the regions of yellow-green-red continuum of the color scale that encompasses accumulation rates ≥100 mg m^{-2} yr^{-1}. These relative comparisons may be summarized further within a simple table that shows the "acreage" of impacted regions: 1,101 km^2 of the area within the model domain (~11%) had eutrophication scenario-differences of ≥100 mg m^{-2} yr^{-1}.

8.6 Research applications

While model applications for project planning may require further peer review (July 2006), the integration of ELM into research advances has been ongoing during its development. This application of ELM is fundamental to model refinement, with an ongoing interaction between the advances in knowledge of the behavior of the Everglades ecosystems, and the extrapolation of those insights across broad spatial and temporal scales.

A separate "Model Synthesis" Chapter was planned[9] for the ELM documentation, discussing a model synthesis of the extensive body of literature on Everglades ecological

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[9] Time constraints did not allow development of this Chapter for the July 10 release of ELM v2.5. Plans still exist for such a synthesis, in collaboration with researchers knowledgeable of the Everglades.

processes. While we have noted elsewhere in this documentation the use of particular data “pieces” in parameterizing and evaluating the ELM, such limited references do not reflect the mutually-beneficial interactions that we have had with various researchers over the years. We hope that further exchanges with these researchers will enhance our mutual understanding of the Everglades landscape, as expressed in a collaborative synthesis of spatio-temporal dynamics of the greater Everglades.

8.6.1 SFWMD Everglades Division

As indicated in the Acknowledgements of this ELM Documentation Report, the primary development and refinement of the ELM was integral with the research teams in the Everglades Division[10] of the South Florida Water Management District (SFWMD). This long-term collaboration continues, and is “accelerating” as part of research efforts into “Options for Accelerating Recovery of Phosphorus Impacted Areas of the Florida Everglades”, part of a larger program involving long term water quality goals for the greater Everglades system[11].

Using the same model code and parameters as the regional ELM, finer-scaled applications (with 100-1000 m grids) in WCA-2A are the principal test beds for assimilating advances in this process-oriented ecological research. Comprehensive field efforts (in the Fire Project and Cattail Habitat Improvement Project) are targeting some of the uncertainties associated with the recovery of previously impacted areas. Enhanced understanding of the effects of fire on soil and vegetation processes will be reflected in more refined model performance. Hierarchical sensitivity analyses (Uncertainty Chapter) have confirmed the importance of the rate processes associated with soils, including the contributions from the overlying floc layer and live plant/periphyton material. Continued advancements in understanding these interactions, in combination with understanding the effects of flow on these components, will provide the scientific insight into restoration potentials – which can be extrapolated across larger spatio-temporal scales via simulation.

8.6.2 Florida Coastal Everglades – LTER

Another research collaboration that will likely prove increasingly productive is the integration of the ELM extrapolations into the Florida Coastal Everglades (FCE) Long Term Ecological Research (LTER) project[12]. As part of the Integration, Synthesis, and Modeling component of the FCE-LTER, one of us (C. Fitz) is a Collaborator on the FCE-LTER project, which was recently successfully renewed for a Phase II component of the decadal-scale research program. In particular, we anticipate that continued sharing of empirical information and insights among the field/lab researchers and the ELM team will extend our ability to understand interactions between the freshwater and estuarine interface(s) in the southern Everglades.

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[10] Everglades Division, SFWMD, http://www.sfwmd.gov/org/wrp/wrp_evg/

[11] Long Term Plan for Achieving Everglades Water Quality Goals, http://www.sfwmd.gov/org/erd/longtermplan/index.shtml

[12] FCE-LTER, http://fcelter.fiu.edu/

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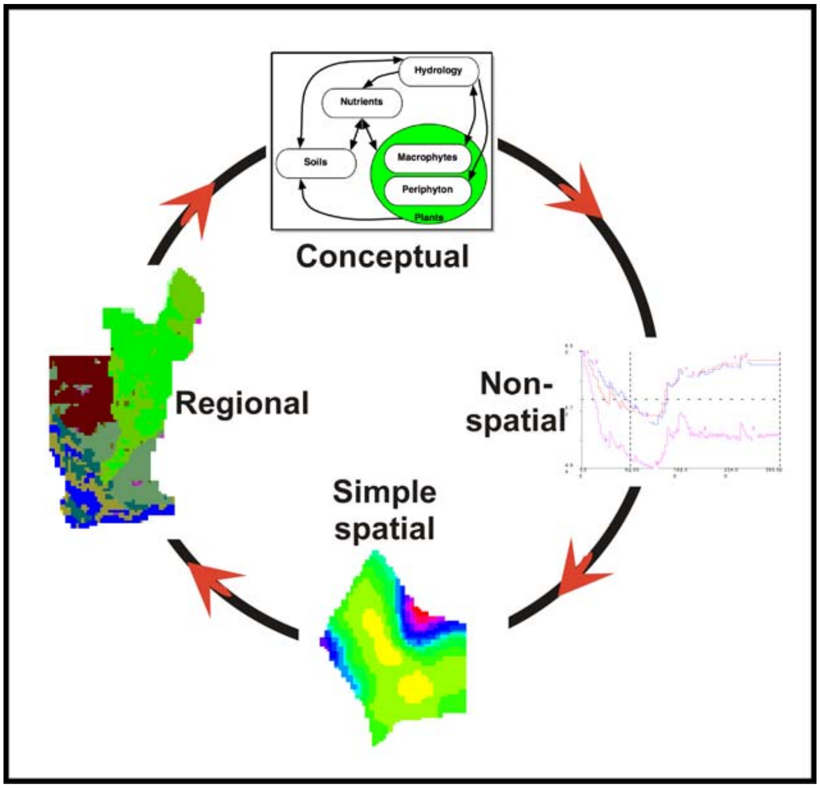
Documentation of the
Everglades Landscape Model:
ELM v2.5

Chapter 9: Model Refinement



http://my.sfwmd.gov/elm

July 10, 2006

Chapter 9: Model Refinement

9.1 Overview

The Everglades Landscape Model (ELM) has been under continuous development and refinement since the inception of the project in the early 1990's. In this Chapter, we provide a high-level summary of the major developments in the timeline of the ELM project. These developments are documented in technical reports and/or peer-reviewed manuscripts, which are available (where possible) on the ELM web site under the Publications section.

All models have uncertainties (see Uncertainty Chapter) and associated limitations. Those limitations, and plans to reduce such limitations if applicable, are outlined in this Chapter. In particular, we hope that our Open Source philosophy will stimulate further collaborations towards continued refinement of this model - for enhanced understanding of the greater Everglades and its restoration.

9.2 Version control

Starting with ELM v1.0, scripts were used to archive major and minor version increments during updates to the model source code and the model input data[1]. One script assembles a compressed unix "tar" file archive of all source code (including scripts), while also forcing the user/developer to create a metadata file containing notes on the nature of the update. Another script performs the same operation for all input data files and databases. These two versioned archives are used to distribute the fully functional ELM project, as described in the User's Guide Chapter. The following are the guidelines that we used in maintaining version numbers in source code and data archives:

- *version numbering (starting with v2.1)*
    a. the version number is based upon the model-release version number for which it was created: x.y.z, where x=primary, y=secondary, z=tertiary version attribute (e.g., version 2.5.1)
    b. version incrementing:
        i. model-release[2] versions are incremented only by the primary and secondary version attributes[3];
        ii. if data or code are developed specifically for updating to a new model-release version, the data/code version is assigned the upcoming primary.secondary version number, appended with a x.y.0 tertiary version attribute;
        iii. based upon the projected model-release version, changed data/code versions are incremented by the tertiary version attribute;

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[1] The ELM code of v2.5.0 was put into the Open Source versioning tool, CVS; an SVN implementation for all code and data is being adopted during summer 2006.

[2] A "model-release" version represents a principal milestone in the model's project development, and includes some level of posting to the ELM's internet web site

[3] Tertiary version attributes are used for developer version control, and omitted from "model-release" version attributes for simplicity. An increment to the secondary version number would be used for any subsequent public release.

   iv. if a change in data/code is associated with change(s) in the model-release version, the primary and secondary version attribute of the new data/code becomes that of the new model-release version, appended with a x.y.0 tertiary version attribute;
   v. a model-release version may be incremented without simultaneously incrementing the version number(s) of data/code file(s), only if the specific data file(s) remain completely unchanged for the model-release update;

c. an associated date of creation/modification specifies the date of the (creation or) modification of the version of the file, and is only modified when the data/code changes and a new data/code version is assigned (changes to *any* numeric information in data file represents a new version and thus date of creation)
d. modification to metadata content or format is not considered a version increment of the data/code

9.3 Version history

The ELM project was initiated in the early 1990's, with the first published components of the model in 1996 (Fitz et al. 1996). The first application was a subregional implementation of the ELM (v1.0) to Water Conservation Area 2A (Fitz and Sklar 1999), a well studied region that supported much of the model parameterization and assessment of the model performance. In ELM v2.1 (Fitz et al. 2003, Villa et al. 2003), refinements were made to the model based on newer data that improved our understanding of the Everglades. The ELM v2.1 was targeted for application to projects in the greater Everglades region, and reviewed for CERP application by inter-agency volunteers in 2002 (ELM_Team 2002, Fitz et al. 2002). The reports and publications available on the ELM web site provide greater detail on the algorithms and the data that were improved with advances in Everglades research. The following lists some of the major changes:

9.3.1 ELM beta (1995)

- baseline of reference to changes
- had very general performance capabilities for regional system (i.e., calibration was based on professional judgment)

9.3.2 ELM v1.0 (1997)

- hydrology refined for horizontal solutions (water management, raster fluxes)
- introduced detailed budget and error analyses for water and phosphorus
- calibrated ecological variables (hydrology, water quality, soils, macrophytes, succession) along phosphorus gradient in subregional application

9.3.3 ELM v2.1 (2000)

- refined vertical integration of surface-ground water (and constituents)
- added organic soil phosphorus storage
- added dynamic carbon:phosphorus stoichiometry

- added floc module to improve soils and biogeochemical dynamics along gradient
- added scripted post-processing for rapid application turn-around
- calibrated hydrology and phosphorus water quality across greater Everglades region
- (2002) documentation enhanced (to v2.1a) for model release version for inter-agency review (subsequent to this, numerical, vs. alphabetic, tertiary version increments were used)

9.3.4 ELM v2.5 (2006)

- added dynamic stage (including tidal) boundary conditions
- added dispersion algorithm for water quality (phosphorus & chloride) constituents
- added automated sensitivity analysis for users
- implemented other subregional applications (at 100, 200, 500, 1000 meter grids)
- validated hydrology and phosphorus water quality across greater Everglades region
- the code and data released on July 10, 2006 for independent peer review were ELM v2.5.2, and the full release is referred to as simply ELM v2.5

9.4 Current limitations

In the current ELM v2.5, we do not offer regional Performance Measures for ecological variables beyond those involving hydrology and phosphorus "water quality". (An earlier version, as listed above, demonstrated those capabilities in a subregional implementation; subsequent improvements have enhanced its capabilities). Some of the principal limitations or uncertainties associated with the current model dynamics are:

- **Hydrologic** flows in the canal system are dependent on the extent to which we segment an actual canal (separated by managed water control structures) into multiple interacting canal reaches with "virtual" structures. Using observed gradients and trends of chloride and phosphorus observations, the grain of reach segmentation generally captures the seasonal/annual distributions of canal-canal-marsh exchanges.
- **Phosphorus** is considered in the aggregated, Total Phosphorus variable. A simple relationship between total phosphorus and bio-available phosphorus is assumed to be representative of the long-term dynamics of the integrated biogeochemistry and plant biology.
- **Soils** are a fundamental property of this wetland system, and it is essential to ensure that they are adequately characterized in the simulation. We have not yet made use of the significant body of new data that are available to compare to the model output and to better parameterize vertical fluxes in the soil, floc and water column modules, throughout the regional system. Moreover, we currently assume that a very simple vertical zonation in the sediment/soil profile allows sufficient differentiation of the deep aquifer and the active soil zone near the surface.
- **Macrophytes** and soils are the principal determinates of the habitat type in the model (and in the field). The macrophytic vegetation type is known to be heterogeneous at scales finer than 1 km^2, and thus those fine-scale patterns are not captured in the regional (1 km^2) implementation of ELM. We thus assume that our ability to discriminate habitat types at the regional scale is representative of the major trends in principal habitats such as sawgrass-cattail transitions over long (decadal) time scales.

- **Fire** is known to be a driving influence in habitat succession of the Everglades. Because we do not simulate fire dynamics, the direct effects of drought are only imparted through soil decomposition and changes to macrophyte mortality and growth. Any short term effects of fire on bio-available phosphorus are aggregated in the long-term phosphorus and macrophyte/soil dynamics.

9.5 Planned refinements

- **General**: 1) Acquire and synthesize more of the ecological monitoring and research data that have been collected/published since the mid- to late- 1990's. 2) Extend the sensitivity and uncertainty evaluations of the model applications. 3) Continue development of integrated databases and post-processors.
- **Hydrology**: our long-term plan is to integrate the biogeochemical and biological modules of ELM into the SFWMD's Regional Simulation Model (RSM); in the near-term, we plan to obtain the additional observed data in the southern and southwest mangrove regions for calibrating the ELM flows and stages in that region. Moreover, we plan on incorporating the updates to 1) land surface elevation data in northern WCA-3A and Big Cypress National Preserve and 2) the spatial time series of potential evapotranspiration for 1965-2000.
- **Soils**: further evaluate the (currently good) performance of the dynamics of peat accretion/oxidation, and phosphorus concentration, to determine the need to modify the algorithms regarding 1) vertical stratification of nutrients and 2) inorganic soil gain/loss.
- **Multi-scales**: two options are feasible for considering finer-scale ecological dynamics: 1) given current fast run-time, moderate dynamic memory (RAM) usage, and modular source code structure, it is feasible to incorporate a dynamic fine-grid array of macrophytes operating within the "coarse" 1 km^2 grid of the regional model; 2) employing the new multi-scale dynamic boundary condition code, it is attractive (in the near-term) to make sequential runs of the regional (1km^2) implementation, followed by a finer-scale subregional implementation with the regional-ELM boundary conditions.
- **Fire**: historical fire maps, available from Department of Interior, are planned be used to generate a probabilistic (non-mechanistic) module to capture subregional trends in fire effects on soil losses and the disturbances that broadly affect macrophyte succession over long time scales.

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Documentation of the Everglades Landscape Model: ELM v2.5

Chapter 10: User's Guide

http://my.sfwmd.gov/elm

July 10, 2006

Chapter 10: User's Guide

10.1 Overview

The ELM is a freely available, "Open Source" project that we hope will be used and modified by others in the scientific community in a collaborative spirit. Other Chapters of the Everglades Landscape Model (ELM) documentation describe the input data, scientific algorithms & source code, model performance, and other material. This Chapter is intended to instruct users on the steps needed to install and apply the ELM in historical (e.g., calibration) simulations.

To use the ELM, one starts with a computer running some "flavor" of the unix operating system (such as Linux). Basic familiarity with unix is required, but advanced expertise is not absolutely necessary. The ELM is installed from a single script that extracts data and code from two compressed file archives. The executable is then built (compiled & linked) from a script, and the model is ready to go.

In the most common/simple application of ELM, a single script is run to verify what output is desired, execute a model run, and archive the results. The user is guided through the several fundamental checks of model output to verify that the model indeed performed as expected. The outputs are described, covering a range of spatial and temporal scales of the landscape. Their interpretation is dependent on an understanding of the science of ELM covered in the other Chapters of this documentation.

As should be apparent from this and other Chapters of the model documentation, the ELM was designed to be applied by modifying databases, not the model source code. "User-friendly" supporting databases are available to select different outputs, change parameters, or explore/edit aspects of the supporting data. However, those databases need not be immediately opened/modified, depending on the user's initial interest.

A few of the more advanced applications of ELM are covered in brief, but are generally beyond the scope of this User's Guide. These topics include the automated sensitivity analysis of the model, the creation of new subregional applications, and evaluating scenarios of future restoration alternatives. While these applications of the model are all data-driven and relatively straightforward, the details of changes to data and requisite quality assurance are left to a subsequent extension of this guide.

10.2 Computing environment

The ELM is truly a multi-platform simulation model, capable of running in a variety of computing environments without modification. No changes to the C source code, scripts, or "makefile" are needed to move among any of the computing environments that we have tested. The compilation and run scripts detect the type of unix operating system, with no user intervention. This allows the ELM developers to modify one set of code (stored on one file system), and routinely compile & run the OS-specific executables from any available platform. The production environment for ELM is Red Hat Linux on an Intel chip, while Apple OS X (Darwin) is a very useful modeling environment.

10.2.1 Hardware

The ELM can be installed and executed on any one of a variety of common hardware architectures that have some form of unix[1] available (Table 10.1 below). Available storage on the file system (hard disk) should be at least 600 MB: roughly 500 MB is needed for all of the input data/databases and source code, while a 20-year run with basic outputs, including animated monthly time series of a handful of variables, uses approximately 100 MB disk space. Different subregional applications (of various grid sizes) vary the memory (RAM) requirements, but the regional ELM application that is in the standard distribution uses less than 90 MB RAM, irrespective of the simulation length.

10.2.2 Software

No commercial software is necessary. The only requirement to install and use ELM is a unix operating system that includes a gcc[2] compiler. No custom libraries need to be modified/installed beyond those already available in a standard operating system installation with a functional compiler. Tools that are technically "optional", but highly desirable, include a Geographic Information System (the Open Source GRASS GIS is recommended), and spreadsheet software (Open Office Calc is recommended). For optional/recommended software tools, see Appendix: Software recommendations.

Table 10.1. ELM compilation and execution has been tested in these environments. At the unix command line, type "gcc --ver" and "uname -a" for this information.

Compiler	Operating System	OS release version	CPU
~~gcc v.3.2~~ (unsupported)	(unsupported) ~~Sun Solaris~~	5.8	sparc
gcc v.3.2.2	Red Hat Linux	2.4.20-27.9smp	i686 (Pentium)
gcc v.3.3	Apple Darwin	6.8	Power Mac (G4)
gcc v.3.3.3	SuSE Linux	2.6.4-52-default	i686 (Celeron)
gcc v.3.4.3	Red Hat Linux	2.6.9-5.ELsmp	i686 (Pentium)

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[1] Our available Sun Solaris and Apple Darwin platforms are outdated, and thus we have not tested the ELM code in more recent versions of these OSs & associated standard libraries.

[2] GNU Compiler Collection, gcc, at http://gcc.gnu.org/ There are no compiler-specific dependencies, and thus other ANSI C compliant compilers should be compatible with ELM code.

10.2.3 Runtimes

One of the platforms available to the ELM developers is an inexpensive Dell™ laptop with an Intel Pentium™ 2.66 GHz processor. On this computer, the run-time for the regional-ELM implementation (10,394 grid cells @1 km^2 resolution), with standard output, is slightly over 1 hour for a 20-year simulation.

10.3 Installing the model

Using an Open Source[3] philosophy, we hope to encourage collaboration in the modeling community. Towards that end, the source code and data are available for download on the ELM web site, and all C source code in the ELM project is documented in detail using the automated "Doxygen" web-based documentation system (see Model Structure Chapter).

10.3.1 Standard

The ELM project is installed in a directory of the user's choosing, without affecting existing operating system "libraries" or other components of the user's file system. To install the ELM, one places the code & data archives into an empty directory, and runs a single script, by following these steps (replacing "X.Y" with "2.5" for ELM v2.5):

1) Obtain the code and data (from CD or http://my.sfwmd.gov/elm)
    a. ELMinstall.sh (installer shell script)
    b. ELMX.Y.data.updateA.B.tar.gz (compressed archive of data, ELM version X.Y, update A.B)
    c. ELMX.Y.src.updateA.B.tar.gz （compressed archive of code, ELM version X.Y, update A.B)
2) Make a home and install your project
    a. Create an empty directory anywhere on your file system, put above 3 files into it, and "cd" into that directory
    b. Run the install script on unix command line: "./ELMinstall.sh"
    c. Note: the install script guides you on how to set up the several environment variables that are needed. One is "$ELM_HOME", which is the absolute path of the directory in which you placed the project.
3) Build the executable
    a. Run the build script on unix command line (ELM version X.Y): "./build ELMX.Y"

10.3.2 Custom

The standard installation is generally all that is needed. However, the user has more flexibility in choosing the location(s) of model output, along with customization of other characteristics of the model. Note that the choice of operating system does not influence any of the installation procedures. For the details of the potential customizations, see this

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[3] http://www.opensource.org/

Chapter's Appendix: Environment variables and Directory/file structure.

10.4 Running the model

The ELM is run from the unix command line through the use of "shell" scripts. Basic familiarity with unix is required, but advanced expertise is not absolutely necessary.

10.4.1 Quick start

For those who want to run a simulation "right now" using the defaults set in the standard distribution of source code and data, simply jump in and invoke a script (after installing the model as described above!). In the commands below, replace "X.Y" with "2.5" for ELM v2.5. For all commands and filenames, remember that unix is case-sensitive.

1) Invoke the Run script, responding to its prompts (ELM version X.Y):
   "./Run ELMX.Y myFirstRun"
2) The Run script asks you a couple of questions. Say no to both for now: the model will run, and then the results will be archived in a new directory called "myFirstRun", within the archive directory "$ELM_HOME/arc_out/"
3) Check/interpret the output as outlined in the "Output" section later in this Chapter.

10.4.2 Runtime configuration files

There are two model configuration (text) files[4] that can be modified prior to running the model. One file, "Driver.parm", is edited to select which ecological module(s) to execute, set the starting and ending dates of simulation, and other such model settings. The other, "Model.outList", is edited to select which variables to output, their output type & location, and output frequency. These two configuration files are directly read by the model during the initialization sequence.

10.4.2.1 Driver.parm

This is the primary configuration file, providing significant flexibility to the user. Some of the more common changes that may be made in this configuration are:

- change location of model output
- change start and end dates of simulation
- change output intervals for budgets, canals, and internal variable averaging
- turn on/off habitat switching module
- turn on/off water management modules
- turn on/off various hydro-ecological vertical solution modules
- run sensitivity analyses on parameters

This text file is self-documented at a brief level of detail. This Chapter's "Appendix:

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[4] in $ELM_HOME/SME/Projects/ELMX.Y/RunParms/

Driver.parm" expands on the information for each of these runtime parameters.

The "Check" script is used to quickly check these settings, and edit them if desired (using the standard unix text editor "vi").

10.4.2.2 Model.outList

This text file is exported from the "ModelOutlist_creator_*version*.xls" interface. That spreadsheet database is found in the "$ELM_HOME/SME/Projects/Dbases/" directory. It is "user-friendly" and fully self-documenting, and is perhaps most commonly used for initially selecting and configuring the different output command options. For basically any dynamic variable in the model, the user can select the following[5] combinations of commands to produce output:

- map time series (animations): "G( )" command
- scale the values of map time series output: "S( )" command (required w/ "G( )")
- point time series (individual grid cells): "P( )" command
- time interval for output (independent for each variable): "O( )" command

The map time series consists of multiple domain-wide spatial maps of the selected variable at the selected output interval, with each variable's multi-file time series put in a separate output directory ("./Output/*.*/"). The point time series are put in the "./Output/PtSer/" output directory, with a time series at the selected output interval in a separate file for each variable, with each file containing multiple points (grid cells).

Note: summaries of all canals & water control structures ("./Output/Canal/"), and all user-defined Basin/Indicator-Region data ("./Output/Budget/") are always output. The user can modify the output frequency of those data via the "Driver.parm" configuration. (Basins and Indicator Regions are defined in an input map; see the "Modifying Data" section of this Chapter).

Although it is relatively quick and easy to use, it is not necessary to routinely use the ModelOutlist_creator spreadsheet interface: once a user becomes familiar with the output commands, the "Check" script can be used to most quickly check the settings in the "Model.outList" text file, and edit them if desired (using the unix text editor "vi").

10.4.3 Scripts

The following are the scripts that are available for a variety of tasks associated with using the ELM. Most of the scripts are "stand-alone", but are designed in a modular fashion so that they can also be controlled by higher-level calling scripts. (For example, the "Run" script shown above is a main controller script that calls the stand-alone scripts of "Check", "go", and "ArchiveRun", while those latter scripts call others such as "PathModel"). Table 10.2 describes the script usage and hierarchy.

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[5] The map time series that are produces are in "unsigned character" binary formats that produce the smallest file sizes, and the output maps are scaled by the user via the interface. Hierarchical Data Format (HDF) was supported in earlier versions of ELM, but is not updated for ELM v2.5. Subsequent versions will support either "hdf" or "cdf" formats.

Table 10.2. Scripts used in the ELM project. The three grey-shaded scripts are all that are needed to install and run the ELM. Scripts are modular and nested in a hierarchy; all scripts can be executed as stand-alone applications (w/ 1 exception). Syntax: *ProjName* is the name of the ELM project (e.g., ELM2.5); *runName* is a user-defined name to denote a particular simulation run

	Primary script	Secondary script	Syntax	Included/called scripts	Purpose of script
Model installation					
	ELMinstallX.Y.sh		ELMinstall*X.Y* .sh, where *X.Y* is model version	none	Install the ELM project in the user's directory. Fully self-documented. (script name came w/ distribution)
	build		build *ProjName*	PathELM_HOME, PathModel, PathOSTYPE	Builds an executable of the model project from the make file (compiles, links source code).
Model run					
	Run		Run *ProjName runName*	Check, go, CopyInput, ArchiveRun, PathELM_HOME, PathModel, PathOutput, PathArchive	Controller script that configures, runs, and archives a simulation.
		Check	Check *ProjName*	PathELM_HOME, PathModel	View and change the model runtime configuration.
		go	go *ProjName*	PathELM_HOME, PathModel, PathOutput, PathOSTYPE	Simply runs the model executable. NOTE: output from a simulation run made via this script is OVERWRITTEN by a subsequent invocation of this script; use ArchiveRun script to save a simulation.
		ArchiveRun	ArchiveRun *ProjName runName*	PathELM_HOME, PathModel, PathOutput, PathArchive, mkOutDirs	Archives a simulation's output and input as a "keeper" under a user-defined name. It moves all output files and copies selected input files to a user-defined new directory in the $ELM_ARCHIVE_PATH.
	finishOutList		finishOutList *ProjName target* , where *target* is file made by ModelOutlist_creator.	PathELM_HOME, PathModel	If ModelOutlist_creator was used: Does the final processing needed on the Model.outList text file that was created by the ModelOutlist_creator workbook (OpenOffice/Excel).
Model distribution/backup					
	ArchiveData		ArchiveData *ProjName descript* , where *descript* is descriptive identifier	none	Archives all input data required for ELM historical (e.g., calibration) runs to a compressed tar archive. Used for ELM-version distributions. To use, modify source and target directories in the script.
	ArchiveSrc		ArchiveSrc *ProjName descript* where *descript* is descriptive identifier	PathELM_HOME	Archives all required ELM source code to tar archives in two locations: an uncompressed one in $ELM_HOME, and a compressed one in a remote directory. Used for ELM-version distributions. To use, modify destination directory in the script.
Utility					
		PathArchive	PathArchive	none	Checks validity of $ELM_ARCHIVE_PATH for model archiving and exports it if needed.
		PathELM_HOME	PathELM_HOME	none	Determines if the (fundamental) $ELM_HOME variable appears valid.
		PathModel	PathModel	PathELM_HOME	Checks validity of the base $ModelPath for the model Project data/executable, and creates & exports that path if needed.
		PathOutput	PathOutput *ProjName*	PathELM_HOME, PathModel	Checks for validity of an existing OutputPath for model output (defined in Driver.parm file) and exports it if valid.
		PathOSTYPE	PathOSTYPE	none	Determines if the $OSTYPE variable reflects a tested platform. (The name of the script is for consistency with similar script names, and OSTYPE is only used in relation to paths/filenames).
		CopyInput	NA (is not stand-alone)	none	Only called from the "Run" script. It has 2 primary purposes: 1) Force the user to write some Notes on simulation about to be run; 2) Create named copies of frequently-changed data files.
		mkOutDirs	mkOutDirs *OutputPath ProjName*	none	Create the required output directory names if they have been removed from the model Project OutputPath.
	rmAnim		rmAnim *OutputPath ProjName*	none	Delete all files in Animation* directories for a project in a given path. For a measure of safety, this is only used as a stand-alone script, and the user needs to manually type in the path, then confirm the deletions.
Advanced: acquire water control structure flows					
	getDSSflow		getDSSflow	none	Acquire flow data. Full instructions for advanced applications not in this current documentation.
	StrNames		StrNames	none	(Compiled binary) to extract names of structures from a "DSS" catalog. Full instructions for advanced applications not in this current documentation.
Advanced: GRASS for animations, vector canal input/visualization, other					
	AnimGrass		NA (not distributed, FYI only)	PathOutput, PathArchive	GRASS (script not distributed): Links model output to a GRASS directory in preparation for animation using xganim.
	AnimGrassNow		NA (not distributed, FYI only)	none	GRASS (script not distributed): Runs xganim within GRASS.
	AnimGrass_rm		NA (not distributed, FYI only)	none	GRASS (script not distributed): Deletes the links to model output and the other GRASS animation files for a particular variable.
	reachin		NA (not distributed, FYI only)	none (but uses ELM variable "$ModelPath")	GRASS (script not distributed): Creates GRASS ascii vector files for all canals contained in the CanalData.chan ELM-input file.
	reachinvect		NA (not distributed, FYI only)	none	GRASS (script not distributed): Import ALL reaches from ascii into Grass binary vector format.
	reach_calib_v2.4		NA (not distributed, FYI only)	none	GRASS (script not distributed): Display canal reaches in distinguishing colors, and show thel water control structures.

10.5 *Input data modification*

Several databases are used to modify and document a variety of important components of the ELM. The purpose of this section is to call the user's attention to these self-documenting databases, which are *critical to the use of the ELM, particularly when learning the model*. Other data sources (described in the Data Chapter) are used for time series data that are input to the model, and some form of GIS (below) is needed to visualize and modify the spatial maps that are input to the model.

10.5.1 Databases

Our goal has been to create a system of integrated, relational databases using the Open Source MySQL. However, these prototype databases are not ready for release, and we instead use the Open Office Calc spreadsheet software[6] to perform the necessary data management functions. Table 10.3 provides an overview of the primary functions of these data management systems.

Table 10.3. Spreadsheet-based databases used in a) data maintenance and documentation of model parameters and model variables, b) generating source code of model, and c) generating output configurations for model runs. Databases are found in $ELM_HOME/SME/Projects/Dbases/.

Database name	**Database functions**
GlobalParms_vX.Y.xls	1) Maintain and document (incl. units and source/metadata) parameters that are globally distributed across model domain. 2) Generate code of header file, transferring parameter documentation to model source code. 3) Generate upper and lower values of all parameters for automated sensitivity analysis.
HabParms_vX.Y.xls	1) Maintain and document (incl. units and source/metadata) parameters that are specific to different habitats in the model domain. 2) Generate code of header file, transferring parameter documentation to model source code. 3) Generate upper and lower values of all parameters for automated sensitivity analysis.
ModelOutlist_creator_vX.Y.xls	1) Generate all input-configuration commands for any model variable, map and point time series output. 2) For all Everglades monitoring sites, calculate model grid cell row-column (at any grid scale) from its geographic coordinates. 3) Maintain and document (incl. units and source/metadata) all variables used in the model. 4) Generate code of multiple header files, transferring documentation of variables to model source code.

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[6] fully compatible with Microsoft Excel

The single exception to the use of Open Source software is our database ($ELM_HOME/SME/Projects/Dbases/Structs_attr_vX.Y.fmp) of the attributes of water control structures, for which we continue to use FileMaker Pro software. This database continues to be very useful in creating new subregional applications or modifying water control structures for evaluating alternative water management scenarios. However, it is not essential to the use of ELM in the mode intended for this User's Guide Chapter: the water control structure attributes for the current simulations are documented through snapshots of the records for all of the necessary water control structures, and the text input file can be viewed or modified using spreadsheet software (see Data Chapter).

10.5.2 GIS

Any software capable of reading raw/generic binary data arrays can be used to edit/visualize the map inputs. The ELM developers use the GRASS GIS (see Appendix: Software recommendations). Through the use of unix symbolic links between the GRASS and the ELM data directories, the ELM directly reads GRASS project data files (uncompressed binary data and text header) as model input. However, no GRASS-specific encoding of binary information is used, and thus the data files may be opened with any program that can read raw binary data arrays. Scripts are available to directly input and visualize the ELM (text) canal vectors in GRASS.

There are three sub-directories within an ELM project's input ./Data/ directory: Map_bin, Map_head, and Map_hist. The model reads each raw binary data file in the Map_bin subdirectory, and reads its associated header description in the Map_head subdirectory. The history and other pertinent metadata are in the Map_hist subdirectory, but that information is not used in the model.

All spatial data are referenced to zone 17 of the Universal Transverse Mercator (UTM) geographic coordinate system, relative to the 1927 North American Datum (NAD). The ELM regional application uses 1 km^2 square grid cells that encompass an area of 10,394 km^2 (4,013 mi^2) in the active domain. All of the maps of the regional application are bounded by a rectangle of UTM coordinates in zone 17 (NAD 1927), as shown in the lines in the below regional-domain example of the text header files:

zone:	17 (UTM zone)
northing:	2,953,489 m (UTM north coord)
southing:	2,769,489 m (UTM south coord)
easting:	580,711 m (UTM east coord)
westing:	472,711 m (UTM west coord)
columns:	108 (number of columns in 2D array)
rows:	184 (number of rows in 2D array)
east-west resol.:	1000 m (grid cell length in 2D array)
north-south resol.:	1000 m (grid cell width in 2D array)
format:	*"X"* bytes/cell, as defined below
compressed:	0 (no compression)

The *"X"* value of "format" of the raw binary data is one of the following:

0.: 1 byte per grid cell
1: 2 bytes per grid cell
3: 4 bytes per grid cell

10.6 Output

During the initialization phase of a simulation, the various configurations that the user chose are echoed to the console (screen). Subsequently, the simulation date is iterated on the console as the computations are made. A successful simulation will end with the following message printed to the screen:
"END. The simulation(s) took zz.zzz minutes to run using your yyyyy OS box.", followed by other messages depending on the scripts that are running.

10.6.1 Quick start

Upon completion of (or during) a simulation, the user is advised to make the following minimal checks to verify that the simulation was "well-behaved".

4) To verify that no errors were in the simulation, search the "Debug/Driver1.out" text file (see below) for the all-caps string "ERROR", which can be the full word or part of a word (i.e., "capacityERROR");
5) View the "Budget/budg_Wcm1" text file, and verify that the cumulative mass balance error variables, "SumERR_*" for each Basin & Indicator Region identity, is reasonable, i.e., on the order of tens of microns height.
6) Peruse one of the spatial time series of map outputs to verify the spatio-temporal dynamics "pass the laugh test" . Viewing an animation, or individual maps, of the "SfWatAvg" (surface water depth, averaged during output intervals) variable is a good choice - assuming the user kept that variable's output commands in the Model.outList configuration.
7) Dive into the other output files as desired, using the below descriptions as your guide.

10.6.2 Output file structure

During a simulation, all output is always written to the "Output/" directory in the user's output path (Table 10.4). After a simulation terminates, the output may be moved (archived) to the user's archive path via the "ArchiveRun" script (which is also called by the "Run" script). In the below directory descriptions, "ProjName" is the Project name (such as ELM2.5) that was input by the user on the command line.

Un-archived output location: "OutputPath/ProjName/Output/", where "OutputPath" is the absolute path to model output, changeable in the "Driver.parm" file.

Archived output location: "$ELM_ARCHIVE_PATH/ProjName/runName", where "$ELM_ARCHIVE_PATH" is the archive path set up by the user[7], and "runName" is a user-defined name to denote a particular simulation run.

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[7] "$ELM_ARCHIVE_PATH" was set up by the user when installing the ELM. The location may be set to anywhere, but initial installation was in "$ELM_HOME/arc_out/"

Table 10.4. Output directories and description of files they contain. These directories are relative to the un-archived or the archived output locations described above.

Output directory	Output description
Animation1...Animation60	Map time series for individual variables, with separate directory for each variable. After archiving a simulation, non-empty directories are moved & renamed with the variable names.
or: VariableA, VariableB, ...	Map time series for individual variables, with separate directory for each variable. Prior to archiving a simulation, the directory names are simply Animation1, Animation2, ..., Animation60 (maximum).
Budget	[BIR] Time series of budgets and pre-set Performance Measures in Basins/Indicator Regions (BIR).
Canal	Time series of a) canal depths and constituent concentrations, and b) water control structure flows and constituent concentrations.
Debug	Variety of detailed output for debugging and error checking.
PtSer	Time series of individual variables at point (grid cell) locations distributed through model domain.

10.6.3 Debug (errors and warnings)

The “Debug/” directory will always contain at least two debug-related files. Truly critical errors (such as missing inputs, memory constraints, etc) will terminate the simulation with an informative message. Numerical errors or warnings do not necessarily terminate the simulation (in order to allow the user to debug the problem). It is important to monitor the Driver*.out files for any errors or warnings, particularly after configuring a new application:

- Driver0.out: text file that echoes input data that were successfully read, including simulation start-end dates, hydro-ecological parameters, output configurations and others.
- Driver1.out: text file that contains a variety of warnings, error messages; details of model output are printed, depending on the level of the “debug” parameter (in “Driver.parm”, see Runtime configuration section of this Chapter).

The “Debug/” directory will contain two debug-related files when running the Water Management modules:

- ON_MAP_CANAL.txt: a tab-delimited 2D array text file of the modifications to the “ON_MAP” file that was done by the “Canal-marsh flux module of the Water Management code (see Model Structure Chapter).
- CanalCells_interaction.txt: text file of list of cells that interact with each canal reach

10.6.3.1 Postprocessing Debug text files

All files in the "Debug/" directory are text files. The Driver*.out files are intended to be searched/queried using any text editor. The "ON_MAP_CANAL.txt" file is best visualized after import into any spatial mapping program or GIS (such as GRASS).

10.6.4 Spatial: Basin & Indicator Region (BIR) time series

Budgets and preset Performance Measure variables are output at the different spatial scales defined by the hydrologic Basins and Indicator Regions (BIR) input map. As discussed in the Model domains section of the Data Chapter ("basins" input Data file), hydrologic basins are "parent" regions that (may) contain "child" Indicator Regions, and parent basins' data include (e.g., sum) the data on all child Indicator Regions contained within them. Basin 0 is the entire model domain. Well-drawn BIR spatial distributions are particularly useful for evaluating output dynamics (budgets and Performance Measures) along ecological gradients. Table 10.5 provides an overview of the budget and Performance Measure variables in each of the output files.

Table 10.5. Budget and preset Performance Measure variables in Basins & Indicator Regions (BIR). The variables are output for each BIR in the individual files.

Budget file name	**Budget file description**	**Budget variables for each BIR**																						
budg_Wacr1...5	Water budget: all storages, acre-feet units	total volume - prior interval	total volume - current interval	rain-in	evaporation-out	transpiration-out							structure-in	structure-out	overland-in	overland-out	levee seepage-in	levee seepage-out	ground water-in	ground water-out	error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_Wcm1...5	Water budget: all storages, height (cm) units	total volume - prior interval	total volume - current interval	rain-in	evaporation-out	transpiration-out							structure-in	structure-out	overland-in	overland-out	levee seepage-in	levee seepage-out	ground water-in	groundwater-out	error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_S1...5	Salt/tracer budget: all storages, mass-per-area units	total mass - prior interval	total mass - current interval										structure-in	structure-out	overland-in	overland-out	levee seepage-in	levee seepage-out	ground water-in	groundwater-out	error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_Par1...5	Phosphorus budget: all storages, mass-per-area units	total mass - prior interval	total mass - current interval	rain-in									structure-in	structure-out	overland-in	overland-out	levee seepage-in	levee seepage-out	ground water-in	groundwater-out	error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_P1...5	Phosphorus budget: all storages, mass units	total mass - prior interval	total mass - current interval	rain-in									structure-in	structure-out	overland-in	overland-out	levee seepage-in	levee seepage-out	ground water-in	groundwater-out	error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_Pwat1...5	Phosphorus budget: water-borne storages, mass-per-area units	total mass - prior interval	total mass - current interval	rain-in	settle-out	surfwat. mineralization-out	porewat. mineralization-out	periph. uptake-out	macroph. uptake-out	desorb-in	sorb_to-out										error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_Pliv1...5	Phosphorus budget: live biotic storages, mass-per-area units	total live mass -prior interval	total live mass -current interval	macroph. mass-current interval	calc.periph. mass-current interval	noncalc.periph. mass-current	macroph. NPProd.-in	calc. periph. GPProd.-in	noncalc. periph. GPProd.-in	macroph. mortality-out	calc. periph. mortality-out	noncalc. periph. mortality-out									error-current interval	error-cumulative sum	avg-inputs	avg-outputs
budg_Pded1...5	Phosphorus budget: dead biotic storages, mass-per-area units	total dead mass -prior interval	total dead mass -current interval	macroph. ToSoil-in	periph. ToSoil-in	decomp.-out	settle-in			sorb_to-in	desorb-out										error-current interval	error-cumulative sum	avg-inputs	avg-outputs
Perf. Measure file name	**File description**	**Performance Measure variables for each BIR**																						
BIRavg1...5	Hydro-ecological Performance Measures	surface water depth	unsaturated water depth	TP conc. surface water	TP conc. pore water	TP conc. soil	noncalc. periph. biomass	calc. periph. biomass	macroph. biomass	land elevation														

10.6.4.1 Budgets (in BIR)

The "Budget/" directory contains tab-delimited text files with budgets of water, phosphorus, and salt/tracer in the BIRs. The reporting time interval is selected by the user (see Runtime configuration section of this Chapter). In each budget, all inflows and outflows to/from each BIR are summed for the relevant variables within each reporting interval. For example, a 30-day reporting interval will result in a hydrologic budget that reports the sum of the different inflows (rain, seepage inflow, etc) and outflows (ET, seepage outflow, etc.) within each 30-day period during the simulation. Numerical errors in mass conservation[8] are always calculated for all budgets, both cumulative during each reporting interval, and cumulative across the model simulation period.

10.6.4.2 Preset Performance Measures (in BIR)

The "Budget/" directory also contains tab-delimited text files with preset Performance Measure averages in BIRs. The reporting time interval is selected by the user (see Runtime configuration section of this Chapter), and is used to calculate the daily arithmetic mean value of each performance measure within the interval. These Performance Measures include hydrologic, biogeochemical, and biological dynamics within the region.

10.6.4.3 Postprocessing BIR text files

All BIR budget and Performance Measure files are in tab-delimited text format, and thus can be directly read into any spreadsheet program such as Open Office Calc or Microsoft Excel. The primary method for ELM postprocessing is the use of scripts written in the Python scripting language. The ELM developers have a flexible set of Python postprocessing scripts that will produce a variety of summaries of these data for visualization and analysis, but that development is not complete enough for release. Spreadsheet templates for different summaries of the output data are available from the developers, but are unsupported.

10.6.5 Spatial: Domain-wide map time series

Virtually any variable in the model may be output as domain-wide maps at a user-specified output interval (see Runtime configuration section of this Chapter). These maps may then be analyzed individually, summarized across time, or animated using visualization software.

If a simulation has not yet been archived, the output maps of any user-selected model variable are placed in one of the AnimationZZ directories in the Output directory, where "ZZ" is an integer between 1 – 60. As described earlier, the model archiving process

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[8] The *maximum* magnitude of cumulative errors in mass balance of water storage dynamics ranges within the order of (positive or negative) 1 to 10 microns, depending on the cumulative interval (monthly or multi-decade period-of-simulation), the presence/absence of canal interactions, and the spatial scale of the budgeted region. The *maximum* magnitude of cumulative errors in mass balance of phosphorus storage dynamics ranges within the order of (positive or negative) 0.001 to 0.01 ug/m^2, depending on the cumulative interval (monthly or multi-decade period-of-simulation), the presence/absence of canal interactions, and the spatial scale of the budgeted region.

renames the directories to those of the variable it contains.

10.6.5.1 Postprocessing map files

As configured by the user via the ModelOutlist_creator interface (see Runtime configuration section of this Chapter), all output maps are 2D rectangular arrays in generic/raw binary format (i.e., they are not encoded with any software-specific attributes).

To save significant disk space compared to floating point arrays, the map files are output as "1-byte, unsigned integer" data. In any given directory containing a time series of maps of a given variable, the numeric values in the 2D arrays range from 0-255. The value of "255" is reserved for grid cells that are "off-map", or outside of the active domain. The parameters in the scaling equation chosen by the user (via the ModelOutlist_creator) for each output variable must be used to rescale the integer maps back to the actual (floating point numbers and) units of the model using the equation:

model_floatValue = outMap_intValue * Multiplier + Offset,

where model_floatValue is the actual value of the floating point number calculated in the model, outMap_intValue is the integer number stored in the map array, and Multiplier and Offset are the scaling multiplier and offset, respectively, input by the user in the Model.outList. The units of the model_floatValue for each variable were given in the ModelOutlist_creator interface. For example, ponded surface water depth (SURFACE_WAT) is often scaled for output using a Multiplier of 0.01 and Offset of 0.0; a value of "90" in the output map is equal to 0.90 m depth calculated by the model.

Any software capable of opening or importing generic/raw binary spatial arrays can be used to analyze and/or animate the time series of output maps. The Open Source GRASS GIS and its associated "xganim" animation program can be used to analyze and visualize the output. As reviewed in the Appendix of this Chapter, many other tools, such as the Open Source OpenDX, or the commercial IDL, are available for geospatial analysis and visualization. The ELM developers have various postprocessing codes (using a custom C program, GRASS, and IDL scripts) for summarizing and visualizing spatial output, but they are not fully developed for public release.

10.6.6 Spatial: Point (grid cell) time series

The "PtSer/" directory contains tab-delimited text files with point (grid cell) time series output. Virtually any variable in the model may be output in this format, at user-selected grid cell locations and output intervals (see Runtime configuration section of this Chapter). A separate file is created for each model variable that is requested for output, and each file has multiple fields (columns) for multiple grid cell locations.

10.6.6.1 Postprocessing point time series text files

All point time series files are in tab-delimited text format, and thus can be directly read into any spreadsheet program such as Open Office Calc or Microsoft Excel. The primary method for ELM postprocessing is the use of scripts written in the Python scripting language. The ELM developers have a flexible set of Python postprocessing scripts that will produce a variety of summaries of these data for visualization and analysis, but that development is not complete enough for release. Spreadsheet templates for different summaries of the output data are available from the developers, but are unsupported.

10.6.7 Spatial: Canal (vector) time series

The "Canal/" directory contains tab-delimited text files with canal (vector) time series output of

- CanalOut: instantaneous water depth in all canal reaches,
- CanalOut_P: instantaneous total phosphorus concentration in all canal reaches,
- CanalOut_S: instantaneous salt/tracer concentration in all canal reaches.

These variables are all of the state variables used in the canals of water management simulation, and the user can select the output interval for this group of outputs (see Runtime configuration section of this Chapter).

10.6.7.1 Postprocessing canal time series text files

All canal (and water control structure) time series files are in tab-delimited text format, and thus can be directly read into any spreadsheet program such as Open Office Calc or Microsoft Excel. The primary method for ELM postprocessing is the use of scripts written in the Python scripting language. The ELM developers have a flexible set of Python postprocessing scripts that will produce a variety of summaries of these data for visualization and analysis, but that development is not complete enough for release. Spreadsheet templates for different summaries of the output data are available from the developers, but are unsupported.

10.6.8 Spatial: Structure (point/cell) flow time series

The "Canal/" directory contains tab-delimited text files with water control structure (vector) time series output of

- structsOut: summed (across each output interval) water flows through all water control structures,
- structsOut_P: flow-weighted (across each output interval) mean total phosphorus concentration at all water control structures, and
- structsOut_S: flow-weighted (across each output interval) mean salt/tracer concentration at all water control structures.

These variables are all of the state variables used in the structure flows of water management simulation, and the user can select the output interval for this group of outputs (see Runtime configuration section of this Chapter).

10.6.8.1 Postprocessing structure time series text files

All water control structure (and canal) time series files are in tab-delimited text format, and thus can be directly read into any spreadsheet program such as Open Office Calc or Microsoft Excel. The primary method for ELM postprocessing is the use of scripts written in the Python scripting language. The ELM developers have a flexible set of Python postprocessing scripts that will produce a variety of summaries of these data for visualization and analysis, but that development is not complete enough for release. Spreadsheet templates for different summaries of the output data are available from the developers, but are unsupported.

10.7 Advanced applications

The following topics are generally beyond the scope of this User's Guide Chapter, but are included in brief summary in order that users may have some guidance if they desire to advance beyond standard, historical simulation runs.

10.7.1 Sensitivity analysis

The user can run the automated sensitivity analysis on model parameters whose results were was described in the Uncertainty Chapter. The "S_ParmName" parameter in the Driver.parm configuration file (see Model configuration section of this Chapter) is used to control which parameters are modified as follows:

- S_ParmName= ALL: evaluate model sensitivity to changes in each of the parameters listed in the input data file SensiParm_list,
- S_ParmName= ParameterName: evaluate model sensitivity to changes in the single parameter whose name is ParameterName, or
- S_ParmName= NONE: no sensitivity analysis, and thus a normal, single simulation run using only the nominal parameter sets

The values of the parameter ranges are changed in the GlobalParms and the HabParms databases: separate "worksheets" are available to calculate and export _LO and _HI (low and high estimates of parameters in) parameter files that are read by the model during the sensitivity analysis. Upon invoking a sensitivity analysis via the S_ParmName parameter, a suite of simulations are executed sequentially when the user executes the model (from either the Run or the go script). An Open Office Calc template is available from the ELM developers for postprocessing the single output file[9] from the multiple runs.

10.7.2 Evaluating project alternatives

To evaluate most (likely all) water management alternative scenarios, no source code needs to be changed, and ecological parameters (in GlobalParms and HabParms databases) generally are not expected to be changed. For a new management alternative, the user just needs to modify the following input data files (which are all described in the Data Chapter):

- CanalData.chan: any changes to the canal/levee topology and attributes,
- CanalData.struct: any changes to the water control structure attributes,
- CanalData.struct_wat: water control structure (daily) water flows (that are output from SFWMM or other tool),

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[9] actually, the single BIRavg output file for all of the sequential simulations can be spread over multiple files (unrelated to sensitivity) if the number of Indicator Regions is large, i.e., BIRavg1 – BIRavg5 as described in the Model output section of this User's Guide Chapter

- CanalData.struct_TP: water control structure (daily) Total Phosphorus concentrations,
- CanalData.struct_TS: water control structure (daily) Total Salt/tracer concentrations.
- (?) GlobalParms_NOM: if appropriate, alter the parameter that estimates the annual rate of sea level rise

To add a new canal, a new canal reach ID is added to the CanalData.chan text file, adding the canal reach attributes and the geographic point coordinates that define the segments of a reach. Existing canal reaches can be "turned off" (ignored by model) by assigning a negative width attribute to that reach. GRASS scripts are used to aid in this process and visualize any new topology of the canal network. Other scripts are used to determine which, if any, new water control structures are required, extracting the appropriate time series of flows from a "DSS" formatted file that was output from the SFWMM (which is the current modeling tool for evaluating hydrology of management alternatives).

The meteorological boundary conditions for the 1965-2000 period of record are contained in the current (rain.BIN, ETp.BIN) input files. The general assumption in forecasting the responses of the system to management changes is the following: If the system were to be subjected to the same meteorological conditions as those observed between 1965-2000, how would the system respond under a new suite of management rules and/or infrastructure?

Obviously (?), there are other assumptions that are involved with forecasting the system responses to future management alternatives. While the data modification/input methods are generally simple and scripted, the details of the steps, including the assumptions and the necessary data quality assurance, are beyond the scope of this User's Guide.

10.7.3 New subregional applications

To implement a new subregional application of the ELM, no source code needs to be changed. The following input files require modification/re-scaling:

- Input maps: all input maps must be reconciled to the spatial resolution and extent of the new domain (i.e., with new data, or rescaling/interpolating existing data)
- CanalData.chan: canal reaches from the regional model application that are within the new domain may be kept (as they use geographic, not grid cell, coordinates); the upper left corner of the origin of the rectangular domain requires changing (if necessary),
- CanalData.struct*: water control structure attributes and flow/concentration data from the regional model application that are within the new domain may be kept, but the Structs_attr.fmp database (or another calculator) should be used to calculate the new grid cell locations of the geographic coordinates of the water control structures; unused structures need to be removed from all CanalData.struct* files,
- Driver.parm: modify the parameter that defines the model grid cell area

- Model.outList: use the ModelOutlist_creator interface to calculate the new model grid cell locations of the named monitoring stations for which output is desired
- gridmapping.txt: run the GridMap preprocessor application to generate the new linked list of the SFWMM grid cells that are mapped to the grid cells of the new ELM application (for boundary condition data on meteorological inputs and stage at the periphery of the new domain)

While the data modification/input methods are generally simple, the details of the steps, including the necessary data quality assurance, are beyond the scope of this User’s Guide.

10.8 Appendix

10.8.1 Driver.parm configuration file

The following table contains extended documentation of all of the adjustable parameters in the “Driver.parm” input file that is input to the model to configure a simulation run.

Parameter	**Brief metadata**	**Extended instructions**
/MyOutputPath/	{output path (absolute path, w/o ProjName) }	Path for model output can be on any file system. If user requests many animations at high output frequency (e.g., 20 variables, daily), a local hard disk directly attached to host machine can become important to model run time.
1/1/1981	{Sim start date (yyyy/mm/dd), min= 1965/01/01 }	User is informed of error if attempting to start simulation outside of the range of available boundary condition data (1/1/1981 or 1/1/1965 through 12/31/2000, depending on project).
12/31/2000	{Sim end date (yyyy/mm/dd), max= 2000/12/31 }	User is informed of error if attempting to end simulation outside of the range of available boundary condition data (1/1/1981 or 1/1/1965 through 12/31/2000, depending on project).
00/00	{Sim re-init date (mm/dd)(no Position Analysis, mo=00)}	Used only in "Position Analysis", in which simulation is re-initialized annually on a given month/day. If month=00, Position Analysis is not invoked. Position Analysis is not fully updated/supported in v2.5.
ELM	{model name (needs to match CanalData input files)}	Used in distinguishing subregional model projects (e.g., ELM_wca2@500m) from the default regional "ELM". Used primarily to ensure model is using correctly geo-referenced data in CanalData.* input files in subregional projects.
Model version= v.2.5	{model version (e.g., v.2.1)}	Model version identifier to label output files.
CellArea= 1000000.0	{grid cell area, m^2}	The area of an individual model grid cell; standard regional application is 1,000,000 m^2 (1 km^2).
budg_Intvl= 0.0	{interval (julian days), BIR stats (0=calendar-month)}	Time interval for summary calculations in all budget output files (./Budget/budg_*) in Basins/Indicator Regions (BIR). Value >0 is julian day interval; a value=0.0 is an exact calendar-month interval (accounting for leap years etc.).
avg_Intvl= 30.0	{interval (julian days), cell-avgs (0=calendar-month)}	Time interval for all internally-calculated temporal means in BIRavg output files (./Budget/BIRavg*) in Basins/Indicator Regions (BIR). Value >0 is julian day interval; a value=0.0 is an exact calendar-month interval (accounting for leap years etc.).
seed= 568	{random number seed; UNUSED in current	UNUSED

	version}	
dt= 1.0	{time step (days, use 1.0) for vertical fluxes}	The model time step for vertical solutions only. The dt should remain at 1 day for any scale application.
hyd_iter= 12	{**EVEN number**, number of horiz iterations per dt}	The number of iterations, or time slices, per dt for horizontal solutions such as cell-cell overland flow. To determine the appropriate value for a new application, see the ELM documentation for theoretical estimates for different model scales and expected velocities. The 1 km^2 regional ELM application uses hyd_iter = 12 (i.e., a 2 hour time step).
debug= 2	{0:Minimal 1:BasinChek 2:Default 3:More 4:Canal 5:Lots}	The choice of how much information to print to a debug (text) output file (./Debug/DriverX.out, X'th simulation, X=1 in a standard run w/o Sensitivity Analysis). The recommended standard is debug= 2. Higher values will produce very large volumes of information and should be used in relatively short simulations. **See text below this Table for details.
debug_point= 62 43	{focal cell (row col) for Driver1.out if debug>2}	The row-column coordinates of the focal grid cell for 5x5-cell windows of output data that are written to the (text) debug file at high values of the debug parameter.
S_ParmName=NONE	{Sensitivity analysis: "NONE", "ALL", or ParameterName}	Invoke an automated sensitivity analysis on "ALL" parameters in the input data file "SensiParm_list", or on a single parameter whose exact name is provided, or "NONE" for a standard, single simulation run. See text of User's Guide for details.
HabSwitchOn= 0	{Habitat switching (succession) on=1, off=0}	Invoke the habitat switching (succession) module of the model. See text of Model Structure Chapter in the ELM documentation for some details on module.
WatMgmtOn= 1	{Water management and canal network on=1, off=0}	Invoke the water management modules, with flows through water control structures in the network of canal/levee vectors. Normally this is "on". If turned "off", all water management network topologies and managed flow dynamics are inoperative, and thus the only flow constraints are those imposed along the periphery of the model domain (aka a simulation of the "Natural System" that is not compartmentalized).
Scenario= calib	{scenario/alternative name (case sensitive)}	Model scenario (alternative) identifier to label output files.
Scenario modifier= myRun	{scenario/alt modifier or descriptor}	An additional descriptor of specifics to add to the model scenario (alternative) identifier to label output files.

Sectors= 1 0 7 10 9 2 8 12 4 99;		The (left-to-right) sequence of calls to ecological modules (sectors) in the time loop of the simulation. See text of Model Structure Chapter in the ELM documentation for details on the structure of the model time loop, and summaries & details of each module. A single-phrase description of each module is given below in this table (and the "Driver.parm" file).
{Below are not input fields; for descriptive purposes only}		
Sequence for calling modules:	1 0 7 10 [13] 9 2 8 12 4 99	Recommended sequence of module calls. See text of Model Structure Chapter in the ELM documentation for details on the structure of the model time loop.
Module #0	hydrology: horiz raster fluxes (& water management if it is on)	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #1	global forcings: vertical fluxes (& succession if it is on)	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #2	algae/periphyton: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #4	DOM/DOP: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #7	hydrology: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #8	macrophytes: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #9	phosphorus: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #10	salt/tracer: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #12	Floc: vertical fluxes	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #13	ESP P settling model mode, do NOT invoke 2,4,8,9,12	See text of Model Structure Chapter in the ELM documentation for details on module.
Module #99	summary budget & stats	See text of Model Structure Chapter in the ELM documentation for details on module.

10.8.1.1 **Debug levels:

- debug =0 Echo short console info on iteration# etc, print critical error/warning info. USE WITH CAUTION.
- debug =1 Report mis-configured basin flows. Currently same level as debug=2.
- debug =2 DEFAULT for general use, more warnings etc.
- debug =3 Echo long console output, prints additional (non-critical) errors/warnings to DriverX.out (for X'th simulation run) file
- debug =4 Prints details of cell vertical and/or horizontal flux data, and details of indiv canal fluxes, to DriverX.out (for X'th simulation run)
- debug =5 Prints grid_map information, and prints to another canal debugging file for special purposes

10.8.2 Environment variables

The required environment variables are the following:

Environment variable	Unix path	Description
ELM_HOME	/My/Directory/	The absolute path to the "home" directory where you install the source code (and by default, the data of multiple projects) of ELM. Can be anywhere on the user's networked file system(s).
ELM_ARCHIVE_PATH	/Any/Directory/arc_out/	The absolute path to the directory where simulation run "keepers" of (multiple) ELM project(s) are archived (and thus not overwritten in subsequent simulation runs!). Can be anywhere on the user's networked file system(s). Suggested default during ELM installation was within the $ELM_HOME.

The highly recommended addition to the user's path (to executables) is:

Add to user's path env.	Description
$ELM_HOME/SME/scripts/	The location of all ELM scripts.

The optional environment variable is the following:

Environment variable	Unix path	Description
ModelPath	/Anywhere /SME/Projects/	The absolute path to the (multiple) project(s) of ELM data and executables. Can be anywhere on the user's networked file system(s). For testing different code sets with one single data location, we can set the $ModelPath as a system environment variable. In the default (distribution) version, the $ModelPath is determined from $ELM_HOME and is not needed as an environment variable.

10.8.3 Directory/file structure

The complete directory structure of an ELM project.

Directory structure	File type	File descriptions
$ELM_HOME/		
include/sme/	source code	header files
SME/		
scripts/	source code	unix shell scripts
SMDriver/Sources/		
Driver_Sources/	source code	main program, utilities
SpatMod/	source code	spatial fluxes
Tools/	source code	I/O tools
UnitMod/	source code	unit model
Dbases/	databases	databases for data export to model
Projects/		
ELM2.5/		
Data/	input data	all input data files (maps in subdirs)
Map_bin/	input data	all map binary arrays
Map_cats/	input data	all map category definitions
Map_head/	input data	all map header definitions
Map_hist/	input data	all map metadata/history
RunParms/	input data	runtime configuration parameters
Load/	executable	compiled model executable
Output/ [1]		
Animation1...60/	output data	multiple directories to hold map outputs
Budget/	output data	budgets and preset Performance Measures
Canal/	output data	canals and structures
Debug/	output data	debug-related
PtSer/	output data	point (cell) time series
$ELM_ARCHIVE_PATH/		
ELM2.5/		
MyFirstRun/		
VarNameA	output data	archived map output of VarNameA
VarNameB	output data	archived map output of VarNameB
VarNameXYZ	output data	archived map output of VarNameXYZ
Budget/	output data	archived budget and preset PMs
Canal/	output data	archived canal and structure summaries
Debug/	output data	archived debug-related files
PtSer/	output data	archived point (cell) time series
Input/	input data	archived input data (subset, parameter files)

[1] Output directory may be anywhere, including outside of $ELM_HOME

10.8.4 Software recommendations

In order to interpret input and output data, it is recommended that the user at least has access to the Open Source software of the GRASS GIS and the Open Office Calc spreadsheet system. Both are available as pre-compiled binaries for a number of computing platforms, and thus are very simply installed.

10.8.4.1 Geographic Information System (GIS)

The GRASS[10] GIS can be used to analyze model input and output data. GRASS excels in raster data processing and analysis, with many useful functions for landscape analysis. It also fully supports the vector (canal) and point (water control structures, monitoring locations) data required for ELM. Through the use of unix symbolic links between the GRASS and the ELM data directories, the ELM directly reads GRASS project data files (uncompressed binary data and text header) as model input. However, no GRASS-specific encoding of binary information is used, and thus the data files may be opened with any program that can read binary data arrays. Scripts are available to directly input and visualize the ELM canal vectors in GRASS. Other GIS and/or spatial mapping software tools can serve similar purposes.

10.8.4.2 Animated visualization

The GRASS GIS and its associated "xganim" animation program can be used to visualize animations of the output. We also use other tools, such as the Open Source OpenDX[11] and IDL[12] for such purposes, as both have advanced functionality relative to xganim.

10.8.4.3 Data management

While MySQL[13] is our targeted relational database system, we currently use the functionality of spreadsheet data systems in Open Office Calc[14] (which is fully compatible with Microsoft Excel). FileMaker Pro[15] has been used for a relational database system for parts of ELM, but will be entirely phased out with MySQL in the future.

10.8.4.4 Advanced scripting

Python[16] (and an associated graphics library PyChart[17]) is our choice for developing object-oriented, advanced script applications for post-processing the model and other tasks.

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[10] http://grass.itc.it/ (Open Source)
[11] http://www.opendx.org/ (Open Source)
[12] http://www.rsinc.com/ (commercial)
[13] http://www.mysql.com/ (Open Source)
[14] http://www.openoffice.org/product/calc.html (Open Source)
[15] http://www.filemaker.com/ (commercial) 30-day trial version of the software
[16] http://www.python.org/ (Open Source)
[17] http://home.gna.org/pychart/ (Open Source)