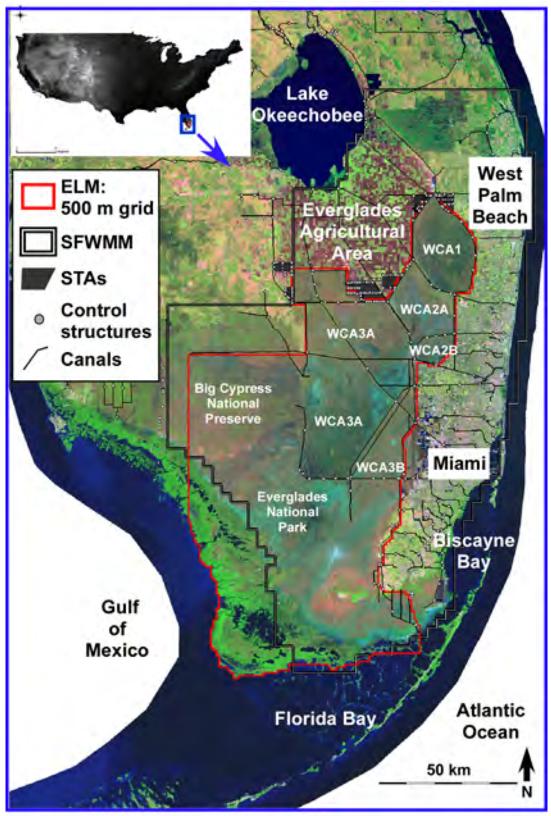
OVERVIEW VERSION OF:

Documentation of the Everglades Landscape Model: ELM v2.8.6 - Sulfate Module



http://ecolandmod.ifas.ufl.edu

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April 18, 2013

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Preface

Documentation purpose

This report documents the update of the Everglades Landscape Model (ELM) from v2.8.4 to v2.8.6 with a new sulfate module, and includes information on *supporting data, algorithms, and performance*. This document and further supporting information are maintained on the EcoLandMod web site:

http://ecolandmod.ifas.ufl.edu

We describe the code and data associated with the **sulfate water quality history-matching model performance** of the regional ELM v2.8.6, the version which is being used in to evaluate sulfate water quality responses to management alternatives for the Comprehensive Everglades Restoration Plan's Aquifer Storage and Recovery Project. (ASR) The results of that ELM appplication are to be contained in a separate documentation report that is specific to that project, to be available on the EcoLandMod web site.

This is a **documentation update, limited to describing changes that were made** in model design and data during the transition from ELM v2.8.4 to ELM v2.8.6[1]. A number of original ELM v2.5 and v2.8.4 Documentation Chapters are not included here, as their content remains unchanged; those reports are also available at the EcoLandMod web site.

The only three Chapters included in this ELM v2.8.6 Documentation Report are those that contain significant new information that is relevant to current application objectives.

Document organization

*(see ELM v2.5) Chapter 1: **Introduction** to the Everglades and the model **Goals & Objectives**.*

*(see ELM v2.5) Chapter 2: General overview of **Wetland Ecological Models**.*

*(see ELM v2.5) 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 updates to ***Data*** that are used in the new model application.
- Chapter 5: Graphical, verbal, and mathematical descriptions of the updates to ***Model Structure*** and algorithms.
- Chapter 6: Analysis of ***Model Performance*** relative to the historical period of record in the regional system (1981 - 2000).

*(see ELM v2.5) Chapter 7: Aspects of **Uncertainty** in the model and associated data, including sensitivity analysis, appropriate model expectations, and model complexity.*

*(see ELM v2.5) Chapter 8: Descriptions of **Model Application** in the regional Everglades system. NOTE: this v2.5 Chapter is outdated; see EcoLanMod web site for published applications.*

*(see ELM v2.5) Chapter 9: Descriptions of past and planned **Model Refinements**.*

*(see ELM v2.5) Chapter 10: **User's Guide** that provides the simple steps to installing and running this Open Source model.*

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[1] The last pubic release of code and documentation was for ELM v2.8.4.

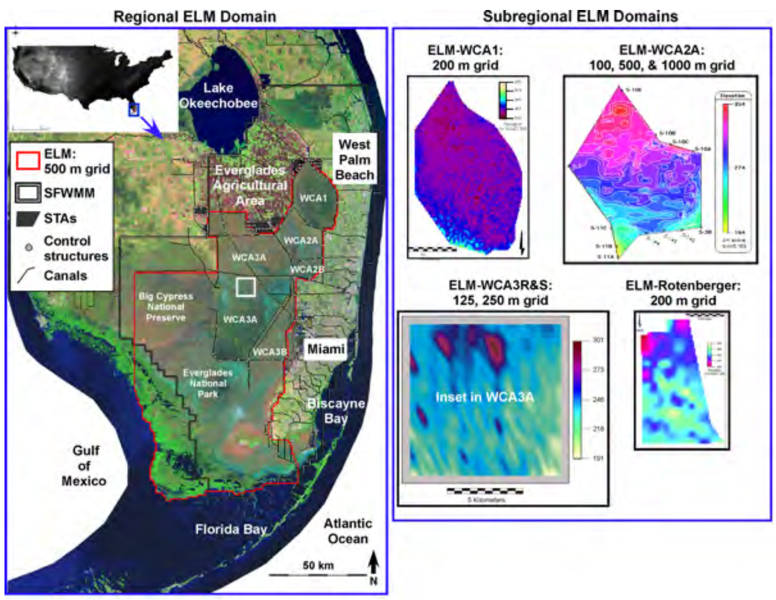
Acknowledgments

Funding for this ELM application update came from the US Army Corps of Engineers. In particular I thank M. Shafer (USACE) for providing the technical guidance in developing the sulfate module for this project, and W. Orem and D. Krabbenhoft (US Geological Survey) for their invaluable expertise that we collaboratively applied towards formulating the sulfate loss algorithms, including their extensive data observations used in the development and refinement of the sulfate module. I also express sincere thanks to the many individuals who have contributed in developing the ELM framework over the years, as cited in prior documentation reports and journal publications.

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.

To support scientific evaluations of restoration plans, computer simulation models can be used to predict the relative benefits of one alternative plan over another. One such tool is the Everglades Landscape Model (ELM). The ELM is designed to improve understanding of the ecology of the Everglades landscape, and can be applied at a range of spatial and temporal scales depending on the project requirements. 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 benefits of alternative project plans with respect to hydrology, water quality* and other ecological Performance Measures.



Existing regional and subregional applications of the ELM, including the 500 m grid resolution application developed for the regional Everglades system.

Because the ELM was designed to be explicitly scalable, it is relatively simple to adapt (spatial input map) data to accommodate the scientific objectives that may call for a particular scale of grid resolution or extent. For v2.8[2] of the model, we developed a 500 m (vs older 1 km) grid resolution regional application.

Subsequent updates included a variety of enhancements, and this latest ***update to ELM v2.8.6 includes a new module to simulate sulfate transport and fate*** in the landscape. This Documentation Report update is specific to the sulfate module, and includes the

[2] The tertiary subversion designation of the first v2.8 public release was v2.8.3.

information necessary for scientists and planners to understand this application of ELM, including *a) the ELM objectives, b) how it works, and c) how well it works*.

The fine spatial scale and very good historical performance of the model may be useful in a variety of projects involving Everglades synthesis and management. Of particular interest with respect to ecological processes and patterns, this scale of ELM hydrologic output exhibited detailed spatial patterns of flow, with improved connectivity among and within habitats (such as sloughs) relative to the 4x (ELM v2.5) or ~40x (SFWMM v5.4) coarser-scale resolution hydrologic models previously available for the greater Everglades region.

The **new sulfate module demonstrated excellent model "skill"** in hindcasting sulfate concentrations in the regional landscape (median offset, or bias, in marshes was 0 mg l^{-1}), consistent with performance of other ELM water quality modules. We are using this fine-scaled regional application to help evaluate multi-decadal, landscape sulfate water quality responses to future management alternatives for the Comprehensive Everglades Restoration Plan (CERP) Aquifer Storage and Recovery (ASR) project.

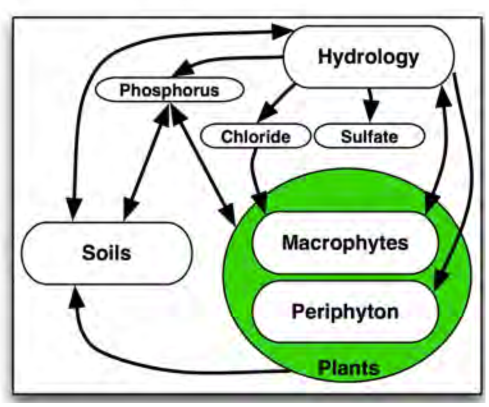
Model Goals (see http://ecolandmod.ifas.ufl.edu/background)

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

Model Design (see http://ecolandmod.ifas.ufl.edu/models)

• Can be applied at multiple spatial or temporal scales, for regional or subregional evaluations
- o Regional application at fine resolution (40x finer than SFWMM[3])
- o Multi-decadal (36-yr) simulation period

• Combine physics, chemistry, biology – *interactions*
- o *Hydrology*: overland, groundwater, canal flows
- o *Chloride & sulfate*: transport and fate
- o *Phosphorus*: cycling and transport
- o *Periphyton*: response to nutrients and water
- o *Macrophytes*: response to nutrients, chloride and water
- o *Soils*: response to nutrients and water



[3] South Florida Water Management Model, the widely-accepted simulation tool used for regional evaluations of water management alternatives

- Combine ecological research with modeling
  - research advances led to model refinements
  - model output aided research designs

Model Reliability (see http://ecolandmod.ifas.ufl.edu/publications)

- Excellent performance (1981 - 2000 history-matching, ELM v2.8.6)
  - *Hydrology*: the offset (median bias) of predicted and observed values of water stage elevations in the marsh was 0 cm
  - *Water quality*: the offset (median bias) of predicted and observed values of phosphorus in the marsh was 0 ug L^{-1}; chloride was 8 mg L^{-1}; **sulfate** was 0 mg L^{-1}
- 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

Model Reviews (see http://ecolandmod.ifas.ufl.edu/publications)

- Open Source
  - All ELM data and computer source code freely available on web site
  - Requires only Open Source (free) supporting software
- Publications
  - 1996-2012: Peer-reviewed scientific journals and book chapters
  - 1993-2013: Technical reports published by SFWMD and UF
- CERP[4] Model Refinement Team
  - 2003: Recommended independent peer review
- Independent Panel of Experts
  - 2006: Peer review of ELM by an independent panel of experts
- CERP Interagency Modeling Center
  - 2007: Review of ELM for CERP applications

Model Application (see http://ecolandmod.ifas.ufl.edu/projects)

- Specific **model objectives** (Performance Measures, multi-decadal scales)
  - **Fine-scale hydrologic** output for use in "driving" other ecological models
  - **Phosphorus** 1) water column concentrations and 2) accumulation in soils along spatial gradients
  - Other ecological Performance Measures as needed for projects: **soil accretion/loss**; **vegetation succession**; **periphyton** dynamics; **sulfate** dynamics

[4] Comprehensive Everglades Restoration Plan

- Appropriate interpretation
    - **Relative comparisons** of Performance Measures under scenarios of alternative water management plans, at multi-decadal, landscape scales
- Recent applications
    - ELM v2.8.1 application to large marsh impoundment near **Davis Pond, Louisiana**, 30 m grid resolution; initial application for use in evaluating **landscape evolution scenarios** in a highly managed coastal marsh
    - ELM v2.8.2 application to subregional domain of **Water Conservation Area 1**, 200 m grid resolution; evaluated hydrologic and water quality responses to **simple management & restoration scenarios**
    - ELM v2.8.4 application to **regional Everglades**, 500 m grid resolution; evaluated water quality and other ecological responses to **CERP Decomp project** Alternatives
    - ELM v2.8.4 application to **regional Everglades**, 500 m grid resolution; for **SERES project**, evaluating water quality and other ecological responses to novel CERP project Alternatives
    - ELM v2.8.5 application to **southeast Spain** region, 200 m grid resolution; evaluating **water resource sustainability** in response to land use & climate change
    - ELM v2.8.6 application to **regional Everglades**, 500 m grid resolution; evaluating sulfate water quality responses to **CERP ASR project** Alternatives

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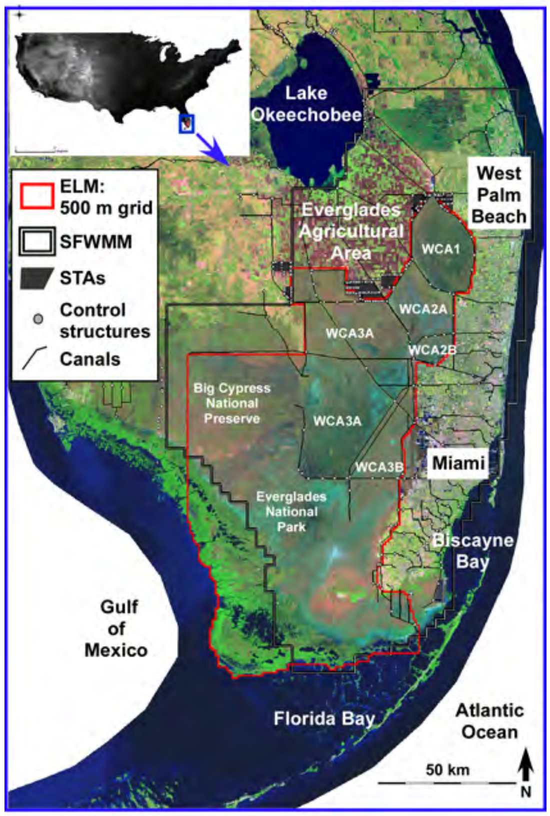
Chapter 4: Data

Ecological Landscape Models



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4.1 Overview

The focus of this Chapter is the description of changes to data used in the 500 m resolution regional ELM v2.8.6 application, relative to those documented for the ELM updates from v2.5.2 through v2.8.4.

For this ELM v2.8.6 regional application, we added a new module of sulfate losses from the surface water (see Chapter 5 Model Structure), and that module has no affect on any of the other simulated hydrologic, biogeochemical, or biological dynamics.

The only changes from v2.8.4 to v2.8.6 are the addition of this sulfate (SO_4) module. Thus the only data changes were the additions of sulfate boundary conditions, a net settling rate map, and observed data for use in calibrating the model performance for sulfate concentrations in surface waters. This ELM v2.8.6 Data Chapter thus makes extensive reference to the regional ELM v2.5.2 and v2.8.4 Documentation Reports' Data Chapters, which are available at:

http://ecolandmod.ifas.ufl.edu/publications

For reader convenience, several fundamental data components (e.g., model domain map) are copied here from the prior v2.8.4 documentation report. New sulfate data components are highlighted in red font.

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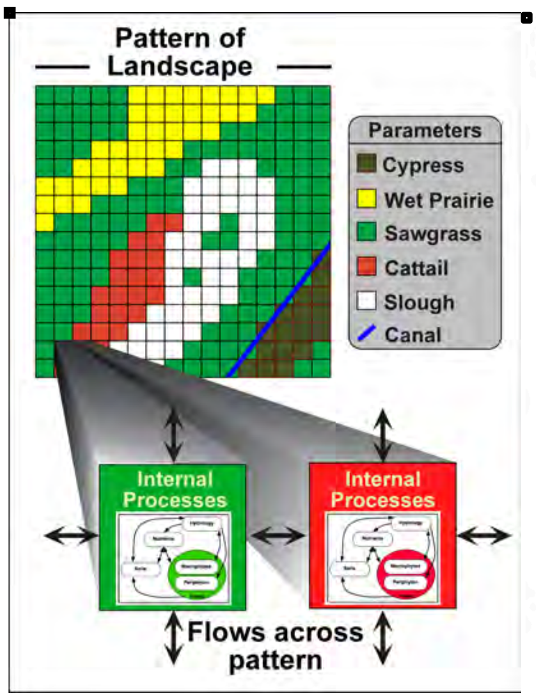
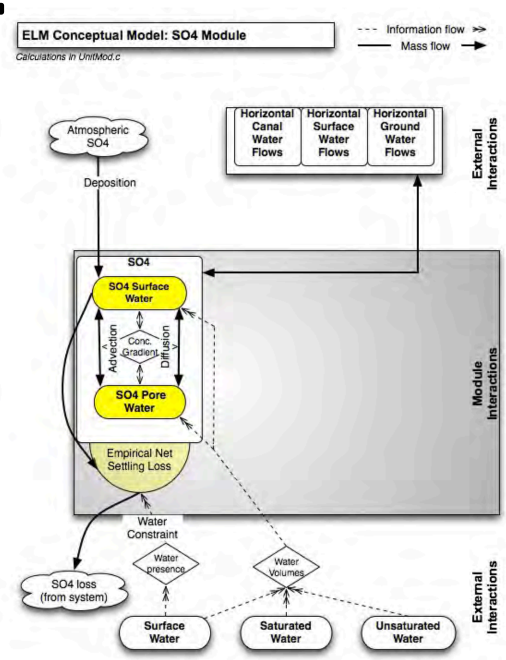
Chapter 5: Model Structure





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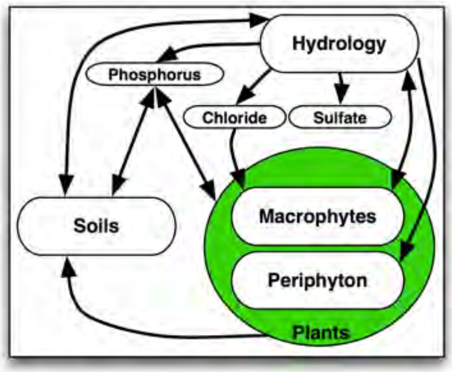
5.1 Overview

The focus of this Chapter is the description of a new sulfate loss module. For this ELM v2.8.6 regional application, we added a new module of sulfate losses from the surface water, and that module has no affect on any of the other simulated hydrologic, biogeochemical, or biological dynamics.



The sulfate (SO_4) module simulates the "vertical solutions" of sulfate dynamics in surface water and groundwater (saturated and unsaturated) storages within a unit grid cell. The modules uses the same equations as the ELM v2.8.4 phosphorus and chloride (vertical solution) modules for a) advection of sulfate with downflows and upflows among surface and ground- water storages, and b) bi-directional diffusion of the constituent across the surface water and groundwater interface. To simulate loss of sulfate from the surface water storage due to soil microbial sulfate reduction, we assume a first-order net settling loss, aggregating all biological and biogeochemical processes in a single parameter. The sulfate loss occurs whenever surface water depth is greater than a threshold parameter value (currently 1 cm depth).

The horizontal (grid cell-to-cell) fluxes of advection and dispersion are simulated using the same equations as those for chloride and phosphorus constituents. A detailed mass-balance budget module provides the same budget (post-processing) analyses as that for chloride.

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 for ELM v2.8.6 serves to update the Model Structure Chapter 5 of the ELM v2.8.4 and ELM v2.5 Documentation Reports, which are available at: http://ecolandmod.ifas.ufl.edu/publications. Therefore, this is not a "stand-alone" document on the overall model structure, but simply describes the new sulfate loss algorithm. For reader convenience, we also provide an updated table summarizing all code revisions since ELM v2.5.2.

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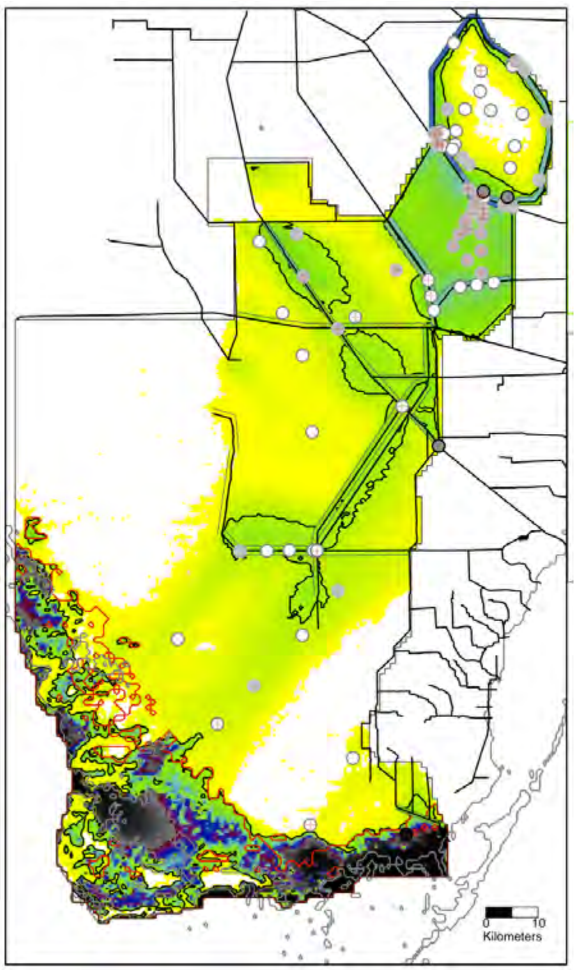
Chapter 6: Model Performance



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6.1 Overview

As described in the Introduction Chapter 1 of the ELM v2.5 Documentation, an overarching goal of the ELM is to understand and predict ecological dynamics across the greater Everglades landscape. For the current ELM v2.8.6, we added a new module for marsh sulfate dynamics, expanding on the functionality of the ELM.

In its regional (~10,000 km^2) application at 0.25 km^2 grid resolution, the current ELM version 2.8.6 was developed to assess relative differences in sulfate dynamics associated with Everglades water management plans - at decadal time scales. As described in the Model Structure Chapter 6, the sulfate module does not affect any other hydro-ecological modules in the ELM (documented in the last update, ELM v2.8.4). In this update to ELM v2.8.6, we maintained all data that affected the previously-documented calibration/validation hydro-ecological performance characteristics of the model. Therefore, this model performance update applies only to the newly added sulfate module.

The overall approach of (developing and) calibrating the ELM for hydro-ecological dynamics was described in Chapter 6 of the ELM v2.5 Documentation Report. For this update, we developed and calibrated the new sulfate module, using the same graphical and statistical methods used previously for other water quality (phosphorus and chloride) constituents.

The sulfate model performance characteristics (with moderate rates of microbially-mediated losses) were expected to be similar to those of the conservative tracer of chloride, and the rapidly-assimilated phosphorus marsh dynamics (due to high uptake and cycling via microbial and plant utilization).

The sulfate module met those performance expectations. The **median seasonal relative bias (observed minus simulated) of sulfate predictions for all stations was 0 mg L^{-1} in marshes and -2 mg L^{-1} in canals**; the median seasonal relative bias was -12% and −8% in the marsh and canals, respectively. For comparison, the median seasonal relative bias in chloride predictions was 11% in both the marsh and canals, with the same phosphorus prediction statistics being 1% and 2% in marshes and canals, respectively.

Thus, the model “skill” in predicting landscape sulfate dynamics at these decadal time scales is consistent with other model performance characteristics. Given these successful performance results, we are using this fine-scaled regional application to help evaluate landscape sulfate water quality responses to future management alternatives for the Comprehensive Everglades Restoration Plan (CERP) Aquifer Storage and Recovery (ASR) project.

NOTE on this Model Performance Chapter 6 update: the following sections are mostly copies of text from ELM v2.5.2 and v2.8.4 documentation, and are provided simply for reader convenience: Sections 6.2 (Performance expectations), 6.3 (Performance evaluation methods), 6.4 (Model updates), and 6.5 (Model configuration)