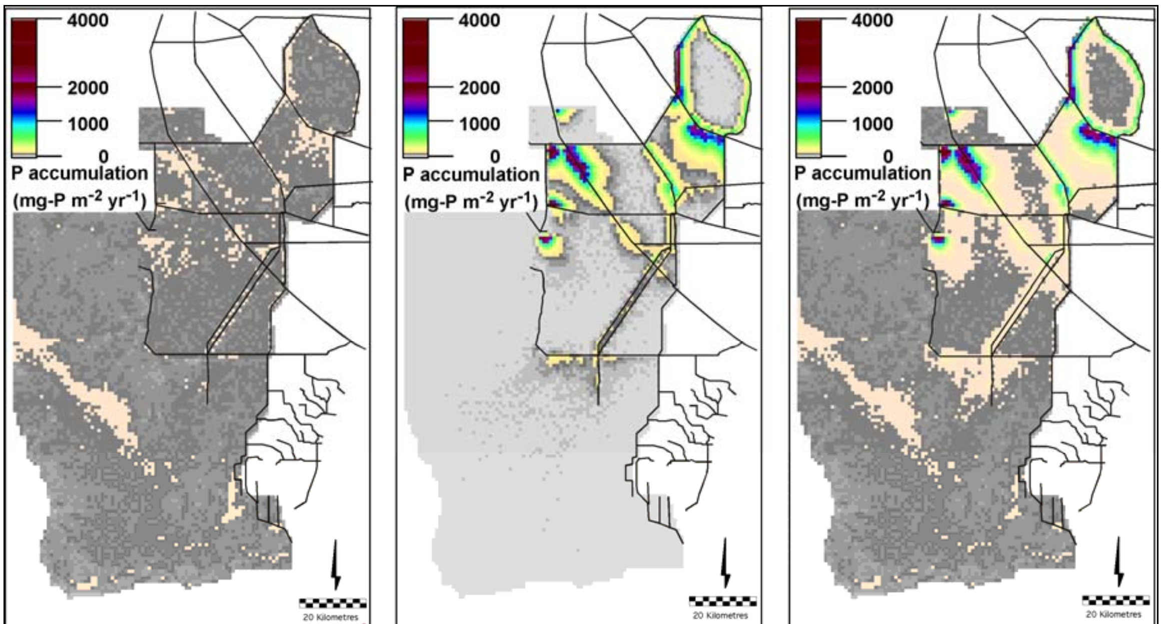
Documentation of the Everglades Landscape Model: ELM v2.5

Chapter 8: Model Application



10 ppb inflows | Difference, Historical minus 10ppb scenarios | Historical inflows

http://my.sfwmd.gov/elm

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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.

[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

[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

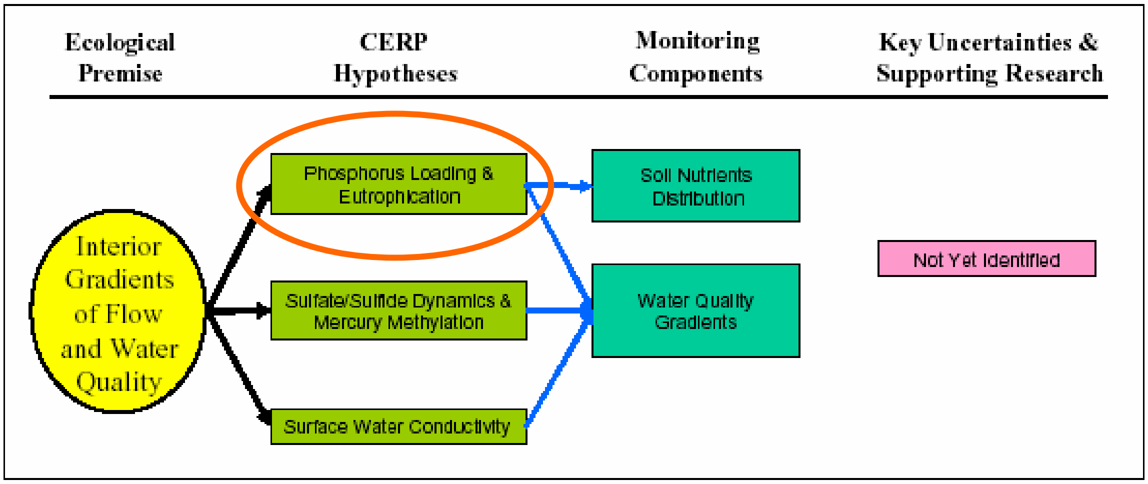
The text in this section describes the surface water phosphorus concentration Performance Measure (GE-4) which is under review by the CERP REstoration COordination and VERification group (May 2006). The format and text were copied from the formal Performance Measure documentation (version dated July 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 $ug \cdot L^{-1}$ (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 $ug \cdot L^{-1}$.

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. [...]*

[8] Tracer of flows that bypass the STAs, for purposes of local flood control or distant water supply.

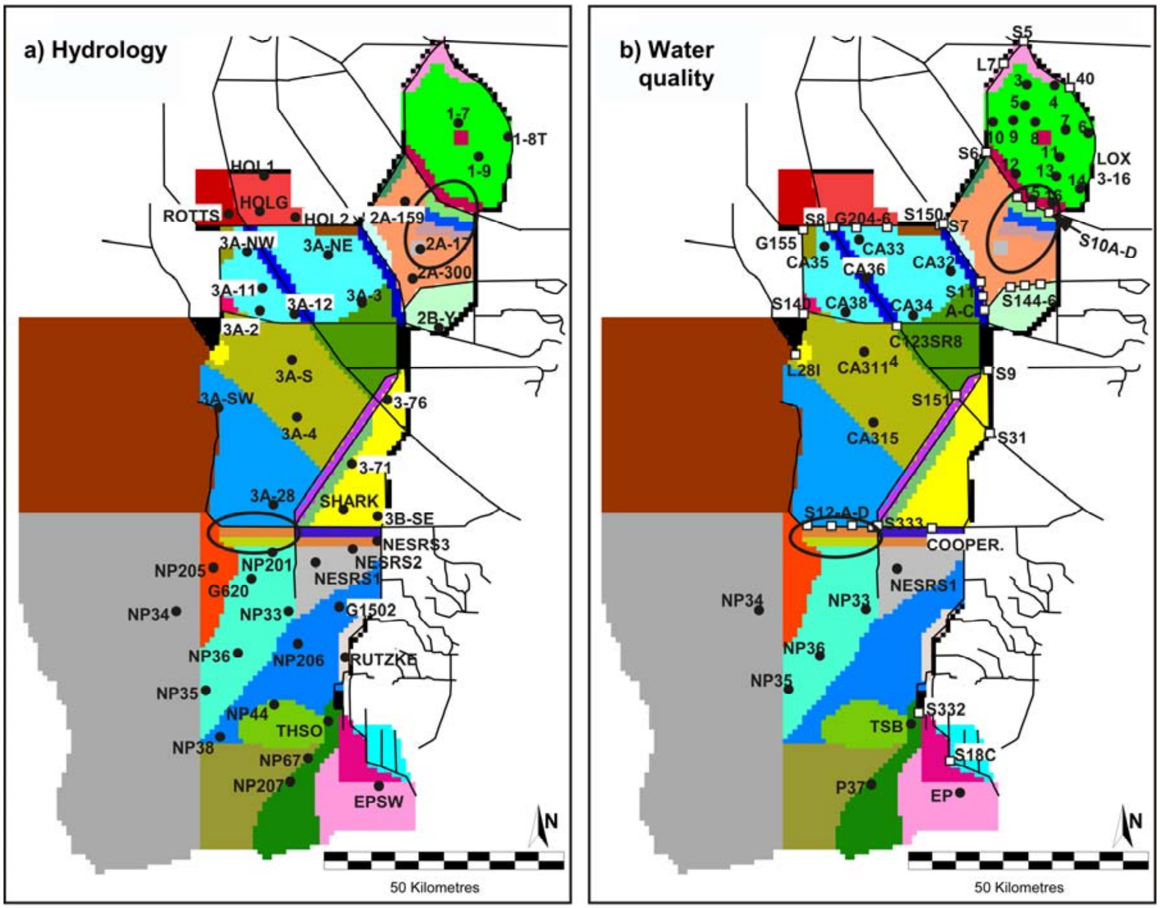

Figure [8.1]. Shaded polygons of indicator regions, and point locations in the Everglades for monitoring a) stage; b) water quality. Circled indicator regions are used in example analyses of model scenario runs. [Figure from Fitz et al. (2004)].

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*$^{-1}$*.*

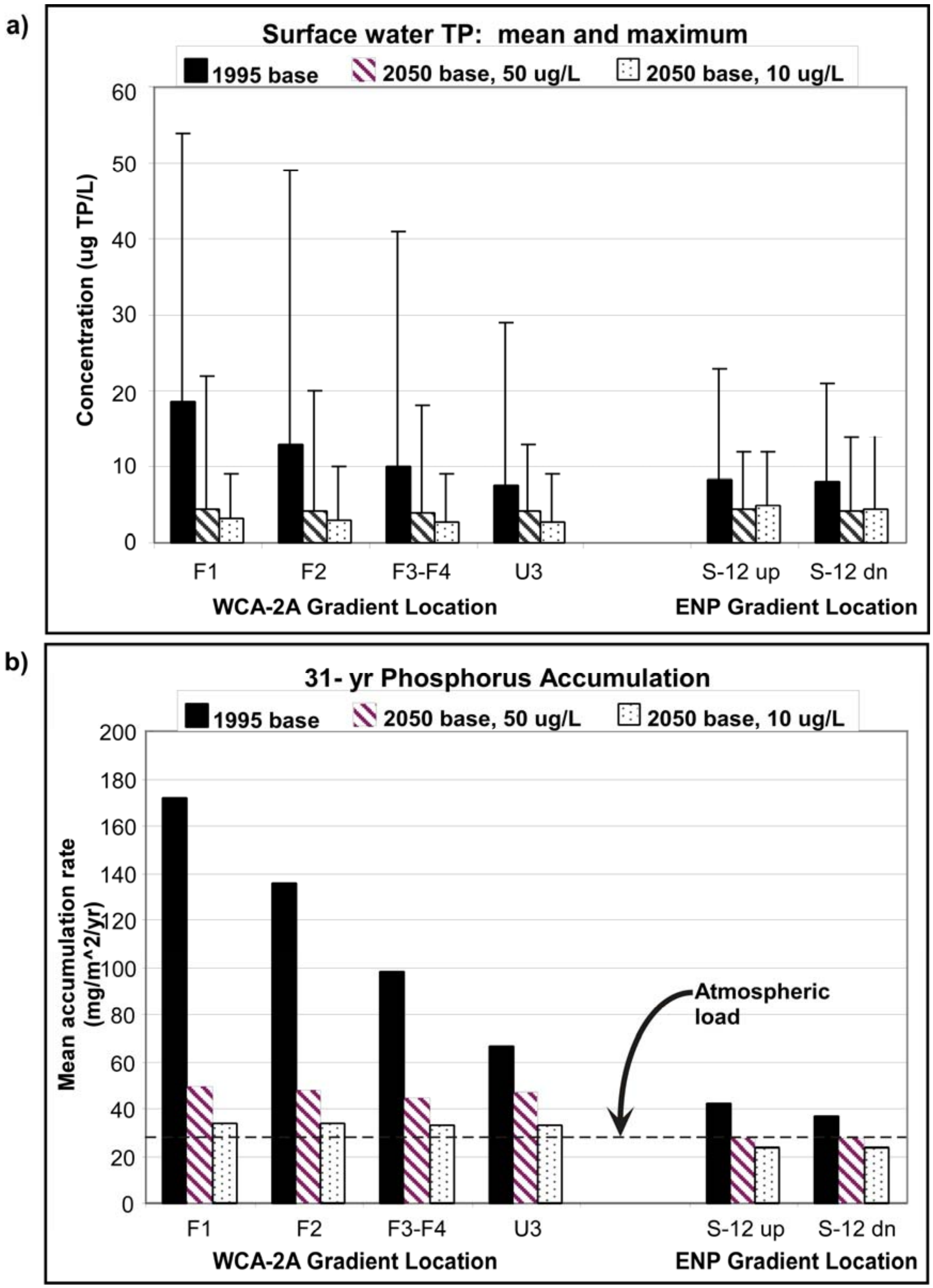

Figure [8.2]. Model (version 2.1) scenario results in the gradients of indicator regions in WCA-2A and in ENP: a) 31-yr mean and maximum concentration of Total Phosphorus (TP) in surface water; and b) 31-yr accumulation of TP in soils and biota (with atmospheric phosphorus loading indicated for comparison). [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).

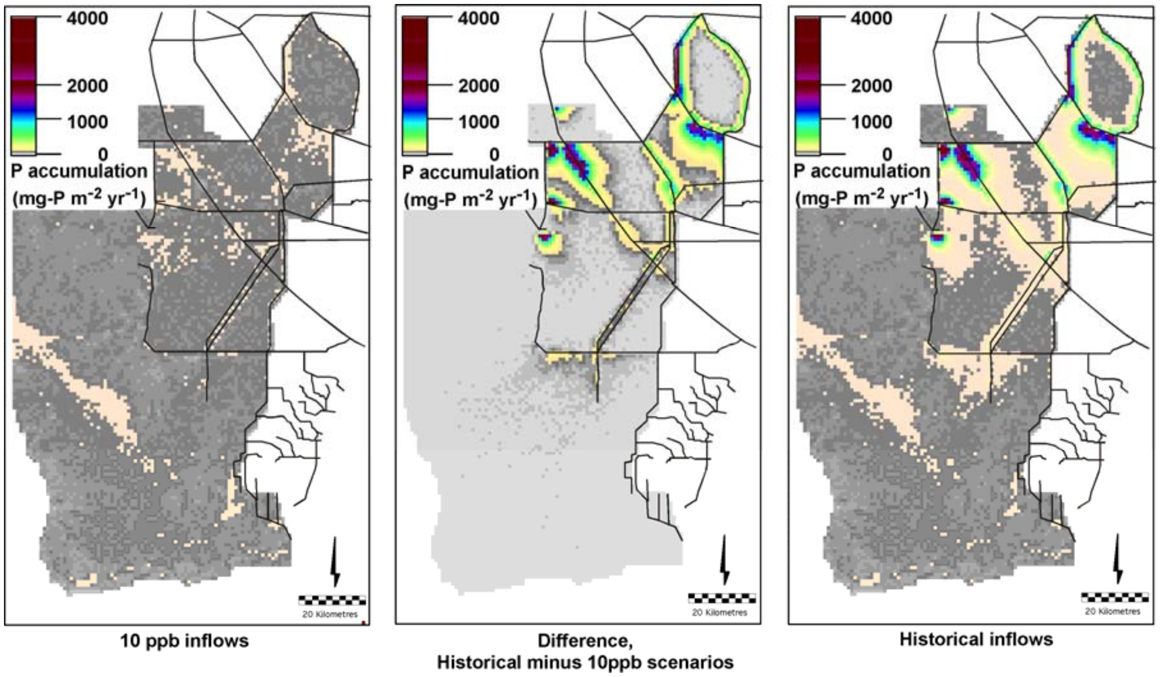

Figure 8.3. Phosphorus (P) accumulation rates during two scenarios of water and phosphorus inflows to the greater Everglades during 1981 - 2000. The left graphic shows the Low-P Alternative simulation of the accumulation that may have occurred if all inflow concentrations were fixed at 10 ug L^{-1} (ppb). 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

[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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