1.0 Performance Measure Title

Greater Everglades Wetlands Basinwide Total Phosphorus Loading and Flow-Weighted Mean Concentration in Inflows

Last Date Revised: January 28, 2007

2.0 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 1970s. At "interior" marsh sites that are generally well-removed from effects of canal inputs, water column P concentration ranged from 4-10 µg L^{-1}, and increased by an order of magnitude or more in proximity to point source discharges (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 (versus instantaneous P concentration observations) on the relative degree of eutrophication in Everglades wetlands. This justification section outlines those results and their implications for ecosystem monitoring and modeling for CERP RECOVER.

Water Column Concentration

Observations of water column nutrient concentrations do not usually capture the degree to which the underlying marsh ecosystem is *currently* assimilating nutrients. This is borne out by attempts to relate long-term surface water quality to ecosystem eutrophication. In a multi-decadal analysis of Water Conservation Area (WCA) 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. 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, 2) understand spatial and temporal trends in the degree to which marshes have assimilated significant quantities of P , and 3) calculate basin specific loading.

Load Accumulation

The 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 Everglades ecosystem. Atmospheric loads within the existing Everglades wetlands vary spatially related to proximity of urban and/or agricultural activities (Redfield 2002). Rainfall at interior sites of the Everglades has median P concentrations of 4-7 µg L^{-1} (McCormick et al. 2002), or at maximum <10 µg L^{-1} (Ahn 1999) at sites along the periphery of the Everglades. 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 likely not influenced by CERP projects.

Another method of estimating the reference P load to the Everglades is through the use of radionuclides found in the soil layers. Early estimates of long-term P accumulation (or net load) rates in areas distant from anthropogenic inputs were 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, b, 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) estimated that background P accumulation rates were approximately 20 mg m^{-2} yr^{-1}, up to perhaps as much as 50 mg m^{-2} yr^{-1}. Using the two lines of evidence, atmospheric deposition and radionuclide markers, it appears that a baseline load for the oligotrophic Everglades is most likely in the range of 10 - 30 mg m^{-2} yr^{-1}. Above estimates can serve as a reference, or background, P load

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). All experiments demonstrated significant changes to Everglades ecosystems along gradients of increasing P loads over time.

Flow is a central component of nutrient load, and thus of wetland water quality dynamics and ecosystem responses. The managed canal network 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. 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 subbasins have continuously/routinely monitored flow and P concentrations, it is feasible to continue calculating 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 loading is reflected in the accumulation of P in a local ecosystem. The concentration of P (that has accumulated) in consolidated soil has been 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). Compared to soils, other components of the ecosystem respond to P loads at faster time scales: while microbially-dominated pathways of flux may respond within 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.

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.

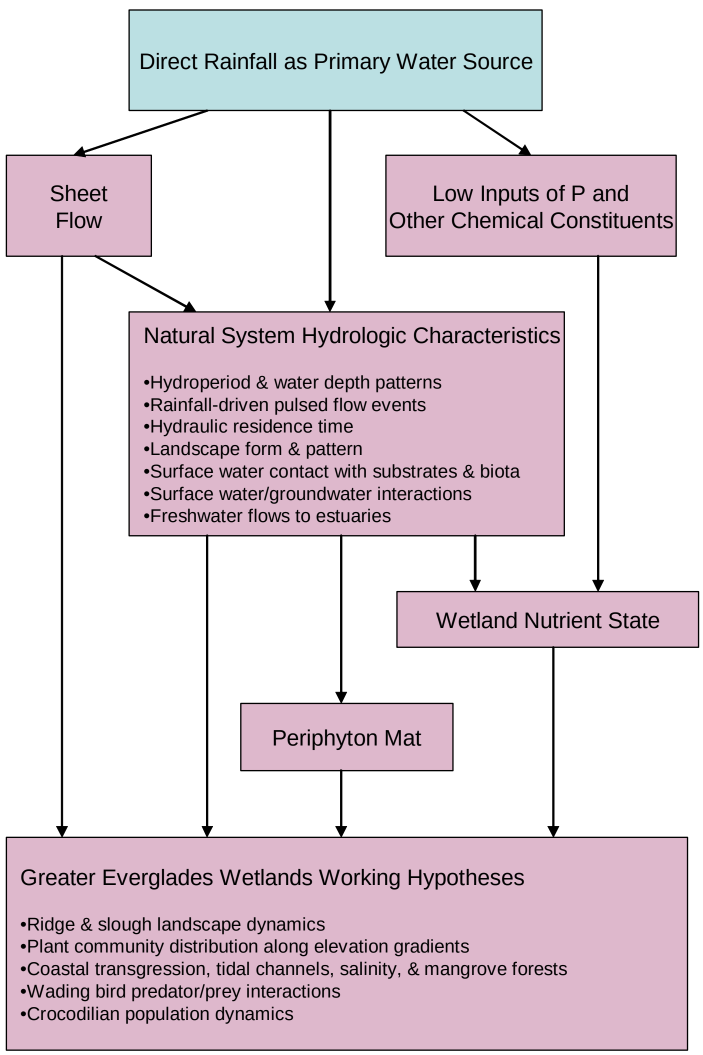
The wide range of experiments and observations discussed above show that P is assimilated and accumulated in rapid response to P loads associated with very low water column concentrations. In order to understand and protect the Everglades landscape, it appears to be imperative that we integrate the existing 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.

3.0 Relationship to CEMs and Adaptive Assessment Hypotheses

Everglades Ridge and Slough Conceptual Ecological Model stressor (Ogden 2005), Total System Conceptual Ecological Model stressor (Ogden et al. 2005)

9.2.3 Integrated Hydrology and Water Quality (RECOVER 2006) Hypothesis Cluster

Integrated Hydrology and Water Quality Conceptual Ecological Model



Hypothesis 2: Nutrient Inputs and Sheet Flow as Determinants of Wetland Nutrient State in the Everglades

The dominance of direct rainfall as the primary source of water and P, in combination with sheetflow and related hydrologic and climatic characteristics, resulted in an oligotrophic, P-limited nutrient state throughout the Greater Everglades wetlands prior to drainage.

Rationale: Increased P concentrations and loads in agricultural runoff water, and replacement of sheet flow with canal flows and point-source discharges, have produced P concentration gradients downstream of canal discharge structures, shifting wetlands from oligotrophic to eutrophic states. Water column total P concentrations are below ~10 ppb under non-enriched conditions in the Everglades. Most harmful ecological responses to P enrichment occur within a range of mean annual water column total P concentrations between ~10-30 ppb.

Hypothesis 4: Periphyton Mat as an Indicator of Integrated Hydrology and Water Quality in the Everglades

Periphyton mat structure and community composition integrate hydrology and water quality across the entire wetland system of the Everglades. Hydrology and water quality interact to create a mosaic of periphyton community types throughout the Everglades.

Rationale: Periphyton responds quickly (weeks to months) to alterations in water management and can serve as early warning indicators of ecosystem change.

Shortened hydroperiods cause:

- Reduced proportion of diatoms and green algae relative to cyanobacteria
- Increased calcareous blue-green algae, possibly reducing food value of periphyton
- Increased proportion of sediment or plant-stem associated mats as opposed to floating mats attached to floating macrophytes (such as Utricularia purpurea).
- Decreased organic ash weight ratio of periphyton

Phosphorus enrichment through increased loading causes:

- Elevated nutrient content of periphyton material
- Increased organic content of periphyton communities
- Reduced calcareous floating and epiphytic periphyton mats
- Replacement of low nutrient-tolerant species by non-mat forming filamentous green algal species

Periphyton productivity is very high in the oligohaline zone of the southern Everglades. Increased freshwater delivery may broaden this zone of high periphyton productivity.

Detection of periphyton response to changes in hydrology and water quality needs to be based on comparison to a habitat-specific baseline (i.e. ridge and slough, marl prairie, rocky glades, or oligohaline zone). In addition, the effects of grazing on the periphyton community composition should be quantified.

4.0 Restoration Expectation

In restoration of Everglades hydrology, CERP projects will maintain or reduce P loads from inflow structures, such that P 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.

4.1 Predictive 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- to 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 water and groundwater. Two relative levels of P accumulation are 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., WCAs, Everglades National Park [ENP]) provides a relative indicator of the extent to which P inputs are changing. Using water flows output from the South Florida Water Management Model (SFWMM), the concentration in Everglades source waters, such as the stormwater treatment areas (STAs), can be evaluated with models such as the Dynamic Model for Stormwater Treatment Areas (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.

4.2 Assessment Parameter and Target

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 in 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 300 - 400 mg kg^{-1} in the tissues of periphyton assemblages
- Probable eutrophication impact: P concentration in excess of 400 - 500 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.

5.0 Evaluation Application

5.1 Evaluation Protocol

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. The Everglades Landscape Model (ELM) (Fitz et al.

2003) has recently been approved for CERP use and may be used to evaluate net P accumulation and water column concentrations. Currently, structural flows into the Greater Everglades, as predicted by the SFWMM, are used as a surrogate for nutrient loading. Specific structures that represent STA outflows (and bypasses), and inflows to WCAs, and ENP will be used to evaluate total phosphorus (TP) loading to the Greater Everglades. Structures will be identified with the help of system modelers and system operations personnel. Below is a tentative list of structures and relevant descriptions. Once the structure list is refined, the Interagency Modeling Center (IMC) will provide a single structure flow output file to be used with regional evaluations.

Structure	Description	Structure	Description	Structure	Description
S5A2SO	S5AS to WCA 1	G155	L4 to WCA 3A	RTTWCA	Rotenberger to WCA 3A
S6	EAA[1] to WCA 1 or STA 2	G204	Holeyland to WCA 3A	HLYNW	Holeyland to WCA 3A
L8TCA1	L8 to WCA 1 via S5AS	G205	Holeyland to WCA 3A	HLYDS	Holeyland flood to WCA 3A
S7	EAA to WCA 2A	G206	Holeyland to WCA 3A	ST3NEA	STA 3/4 to WCA 3A
S8	EAA to WCA 3A	G123	NNRC[2] to WCA 3A	ST3TNW	STA 3/4 to WCA 3A
S150	EAA to WCA 3A	S174	L31 to L31W (S332)	S142W	S142 to WCA 3A via G123
NSIMP2	NS[3] to WCA 2	S5AWC1	LEC[4] WS[5] from Lake Okeechobee	S332D	L31N to ENP
NSIMP3	NS to WCA2	ST1WQ1	STAW1 to WCA1	S332B	L31N to ENP
S9	C11W to WCA3A	ST1EQ1	STA1E to WCA1	S332~~A~~C	L31N to ENP
S9A		L101OT	L101 overflow to WCA	S356	L31N to ENP
ACMERF	ACME[6] to WCAT[7]	S6LCWS	LEC WS from Lake Okeechobee	S356A	L31N to ENP
L28WQ	L28 (S-190) to WCA 3A	ST2OT1	STA 2 to WCA 2	S356B	L31N to ENP
S142W	NNRC (G123) to WCA 3A	ST2BYP	EAA/Lake Okeechobee to WCA 2	S18C	C111 to ENP
S140A	L28 to WCA 3A	ST6WCA	STA6 to WCA 3A	CULV	C111 to 31W

5.2 Normalized Performance Output

[1] EAA – Everglades Agricultural Area
[2] NNRC – North New River Canal?
[3] NS -
[4] LEC – Lower East Coast
[5] WS – water supply
[6] ACME – Acme Basin (?)
[7] WCAT - ?

Normalization of output is currently being discussed by the Greater Everglades Subteam and Module Team. No established normalization protocol exists. In some cases, a best and worst case scenario can be used to derive a water quality index curve upon which alternative assumptions can be overlaid to derive a performance index.

5.3 Model Output

5.4 Uncertainty

Recognition of model uncertainty is needed when interpreting the ecological significance of model output. The Model Uncertainty Workshop Report provides guidance on the potential implications of uncertainty on model output interpretation (RECOVER 2002).

6.0 Monitoring and Assessment Approach

See CERP Monitoring and Assessment Plan: Part 1 Monitoring and Supporting Research - Greater Everglades Wetlands Module section 3.1.3.1 (RECOVER 2004)

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 2005b)

7.0 Future Tool Development Needed to Support Performance Measure

7.1 Evaluation Tools Needed

A predictive model for water quality is a significant gap in the series of tools needed to evaluate performance in the Greater Everglades.

7.2 Assessment Tools Needed

The existing stations in the water quality network will be used to compare to predictive output. Additional flow measures, within the interior marshes of the Greater Everglades, could be coupled with the concentration data to better understand loading beyond (downstream of) the structures noted above.

8.0 Notes

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 approximately 0.5 cm sec^{-1}, or approximately 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.

Statistical and Simulation Methods

Statistical Assessments

Calculations of input loads are feasible when sufficient data are available on the relatively continuous input flows and P concentrations. At water control structures, 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 P 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.

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 P loss from the water column. Such an approach (Walker and Kadlec 2003) appears to reasonably simulate long-term, historical P accumulations in cases where the flows are well constrained, and the underlying mechanisms (assumptions) of P removal remain constant over long time periods. This fixed settling rate simulation method makes the critical assumption that the principal drivers of P 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 STAs that flow into the Everglades. Coupled with water flow predictions from the 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, one dimensional flows. To accommodate spatial considerations, the simple "net settling rate" method has been applied using two-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 during the 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 ELM (http://www.sfwmd.gov/org/wrp/elm). This specific settling rate approach, or that updated as in the DMSTA (Walker and Kadlec 2003), could also be incorporated into other two dimensional hydrologic models such as the Regional Simulation Model (RSM) (http://www.sfwmd.gov/site/index.php?id=342).

Mechanistic Simulation

ELM (http://www.sfwmd.gov/org/wrp/elm/) dynamically integrates simple modules of the primary ecosystem components: hydrology, water column and 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. 2003, Villa et al. 2003). Fitz et al. (2003) 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. The model has just been made available (February 2007) for CERP application.

Please note this performance measure is also related to Hypotheses 1-3 in the Wetland Landscape and Plant Community Dynamics hypothesis cluster of the Assessment Strategy (RECOVER 2006).

This performance measure supersedes and addresses GE-5 Greater Everglades Wetlands Basinwide TP Loading and Flow-Weighted Mean Concentration in Inflows (Last Date Revised: November 22, 2005).

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10.0 Acceptance Status

GE Working Group	August 4, 2005
ET	
AT	
Public Review	
Final Acceptance Date	

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