FINAL DRAFT

Everglades Nutrient Threshold Research Plan *

Research and Monitoring Subcommittees
Everglades Technical Oversight Committee

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Introduction

Research efforts to define relationships between nutrient inputs from cultural eutrophication and environmental damage to the Everglades Protection Area are identified in the Everglades Settlement Agreement. The Agreement specifies that the South Florida Water Management District and Florida Department of Environmental Regulation, with support from the National Park Service, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, and U.S. Army Corps of Engineers, will:

1. assess responses of the Everglades to nutrient inputs, and

2. determine maximum levels of nutrients that will not cause ecological imbalances.

Phosphorus is the nutrient which most often limits biologic productivity in the Everglades. Ecological communities in certain areas of the Everglades have been altered as a result of anthropogenic phosphorus loads. This study will determine a "threshold" level for total phosphorus concentration in marsh waters. Maintenance of phosphorus concentration below the threshold is necessary to avoid ecological imbalances which constitute violations of Florida Class III water quality criteria. The threshold concentration will provide a basis for regulating phosphorus discharges to the EPA.

Legal Mandates

As an applicant for a 5-year discharge permit for stormwater treatment areas (STA's) and in accordance with Section (6)(a)(1) of the Marjory Stoneman Douglas Everglades Protection Act (373.4592 FS), the District is required to "recommend ambient concentration levels ... for phosphorus appropriate to achieve ... applicable state water quality standards". These standards are set forth in Rule 17-302, Florida Administrative Code (FAC) as follows:

> **Rule 17-302.510 (5)** - "Substances in concentrations which result in the dominance of nuisance species -- none shall be present."
>
> **Rule 17-302.560 (29)** - Nutrients - "In no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna."
>
> **Rule 17-302.560 (9)** - Biological Integrity - "The Shannon-Weaver diversity index of benthic macroinvertebrates shall not be reduced to less than 75% of established background levels as measured using organisms retained by a U.S. Standard No. 30 sieve and, in predominantly fresh waters, collected and composited from a minimum of three Hester-Dendy type artificial substrate samplers of 0.10 to 0.15 m^2 area each, incubated for a period of four weeks; ..."
>
> **Rule 17-302.560 (21)** - Dissolved Oxygen - "In predominantly fresh waters, the concentration shall not be less than 5 milligrams per liter. ... Normal daily and seasonal fluctuations above these levels shall be maintained in both predominantly fresh waters and predominantly marine waters."

Phosphorus-enriched discharges from the EAA to the EPA are documented to have caused or contributed to violations of at least four of these criteria (Nearhoof, F.L., "Nutrient-Induced Impacts and Water Quality Violations in the Florida Everglades", Water Quality Technical Series, Volume 3, No. 24, Florida DER, Draft, April 1992).

The Settlement Agreement reinforces this requirement in Section 11.A.1., specifying that research must be conducted to:

> "numerically interpret the narrative Class III nutrient water quality criteria (i.e. the nutrient levels which cause an imbalance of flora or fauna in the units of the EPA)."

In Section 1.F., the Agreement defines imbalance of flora or fauna and specifies that:

> "Numerical interpretation of imbalance shall specifically include an array of indices to measure sensitivity of the ecosystem to small changes in nutrients, such as nutrient cycling processes and the basic components of the Everglades ecosystem, including periphyton and other sensitive indicators of nutrient enrichment..."

Neither the Marjory Stoneman Douglas Act nor the Settlement Agreement dictates the approach to be used, the array of indices to be adopted, or the specific studies required to determine Class III water quality standards. The Agreement creates a Technical Oversight Committee (TOC) to review all monitoring, research, modeling conducted during implementation of the Settlement Agreement, including activities needed to define the phosphorus threshold. All research and monitoring projects associated with the Everglades Nutrient Threshold Research Plan will conform to the Quality Assurance/Quality Control requirements of the Settlement Agreement and Rule 17-160, FAC.

Goal

In accordance with the above mandates, the study goal is to numerically interpret Florida Class III water quality criteria by establishing a threshold total phosphorus concentration, above which an imbalance in natural populations of Everglades flora or fauna result. The study may identify values of threshold phosphorus concentration which are specific to certain habitat types and/or regions. Although focused on phosphorus, the study may also identify other water quality components which must be regulated in order to achieve compliance with Class III criteria.

Objectives

1. Compile and summarize existing data from monitoring and research programs at Everglades sites which have and have not been impacted by anthropogenic phosphorus loads.

2. Formulate and test specific hypotheses regarding threshold phosphorus concentration using these historical data.

3. Identify data gaps for determination of threshold phosphorus concentration; design and conduct expanded monitoring and experimental programs to fill these gaps.

4. Identify/develop appropriate biological, chemical, and physical indices to characterize trophic status of Everglades ecosystems. Nutrient impacts should be assessed by comparing data from stations with similar habitat (eg.,slough, wet prairies, etc.), similar hydroperiod, and different nutrient concentrations.

5. Determine the most suitable biological, chemical, and physical measurements to evaluate compliance with Class III water quality criteria, with particular attention to phosphorus.

6. Quantify the natural variability and required analytical precision of these measurements and develop statistical criteria that can be used to document violations of Class III water quality criteria.

7. Evaluate roles of related factors which may impact quantification of threshold phosphorus concentration (e.g., habitat type, hydroperiod, fire, N:P ratio, soil/water characteristics, pH).

8. Increase basic understanding of phosphorus cycling in the Everglades; characterize mechanisms and pathways primarily responsible for phosphorus retention in soils.

Implementation

A research program consisting of field monitoring, perturbations in constructed flow-ways, and laboratory experiments should be designed to accomplish these objectives. Organization of the study is depicted in Figure 1. The following components are suggested:

1. The TOC should provide general oversight, guidance, and review. The following critical functions should be performed by qualified scientists designated by TOC:

    a. **ADMINISTRATIVE COORDINATION**: monitor the overall program, provide logistic support, administrate contracts, facilitate communication among study participants.

    b. **SCIENTIFIC COORDINATION**: ensure that research elements are designed and conducted properly and in a manner which is consistent with achieving study goals and objectives; formulate specific hypotheses to be tested using field monitoring data, field perturbations, and laboratory experiments.

    c. **INTEGRATION**: provide overall decision support, including statistical aspects of experimental design, hypothesis testing, and an analytical framework to quantify imbalance and threshold phosphorus concentration.

2. **RESEARCH ELEMENTS (Field Monitoring, Field Perturbations, and Lab Experiments)** should be coordinated within this framework. These elements should develop the information necessary to achieve the goal and objectives outlined above.

3. **ANALYTICAL SUPPORT GROUPS** should be shared by research elements. Each group should provide analytical services of a certain type (e.g., hydrology, water chemistry, soil chemistry, biology, remote sensing, data management, statistical analysis, etc.). This will promote consistency of measurement techniques and data communication across research elements.

Research Elements

Key questions to be answered in the research conducted within the above framework include the following:

1. What are the most sensitive, quantifiable, and reliable indicators of imbalance in natural Everglades microbial, plant, or animal communities ?

2. Are these imbalances more directly related to (a) historical water column P, and/or (b) sediment P? Are imbalances more related to one form of P than another?

3. If 2(b), how are phosphorus concentrations in surficial sediments related to historical water-column phosphorus concentrations and/or loadings ?

4. Are responses to phosphorus in native Everglades communities significantly influenced by other identifiable factors?

Suggestions for design of field monitoring and experimental programs to address these questions and to accomplish the study goal are given below.

Field Monitoring

Extensive, though incomplete historical data exist for characterizing the hydrology, water quality, and ecology of Everglades communities and for characterizing responses to nutrient enrichment. More complete and concise summaries of existing data are needed to elucidate data gaps. These summaries should support design of future monitoring and experimental programs required to achieve the study goal.

Considerable historic data exist at marsh stations routinely monitored by SFWMD in WCA-2A (starting 1975-1985) and ENP (starting 1985). Less extensive SFWMD data also exist for WCA-1 and WCA-3A. A logical first step in designing future monitoring programs would be to summarize existing data with respect to the following:

1. location (latitude, longitude, ground elevation)

2. water quality: nutrients, inorganic species, oxygen, etc.
(medians, means, ranges, variance components, trends, correlations with stage/depth)

3. hydrology (water elevations, depths, hydroperiod, rainfall)

4. habitat type

5. vegetation & soil types

6. special studies (periphyton, macrophytes, soil phosphorus, etc.)

Determination of threshold phosphorus concentration based upon existing data is more likely to be limited by availability of biological response data than by availability of water quality or hydrologic data. Compilation and interpretation of existing information should help to elucidate additional data needs. Expanded monitoring plans should be developed and implemented accordingly. Spatial and temporal variability should be characterized from existing data sets and used as criteria in setting sampling frequency and spatial resolution.

Aside from SFWMD efforts, ENP and WCA transects studied by Florida International University provide additional background information. These studies are particularly useful for initial evaluation of phosphorus threshold concentrations because they include coupled measurements of water chemistry, soil phosphorus concentrations, soil oxygen levels, and alkaline phosphatase activity.

Coupling of hydrologic measurements with water quality and biological measurements is critical to interpretation of field monitoring and experimental data. Ground-surface elevations and daily stage records are needed to characterize hydroperiod. Although several "continuous" stage recorders have been operated in the WCA's and ENP, records are generally incomplete, as a result of equipment failure, etc.. "Preferred data sets" (term used in SFWMD's hydrologic data base) should be developed and maintained to provide a continuous record of water level at each marsh monitoring station over the period of water quality monitoring. This would involve estimation of missing values in historic stage data (using data from adjacent gauges and/or hydrologic model output) and spatial interpolation (perhaps guided by hydrologic model output). Although a continuous stage recorder may not be necessary at each monitoring site, the spatial density of such recorders should be sufficient to provide data for spatial interpolation. In addition, further development and maintenance of preferred data sets are suggested for (a) rainfall in the WCA's/ENP and (b) flow at each WCA inflow/outflow point.

Computer software interfaces should be constructed to promote timely, accurate, and concise flow of monitoring and experimental data among study participants. In particular, interfaces with the SFWMD's hydrologic and water quality data bases should be improved to provide timely access to data in readily useable and transferrable forms (e.g., spreadsheets, SAS data bases, etc.). To facilitate communication and use of monitoring and experimental data, the "Water Conditions Report" being developed by SFWMD should provide routine reports on hydrology and water quality at WCA inflow points, WCA outflow points, and marsh stations.

Local variations in topography and hydraulic conductivity may have significant impacts on flow paths and on the interpretation of monitoring data from marsh transects or individual stations. Spot and transect measurements of ground surface elevation are critical. Impacts of different vegetation types on hydraulic conductivity need to be quantified. Reconciliation of standing water depths at sampling times against daily stage records can provide indications of hydraulic anomalies. Depending upon site-specific conditions, it may be appropriate to verify flow paths along certain transects via dye studies and/or mass-balance modeling of conservative constituents (e.g., chloride). Flow-path uncertainty has greater potential impact on estimation of phosphorus uptake rates from field transects than on quantification of relationships between water-column phosphorus concentration and biological responses.

The refined monitoring program should provide data which are useful for the following purposes:

1. Assessing responses to phosphorus load controls (Best Management Practices, Stormwater Treatment Areas, etc.);

2. Assessing the adequacy of Interim and Longterm Phosphorus Limits specified in the Settlement Agreement for ENP Inflows and LNWR Marsh Stations to protect these ecosystems; and

3. Quantifying threshold phosphorus concentrations for a range of hydroperiods and variety of habitats.

The historic network of marsh monitoring stations should be augmented to reflect a range of habitats, hydrologic conditions, and water quality conditions. Stations should be selected to provide a basis for characterizing associations among biological indicators, phosphorus, and other variables. Soil phosphorus levels should be given special consideration in selecting sites which are representative of unimpacted conditions.

Based upon existing summaries of historical data, it is anticipated that the expanded list of marsh stations could include the following:

1. historical water-quality stations in WCA-1, WCA-2A, WCA-3A, WCA-3B, and ENP, to maintain continuity with previous monitoring activities and to continue development of longterm data sets useful for detecting trends and quantifying other temporal variance components.

2. additional isolated marsh stations located so as to reflect, to the extent possible, unimpacted conditions for representative ranges of habitat, region, and hydroperiod.

3. additional marsh stations located along transects extending from impacted to unimpacted areas, to characterize continuous spatial gradients in water quality, biological indicators, and physical factors.

Biological indicators, such as bacteria, periphyton, macro-invertebrates, and macrophytes, should be monitored in conjunction with marsh water quality, atmospheric deposition, and water levels. It is assumed that existing monitoring at WCA inflow and outflow structures will be continued without a reduction in intensity.

The final selection of additional marsh stations/transects should be determined after review of existing data during initial stages of the study. The following examples are suggested for consideration:

1. transects through the western, eastern, and southern borders of WCA-1 extending approximately 7 miles from the internal canal inward toward the interior marsh;

2. transects south from S10C/D and east from S7, extending approximately 10 miles into WCA-2A;

3. transects north and south from the Miami Canal in WCA-3A, at approximately 5 and 15 miles from the S-8 inflow. At least one transect northwest from S-9 in WCA-3A;

4. transects north and south from L-29, extending approximately 15 miles into WCA-3A and ENP.

Suggested variables and frequencies consistent with DER recommendations are listed in Table 1.

Field & Laboratory Experiments

As distinct from ambient monitoring programs, field and laboratory experiments can permit investigation of specific processes and responses with greater control over ranges of driving variables and extraneous factors. Experiments can provide improved bases for testing causal hypotheses. Two basic types of experiments are proposed:

1. field dosing studies in unimpacted environments, and

2. laboratory mesocosm and microcosm experiments.

Specific hypotheses to be tested experimentally should be developed by the TOC and investigators to elucidate mechanisms and facilitate causal interpretation of data collected under historical and ongoing monitoring programs.

Biological Indicators

Four categories of biological measurements have been identified as sensitive indicators of ecological imbalance: microorganisms/biogeochemistry, macroinvertebrates, macrophytes, and landscape-scale observations. Potential roles of these measurements in field monitoring and experimental programs are discussed below.

Microorganisms/Biogeochemistry

Sufficient data from the Everglades and other wetland ecosystems exist to indicate that microorganisms (algae, bacteria) and their metabolic influences on organic detrital and soil components are critical to the retention, cycling, and biological impacts of phosphorus. Organisms with the fastest turnover rates respond most rapidly to P enrichments. Their growth rates and composition provide initial indicators of imbalance. Water-column plankton, benthic microbial/algal mat communities, attached epiphytic organisms, and soil microorganisms all constitute potential indicator communities.

Integrated field and controlled experimental studies are essential to provide effective evaluation of capacities of the different Everglade subsystems to retain phosphorus under differing loadings, hydraulic conductivities, inorganic and organic water chemistries, light/macrophyte canopies, and other factors. Possible experiments include:

1. Microbial composition/productivity and phosphorus cycling/retention should be evaluated along gradients in large-scale field experiments in which P dosing is performed to evaluate responses to P variations.

2. A series of flow-way experiments in mesocosms and under controlled, highly replicated laboratory studies should be conducted to quantify effects of interactive variables on the responses of the microorganisms, algae, macrophytes, and soil/sediment retention and fluxes of P. Both steady-state and pulsed enrichment should be evaluated.

3. Combined laboratory and field experiments should be performed to quantify kinetics of P fluxes of the biota, physio-chemical uptake and retention mechanisms, and recycling of stored P. This should include evaluations of changes in microbial community respiration rates with P enrichment, as well as measurements of methanogenisis, sulfate reduction, denitrification, and other metabolic indicators of microbial activity.

4. Intensive studies of diel changes in water-column oxygen concentrations in pristine and impacted zones should be considered, both in monitoring and experimental programs. Such studies would be designed to quantify relationships between oxygen levels in water and reduced conditions in soil profiles. To accommodate potential effects of changing water levels, establishment of areal (vs. volumetric) standards for oxygen should be considered. (A given periphyton should cause a greater diel oxygen change on a volumetric basis in shallower water.)

Field monitoring and experimental studies should quantify the physical, chemical, and biological responses to P in relation to potential interactive effects of hydroperiod, P speciation (particularly organic fractions), N:P ratios, carbonate precipitation, oxygen/redox, and other parameters that may influence the quantitative definition of a threshold concentration. Field and experimental studies should be conducted simultaneously and be related to field observations of P concentration gradients.

Macroinvertebrates

Monitoring of macroinvertebrate populations in field transects and experiments provide a measure of imbalance, as reflected in the Rule 17-302.560 definition of Biological Integrity (see **Legal Mandates**). Samples should be collected using Hester Dendy samplers, cores, or discrete sweep samples at selected sites along transects to detect any consistent pattern which reflects imbalance. With enrichment, it is generally thought that increases in individual numbers are accompanied by decreases in the numbers of species and corresponding decreases in species diversity. Furthermore, macroinvertebrate species composition often reflects the degree of enrichment at a site.

Research should compare Everglades macroinvertebrate communities occurring at "unimpacted" sites with macroinvertebrate communities occurring at "impacted" sites to determine relationships between nutrient enrichment and macroinvertebrate species composition. Research should also assess nutrient-related responses in secondary productivity by macroinvertebrates of particular significance in the Everglades, such as the apple snail and crayfish.

Macrophytes

The secondary ecosystem response to nutrient enrichment should be investigated in communities that are affected over months and years instead of hours and days. Macrophytes, including *Cladium jamaicense* (sawgrass), *Typha* spp. (cattail), and *Eleocharis* spp. (spikerush) should be used in field and greenhouse experiments to determine levels of P, under various hydroperiods and water levels, that promote competitive advantage among species. Sawgrass and spikerush are proposed as indicators of the shorter-hydroperiod sawgrass prairie and longer-hydroperiod slough communities, respectively, of the natural Everglades. Currently, the relative roles of hydroperiod and nutrients in causing shifts from sawgrass and open slough to monotypic and mixed communities of cattail are not experimentally documented. Threshold P concentrations and loading, as well possible interactive effects of hydrology (duration and water level), should be identified in a series of greenhouse and field experiments. Careful measurements of growth **rates**, in addition to species composition, are essential to evaluate impacts of nutrient enrichment on macrophyte communities.

Algal, microbial, and macroinvertebrate monitoring in cores of vegetation undergoing nutrient and hydroperiod manipulations should provide additional information on direct causal effects. This should supplement ecosystem-level measurements and facilitate causal interpretation of correlations identified in field monitoring data.

Aerial photography and plant quadrat sampling along transects within the scope of the monitoring program should also address macrophyte changes associated with various nutrient levels and hydroperiod changes. This approach should include other species not accounted for in the experimental research.

Plant responses (competitive exclusion, growth, photosynthesis, nutrient uptake, etc.) to nutrients, hydroperiod, and other factors should be measured in controlled experimental mesocosms and in field dosing experiments.

Landscape-Scale Observations

Landscape-scale observations are useful for analyzing impacts of nutrient enrichment and for monitoring ecosystem recovery as a result of restoration projects. Long-term impacts of nutrient enrichment and other factors can be evaluated using historical photographic and remote sensing data. Current efforts are underway to establish statistical relationships between soil P distribution and vegetation classes based on remote sensing in WCA-2A. These efforts should be expanded to include hydroperiod, water level, and biological factors. Guided by the "ground truth" established in routine monitoring and field experimental efforts, remote sensing can be useful for describing and quantifying the entire region with respect to community types and extent of impact.

Integration & Modeling

Development of a decision-support system to compliment research elements should be considered. Such a system would provide quantitative guidance in the design of monitoring programs, design of experiments, testing of hypotheses, and integration of results. The system would invoke a combination of mechanistic models, empirical models, and expert scientific judgment and would provide an analytic basis for decisions on imbalance and phosphorus threshold. Typical applications to monitoring design and analysis are given below.

Monitoring should begin with specific questions to be addressed and then proceed to design. Specific questions regarding the phosphorus threshold should pertain to relationships between indicators of imbalance and water-column phosphorus concentrations. For example:

1. What periphyton measures (qualitative/quantitative) should be used to define imbalance?

2. What is the relationship between this (these) measure(s) of periphyton and water-column total phosphorus concentration?

Initial responses to both questions should be derived from existing information. For example, the periphyton literature may provide an initial response to the first question. The second question is to be answered based on the monitoring program; existing data should be used to provide estimates of background variability for the statistical analysis necessary for monitoring design. Essential components for the monitoring design are:

1. precisely-stated questions,

2. background estimates of variability, and

3. desired precision to be achieved in the quantity to be estimated based on monitoring.

It is possible that, for some indicators of imbalance, there is no phosphorus "threshold", or level below which biological responses are not detectable; instead, a response continuum is observed. In such cases, the design/integration could proceed by:

1. identifying unimpacted (pristine) and impacted sites for sampling, and

2. defining ranges of variables associated with impacted and unimpacted sites by applying nonparametric discriminant analysis or some other appropriate statistical technique to the monitoring data.

Efforts should be made to identify/develop appropriate models to assist in integrating relevant information on threshold response and to assist in Everglades protection efforts.

Figure 1

Threshold Study Organization

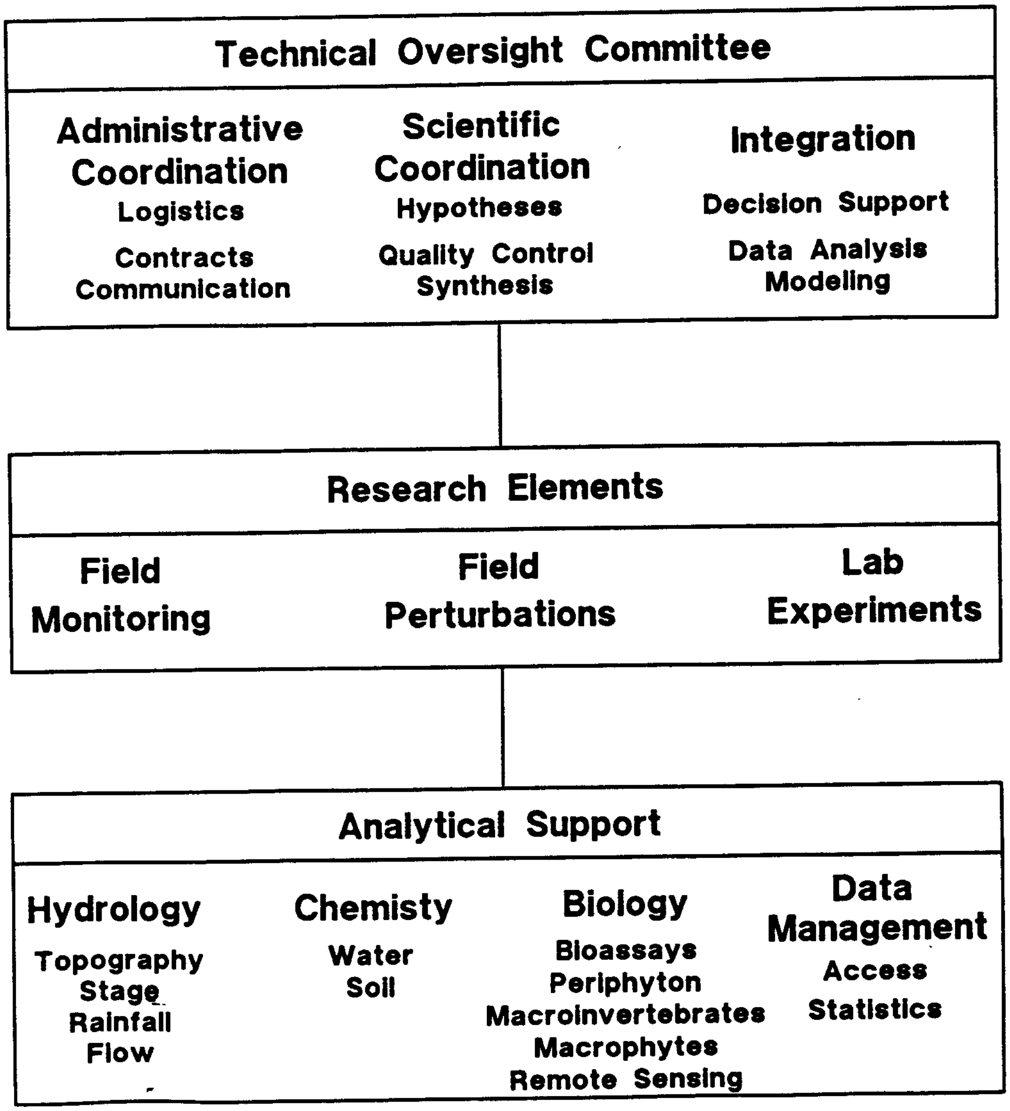

Table 1
Suggested Design for Marsh Sampling Program Consistent with DER Recommendations

Variable	Frequency
Hydrology:	
stage *	continuous
ground elevation	once
standing water depth	2 weeks
Atmospheric Deposition *	continuous
Basic Water Chemistry:	2 weeks
dissolved oxygen, temperature	
Ph (field & lab), alkalinity, hardness	
nutrient species	
SRP, TP, TDP (detection limit < 1 ppb for P < 20 ppb)	
TOC, TDOC	
TN, TKN, NH_4-N, NO_2-N, NO_3-N	
particulate carbon, nitrogen, & phosphorus	
major ions (Na, Cl, Ca, SO_4)	
DOC fluorescence & color	
total suspended solids & total dissolved solids	
corrected chlorophyll-a	
Other Water Chemistry:	
metals/methylmercury	13 weeks
pesticides/herbicides	13 weeks
anions/cations	4 weeks
alk. phosphatase (filtered & nonfiltered)	4 weeks
diel dissolved oxygen *	4 weeks
Biology:	
limiting-nutrient bioassays	13 weeks
algal growth potential	4 weeks
periphyton	4 weeks
periphytometers & cores	
enumeration, species composition	
biomass (corrected chlorophyll-a)	
macroinvertebrates (hester-dendy & cores)	4 weeks
macrophytes	
identification (may incl. aerial photography, etc.)	6 months
biomass & productivity *	4 weeks
Soil/Soil Water:	
P, N species	semi-annual
soil bulk density	semi-annual
soil accumulation rate *	once
soil metals/methylmercury	annual
soil pesticides/herbicides	annual

* at selected stations