WETLANDS AND WATER QUALITY: EPA'S RESEARCH AND MONITORING IMPLEMENTATION PLAN FOR THE YEARS 1989 - 1994

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EPA'S RESEARCH AND MONITORING IMPLEMENTATION PLAN

FOR THE YEARS 1989 - 1994

by

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ABSTRACT

EPA wishes to assure, through its research and monitoring efforts, that existing surface water quality criteria are adequate for protecting the chemical, hydrological, and biological integrity of the wetland resource. The Agency wishes to develop technical information to support designation of particular wetlands for certain "uses" (e.g., wildlife production, aquaculture). The Agency also wishes to estimate the limits of different wetland types, both constructed and natural, for intentionally or passively assimilating nutrients and contaminants.

To accomplish these objectives, this plan proposes that EPA (a) identify, from the existing knowledge base, specific substances likely to exhibit enhanced mobility and toxicity in the unique physicochemical environments which typify wetlands; (b) initiate funding agreements with researchers to perform experimental dosing of wetlands with these identified substances, for the purpose of defining wetland response and identifying the most sensitive community metrics; (c) develop and refine cost-effective procedures for rapidly monitoring wetland integrity, and quantifying the uncertainties associated with such measurements; (d) implement a broad-scale network of long-term wetland monitoring sites, to be used to define regionally expectable levels for certain community metrics; (e) compile and empirically analyze existing, landscape-level data sets with regard to the effects of wetlands on regional water quality; and (f) integrate the efforts by the iterative use of predictive, quantitative models having minimal data input requirements. These tasks will be tightly integrated to the degree that institutional considerations and funding allow. The effort will be closely coordinated with related efforts of other agencies and institutions. Serious consideration will be given to using existing research sites if these sites meet criteria for statistical representativeness.

Implementation of this effort cannot occur without modest increases in current research and monitoring budgets. If fully funded, the above effort should provide EPA, within 6 years, with a capacity to determine (a) whether existing criteria for surface waters are adequate for protecting wetlands and their functions, (b) whether wetlands regulation is succeeding, and (c) quantified limits for use of wetlands as purifiers of water, particularly with regard to their effectiveness in passively treating nonpoint runoff. With no increase in current funding, the ongoing Wetland Research Program is capable in the next 6 years of addressing only the last of these objectives, for a single wetland region or type.

Sites were included if the same ecological measurements were made (or are funded to be made) at least once every 3 years at exactly the same location. The EPA Wetlands Research Program has ongoing efforts to update this map (see p. 31) and appreciates hearing of locations not shown. Abbreviations: CE (U.S. Army Corps of Engineers); LTER (Long Term Ecological Research, funded by National Science Foundation); NPS (National Park Service); USGS (U.S. Geological Survey); DOD (U.S. Department of Defense); DOE (U.S. Department of Energy); WDOE (Washington Department of Ecology).

1. Everglades (NPS)
2. Apalachicola (U.FL, USGS)
3. Okeefenokee (U.GA)
4. Buttermilk Sound (CE)
5. Savannah River (DOE)
6. North Inlet LTER (NSF, U.SC)
7. Coweeta LTER
8. Dismal Swamp (USGS)
9. Windmill Point (CE)
10. Virginia Barrier Is. LTER
11. Nott Island (CE)
12. Niering wetland (Conn. Col.)
13. Hubbard Brook LTER
14. Houghton Lake (U.Michigan)
15. Kellogg LTER
16. Des Plaines mesocosm
17. Monroe Lake (U. Indiana)
18. Cache River (CE)

19,20,21. Ill.- Miss. R. LTER

22. N. Temperate Lakes LTER
23. Cedar Creek LTER
24. Cottonwood Lake (USGS)
25. Konza LTER
26. Bolivar Peninsula (CE)
27. Jornada LTER
28. Niwot Ridge LTER
29. Central Plains LTER
30. Miller Sands (CE)
31. S. San Francisco Bay (CE)
32. King County (WDOE)
33. Nebraska Sandhills (USGS)
34. ELF study (USDOD)
35. Rhode R. (Smithsonian)
36. Creeping Swamp (USGS)

1.0 INTRODUCTION

This document describes products which the USEPA Wetlands Research Program proposes to develop during the years 1989-1994. The general protocols used to develop these products are also described. All these products are intended to address concerns about wetlands and water quality, and are part of a larger set of products EPA is developing to deal with other aspects of wetlands.

The need for a coordinated research program on wetlands and water quality was highlighted most recently in the report of the Wetlands Forum, a group convened at the request of the EPA Administrator and representing industry, environmental, and governmental interests. The Forum (p. 46, The Conservation Foundation, 1988) recommended that:

> **"EPA and the state water pollution control agencies review the implementation of their water quality programs to ensure that they are offering adequate protection to the chemical integrity of wetlands."**

EPA's concerns about wetlands and water quality can be generally categorized as follows:

I. Water Quality Criteria to Protect Wetland Function
II. Ecological Status of the Wetland Resource
III. Waste Assimilation Limits of Wetlands

These concerns are highly interrelated. The ability of some types of wetlands to assimilate wastes (III) is well-documented. However, while assimilating wastes, wetlands may be losing some of their other functions, particularly those related to life support. Existing criteria need to be examined with regard to their ability to protect all potential wetland functions (I), and the geographic extent of functional losses that are occurring through contamination must be documented (II).

The specific products EPA would prepare include technical reports that address the following questions for a portion of the wetland types that exist in North America:

I. <u>Water Quality Criteria to Protect Wetland Function</u>

o Can technically sufficient and reproducible narrative standards be developed to protect wetland integrity, or are numeric standards essential as well?

o What are the best indicators of water quality condition?

o At what thresholds do these indicators suggest changes in wetland integrity?

- What are appropriate buffer widths for protecting wetland integrity, given various scenarios?

- Where in a wetland should the most revealing samples be collected?

- When and how should samples be collected, and what is the expected variability?

II. Ecological Status of the Wetland Resource

- What are the regional background levels of the indicators?

- What percent of the region's wetlands exceed background?

- Do prevailing background levels fully support wetland ecological integrity?

- What percent of the region's wetlands exceed criteria recommended for protecting ecological integrity?

III. Waste Assimilation Limits of Wetlands

- What transformation rates for nutrients (nitrogen and phosphorus), metals, and synthetic organics can be expected under various combinations of vegetation type, sediment type, loading rate, duration of exposure (age) and detention time?

- Consequently, what loading levels can be assimilated over the long-term? Can the ecological integrity and assimilative capacity of a heavily loaded wetland recover after a "resting period"? What determines how long this period should be?

- In what situations is aluminum a valid predictor of long-term phosphorus retention?

- Are there soil characteristics or observable landscape features which correlate with high sediment aluminum?

- Are there soil characteristics or observable landscape features which correlate with high denitrification rates?

- Are there soil characteristics or observable landscape features which correlate with high rates of long-term detention for selected metals and synthetic organics?

Technical and policy reasons for examining these particular topics are described later in this plan (in section 5.0).

2.0 PLAN BACKGROUND

EPA currently has a Wetlands Research Program based on the Administrator's approval of a formal Research Plan (Zedler and Kentula 1986). One of three components of the Plan, which covers the period 1986-1990, concerns the effects of wetlands on water quality. In 1987, the EPA Corvallis Environmental Research Lab (Corvallis-ERL) was requested by the EPA Office of Wetlands Protection to prepare a conceptually expanded version of this Plan dealing specifically with the water quality component. The present document represents that expanded version, and is designated a Research Implementation Plan.

Factors responsible for initiating this new planning effort include the following:

- Increased concern that degradation of the nation's wetland resource was not being fully accounted for by figures that expressed losses solely in terms of acreage.

- A related concern about the adequacy of existing surface water quality criteria to protect wetlands, a concern that the original (1986) research plan was not intended to address.

- A growing awareness that existing surface water criteria may be unrealistic when applied to some wetlands which, due only to natural factors, exceed some of these criteria, e.g., for oxygen.

- Increased recognition of uncertainties regarding the national extent of wetland contamination and its consequences.

- Increased administrative interest in the use of wetlands as a low-cost alternative to wastewater treatment plants, and especially as <u>de facto</u> treatment for nonpoint runoff and stormwater treatment.

- An increased committment to assuring that needs of the users are carefully considered at every point in the development of research products, and that the research results are effectively transferred to the users (i.e., USEPA and state personnel responsible for implementing sections 401 and 404 of the Clean Water Act).

- The need for a plan which describes in more specific terms the actual research protocols to be used, i.e., an Implementation Plan, rather than being limited to a general discussion of the objectives, concepts, and protocols.

The 1986 Plan has the following goals for water quality research:

> "To quantify the water quality functions of wetlands; to model the aggregated role of wetlands in altering the quality of water in receiving water (at the wetland, watershed, and ecoregion scale); to design simple decision criteria for evaluation of water quality functions, and to assess the effects of cumulative wetland losses on the quality of water in receiving water (at the wetland, watershed, and ecoregion scale)."

More specifically, the effort described in the 1986 Plan was to focus on three areas:

1. Quantification of rate functions for the retention or transformation of organic chemicals, heavy metals and nutrients;

2. Quantification of interactions among these substances and their impacts upon wetland water quality function; and

3. Preparation of simple models or criteria for determining which wetlands are effective assimilators of wastes.

The Plan emphasized the use of artificial "mesocosms" in conjunction with _in situ_ field experiments and the modification of existing EPA hydrological simulation models. Mesocosms are confined portions of wetlands, either natural or constructed, which approximate the structure (both physical and biological) and function of the larger wetland of which they are a part, and which can be experimentally manipulated (e.g., dosed with known levels of chemicals, voided of particular organisms, isolated from specific influences). Mesocosm implies greater size (on the scale of several square meters) than microcosm, although these are relative terms.

To date, the modeling and field experimentation efforts of the 1985 Plan have been partially implemented through the EPA-Athens Environmental Research Lab. Mesocosm work has not begun and the recommended work on retention/transformation rates has been limited to nutrients. The work on organic chemicals, heavy metals, and their interactions was not approved for implementation due to budget constraints and Agency priorities at the time.

The current effort to prepare a Research Implementation Plan has had two major components:

- **Survey of Experts.** In June 1988, the Center for Wetlands at the University of Florida invited over 200 scientists to respond to selected questions contained in a longer documentwhich comprehensively considered the wetlands/water quality issue. The survey format and analysis protocols were designed by the firm of Roy F. Weston, Inc. The technical content was developed jointly by the University of Florida Center for Wetlands, the EPA Wetlands Research Program, and a panel of independent scientists. Scientists who were contacted represented a broad spectrum of sub-disciplines, including toxicology, remote sensing, hydrology, geochemistry, biology, and statistical design. The overall response rate was about 25%. Results are described in Appendix A.

o **Workshop.** In August 1988 some 40 scientists attended a workshop in Easton, Maryland, to focus on specific research priorities and protocols. The results of the above-noted survey were used as a springboard for small-group discussions, in an effort to derive a consensus opinion. A detailed workshop summary is provided in Appendix A. In general, the participants urged EPA to place greater emphasis on estimating the sensitivity and resilience of different wetland types, and as a precursor, EPA was urged to determine which taxa, processes, or measurements best indicate wetland integrity.

Following the Workshop, a Draft Implementation Plan was prepared. Although prepared by Corvallis-ERL, this was a cooperative effort involving wetland scientists from the EPA Duluth Environmental Research Lab (Duluth-ERL) and Roy F. Weston, Inc. The Plan was circulated for peer review to all workshop participants and others who offered to review it.

Although the overall intent was to make the Implementation Plan as congruent as possible with the general concepts outlined in the 1986 Plan (as well as a 1988 internal EPA proposal, "Ecosynthesis: Inland Wetlands Research and Monitoring Plan, 1990-2000), all water quality aspects were re-opened for discussion. This Implementation Plan is also intended to be consistent with:

o the EPA Task Force on Wastewater Discharge to Wetlands, coordinated by the EPA Office of Federal Activities (1987)

o the EPA Office of Water's "Draft Framework for the Water Quality Standards Program" (USEPA 1988).

3.0 INSTITUTIONAL BASIS FOR EPA CONCERNS

EPA has a number of direct and indirect legislative mandates for wetland protection and research, and many of these relate directly to water quality issues.

The users of the outputs from a wetlands/water quality research program would likely be the wetland program coordinators in federal, state, and local agencies. Uses of the research outputs might include the following:

- Determining what stipulations to include in a permit (e.g., permits under sections 401 and 404 of the Clean Water Act, and involving NPDES activities and wetland dredge and fill) for discharges or for minimum stream flow (water rights issues) and other hydrologic needs of wetlands;
- Providing technical guidance for nonpoint source control programs (sections 301 and 319 of the Clean Water Act);
- Measuring the effectiveness of existing laws to protect water quality, and suggesting changes as needed;
- Supporting a biophysical categorization scheme which would result in the primary use of certain kinds of wetlands being "water purification" (i.e., use designations);
- Recommending designs for created wetlands which would maximize their ability to purify wastewater while sustaining their ecological values;
- Recommending screening criteria for purchase (e.g., under section 318) of wetlands potentially useful for wastewater treatment;
- Assisting in the design of remedial actions for Superfund sites which will not destroy important wetland functions;
- Establishing EPA's national policy regarding use of certain wetlands for point/nonpoint effluents.

4.0 UNIFYING PRINCIPLES and STRATEGY CHOICES

Before describing the specifics of the proposed plan, certain unifying principles and choices of research strategy will be briefly noted. These principles and strategies apply not just to particular components of the plan, but to the plan as a whole. They are critical to the plan's success, and an attempt will be made to integrate them with specific protocols at every step of the plan's implementation.

4.1 Principles

EPA research on wetlands and water quality should be:

- **Clearly defined**, with the connections among different projects, using different methods, in different regions and states being well-explained.

- **Long-term**, because wetlands are extremely dynamic and complex systems. What is true during one season or year is often not representative, and natural climatic variability may induce changes as great as that from some anthropogenic stressors. Moreover, the symptoms of excessive loading may not appear for several years, but nonetheless may be catastrophic.

- **Interdisciplinary**, because the influences of hydrology, geochemistry, and biota are intricately intertwined.

- **Integrated** at several levels, e.g., models and data; basic and applied approaches; laboratory and field data; structural and functional information. In all these examples, a feedback mechanism must exist so the activities are mutually beneficial and result in greater predictive power.

- **Hierarchical**, because effects occur at the level of the individual organism, the population, and the community.

- **Multi-Scaled**, because effects may be detectable only at the level of the region, watershed, wetland, or microsite.

- **Stratified**, by wetland functional type and region, because water quality processes and indicators are thought to be extremely variable from region to region and type to type. With a limited budget, every opportunity must be sought to generalize from a few studies to the whole resource.

- **Coordinated** with other similar efforts, both within EPA, with other Federal and State agencies, and with private institutions.

- **With uncertainty clearly measured and articulated,** so that results can be appropriately extrapolated to other regions and wetland types.

- **With users involved in transfer of the results**, so that the research provides EPA with more than just an elegant understanding of a technical process.

4.2 Strategies

4.2.1 Choices

Regardless of which of the water quality components (I, II, III-- see Introduction) are being addressed, basic decisions must be made regarding the relative emphasis to be placed on:

- particular regions or wetland types;

- defining relationships from **empirical analysis** of spatially extensive data (Peters 1986) as opposed to defining these through development of **mechanistic models** or manipulative **mesocosm** experiments (as described earlier, mesocosms are confined portions of wetlands which approximate the physical and biological structure and function of the larger wetland of which they are a part, and which can be experimentally manipulated);

- **intensive vs. extensive** study designs, e.g., whether EPA obtains a better ability to extrapolate to the nation by studying just a few wetlands constantly and with sophisticated methods for many years, or studying more wetlands with less detailed methods or for shorter time periods.

Under ideal fiscal circumstances, these difficult choices would be unnecessary. Mathematical models would be developed and used to guide the research, and would provide a format for presenting the research results. Results of the exploratory statistical analyses associated with "real-world" empirical studies would be used to formulate hypotheses for testing in the more artificial environment of manipulative mesocosm experiments. Coefficients from both the empirical and manipulative studies would be used to calibrate and fine-tune the models. Intensive studies would be conducted at a few sites representing a subset of an extensive network of monitoring sites, so that the temporal, spatial, and procedural limitations of data from the extensive network become known.

Because EPA, even in combination with the efforts of other agencies, does not have the resources to approach this ideal, choices must be made. With regard to research, **this plan recommends that EPA emphasize the use of manipulative mesocosm experiments, at the possible expense of fully-implemented empirical and modeling efforts**, to address the three key components of the water quality effort. With regard to monitoring, this plan recommends that efforts be devoted to intensive, long-term measurements unless allocated resources (on the order of $10K to $50K per site) are of sufficient magnitude to allow for extensive monitoring as well. In both instances (i.e., research and monitoring), the empirical and survey approaches, and deterministic modeling, should continue to have a role, but should be subordinate to the favored approaches.

Regardless of the approach chosen or the water quality issue, the cost-effectiveness of the research will be greatest if it focuses on the most important water quality stressors in priority wetland types and regions, particularly if this can involve building upon ongoing studies in the priority regions.

At the workshop, participants considered metals and synthetic organics to be of greatest concern in terms of their **effects on wetlands**, while nutrients and sediment were most important with regard to the converse--the **effects of wetlands on receiving water quality**. The most severe and extensive wetland stressor in many regions was considered to be **nonpoint runoff**. Activities that were viewed with greatest concern (based on their extent and severity of impact to wetland water quality) were considered to be agricultural and forestry runoff, domestic/industrial wastes, effluents from land clearing, land drainage, irrigation, dike/levee installation, and channelization. Again, it was noted that the relative **importance of these varies greatly by region** and wetland type, and research will be most cost-effective if it can be focused accordingly.

For the purpose of establishing priorities, geographic or ecoregional descriptors (e.g., New England, the Southeast) can be merged with wetland type descriptors from the Cowardin classification system to define wetland "**region-types**" (e.g., Southeast forested nontidal = bottomland hardwood wetlands). Climate, wetland contiguity, and other landscape conditions may be used to refine this categorization scheme, whose sole purpose is to consolidate the regions and wetland types in order to facilitate priority-setting. At the workshop, the following region-types (in no order of priority) were suggested by various participants as being relatively homogeneous and containing wetlands most threatened by water quality impacts: bottomland hardwoods, prairie potholes, western riparian, northeastern forested palustrine, urban tidal.

4.2.2 Reasons for Favoring the Mesocosm Approach

The recommendation for use of mesocosms is consistent with many previous reviews, conferences, workshops and the prior EPA Research Plan for wetlands (e.g., Nixon and Lee 1987, Bayne et al. 1988, Zedler and Kentula 1986). Major advantages of manipulated mesocosm systems include the greater ability to control the independent variables of wetland hydrology (flow, duration, degree of saturation or inundation, etc.) and loading rates of water quality contaminants (dose levels). For example, it may not be possible to control hydrology in natural wetlands due to annual and longer-cycle (20 years or more) variation in climate (van der Valk et al. 1988). With mesocosms, these treatment conditions can be selected and maintained with greater assurance than in unconfined natural wetlands.

Manipulation also provides greater commonality of general site conditions (climate, substrate, biotic community species composition) than may be easily obtained in empirical studies. Likewise, they afford greater savings in the logistical resources of data collection, when multiple manipulated systems are grouped at one location. Uniform manipulated conditions and small scale system definition also provide for replication of treatments within one location. Systems can also be designed so that sampling may be conducted over longer periods of time and with less damage to the wetland under study (Zedler and Kentula 1986). Formal cost comparisons have not been made between mesocosm and empirical approaches, but it is believed that the mesocosm approach's reduced costs for site screening, travel, and data analysis (per dose-response relationship examined) will result in greater savings.

Despite these advantages, many participants at the workshop favored the empirical approach, partly because of its "real-world" character. Every wetland located downstream of a wastewater treatment facility or every headwater wetland receiving agricultural runoff could be studied for its response to water quality. In this perspective, a great range of "experiments" are already underway all across the nation. All that needs to be done is conduct the studies. However, the resource and time requirements needed to conduct a series of valid empirical studies may be beyond the means presently available to the Wetland Research Program.

To illustrate, consider a situation where EPA desires to categorize wetlands, for policy reasons, according to their ability to sustain continued loadings of wastewater. To support such a categorization, comparable data would need to be collected or synthesized regarding the following:

loading rates (5 different rates, for example)
detention times (5 different times)
years of operation (4 different ages)
sediment types (4 different types)
flow distributions (5 spatial configurations)
wetland types/regions (3 vegetation types)

Existing knowledge of wetlands indicates that it is unlikely that a simpler framework (fewer variables and classes) would adequately categorize wetlands for this purpose. Indeed, many would argue that the above list should be longer to adequately consider the complexity of wetlands. Perhaps what is desirable, then, is to seek an understanding of levels of function associated with broad wetland types, rather than seeking to categorize all wetlands based on function.

If such a data collection effort were implemented, the number of cases (wetlands) must be at least 2 to 5 times the number of variables, which in this case is 6, in order to meet minimum statistical criteria. A statistically better, factorial, parametric approach requires that all possible combinations be tested. This would require sampling in 6000 wetlands (5 x 5 x 4 x 4 x 5 x 3), not including replication.

Ideally, to generate data with maximum explanatory power, an empirical study design also should be "orthogonal" and "balanced" (Skalski and McKenzie 1982). An "orthogonal" design requires that a level of a factor appears with approximately equal frequency with all levels of another factor. For example, within the factor "years of operation", each combination of detention time and flow distribution present in the pre-loading period (year 0) must also be present in each of the post-operational periods. In order for a design to be "balanced", each unique treatment combination should be replicated a nearly equal number of times. Thus, the duration and intensity of sampling ideally should be nearly equal during the pre- and post- loading periods.

Few empirical studies in ecology approach this ideal. Partly because of this, the resultant multivariate equations, even if they are at all statistically significant and explanatory of the variance, usually cannot be applied in a predictive sense to situations beyond those of the study area. Although randomization and use of non-parametric procedures can soften these requirements somewhat, **the requirements of empirical studies for unaffordable sample sizes remains a potential barrier.**

Another difficulty encountered in analyzing data from a set of wetlands which have encountered various degrees of anthropogenic stress is that critical **historic information on the hydrology of all wetlands in the set is typically lacking.** Often, such empirical studies become experiments with inadequate pre-treatment data. A solution is to use wetland creation projects as a pre-treatment case, but (a) the ability of created wetlands to simulate natural wetlands remains debatable, thus limiting the applicability of conclusions just to the set of created wetlands, and (b) conclusions from such studies would not become available for many years. Although this plan proposes an integrated approach involving mesocosms, empirical studies, and literature syntheses, if such an approach turns out to be financially prohibitive, the mesocosm approach would be preferable to using the others alone.

5.0 RESEARCH COMPONENTS AND TECHNICAL APPROACH

As noted in the Introduction, the Water Quality/Wetlands issue has three major interrelated components:

I. Water Quality Criteria to Protect Wetland Function
II. Ecological Status of the Wetland Resource
III. Waste Assimilation Limits of Wetlands

In the remainder of this plan, we describe the procedures that would be used to implement the objectives of each component. The manner in which the tasks and components are interrelated, and their relationship to program goals, is shown in Figure 1.

5.1 <u>Water Quality Criteria to Protect Wetland Function</u>

5.1.1 Rationale

The process of developing water quality criteria for wetlands poses a fresh opportunity for avoiding some of the pitfalls of previous approaches applied to non-wetland surface waters (e.g., see Karr 1981, USEPA 1987, Ongley et al. 1988). These criticisms include:

- o There are hundreds of obscure chemicals whose toxicity is mostly unknown, and the cost of testing the effects of all of these would be astronomical.

- o Efforts to monitor chemical concentrations in the environment often miss episodic events when greatest concentrations or exposures occur.

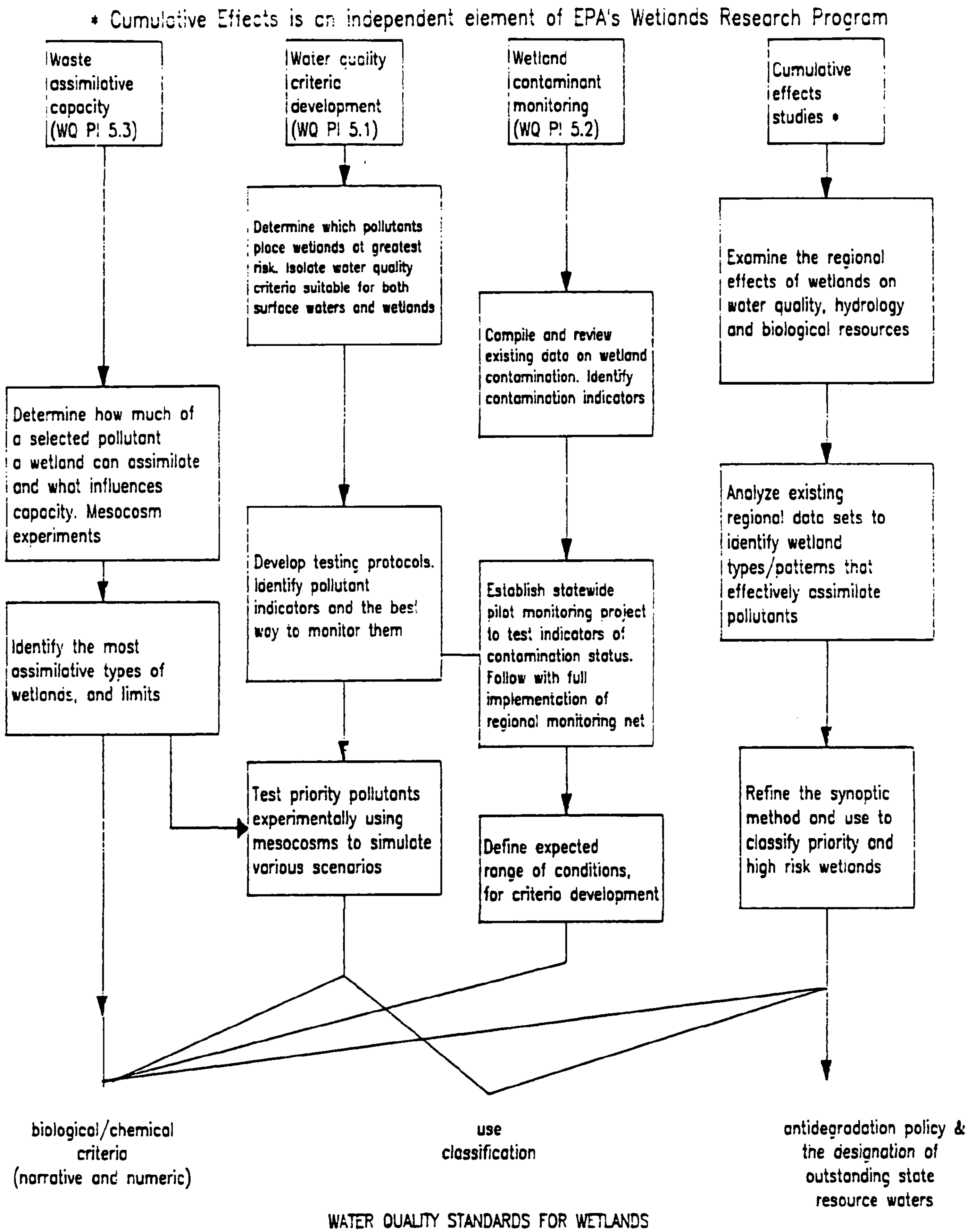
- o The resources which are to be protected are partly biological, whereas monitoring programs typically focus on chemical measurements which purportedly are linked to biological conditions;

- o There are hundreds of species and life stages whose long-term, sublethal sensitivity to contaminants is unknown, and the cost of testing for effects on these would be extreme;

- o Even where surface concentrations and potential toxicity are known, the actual exposure of sediment-dwelling biota and trophically higher consumers to the contaminants may not be, due to behavioral and other factors.

- o The antagonistic toxicities of chemicals and physical stresses are mostly unknown, particularly the cumulatively stressful combinations of hydroperiod alteration, toxicants, and excessive nutrients.

Figure 1. Research Workload Model: State Water Quality Standards for Wetlands



EPA has responded to these concerns by modifying some of its ecotoxicological procedures (e.g., see "Philosophy of Criteria" in Appendix C of USEPA 1986). Still, there are additional technical concerns about the wisdom of applying criteria intended for surface waters to wetlands. Wetlands frequently have lower (and more spatially variable) pH, lower dissolved oxygen, extreme reducing conditions, more potential for photodegradation and biodegradation, greater potential for chelation and organic complexation, and higher sulfide concentrations than do surface waters generally. Under certain circumstances any of these conditions can profoundly affect the rate and direction of contaminant cycling in wetlands, as well as the bioavailability of contaminants. Moreover, wetlands are distinguished by their exceptional concentrations of aquatic life, heightening concerns about the potential for bioaccumulation and ultimate loss of the life support function. Yet, existing ecotoxicological protocols have not involved the testing of typical wetland species under background physicochemical conditions which typify wetlands, so the validity of applying existing surface water criteria to wetlands is unknown. Moreover, the indicators of ecological integrity in wetlands, unlike the situation with quality indicators in other surface waters, are unlikely to be synonymous in concept with concentration levels of contaminants.

5.1.2 Approach

In considering the adequacy of existing criteria, a fundamental question is, "What should EPA be trying to protect?" Participants at the workshop responded by describing the target as "wetland integrity," which was defined as follows:

> " the persistence of physical, chemical, and biological conditions which sustain the long-term processes and structure of the regional wetland resource."

The effort should then progress as follows:

Task 1. Examine chemical mobility effects specific to "wetland" environments.

Through literature review and interviews with key scientists, available information on the probable effect of the "wetland" characteristics (e.g., organic matter concentrations, others listed above) on the cycling and bioavailability of EPA priority pollutants would be compiled. If funded, this effort would be conducted by the Duluth ERL. The result could be a ranking of pollutants of most concern in wetlands because of their mobility characteristics. Recognizing the paucity of data to support such a ranking, its purpose will be to focus research, rather than stimulate regulation in a particular area.

Task 2. Consider the potential toxicity of mobile contaminants.

The mobility-based ranking of pollutants described above could be compared with a classification of contaminants based on their ecotoxicity and bioaccumulation potential, and probability of wildlife exposure. A preliminary ranking of this type was recently developed by the U.S. Fish and Wildlife Service (USFWS).

Task 3. Prioritize contaminants for further testing.

The Wetlands Research Program may suggest that chemicals which appear on both lists receive priority for ecotoxicological testing under wetland-like conditions.

One objective of such testing would be to determine if the sensitivities of selected wetland organisms to such chemicals are analogous to the sensitivities of organisms typically employed for toxicological testing (e.g., fathead minnow, rat). The selection of wetland species for this calibration effort would be based in part on initial results from ongoing field studies in Minnesota, and later on the data from mesocosm studies in other wetland types.

The other objective would be to determine if the effect of stereotypical "wetland" conditions on published cycling rates is significant enough to warrant modifications of the existing surface water criteria. These efforts would be coordinated with EPA efforts aimed at developing quality criteria for sediment environments.

The EPA Wetlands Research Program does not currently have the resources or mandate to conduct extensive laboratory bioassay testing. However, other branches of EPA and the USFWS are actively engaged in such testing, and the Research Program, acting through EPA's Office of Wetlands Protection, will seek to become involved in the design and review of such studies.

Task 4. Employ mesocosms to refine field monitoring and data reduction protocols.

There appeared to be a consensus of workshop participants that EPA, before or during its implementation of expanded ecotoxicological and geochemical studies, should determine how field monitoring data could later be compared with existing, traditionally-derived, laboratory bioassay data to judge "wetland integrity." **The participants saw great potential value in the use of indicator taxa and processes for measuring wetland integrity, but only after (a) replicable protocols are refined for monitoring these and presenting their data in a meaningful format, and (b) toxicity data become available from manipulative**

experiments.

However, field monitoring and data presentation protocols for wetland communities were felt to be still in a largely developmental stage, with regard to actually linking specific metrics to wetland integrity. Thus, refinement is needed before wetland protocols can be used to adequately assess the effectiveness of water quality criteria for protecting wetland function.

Mesocosm studies (dose-response manipulation of confined natural systems) are a relatively cost-effective way of identifying the best indicators of wetland integrity. Particular monitoring protocols would be examined first in mesocosms, by **dosing confined parts of wetlands with known concentrations of prioritized contaminants**, and then comparing the relative abilities of different monitoring methods and metrics for detecting expected change in concentrations, taxa, and processes. A similar sensitivity analysis using marine mesocosms was recently conducted and summarized by Bayne et al. (1988). That team of researchers recommended use of dose-response curves based on community-level metrics. Some of their data reduction techniques are listed in Table 1. They also examined the cost-effectiveness and sensitivity thresholds of alternative monitoring protocols. Elements of statistical design for aquatic mesocosms are addressed by Clark and Green (1988).

The mesocosms themselves could be situated in either natural or created wetlands. **Although created wetlands may be easier to manipulate and usually have a known history, a concern exists that data are as yet inadequate to demonstrate that they are sufficiently similar to natural wetlands, at least in the context of mitigation policy decisions, to be considered the same.** Consequently, there are concerns about the ramifications of extrapolating the results of mesocosm research conducted in created wetlands to natural systems.

Regardless of where the mesocosms are located, a few design or selection elements are important (Giesy 1980, Bayne et al. 1988, van der Valk et al. 1988). In considering unit size, mesocosms would be as large as feasible, in order to encompass the variation found in the natural wetland and to avoid both edge and sampling effects. This may be important when considering the size of vegetation patches or habitat of important animal species. Small system size is more subject to cumulative disturbances, and lack of normal exchange with adjoining surface and ground waters can lead to large growths of periphyton and other aberrations (Schindler 1987), particularly for experiments of longer duration.

TABLE 1. Investigative Techniques for Biosurveys (Bayne et al. 1988)

Multivariate Methods

Classification:
Hierarchical agglomerative clustering based on group-averaging of Bray-Curtis similarity measures.

Ordination:
Multidimensional scaling, detrended correspondence analysis, principal components analysis and reciprocal averaging.

Discrimination tests:
Analysis of similarity, Roy's greatest root criterion and Malhanobis' distance tests, plus canonical discriminant analysis.

Univariate Methods

Comparative, or with reference samples:
Number of taxa (S), total abundance (A), total biomass (B), abundance ratio (A/S), size ratio (B/A), abundance and biomass group distributions, dominance distributions, diversity and evenness indices, comparison of functional groups, biomass spectra.

Single sites without reference samples:
Identification of indicator organisms, abundance/biomass comparison curves (ABC).

Correlating community metrics with pollution levels

Visual pattern analysis of mapped, separated factors, metrics, and pollution levels.

Establishing pollution-community, cause-effect relations
Mesocosm studies.

The scale of the manipulated system units could range from very small, short term, bag enclosures to entire wetlands. This would depend mostly on the type-region of wetland under study. Forested wetlands would need to be investigated through subdivision of natural wetlands, while emergent systems may be addressed partly by use of bag enclosures (Zedler and Kentula 1986, and Herron 1985). What remains most important is the representativeness of the unit design to the wetland type-region under study.

Studies using subdivision of natural wetlands would be required to investigate wetland qualities which may **not** be developed in created or artificial wetlands. This would be particularly evident when investigating properties related to soil structure, such as the relation suggested between the level of extractable aluminum and long-term phosphorus retention. Subdivision isolation of a uniform wetland type area through berms, dikes or other barriers would seem appropriate for many wetland types (van der Valk et al. 1988, Herron 1985), but may be unwarranted due to cost, sampling or the dynamics of the key wetland processes under investigation. A critical consideration is representation of the hydrologic pattern, which drives the processes and function of the particular wetland type.

In summary, EPA's decision on where to locate the mesocosm experiments should be based on several factors, including the following:

- o representativeness of the site;
- o ability to control and measure inputs and outputs;
- o presence of existing control works (for economic reasons) which appear to have had minimal impact on the naturalness of the site;
- o existence of long-term, interdisciplinary, baseline data on the site;
- o proximity to qualified research scientists and opportunities for cooperative efforts.

EPA's effort might parallel the mesocosm effort of Bayne et al.(1987), and address the following similar questions:

- o Where in a wetland should the most revealing samples be collected?
- o When and how should samples be collected?
- o What is the expected variability?
- o What are the best indicators (taxa or processes, and their related metrics) of wetland water quality?

- o At what thresholds do these indicators suggest changes in wetland integrity?

As part of the present planning effort, the Corvallis-ERL has developed a list of potential indicators and community metrics for wetlands. This list also describes the known advantages and disadvantages/limitations of each, particularly with regard to the influence that wetland type and contaminant type have on their applicability. This material was distributed at the workshop as a springboard for discussion.

Workshop participants felt that **data are insufficient to suggest that either processes (function) or taxa (structure) are better indicators of anthropogenic water quality stress in wetlands. Survey respondants urged that both be measured** if possible, and that the potential for correlations be examined in different wetland type-regions. A recent workshop addressing similar issues using marine mesocosms (Warwick 1988, Bayne et al. 1988) concluded that multivariate and graphical methods of description and testing were preferred, since they are more sensitive than diversity indices. Studies in lake mesocosms (Schindler 1987) have indicated the sensitivity of **species dominance and life-table methods** of data reduction, as opposed to measurements of ecosystem processes, for detecting contamination. However, the data requirements for use of life-table methods would probably be too severe to allow their use as a routine tool throughout an extensive network of monitoring sites, so results of this approach should be correlated with simpler measurements on a subset of monitored sites. A similar conclusion pertains to sampling and chemical analyses of tissues.

With regard to structural measurements, participants saw considerable need for documenting and regionalizing the Florida criteria for wastewater effluent discharges to wetlands (see Appendix A). Many believed that community metrics based on **certain invertebrate taxa, especially the less mobile species (e.g., amphipods) have the greatest potential for forming the basis of a wetland "index of biotic integrity (IBI)"**, similar in concept to IBI's developed for other surface waters and primarily using fish. However, such metrics must be used cautiously due to the extreme temporal and spatial variability within wetlands, as well as the potential for genetic adaptation to contaminants. The response of wetland vegetation to contaminants was judged by survey respondants to be too slow, too insensitive, and too interrelated to other factors to serve, alone, as a practical indicator of contaminants. However, vegetation is a very sensitive indicator and integrator of hydrologic stresses, and some species can be highly sensitive to particular contaminants. Considerable support was shown for **measuring hydroperiod variation, sediment processes, and sediment chemistry** as reflections of long-term alterations of wetland integrity. No wetland-focused, regional monitoring networks currently exist for these indicators, and considerable effort might need to be focused on testing and developing their use as part of a rapid assessment protocol.

In summary, the following features were believed to be most important or promising as indicators of wetland integrity overall, although priorities may shift by region and wetland type:

POTENTIAL INDICATORS OF STRESSOR STATUS:

1. **Hydroperiod,** i.e., abnormal (compared to reference wetlands) degrees and variability of the duration and frequency of flooding.
2. **Sediment and organic matter accretion.**
3. **Metals.** Selection of specific ones would be dependent on our analysis of expected exposure (geology, land use) and bioaccumulation/toxicity potential. Likely exposure scenarios could be generally identified using existing source inventories (e.g., Resources for the Future database) and noting likely source-receptor pathways.
4. **Synthetic organics.** Specific ones dependent on our analysis of expected exposure and bioaccumulation/toxicity potential, as above.
5. **Nutrients.** Ratio of organic to inorganic; ammonium, nitrate, total nitrogen, total phosphorus, soluble reactive phosphorus, phosphorus-sorption capacity.
6. **Cofactors:** Conductivity, temperature, pH, sediment organic matter, oxygen demand, watershed characteristics. These alone do not indicate stressor status, but are needed to explore causality.

POTENTIAL INDICATORS OF ECOLOGICAL STATUS:

7. **Vegetation.** The selection of particular taxa and communities would be dependent on the region and wetland type. Use of remote sensing for monitoring would be emphasized.
8. **Macroinvertebrates,** particularly non-emergent ones (crayfish, mollusks, amphipods). Addresses contamination which may be less likely to be immediately sensed by vegetation.
9. **Waterbirds,** at least those with expected high-sensitivity or rarity. This indicator is included mainly because of availability of national, long-term, comparison data sets (USFWS Breeding Bird Survey and Christmas Bird Counts) and because of its status as a socially-recognized assessment endpoint.

Task 5. Conduct a coarser-scale comparison of the monitoring and data reduction protocols.

Any manipulated system, whether natural or artificial, should not be used alone, but should be studied in conjunction with studies in uncontrolled natural wetlands. **A coordinated iteration of manipulative and empirical studies is preferred, and would be implemented to the extent that resources allow.** Such an approach utilizes the strengths of each approach, while ensuring the representativeness of manipulated systems and paving the way towards the larger goal of extrapolating study results to other wetland types and regions.

In order to approach this objective and perfect the field monitoring protocols, the mesocosm studies would be used to complement the results from an ongoing, 2-year empirical analysis of Minnesota wetlands, being conducted jointly by the Duluth ERL and the Natural Resources Research Institute of the University of Minnesota. This study of about 30 wetlands **will partly address monitoring issues that cannot be fully considered at the mesocosm scale.** The Corvallis ERL's experiences with field protocols for comparing created wetlands with natural wetlands would also be reviewed for their applicability; these procedures have already been field-tested in 3 regions and been approved by EPA QA/QC officials.

5.1.3 Outputs

Task 6. Produce Research Syntheses

The results of the mesocosm experiments and the already-initiated empirical studies may be presented as peer-reviewed journal papers or EPA reports. To whatever extent allowed by the data, the results of the dose-response studies could be presented as quantitative **ecotoxicological models,** and results from the Minnesota field study might be presented as proposed **regional biological criteria** for that study area. Results would be presented in the context of related ongoing ecotoxicological work performed by other agencies or divisions of EPA. Another important output would be a tested **field manual for wetland monitoring,** describing protocols appropriate to geographic and budgetary situations similar to those encountered in our mesocosm and limited empirical studies.

5.1.4 Potential Sources of Funding; Schedule

Potential Funding Sources

We estimate the proposed effort will require a total of $3.5

million over the 6-year period. Funding for the first empirical study (Minnesota wetlands) exists for FY89. However, funding **does not presently exist for most of the activities outlined above.**

		1989 - 1994 Needed $K
Task 1.	Mobility Literature Review	10
Task 2.	Toxicity Cofactor Literature Review	20
Task 3.	Selection of Candidate Indicators	20
Task 4.	Dose-response Testing of Candidate Indicators	2000(1)
Task 5.	Empirical Field Studies of Candidate Indicators	1250(2)
Task 6.	Research Synthesis	200(3)

(1) Assumes testing of indicators in 5 mesocosms (experimental wetland region-types), each test requiring 2 years, and costing $200K per mesocosm per year to test the response of various taxa/processes to stressors of greatest concern (probably 2 heavy metals, nutrients, and a few synthetic organics). Assume a need for proportionately greater funding if a wider variety of wetland types and/or stressors are to be examined in the same period of time.

(2) Assumes collection of regional field data in 5 region-types (preferably same region as mesocosm), each collection occurring in one year and costing $250K. The ability of 3-5 taxonomic/process measures to indicate ecological integrity when presumably exposed to particular stressors would be investigated, and results compared to those from mesocosms.

(3) Involves literature review updates, development of simple ecotoxicological models, research synthesis, interim progress reports, publication of a wetlands field monitoring manual, and technological information transfer.

Schedule

The schedule for the tasks described above is shown graphically in Figure 2, and is presented narratively below. Again, note that this schedule is contigent upon the specified full-funding levels.

Fiscal Year 1989

The ongoing empirical studies in Minnesota will continue, and preliminary results will be used to focus the design of the first mesocosm study.

Figure 2. Schedule and needed budget ($K) for **COMPONENT I: Water Quality Criteria to Protect Wetland Function**

		FY89
Task 1.	**Mobility Literature Review**	10
Task 2.	**Toxicity Cofactor Literature Review**	20
Task 3.	**Selection of Candidate Indicators**	20

Task 4. Dose-response Testing of Candidate Indicators:

FY:	89	90	91	92	93	94
wetland type/region 1*	200	200				
wetland type/region 2*		200	200			
wetland type/region 3*			200	200		
wetland type/region 4*			200	200		
wetland type/region 5*			200	200		

Task 5. Empirical Field Studies of Candidate Indicators of Wetland Integrity

FY:	89	90	91	92	93	94
wetland type/region 1*	250					
wetland type/region 2*		250				
wetland type/region 3*			250			
wetland type/region 4*			250			
wetland type/region 5*				250		
Task 6. Research Synthesis:		25	25	25	25	100

TOTAL $K, COMPONENT (I):

FY89:	450
FY90:	675
FY91:	675
FY92:	875
FY93:	675
FY94:	100

* Region numbers are hypothetical and do not necessarily correspond with EPA administrative regions.

Fiscal Year 1990

Manipulative experiments would be concluded on the first wetland type-region mesocosm, and a second mesocosm study would begin. The Minnesota study will also conclude, with a report describing those wetland variables most affected by wetland or watershed disturbances. A second empirical study (building upon the Minnesota one) would concurrently be implemented in the same priority wetland type-region. This study would focus on a priority stressor/activity, perhaps examining wetlands at sewage outfalls, stormwater basins, Superfund sites, or intensive agricultural runoff areas. Multivariate analyses will be used in an exploratory manner to help discern which indicators most faithfully indicate high loading rates and/or presumed contamination.

Fiscal Year 1991

Manipulative studies would be initiated in a third priority wetland type-region, and would be concluded on the second. A third empirical study would be initiated.

Fiscal Year 1992

Manipulative studies from the third mesocosm study would be concluded, and a fourth mesocosm and empirical study initiated .

Fiscal Year 1993 - 1994

Mesocosm and empirical studies (all 5) would be concluded and a synthesis of the results would be prepared.

5.2 Wetlands Quality: Ecological Status of the Wetland Resource

5.2.1 Rationale

There is an increasing concern that **degradation of the nation's wetland resource is not being fully accounted for by figures that express losses solely in terms of acreage.** Stresses imposed by heavy metals, synthetic organics, excessive nutrients and sediment, and inadequate minimum flows (or other hydrologic disruptions) may be seriously degrading the beneficial functions of the wetland resource. However, while data on acreage trends is being compiled by the U.S. Fish and Wildlife Service, the extent of chemical degradation and its trend is not being widely measured.

EPA does not have the resources to monitor vast numbers of wetlands of all types in an attempt to determine the extent of stress. Participants at the Easton workshop were emphatic in **recommending that EPA not divert its limited resources to a national monitoring program unless adequate funds are allocated for appropriately intensive studies of a significant portion of the sites.** This is the intent of the approach proposed in the following section (5.2.2).

A national wetlands monitoring program would have two main objectives:

- to quantify **regionally expectable conditions of wetland integrity**, i.e., by examining levels of chemical substances, community structure, and community function (using metrics tested in Component I, above) in the most apparently "pristine" wetlands in a region;

- to quantify **changes over time** in the set of monitored wetlands, using the same metrics.

A number of states are implementing the first objective in streams using macroinvertebrates or fish. For example, Ohio, Maine, North Carolina, and Arkansas are using extensive field biological data sets for defining what constitutes "expectable" species richness, density, incidence of tumors, and/or percentage of exotic species in environments which are believed to be the most relatively "pristine" available. The variability within this data set is also quantified. Through a public involvement process and a review of toxicological data, "thresholds" for agency action are established. These are intended to trigger more finely-tuned (and costly) investigations of individual sites to establish causal relations with specific contaminants, and provide engineering recommendations for remedial action. In establishing reference (expectable) values for a region, physical or chemical measurements can be used as well. For example, to estimate the extent of acidification of surface waters in the United States, EPA sampled hundreds of streams and lakes a minimum of one time during a carefully selected season(s) and at a point where a sample would be most likely to represent the entire surrounding aquatic environment. While this did not provide definitive answers regarding the causes or consequences of acidification, it provided information useful for policy decisions. It did so by quantifying the approximate portion of sampled waters in various numerical range categories (e.g., of alkalinity and other metrics), and described their spatial variability. More geographically focused studies have followed.

The wetlands effort would not be as simple, due to the extreme spatial variability within and among wetlands, as well as the need to consider multiple interacting stressors (metals, nutrients, hydroperiod alteration) rather than a single stressor (acidic precipitation). Nonetheless, after initial testing of protocols and indicators, a synoptic monitoring network for wetlands could use biological and/or physicochemical measurements to achieve **a first approximation of the extent** of wetland ecological impairment, either nationwide or for specific wetland types-regions.

5.2.2 Approach

This effort would be closely coordinated with and would build upon the interrelated effort described above to examine water quality criteria for wetlands (Component I). Specifically, the field methods and remotely sensed metrics tested by Component I would be put into practice in Component II.

Task 1. Review of existing field protocols and data sources.

A first step would involve compiling existing measurements of wetlands (e.g., invertebrate richness, sedimentation rates, dissolved organic carbon) into type-region databases. Although such numerical data would be based on diverse (and sometimes undescribed) measurement protocols, it could be examined to obtain a first estimate of the variability which may be expected, and to place in a broader context any subsequent data collected by EPA. It can also be used to identify sites where ongoing data collection programs could be economically augmented by EPA. Simultaneously, the limited literature concerning wetland indicators would be synthesized and measurement techniques compiled.

Task 2. State-level prototype study.

Implementation of the monitoring network would begin by establishing a state-level prototype. State-level programs would be sought which could provide, through the amplification of matching funds and use of locally experienced personnel, the first broad, field-based testing of the wetland monitoring methods. The state survey would provide numerical reference points for several metrics in various wetland types. This field survey approach would also help EPA further refine its monitoring protocols, choice of indicators, and metrics.

Task 3. Full implementation.

At the completion of the first state prototype, the wetland monitoring network would be expanded to encompass at least some of the priority type-regions, and perhaps the entire nation. **A different priority wetland type-region would be surveyed per year with a rotation for resurveys every 3 to 5 years.** The projected level of effort assumes monitoring about 150 wetlands per priority wetland type-region per year at about $10,000 per wetland, for a total of $1.5 million, or half of the projected annual budget for the task. (This would be exclusive of costs for data analysis and remote sensing data collection.) The selection of the majority of these 150 sites should be stratified according to systematic criteria such as the following.

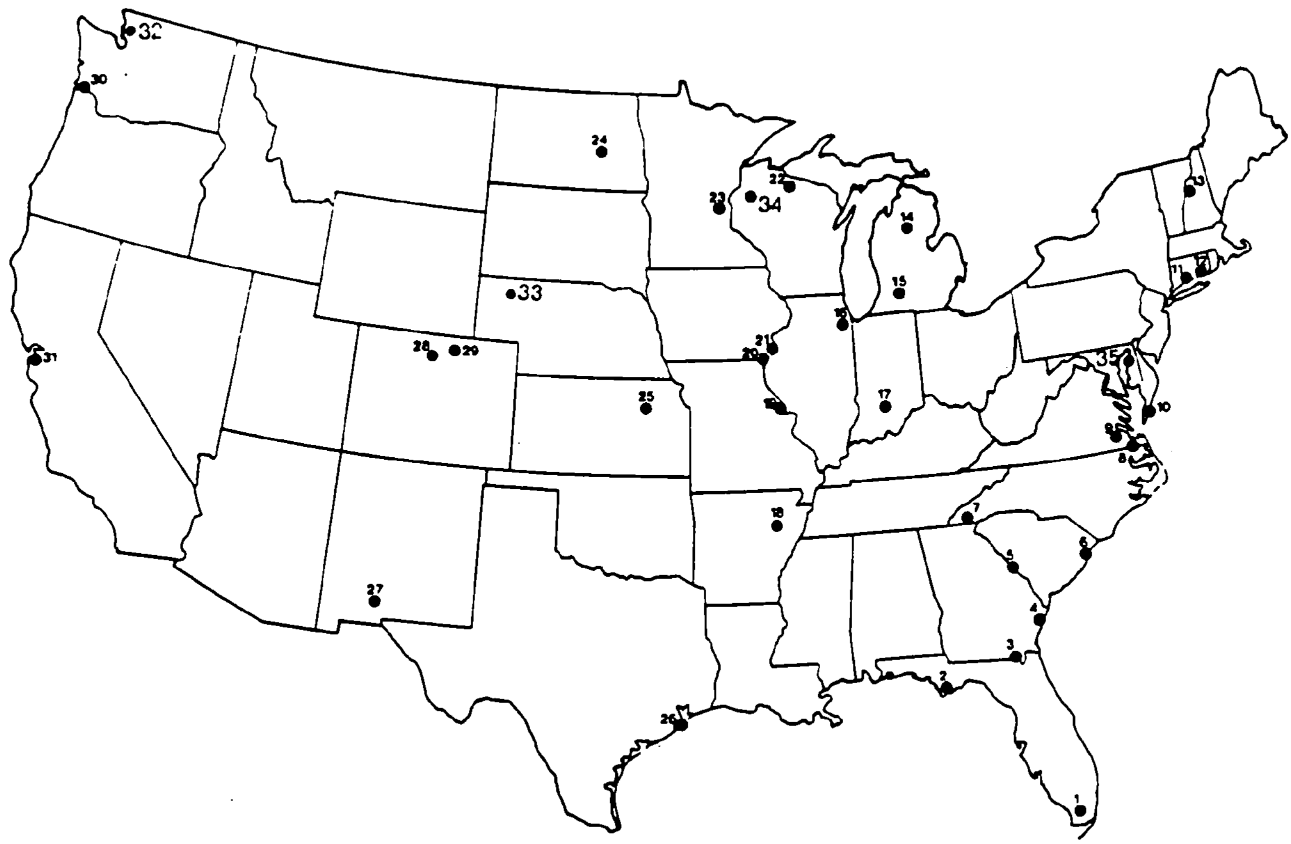
One subset of about 10 of the projected 150 wetland sites would be in previously **well-studied wetlands**, such as the National Science Foundation's Long Term Ecological Research (LTER) sites and/or others shown in Figure 3. In these, more detailed (intensive) measurements would be performed. Another subset of about 40 of the 150 wetlands would include wetlands known to contain **"special" taxa** (ones especially sensitive to priority contaminants, or which are regionally rare/declining).

The remaining sites (about 100) within each priority type-region would be used to establish the array of "reference" or "benchmark" wetlands. These sites would be randomly selected, with consideration for **representing the spectrums of both a general exposure to degradation from water quality (near-pristine to degraded sites) and the range of stressor-taxa combinations.** About one-third of such an array of status or reference wetlands would hopefully represent nearly pristine conditions.

Thus, if monitoring involves a 3-year cycling of the recurrent measurements, a total of about **450** wetlands nationwide (i.e., 3 region-types) would be examined recurrently; a five-year cycling would involve **750** wetlands (i.e., 5 region-types). The monitoring protocols would be continuously fine-tuned as monitoring progresses, to improve the validity of the measurements. EPA

Figure 3.

Existing Long-term Wetland Data Sets: Preliminary Inventory of Freshwater Sites



Sites were included if the same ecological measurements were made (or are funded to be made) at least once every 3 years at exactly the same location. The EPA Wetlands Research Program has ongoing efforts to update this map (see p. 32) and appreciates hearing of locations not shown.

1. Everglades (NPS)
2. Apalachicola (U.FL, USGS)
3. Okeefenokee (U.GA)
4. Buttermilk Sound (CE)
5. Savannah River (DOE)
6. North Inlet LTER (NSF, U.SC)
7. Coweeta LTER (NSF)
8. Dismal Swamp (USGS)
9. Windmill Point (CE)
10. Virginia Barrier Is. LTER
11. Nott Island (CE)
12. Niering wetland (Conn. Col.)
13. Hubbard Brook LTER (NSF)
14. Houghton Lake (U.Michigan)
15. Kellogg LTER (NSF)
16. Des Plaines mesocosm
17. Monroe Lake (U. Indiana)
18. Cache River (CE)

19,20,21. Ill.- Miss. R. LTER
22. N. Temperate Lakes LTER
23. Cedar Creek LTER
24. Cottonwood Lake (USGS)
25. Konza LTER (NSF)
26. Bolivar Peninsula (CE)
27. Jornada LTER (NSF)
28. Niwot Ridge LTER (NSF)
29. Central Plains LTER (NSF)
30. Miller Sands (CE)
31. S. San Francisco Bay (CE)
32. King County (WDOE)
33. Nebraska Sandhills (USGS)
34. ELF study (USDOD)
35. Rhode R. (Smithsonian)
36. Creeping Swamp (USGS)

proposes that this monitoring effort be permanent, extending into several future decades.

These sample sizes may not be sufficient to statistically predict the condition of the regional wetland resources as a whole. Nonetheless, the creation of this database would considerably improve on our current knowledge of expectable "baseline" (or reference) conditions in several regions, and its typical variability.

5.2.3 Outputs

The results of the state-level prototype as well as the national monitoring network would be presented as peer-reviewed EPA reports. Results would be presented in the context of related measurements that have been made by other researchers, agencies, or divisions of EPA. The data would be analyzed to answer the following questions:

- What are the regional background levels of the indicators, and what percent of the region's wetlands exceed background?
- Do prevailing background levels fully support wetland ecological integrity?
- What percent of the region's wetlands exceed criteria recommended for protecting ecological integrity?

5.2.4 Potential Sources of Funding; Schedule

Potential Funding Sources

We estimate the proposed effort will require approximately **$3 million per year** when fully operational in 1993, **plus a total of $1.1 million during the years 1989-1992.**

	1989 - 1994 Needed $K
Task 1. Construct & Review Database	80(1)
Task 2. State-level Prototype Study	800(2)
Task 3. Full Implementation	3000(3)

(1) Assumes the 1989 effort is covered by existing funds, and $20K per year is needed for updating and maintenance.

(2) One-year (1992) study only. Assumes partial matching funds available from the state in which the prototype is conducted.

(3) Per year, beginning in 1993.

Schedule

The schedule is shown graphically in Figure 4, and is presented narratively below.

Fiscal Year 1989

A regional compilation of wetland biomonitoring methods and value ranges for community metrics will be prepared.

Fiscal Year 1990

Locations of existing wetland data would be entered onto a Geographic Information System for analysis. As the database is formulated, calculation of regional medians and variances could begin.

Fiscal Year 1991

Analysis of existing biomonitoring data would be completed. Planning would be completed for the 1992 state-level pilot study.

Fiscal Year 1992

The state-level pilot study could be conducted. Results would be analyzed for applicability to any national monitoring network EPA may develop.

Fiscal Year 1993

This would be the first full year of the priority-based national monitoring network.

Fiscal Years 1994 to 1995 (3-year cycle) or to 1997 (5-yr cycle)

Implementation of the same program of Fiscal Year 1993.

Fiscal Year 1996 (3-yr cycle) or 1998 (5-yr cycle)

Resurveys of priority-based wetland type-regions would begin.

Figure 4. Schedule and **needed** budget ($K) for **COMPONENT II. Ecological Status of the Wetland Resource**

FY:	89	90	91	92	93	94
Task 1. Database Construction	100	100	100	20	20	20
Task 2. State-level Field Prototype Monitoring of Ecological Status				800		
Task 3. Full Implementation					3000	3000

TOTAL $K, COMPONENT (II):

FY89:	100
FY90:	100
FY91:	100
FY92:	820
FY93:	3020
FY94:	3020

5.3 Waste Assimilation Limits of Wetlands

5.3.1 Rationale

Wetlands are commonly reputed to be transformers of undesirable chemicals, and in the process of transforming these, the chemicals may be removed or rendered harmless to life in receiving waters. Thus, quantitative estimates of waste assimilative limits of wetlands are of practical use to EPA for several reasons. Constructed wetlands can be used in some situations, with due regard for potential bioaccumulation and dispersal of contaminants, as low-cost alternatives to wastewater treatment plants. Natural wetlands can be used to intercept and purify some types of nonpoint runoff, in situations where sources are too numerous for engineering solutions and control of pollutants at the source is impractical. On a landscape level, this leads to a question: "What acreage of what type of wetlands do we need to maintain or restore the water quality of a particular receiving water?" On an individual site level, this leads to a design question: "What engineering and biological characteristics in constructed wetlands are optimal for assimilating wastes?"

Hundreds of studies, many sponsored by EPA, have examined the ability of wetlands to process various anthropogenic substances, especially nutrients (Table 2, part 3). There are also manuals which propose engineering specifications for optimal waste processing by constructed wetlands. **Yet, the existing knowledge has been inadequate to provide EPA with answers to some important questions.**

Of foremost concern is that we do not know, except for a few individual wetlands, **what are the "safe" loading rates** for wetlands. This gap has occurred because (a) wetlands lose their assimilative capacity over time, yet few wetlands have been studied for appropriately long periods, and (b) in the absence of regional background data on unaltered wetlands, there has been no consensus as to how to recognize "safe" loading, i.e., what is a wetland with acceptable "integrity"?

There are other difficulties in generalizing from the host of existing studies. **Most study sites were chosen opportunistically, without randomization or testing of their regional representativeness, so that extrapolation is uncertain.** Many studies did not measure key hydrologic variables, thus invalidating most of their conclusions. And many studies sought only to prove that wetlands do transform substances, but never (perhaps because of inadequate sample sizes) indicated **which characteristics of the wetland were most influential** based on statistical analyses or calibrated models. In a few cases where predictive factors and their thresholds have been identified, the complexity and time requirements of their measurement has slowed

Table 2. Major literature reviews and syntheses.

I. EFFECTS OF WATER QUALITY ON WETLAND BIOTA

Benforado, J. 1984. The Ecological Impacts of Wastewater on Wetlands: An Annotated Bibliography. EPA-905/3-84-002. U.S. Environmental Protection Agency, Chicago, Illinois.

Biddinger, G.R. and S.P. Gloss. 1984. The importance of trophic transfer in the bioaccumulation of chemical contaminants in aquatic ecosystems. Residue Reviews 91:103-145.

Farnworth, E.G., M.C. Nichols, C.N. Vann, L.G. Wolfson, R.W. Bosserman, P.R. Hendrix, F.B. Golley, and J.L. Cooley. 1979. Impacts of Sediment and Nutrients on Biota in Surface Waters of the United States. U.S. EPA EPA-600/3-79-105. 331 pp.

Godfrey, P.J., E.R. Kaynor, S. Pelczarski, and J. Benforado (Eds.). 1985. Ecological Considerations in Wetlands Treatment of Municipal Wastewaters. Van Nostrand Reinhold Co., New York.

Grue, C.E., L.R. DeWeese, P. Mineau, G.A. Swanson, J.R. Foster, P.M. Arnold, J. N. Huckins, P.J. Sheehan, W.K. Marshall, and A.P. Ludden. 1986. Potential impacts of agricultural chemicals on waterfowl and other wildlife inhabiting prairie wetlands: An evaluation of research needs and approaches. Trans. N. Am. Wildl. Nat. Res. Conf. 51:357-383.

Johnson, W.W. and M.T. Finley. 1980. Handbook of Acute Toxicity of Chemicals to Fish and Aquatic Invertebrates. Resource Publication 137. U.S. Department of the Interior Fish and Wildlife Service, Washington, DC. 98 pp.

Mayer, F.L., Jr. and M.R. Ellersieck. 1986. Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals. Resour. Pub. 160, US Fish Wildl. Serv., Washington, DC. 579 pp.

Olsen, L.A. 1984. Effects of Contaminated Sediment on Fish and Wildlife: Review and Annotated Bibliography. U.S. Fish Wildl. Serv. FWS/OBS-82/66.

Reynoldson, T.B. 1987. Interactions between sediment contaminants and benthic organisms. Hydrobiologia 149:53-66.

Smith, J.A., P.J. Witkowski and T.V. Fusillo. 1988. Manmade Organic Compounds in the Surface Waters of the United States--A Review of Current Understanding. U.S. Geol. Surv. Circular 1007. 92 pp.

Willford, W.A., M.J. Mac, and R.J. Hesselberg. 1987. Assessing the bioaccumulation of contaminants from sediments by fish and other aquatic organisms. Hydrobiologia 149:107-111.

GUIDANCE DOCUMENTS:
II. METHODS FOR SAMPLING WETLANDS

Borthwick, S.M. 1988. Impact of Agricultural Pesticides on Aquatic Invertebrates Inhabiting Prairie Wetlands. M.S. Thesis, Dept. Fishery and Wildlife Biology, Colorado St. Univ., Ft. Collins, Colorado. 90 pp.

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their routine use by EPA personnel, who often have but a few hours or days to review an application for wetland alteration, or to perhaps decide whether to assign a designated use of "water quality purification" to a series of natural wetlands.

5.3.2 Approach

Task 1. Use Mesocosms to Identify Determinants of Loading Limits

EPA proposes to rely primarily on manipulative experiments in freshwater wetland mesocosms to address the unanswered questions. These mesocosm experiments should be integrated with an effort to develop rapid quantitative models requiring only very minimal, easily obtainable input data.

As noted above, a major hindrance has been recognition of what constitutes a "safe" condition. However, the parallel effort in Components I and II of this plan, by revealing appropriate indicators and metrics, and attainable levels, could serve as a foundation for setting this standard on a wetland type-region basis.

Task 2. Conduct coarser-scale studies of selected determinants.

Data from empirical studies being conducted under a separate part of EPA's Wetlands Research Program (Cumulative Effects) would also be used to draw conclusions and improve the applicability of the mesocosm results and models to coarser scales. Other empirical studies, involving analysis of existing data sets (e.g., studies of wetlands located below waste discharges and subject to long-term loading) would also be initiated at a lesser level of funding than the mesocosm studies.

The problem of identifying factors responsible for the long-term assimilative limits of wetlands, and recovery from the loss of assimilative capacity, is not easily addressed by use of mesocosms. Phosphorus is a key element of concern in the unintended use of wetlands for nonpoint runoff treatment, and Richardson (1985) found that sediment aluminum (in its amorphous, extractable form) is a key predictor of long-term assimilative limits for phosphorus. The empirical studies we propose could, with some limited additional field sampling, seek to correlate extractable aluminum to soil series and other landscape-level characteristics. If this succeeds, and among-wetland variation is greater than within-wetland variation, then regulatory personnel may be able to use soil maps with supporting material to provide a first approximation of wetlands likely to retain phosphorus for long periods.

Throughout the Component III effort, **simple wetland models will be used to help design the research.** Both conceptual and quantitative wetland models exist, but have high data input and processing power demands. Simpler versions of these could be tested and possibly calibrated in the mesocosm work. Much of the manipulative experimentation would be designed to **measure rate coefficients and determine their spatial variability and association with observable (particularly, remotely sensed) wetland characteristics.** The more easily measured rate coefficients may be monitored in the Component II effort as well, to develop these statistical associations. However, wetland models will not be the primary output of the research, but rather will help to guide it. In the near-term, these wetland models could be refined for use **at the scale of the individual wetland,** rather than for illustrating the cumulative interacting role of many wetlands in a watershed.

Opportunities exist for collaboration. There are advantages and disadvantages of using the same mesocosms in both the Component I and Component III efforts. There are also opportunities for influencing ongoing studies related to engineering design of constructed wetlands, and empirical studies of stormwater basins in Washington, Maryland, and other locations. **All potential collaborative opportunities must be viewed from the perspective of providing EPA with information that can be used to develop a categorization scheme or pollutant loading rate criteria for wetlands of a given type generally,** and which would be based on observable characteristics which correlate with long-term assimilative limits.

5.3.3 Outputs

Task 3. Report on "Safe" Loading Limits

"Safe" loading limits for six wetland type-regions might be specified for phosphorus, nitrogen, two heavy metals, and a limited number of priority organics. At greater funding levels, "safe" levels for other wetland type-regions, or criteria in a single type region for hydroperiod alteration and additional contaminants, could be included. Models could be developed to enable the user, given information on soil series or other landscape features, to categorize wetlands according to their probable long-term assimilative limits. Products would also include peer-reviewed papers, EPA reports, and/or software.

5.3.4 Potential Sources of Funding; Schedule

Potential Funding Sources

We estimate the proposed effort will require approximately $2.63 million over the 6-year period. In contrast, only limited funds--approximately $200K per year--are available at present from EPA's Wetlands Research Program. Additional funds might become available through a "Constructed Wetlands Initiative" being coordinated through the EPA-Cincinnati Lab. However, funds in addition to those from these two sources are likely to be required to successfully meet the program objectives.

	1989 - 1994 Needed $K
Task 1. Mesocosm Identification of Determinants	1680 (1)
Task 2. Empirical Studies of Determinants	750 (2)
Task 3. Report on "Safe" Loading Limits	200 (3)

(1) Assumes 6 mesocosm studies, each completed in 2 years and each costing $280 ($140K per year). Objective is to identify what determines wetland assimilation limits for phosphorus, two heavy metals, and a limited number of priority organics. Assume a need for proportionately greater funding if a wider variety of wetland types and/or stressors are to be examined in the same period of time.

(2) Assumes 5 regional analyses of existing data sets (beginning in 1990), costing $150K each. These would involve correlational examination of remotely-sensed landscape predictors of wetland water quality function. Assume a need for proportionately greater funding if more regions are examined per year.

(3) Involves literature review updates, development of simple models, research synthesis, interim progress reports, and technological information transfer.

Schedule

The schedule is shown graphically in Figure 5, and is presented narratively below.

Fiscal Year 1989

A 2-year study will be initiated in a single type-region mesocosm, with paired control site. Preference may be given to the use of natural wetlands, for the reasons described in Component I. Simple wetland models will be used both for experimental design, and to help predict the assimilative limits of the studied wetlands.

Fiscal Year 1990

Manipulative experiments will be concluded on the first wetland

Figure 5. Schedule and needed budget ($K) for **COMPONENT III. Waste Assimilation Limits of Wetlands**

Task 1. Mesocosm Identification of Determinants of Limits

FY:	89	90	91	92	93	94
wetland type/region 1*	140	140				
wetland type/region 2*		140	140			
wetland type/region 3*			140	140		
wetland type/region 4*			140	140		
wetland type/region 5*				140	140	
wetland type/region 6*				140	140	

Task 2. Empirical Studies of Determinants of Limits

FY:	89	90	91	92	93	94
wetland type/region 1*		150				
wetland type/region 2*			150			
wetland type/region 3*				150		
wetland type/region 4*					150	
wetland type/region 5*						150

Task 3. Reports on "Safe" Loading Limits

FY:	89	90	91	92	93	94
		25	25	25	25	100

TOTAL $K, COMPONENT (III):

FY89:	140
FY90:	455
FY91:	595
FY92:	735
FY93:	455
FY94:	250

* Region numbers are hypothetical and do not necessarily correspond with EPA administrative regions.

type-region mesocosm, and a second mesocosm study would begin. The first empirical study of determinants of wetland water quality function would be implemented, and may emphasize remotely-sensed landscape predictors of aluminum and denitrification.

Fiscal Year 1991

A third and fourth mesocosm would be added, while the second year of research continues on the second system. Empirical landscape studies as developed in the previous year for studying aluminum may be focused upon the investigation of denitrification in a new region.

Fiscal Year 1992

Manipulative approaches and empirical landscape studies would continue. Models to predict assimilative limits of wetlands would approach completion, with reports issued on draft models.

Fiscal Year 1993

Manipulative approaches and empirical landscape studies would continue. Models to predict assimilative limits of wetlands would approach completion, with reports issued on draft models.

Fiscal Year 1994

Models to predict assimilative limits of wetlands would be completed for the 5 wetland type-regions studied, with reports and software issued on final models.

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APPENDIX A. SYNOPSIS OF THE SURVEY RESPONSES AND THE EASTON WORKSHOP

As described in Section 2 of this Implementation Plan, scientific input was sought by means of a questionnaire distributed by the University of Florida, and by holding a workshop. Because the workshop was structured to focus on the same questions as were asked in the questionnaire, we have used these questions to organize the input.

I. EFFECTS OF WATER QUALITY ON WETLANDS

QUESTION I.1: WETLAND HEALTH

The questionnaire gave a working definition of wetlands health as:

"The presence of physical, chemical, and geographic conditions which will sustain the long-term aesthetic, assimilative, and productive dynamics of the wetland resource and its regionally indigenous organisms."

Both the questionnaire respondents and the workshop participants urged replacement of the term "health" with "integrity".

Questionnaire respondents frequently recommended the inclusion of a biological term, a hydrology term, deletion of the geographic and aesthetic terms. At the workshop, participants discussed the appropriate application of the following terms: aesthetic, assimilative, geographic, biogeochemical, function, productive, regional and indigenous organisms. They urged that a biological term should be added as an explicit condition, although it is also an objective. The importance of hydrology was stressed, but was left as an assumed component of the physical term. "Processes" were considered more inclusive than "function" or "dynamics". Other deleted terms were considered too anthropomorphic or restrictive.

QUESTION I.2; "STRAWMAN" GUIDELINES FOR PROTECTING WETLAND HEALTH

Most of these guidelines were developed and implemented by the State of Florida in response to projects involving wastewater additions to wooded wetlands.

Respondents were asked to indicate the adequacy of each of the guidelines for protecting wetland health. Specifically, respondents were asked to consider limitations associated with broadening the guidelines to include herbaceous (tidal, nontidal), created, and hydrologically altered wetlands. Evaluation criteria dealt with technical adequacy, relative importance, clarity, and consistency among guidelines.

The questionnaire respondents were asked to register their opinion of the technical adequacy of each guideline as "Quite adequate", "Somewhat adequate", or "Inadequate". The subsequent statistical analysis of these responses can indicate the strength of agreement, as well as of preference. However, when the responses show a strong central tendency (i.e., nearly all respondents answering "somewhat adequate"), results are difficult to interpret. In these

cases, whenever the skewing was towards "adequate", we have characterized the group response as "slightly adequate", whereas when it was skewed toward "inadequate", in the summary below we have called the group's response "slightly inadequate".

The 15 guidelines and the group responses are as follows:

#1. Guideline:
SPECIAL AREAS: Wetlands designated as shellfish areas, habitats of endangered/threatened species, designated ecologically critical areas, and public water supply areas shall not be used for wastewater treatment, and outfalls from any treatment wetland must be > 24 hr. hydrologic travel time (average annual) upstream from such areas".

#1 Response:
Guideline is slightly "adequate" for protecting the integrity of natural and altered wetlands.

#2 Guideline:
EMERGENT WETLANDS: Primarily forested and shrub wetlands shall be used; emergent wetlands (>30% herbaceous ground cover) shall not be used unless dominated by cattail".

#2 Response:
Guideline is "inadequate" for protecting tidal-herbaceous wetlands, and created and altered wetlands.

#3 Guidelines:
"LIMIT ROUGH FISH: In wetlands containing fish, a 10% decrease in biomass of forage fish, or of sport and commercial fish; or a 25% increase in rough fish is not allowed unless the ratio of sport and commercial fish to rough fish is maintained".

#3 Response:
"Adequate" for nontidal-herbaceous wetlands, "inadequate" for created wetlands.
#4 Guideline:

"LIMIT FISH BIOMASS IMPACT: Significant changes in biomass in any fish species will be allowed only if the change can be attributed primarily to changes in volume and depth of the flooded area which are not related to the discharge (using statistical covariance techniques)."

#4 Response:
"Inadequate" for created wetlands.

#5 Guideline:
"LIMIT TREE IMPACT: The importance value (a botanical metric) of any of the dominant plant species in the canopy and subcanopy at any monitoring station cannot be reduced by >50% (excluding certain exotics)."

#5 Response:
"Slightly inadequate" for nontidal wetlands, "inadequate" for created and altered wetlands.

#6 Guideline:
"LIMIT AVERAGE TREE IMPACT: The average importance value of any of the canopy dominants shall not be reduced by >25%.

#6 Response:
"Adequate" for nontidal-wooded wetlands, slightly "adequate" for tidal-herbaceous, "adequate" for created, and slightly "inadequate" for altered wetlands.

#7 Guideline:
"MAINTAIN DIVERSITY INDEX: The Shannon-Weaver index (reflecting diversity of benthic and epiphytic m acroinvertebrates, excluding Chironomidae) shall not be reduced to < 50% of background levels".

#7 Response:
"Inadequate" for created wetlands.

#8 Guideline:
"LOADING & DETENTION: Hydraulic loading rate shall be <5 cm/wk; detention time shall be > 14 days unless demonstrated that shorter times can meet above criteria".

#8 Response:
"Adequate" for wooded nontidal wetlands.

#9 Guideline:
"CONCENTRATIONS: Criteria for discharges of effluent into natural wetlands shall be as follows (mean monthly values): total nitrogen: 19 mg/l; ammonium: 2 mg/l; total phosphorus: 1

mg/l; pH: within 1.0 of background".

#9 Response:
"Adequate" for natural nontidal and tidal wetlands.

#10 Guideline:
"SHEET FLOW: Channeling of flow shall be minimized; sheet flow through the wetland shall be encouraged".

#10 Response:
"Inadequate" for wooded wetlands, "adequate" for tidal-herbaceous wetlands, and strongly "adequate" for tidal-herbaceous, created and altered wetlands.

#11 Guideline:
"PHYSICAL DIVERSITY: The diversity of physical habitats shall not be measurably reduced from baseline condition".

#11 Response:
Responses showed no trends.

#12 Guideline:
"ENCOURAGE REGIONAL BIODIVERSITY: Where physically possible, activities shall be located or designed so as to favor hydroperiods and/or indigenous plants/vegetation types which are relatively uncommon in the region (particularly those types which have experienced greatest losses), and their sustaining conditions."

#12 Response:
"Slightly inadequate" for natural nontidal wetlands.

#13 Guideline:
"MAINTAIN HYDROPERIOD: Baseline conditions with regard to duration, frequency, timing, and extent of wetland surface water shall be maintained."

#13 Response:
"Adequate" for natural wetlands and slightly "adequate" for created wetlands.

#14 Guideline:
"MAINTAIN REDUCING CONCENTRATIONS: The identity and proportions of reducing substances of the baseline (pre-efficient) wetland, or that are typical (>80% similarity) of similar wetlands in the region shall be maintained.

#14 Response:
"Inadequate" for natural nontidal wetlands and slightly

"adequate" for tidal wetlands.

#15 Guideline:
"SEDIMENT ORGANIC ACCUMULATION: Sedimentation and organic accumulation rates of the baseline wetlands, or that are typical of similar wetlands in the region, shall be maintained.

#15 Response:
Slightly "adequate" for tidal wetlands.

General Evaluation of the Florida Criteria:

Despite their pleas for further research directed at refining the criteria, questionnaire respondents believed that the criteria, taken as a collective whole, are probably "adequate" for wooded nontidal and created wetlands, and slightly "adequate" for herbaceous and altered wetlands. The workshop participants, too, were generally positive about these guidelines as a whole, although most of the specific guidelines were considered either "inadequate" for broad application to wetland types or "inadequate" to approach. Participants generally felt the guidelines were more adequate for created or altered wetlands than for natural wetlands.

Participants strongly urged that the guidelines be modified through research to reflect differences in wetland types-regions, but fell short of suggesting specific changes that should be made or hypotheses that could be tested.

Guidelines that were viewed as most critical for protecting wetland integrity were those related to maintenance of hydroperiod, loading and detention, physical (habitat) diversity, sediment/organic accumulation, and concentrations.

Participants urged that different guidelines be applied to non-point and point sources, but there was little discussion of specific adaptations that should be made. Some guidelines, such as those dealing with vegetation and fish, were considered appropriate in concept, but their numeric quantification was questioned, considering the existing lack of supporting data. The use of vegetation in criteria to assure wetland integrity was questioned, considering the lack of data, difficult of quantification, and the relatively slow and perhaps insensitive response for some vegetation types.

The emphasis in several guidelines on maintaining diversity was questioned, because "healthy" wetlands need not necessarily be diverse. Sheet flow was also viewed as not being a prerequisite to wetland integrity. Such guidelines may be especially applicable to created and altered wetlands. Encouragement of regional biodiversity was seen to be in conflict with many of the other guidelines. It might be applied more appropriately to created or altered wetlands, or considered in permit conditions on a case-by-case basis.

QUESTION I.3: ADEQUACY OF EXISTING SURFACE WATER CRITERIA

An official list of EPA priority pollutants was presented under the categories of nutrients, heavy metals, pesticides, organics, synthetic organics and other water quality conditions. Respondents were asked to indicate (a) the adequacy of existing water quality criteria (for each substance) to protect wetland health, (b) the likelihood that natural processes cause excedence of the criterion, and (c) extent of personal experience with specific criteria.

The questionnaire responses were too insufficient in number and completion to be analyzed. Workshop participants generally felt unqualified to assess specific numeric criteria. A matrix showing the effect of some water quality conditions on a few water contaminants drew some response.

QUESTION I.4: ACTIVITIES THAT AFFECT WETLANDS

Participants were asked to indicate the extent and severity of various activities and contaminant sources for their state. Response categories were "very extensive or severe", "moderately extensively or severs", or "not extensive or severe."

Land clearing and tillage were generally viewed as the most important threats to wetland water quality. Channelization and dike-levee operation were also high in both scales.

Non-point sources were suggested as most extensive, but of moderate severity. Agricultural runoff was the most extensive followed by land drainage-irrigation and stormwater runoff, then community landfills and forest management. All of these were considered moderate in severity. Hazardous waste sites were not considered extensive, but their severity was considered very high.

Point sources were likewise ranked as not extensive, but severe in impact. Domestic/industrial wastewater was the leading type of activity impact (most extensive and severe) on wetland water quality. Mineral/oil exploration and hazardous waste sites followed in importance.

QUESTION I.5: PRIORITIZING THE CONTAMINANTS

Respondents were asked to indicate the extent and severity of major contaminant categories on three wetland types. Metals and toxic elements were most consistently considered to have a very extensive (severe) impact on wetland water quality. Synthetic organics were second in importance, with both having lesser severity in tidal wetlands. Sedimentation was seen as severe in non-tidal wetlands. Nutrients were recognized as extensive with their severity of effect decreasing from non-tidal surface water wetlands, to tidal wetlands, to non-tidal-no surface water wetlands.

QUESTION I.6 AND I.7: WETLANDS MONITORING NETWORK

Respondents were asked to indicate taxa and process/conditions (from lists provided) which might show promise as indicators of wetland health, given various types of stressors. A second part of the question requested evaluation of thirteen community metrics commonly used to evaluate structural data.

The questionnaire responses were too insufficient in number and completion for analysis. At the workshop, participants were asked to assume a budget of $2000 per wetland per year. There was strong sentiment that this would be insufficient for establishing a credible regional wetland monitoring network. However, if such a network were implemented, participants felt that effort should focus on analysis of sediments (deposition rates, organic content, contaminant levels). Macroinvertebrates (especially sessile detritivores and filter feeders) were listed as potentially useful indicators of metals and toxics (and mentioned for sediment). Community composition descriptions were mentioned as an indicator of change for all pollution types. Among process measurements, productivity was considered as a potentially suitable indicator of artificial nutrient enrichment. The temporal and episodic variation of water monitoring versus biological monitoring was a major discussion topic among workshop participants.

QUESTION I.8: REMOTE SENSING

Questionnaire respondents suggested that the most easily measured feature using remote sensing would be the ratio of vegetated to open water areas.

However, the feature most relevant to determining wetland integrity would be vegetation cover type.

From a list of biological features that might be remotely sensed, workshop participants believed that biomass was the most relevant remotely-sensed feature, followed by cover type. Leaf area is a difficult parameter for remote sensing (if the intent is leaf area index and not just percent ground cover) and generally was not recommended. Greenness, although a historical remote sensing term, has a confusing interpretation in an ecological framework and is likewise not preferred.

The percent area of shallows containing emergents was judged most relevant to estimating wetland integrity, with moderate ease of measurement. The ratios vegetation/open water, wetland/deep water and edge irregularity index, although easy to measure, were not seen as very relevant, necessarily, to wetland integrity. A measure of the flushing or exchange surface (open water to wetland flux) were added suggestions.

From a list of physical properties that might be remotely sensed, participants believed that hydroperiod was relatively easy to determine and had high relevance. Turbidity was rated slightly lower than hydroperiod. Flow braiding was seen to have low relevance to integrity, but is easy to measure. Organics and geomorphic conditions were additionally suggested as properties that might be both remotely sensed and sensitive to anthropogenic stress.

QUESTION I.9: TYPE OF SUPPORTING DATA COLLECTION

Respondents were asked what relative emphasis they would assign to regional surveys vs. laboratory bioassays, given the goals of cost-effectively developing and enforcing water quality criteria for wetlands. No clear preference was shown among questionnaire respondents, but workshop participants preferred regional surveys. Also, no preference was apparent for using stratified random sampling (as opposed to intentionally selecting the "most pristine" sites), nor was any preference shown for using tissue analysis (vs. field biosurveys or chemical surveys). If bioassays are used, but the respondents and the workshop participants favor multiple species, in situ bioassays over the traditional single-species laboratory approaches.

II. EFFECTS OF WETLANDS ON WATER QUALITY

QUESTION 1. RESEARCH APPROACHES: INTERIM AND LONG-TERM

Respondents and workshop participants were asked to indicate the probability of success, and cost effectiveness, of Literature Reviews, Workshops, Empirical Landscape Analyses, and Mechanistic Model Simulations for addressing short-term EPA needs.

As expected, the need for integration of all these components was emphasized. Literature reviews and workshops were viewed as being lower-cost options, and use of existing models in simulations was viewed as being less likely to succeed than developing new models, or using the other approaches.

QUESTION II.2: KEY FACTORS

Respondents and participants were asked to indicate the usefulness of several factors, if these were used in mesocosm manipulations and ultimately are used for classifying wetlands according to their assimilative capacity.

For tidal wetlands, the vegetation density, duration of tidal inundation, and loading rate were viewed as most useful descriptors of assimilative capacity.

For non-tidal surface-water wetlands (e.g., deep marshes), the hydroperiod, detention time, sediment organic content, redox potential, position in watershed, and loading rate were viewed as most useful.

For non-tidal no -surface-water wetlands (e.g., bogs and wet meadows), the duration of inundation and position in watershed were considered most useful.

QUESTIONS II.3 AND II.4: CONFLICTING HYPOTHESES, THRESHOLDS

These questions dealt with commonly-stated hypotheses about wetlands which seem to be in conflict, and with advisable widths for buffer zones. Responses were insufficient to allow analysis, and at the workshop, time was insufficient to adequately address these.