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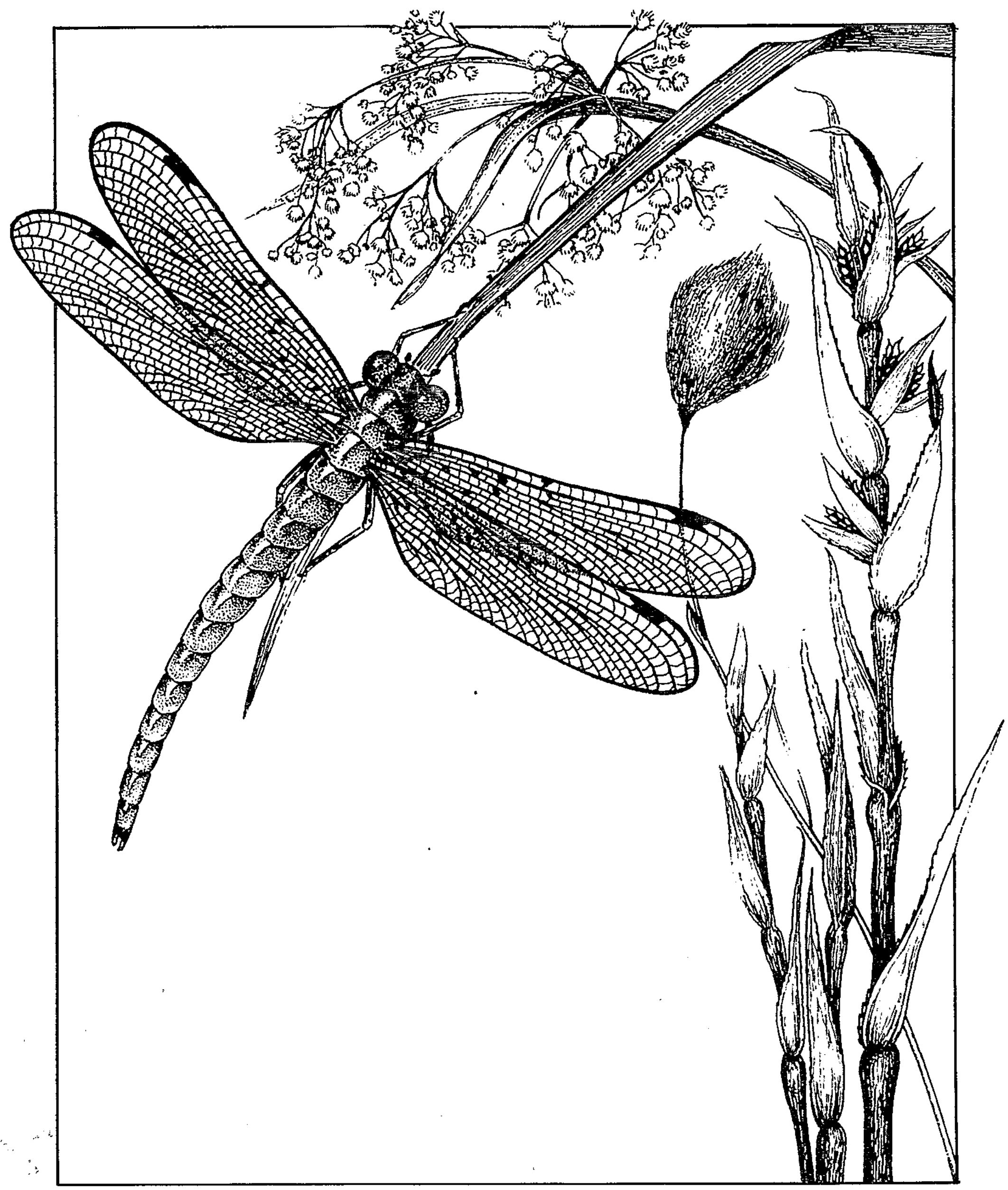
March 1992

EPA

Wetlands Research Plan FY92-96

An Integrated Risk-Based Approach



EPA/600/R-92/060
March 1992

WETLANDS RESEARCH PLAN FY92-96: AN INTEGRATED RISK-BASED APPROACH

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TABLES

ACRONYMS

BOR	Bureau of Reclamation
BPJ	best professional judgment
COE	Corps of Engineers
CWA	Clean Water Act
DQO	data quality objective
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ERL	Environmental Research Laboratory
FHWA	Federal Highways Administration
FTE	full-time equivalent
FWS	Fish and Wildlife Service
FY	fiscal year
GIS	Geographic Information System
LDI	Landscape Development Index
LULC	land use/land cover
NWI	National Wetlands Inventory
ORD	Office of Research and Development
OST	Office of Science and Technology
OWRS	Office of Water Regulations and Standards
QA	quality assurance
QC	quality control
SAB	Science Advisory Board
SCS	Soil Conservation Service
TP	total phosphorus
TVA	Tennessee Valley Authority
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WET	Wetland Evaluation Technique
WRP	Wetlands Research Program

ACKNOWLEDGMENTS

The production of this research plan has been funded wholly or in part by the U.S. Environmental Protection Agency through Contract No. 68-C8-0006 to ManTech Environmental Technology, Inc., Contract No. 68033544 to ASci Corporation, and Contract No. 68-CO-0021 to Technical Resources, Inc.

Personnel from the Wetlands Division of EPA's Office of Wetlands, Oceans, and Watersheds and the Regions have been extremely supportive throughout the development of this research plan. They responded to our requests for information, attendance at meetings, lists of research priorities, and reviews in addition to dealing with the pressing regulatory matters that were before them. Their efforts have helped to guarantee that the Wetlands Research Program has focused on issues important to the Agency. We continue to appreciate the personal support of John Meagher, Director, Wetlands Division. In particular, we want to thank Doreen Robb, Wetlands Divisions' liaison to the research program, for her efforts to help us communicate Agency needs effectively and accurately, coördinate input from the Office, and resolve the myriad of questions that came up.

The Wetlands Research Program (WRP) would also like to acknowledge the contribution of the people who supported the authors in the production of this plan. Ann Hairston and Perry Suk provided technical editing; Kristina Miller, word processing and graphics production. William Norris coordinated the meetings and provided input to the first drafts. Arthur Sherman advised on quality assurance issues. William Kruczynski and Raymond G. Wilhour of EPA's Environmental Research Laboratory in Gulf Breeze, FL, developed the section on the pilot study to develop preliminary technical support for the establishment of water quality criteria for coastal seagrass systems.

The WRP thanks all those who generously gave of their time to review the various drafts of the plan. In particular, we would like to recognize those who participated in an early planning meeting. Their input did much to shape the overall direction of the Program. Participants were Robert Brooks of Pennsylvania State University, Stephen Cordle, EPA's Office of Environmental Processes and Effects Research, Michael Durako of the Florida Department of Natural Resources, Charles DesJardins of the Federal Highway Administration, Gerald Grau of the U.S. Fish and Wildlife Service's National Wetlands Research Center, Richard Horner of the University of Washington, Carl Johnston of the University of Minnesota, Jill Minter of EPA's Office of Science and Technology, Gordon Thayer of the National Marine Fisheries Beaufort Laboratory, Russell Theriot of the U.S. Army Corps of Engineers' Waterways Experiment Station, Arnold Van der Valk of Iowa State University, Gary Williams of the Bureau of Reclamation, Chief Wu of EPA's Office of Environmental Processes and Effects Research, and Joy Zedler of San Diego State University. In addition, Carolyn Hunsaker of the Oak Ridge National Laboratory, Joseph Larson of the University of Massachusetts-Amherst, and William Mitsch of Ohio State University provided comprehensive written reviews of an early draft.

Finally, the WRP thanks the members of EPA's Science Advisory Board (SAB) for their review and endorsement of the plan. Their input guided and strengthened the final version of the plan. Members of the review panel were Allan Hirsch, Chairman; Betty Haak Olson, Vice-Chair; Members--Donald F. Boesch, George F. Carpenter, and C. Herb Ward; Consultants--Barbara

Bedford, James Gosselink, Joseph Larson, and Curtis Richardson; Federal Agency Liaisons--Ann Bartuska (U.S. Forest Service), David E. Chalk (U.S.D.A. Soil Conservation Service), Robert Stewart (U.S. Fish and Wildlife Service), and Russell Theriot (U.S. Army Corps of Engineers); and SAB Staff--Edward S. Bender, Marcia Jolly, Robert Flaak, and Donald G. Barnes.

WETLAND RESEARCH PLAN FY92-96: AN INTEGRATED RISK-BASED APPROACH

EXECUTIVE SUMMARY

The Wetlands Research Program (WRP) was initiated in 1986 within the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD). This document presents the research objectives and strategy for the WRP for Fiscal Years (FY) 1992-1996.

PROGRAM OBJECTIVES

The WRP is an applied research program. Its primary purpose is to provide technical support to the EPA programs within the Office of Water and the Regions to improve the Agency's ability to carry out its regulatory responsibilities relating to wetlands. Thus, the research conducted by the WRP must be scientifically sound and represent a significant contribution to wetland science and also directly serve the needs and priorities of the EPA program offices.

Based on the priority research needs identified by the EPA program offices, the specific objectives for the WRP for FY 1992-1996 are as follows:

- Develop and demonstrate a risk-based framework for wetland protection and management.
- Determine the contribution of individual wetlands to water quality improvement, habitat, and hydrologic functions, and develop techniques for enhancing these functions.
- Evaluate the role of the aggregate of wetlands in the landscape on water quality, habitat, and hydrologic functions at a landscape scale, and the influence of wetland characteristics on these landscape functions.
- Quantify the effects of environmental stressors and landscape factors on wetland functions.
- Characterize and compare the functional status of populations of natural, restored, and created wetlands in different landscape settings.
- Provide technical support for the development of biological criteria for wetlands in support of the Office of Water.
- Provide technical support for the development of design guidelines and performance criteria for wetland restoration and creation.
- Using the information and methods listed above, conduct an integrated risk assessment for at least one major wetland type to provide technical support on two major issues:

    -- the national policy of no net loss of wetland area and function, and

    -- the role of wetlands in reducing nonpoint source pollution.

PROGRAM ORGANIZATION

To achieve the objectives of the WRP will require information gathered at three spatial scales. Detailed studies at **individual wetland sites** are needed to better understand the processes within wetlands that contribute to wetland functions, wetland responses to environmental stressors, and wetland assimilative capacity. Information also is needed on the characteristics of **populations of wetlands** (i.e., groups of wetlands of the same type) to compare the functions of natural, restored, and created wetlands within different landscape settings. Finally, research is needed on the role of wetlands within **regional landscapes**. The incorporation of landscape-level research into the WRP is essential because (1) the formation and maintenance of wetlands are highly dependent on landscape processes, such as regional hydrology, and (2) the functions that wetlands provide often arise from complexes of wetlands and the interactions between wetlands and other ecosystems in the landscape.

The methods and analyses employed in wetland research tend to vary depending on the spatial scale of interest. For this reason, the WRP has been organized into four project areas, three of which will emphasize studies at a different spatial scale. The fourth project will synthesize the results of the other three projects to address more complex, multiple-scale issues (Figure 1):

1. **Wetland Function Project** -- focuses on processes within individual wetlands or small groups of wetlands along a gradient of environmental impacts, to quantify wetland functions, stressor/response relationships, and wetland assimilative capacity.

2. **Characterization and Restoration Project** -- develops methods and information to characterize and compare the functional attributes of wetland populations, and also develops design guidelines and performance criteria for wetland restoration and creation.

3. **Landscape Function Project** -- examines issues at the landscape scale, studying the aggregate of wetlands within a given landscape unit to determine how wetlands contribute to landscape functions (e.g., regional water quality, biodiversity) and how landscape factors (e.g., regional hydrology) affect wetland functions.

4. **Risk Reduction Project** -- integrates findings from the other three projects to address comprehensive issues at multiple scales, including the development and demonstration of a risk-based framework for wetland protection and management.

The WRP also includes two other research projects: Constructed Wetlands and the wetland component of the Environmental Monitoring and Assessment Program (EMAP-Wetlands). Although formally a part of the WRP, Constructed Wetlands and EMAP-Wetlands are funded separately and have separate research plans. The Constructed Wetlands Project also responds to a different EPA program office. For the purposes of this document, therefore, the WRP or "Program" refers specifically to the Wetland Function, Characterization and Restoration, Landscape Function, and Risk Reduction Projects; research for Constructed Wetlands and EMAP-Wetlands is not included.

Three ORD Laboratories are involved in the WRP. The Characterization and Restoration, Landscape Function, and Risk Reduction Projects, and Technical Information Transfer are the responsibility of EPA's Environmental Research Laboratory (ERL) at Corvallis, OR. ERL-Corvallis

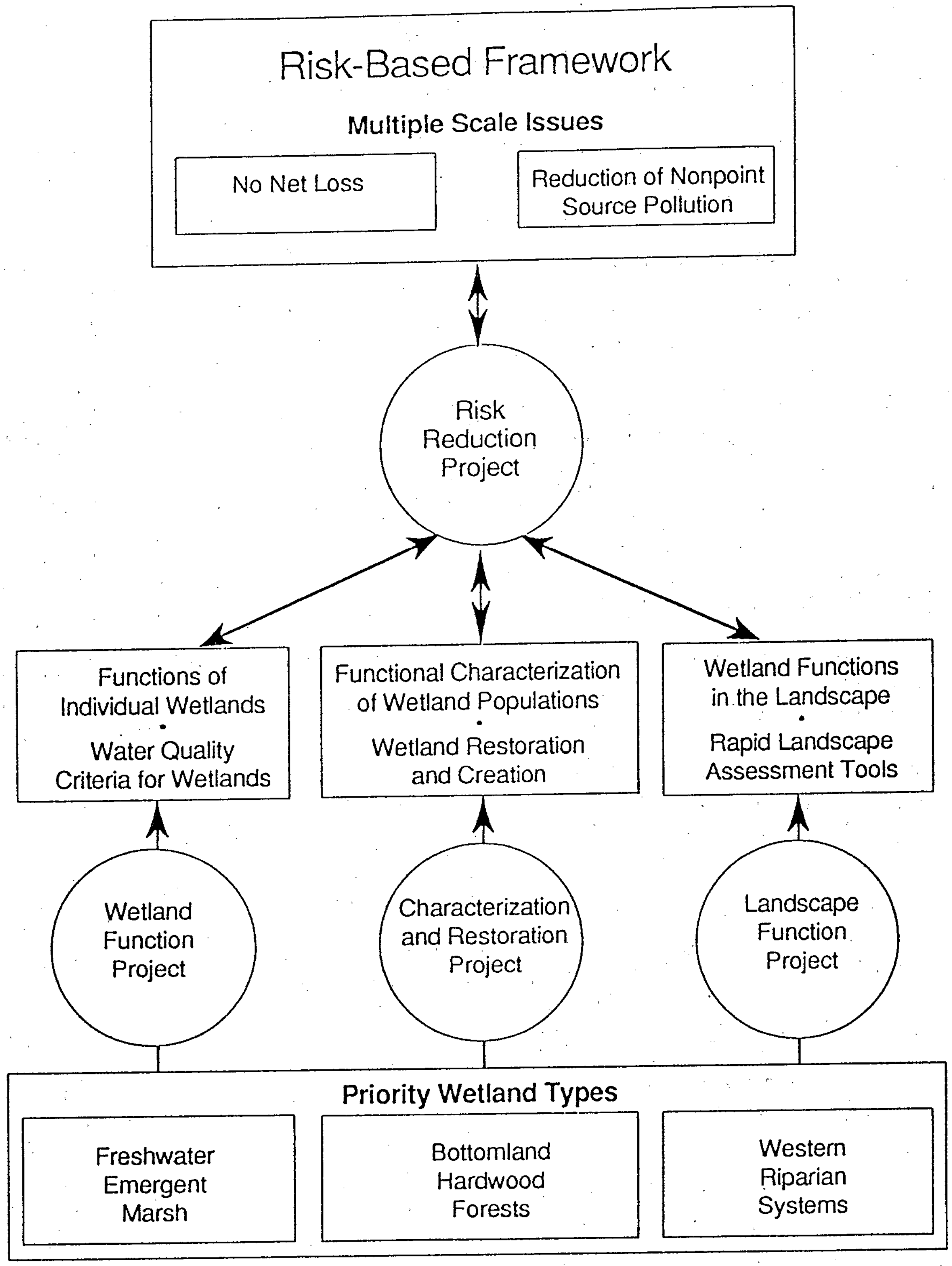

Figure 1. Proposed research strategy for the Wetlands Research Program.

also will act as matrix manager for the Program as a whole and will provide oversight of Program Quality Assurance. ERL-Duluth (Minnesota) is responsible for the inland component of the Wetland Function Project. ERL-Gulf Breeze (Florida) will conduct the pilot study for the proposed coastal component of the Wetland Function Project.

PRIORITY WETLAND TYPES

Based on discussions with EPA program offices and with wetland scientists participating in a WRP planning workshop in February 1991, three wetland types were identified as priorities for research in FY 1992-1996: (1) freshwater emergent wetlands, (2) bottomland hardwood forests, and (3) western riparian systems.

Freshwater emergent wetlands are shallow wetlands that form in depressions, lake and stream edges, and freshwater tidal zones. Prairie potholes, which occur in depressions within the glacial deposits of the North American prairie, are a specific type of freshwater emergent wetlands that is of special interest. Prairie potholes are the principal production area for many North American duck species. Agricultural activities in the area have resulted, however, in significant wetland losses and large inputs of sediment, nutrients, and agricultural chemicals that may degrade wetland functions.

Bottomland hardwoods are extensive forested wetlands that occupy the alternating wet and dry hydrologic zone adjacent to many rivers in the southcentral and southeastern United States. These forests provide important functions, such as flood storage, water quality improvement, and wildlife habitat, yet have been degraded by extensive timber clearing, the construction of dams and levees that have modified the hydrologic regime, and other cumulative impacts.

Riparian systems (i.e., the interface between aquatic and terrestrial systems, in floodplains and adjacent rivers and streams) contain the principal freshwater wetland type in the arid and semi-arid regions of the western United States. These systems provide important habitat for wildlife, and many of the endangered and threatened species in the area occur within riparian habitats. Water diversions, urbanization, cattle grazing, and other impacts have resulted in extensive and continuing loss and degradation of these systems and their associated wetlands.

Three other types of wetland resources have also been identified as warranting additional research: (1) "drier" wetlands that are saturated with water during only some seasons of the year, (2) wetlands in urban landscapes, and (3) wetlands in coastal areas. Research will be conducted on these wetland resources to the degree possible within the budget constraints of the WRP. Information on drier wetlands is of particular interest because these wetland resources may provide an important resource for control of nonpoint source pollutants and flood attenuation, but may no longer be protected under proposed changes in federal wetland policy and wetland delineation. Wetlands in urban landscapes are used and valued by relatively large segments of the general public, yet are also subject to high loss rates and a diversity of impacts. Information on wetlands in coastal areas is needed on (1) the effects of stressors on coastal wetlands; (2) the role of inland wetlands in moderating the transport of nutrients, sediments, and chemical contaminants from the landscape to estuaries; and (3) appropriate water quality criteria and management strategies for the protection of coastal wetlands. All three of the priority wetland types noted above may include areas of drier wetland or occur within an urban setting; freshwater emergent wetlands and western riparian systems can occur in coastal areas.

RISK-BASED FRAMEWORK FOR WETLAND PROTECTION

EPA's Science Advisory Board has recommended that EPA focus their environmental protection efforts on those problems that pose the greatest risk and on the areas and problems in which the greatest risk reduction can be achieved. Therefore, one of the major objectives of the WRP for FY 1992-1996 is to develop and demonstrate the utility of a risk-based framework for wetland protection and management. Eventually, after this framework has been tested and refined, it can serve two important purposes: (1) to provide a basis for management decisions regarding wetland protection that incorporate the best available technical information, and (2) to define future WRP research needs and priorities.

The goal of the risk reduction process, as proposed by the WRP, is to **minimize the loss of valued wetland functions.** The proposed WRP risk-based framework includes three basic components, each of which includes both technical and policy input (Figure 2):

1. **Risk Assessment** -- the estimation of the risks associated with various stressors and identification of those wetlands of greatest value that are at greatest risk of functional loss and also have low replacement potential

2. **Risk Management** -- the development and implementation of an effective management strategy to control and manage the most serious risks

3. **Monitoring and Evaluation** -- follow-up monitoring to evaluate the effectiveness of management actions and identify new problems that may arise

To serve the needs of wetland managers and regulators, the risk-based framework must be both technically and programmatically feasible. The types of technical data and analyses required for any given application must not be prohibitive. Thus, for most management applications, the framework will be implemented hierarchically, increasing the level of effort at each stage and continually focusing on those aspects that will contribute the most to improving management decisions. Frequently, it may also be effective to implement the framework hierarchically on a spatial scale, conducting assessments initially at a landscape scale (watersheds or ecoregions). Site-specific data collection may or may not be necessary depending on the management objectives, desired level of resolution and confidence, and nature and extent of existing data. The specifics of how best to implement the risk-based framework will vary depending on the management context and management objective being evaluated.

The risk-based framework will provide a structure for integrating the results from all four of the WRP projects. The Risk Reduction Project, however, has the primary responsibility for framework development and demonstration.

WETLAND FUNCTION PROJECT

The Wetland Function Project focuses on those tasks and information needs best provided through relatively detailed studies of processes and responses in individual wetlands or small groups of wetlands. Consistent with the EPA program priorities, four studies will be conducted during FY 1992-1996, evaluating (1) the functional response of prairie pothole wetlands to sediments and sediment-associated pollutants; (2) the effects of management practices and

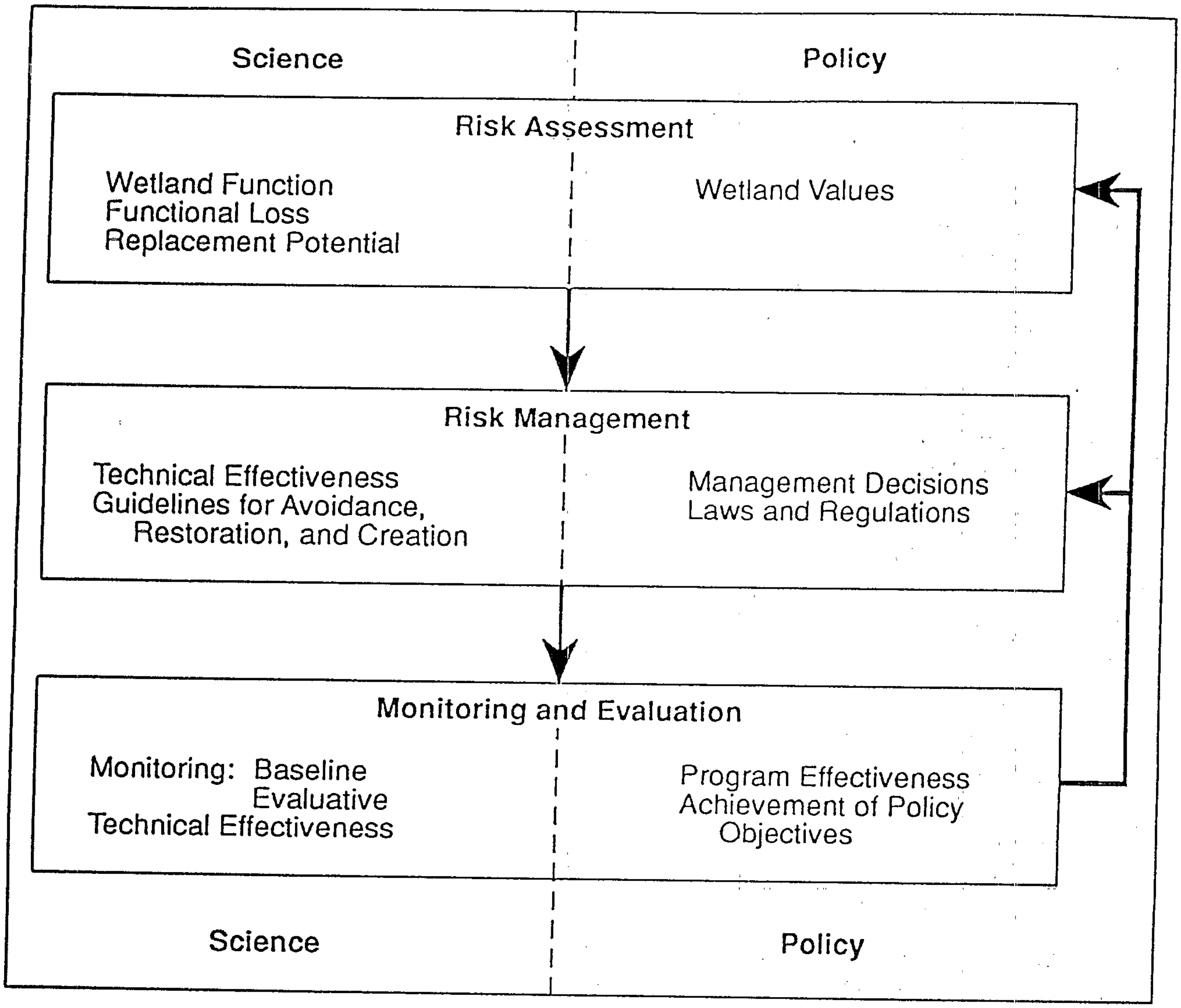

Figure 2. Components of the WRP risk-based framework for wetland protection and management. All three components require both technical and policy input.

nonpoint source pollution on the water quality and habitat functions of bottomland hardwood forests in agricultural landscapes of the southeastern United States; (3) the effects of hydrological modification on the water quality and habitat functions of freshwater emergent marsh in an urban setting; and (4) a pilot study of the effects of stressors on coastal seagrass communities.

Each study will incorporate, as appropriate, four major types of activities (Figure 3):

1. Develop literature syntheses and conceptual models to identify the wetland stressors of concern, potential indicators of wetland condition and function, and hypotheses regarding wetland processes and stressor effects.

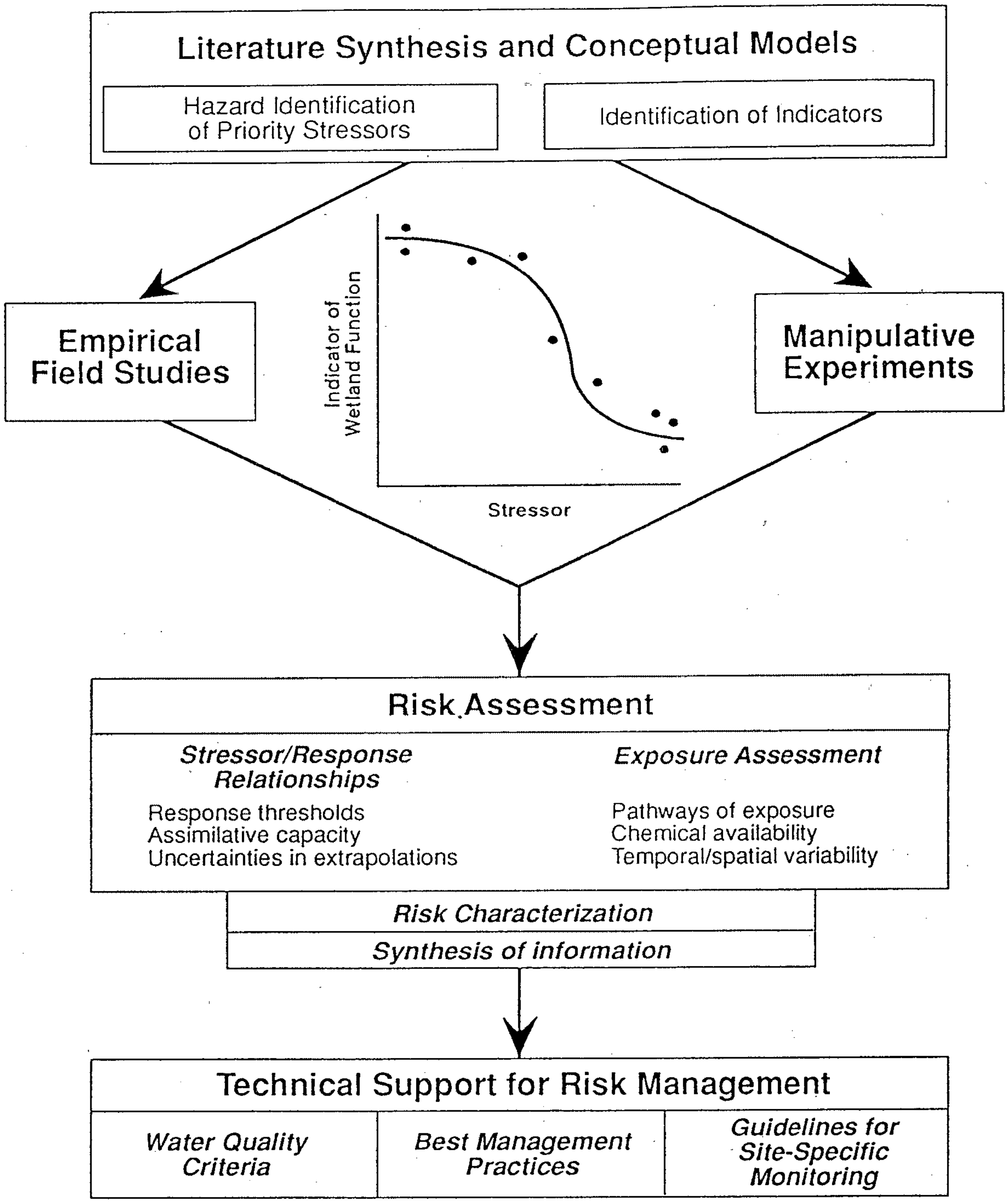

Figure 3. Flow chart for the research strategy for the Wetland Function Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships.

2. Conduct empirical field studies to characterize wetland conditions (a) along a gradient of an environmental stressor(s), (2) before and after the occurrence of a disturbance or stressor, and/or (3) in wetlands with varying wetland or watershed management strategies, to evaluate stressor/response relationships, exposure pathways, and the effectiveness of various management practices for wetland protection.

3. Perform manipulative experiments in the field or laboratory to determine the response of specific processes and wetland attributes to a controlled range of concentrations or conditions associated with a specific stressor as well as to a range of modifying factors (e.g., sediment organic carbon content).

4. Integrate the project results within the risk-based framework to provide technical support for risk management, including the development of water quality criteria (especially numeric biocriteria) for wetlands, best management practices, and guidelines for monitoring.

CHARACTERIZATION AND RESTORATION PROJECT

The Characterization and Restoration Project focuses on those information needs and objectives best achieved through field studies of wetland populations. The overall strategy for the project is illustrated in Figure 4. Four major tasks will be conducted:

1. Characterize wetland populations, including natural, restored, and created wetlands, to quantify wetland functions and among-wetland variability within specific geographic and land use settings.

2. Evaluate the performance of wetland restoration and creation projects and determine the attainable levels of wetland functions in various landscape settings.

3. Develop specific performance criteria and technical design guidelines to enhance the performance of wetland restoration and creation projects and accelerate project development.

4. Develop and test an approach for prioritizing sites for wetland restoration and creation.

Indicators of wetland function will be measured in a representative sample of wetlands for each wetland population of interest (e.g., natural, restored, or created wetlands within areas dominated by urban or agricultural land use). Results from these field surveys will be used to characterize and compare the functional status of wetland populations and to evaluate the performance of wetland restoration and creation projects. Information on the long-term development of restored and created wetlands over time, relative to conditions in natural wetlands in similar settings, is of particular interest. Manipulative experiments may also be conducted to assess alternative design features that may improve or accelerate the development of valued functions in restored or created wetlands.

Three priority studies have been targeted for implementation during FY 1992-1996: (1) the characterization of agriculturally converted wetlands in the Prairie Pothole Region, (2) the development of objective protocols for selecting priority sites for restoring western riparian

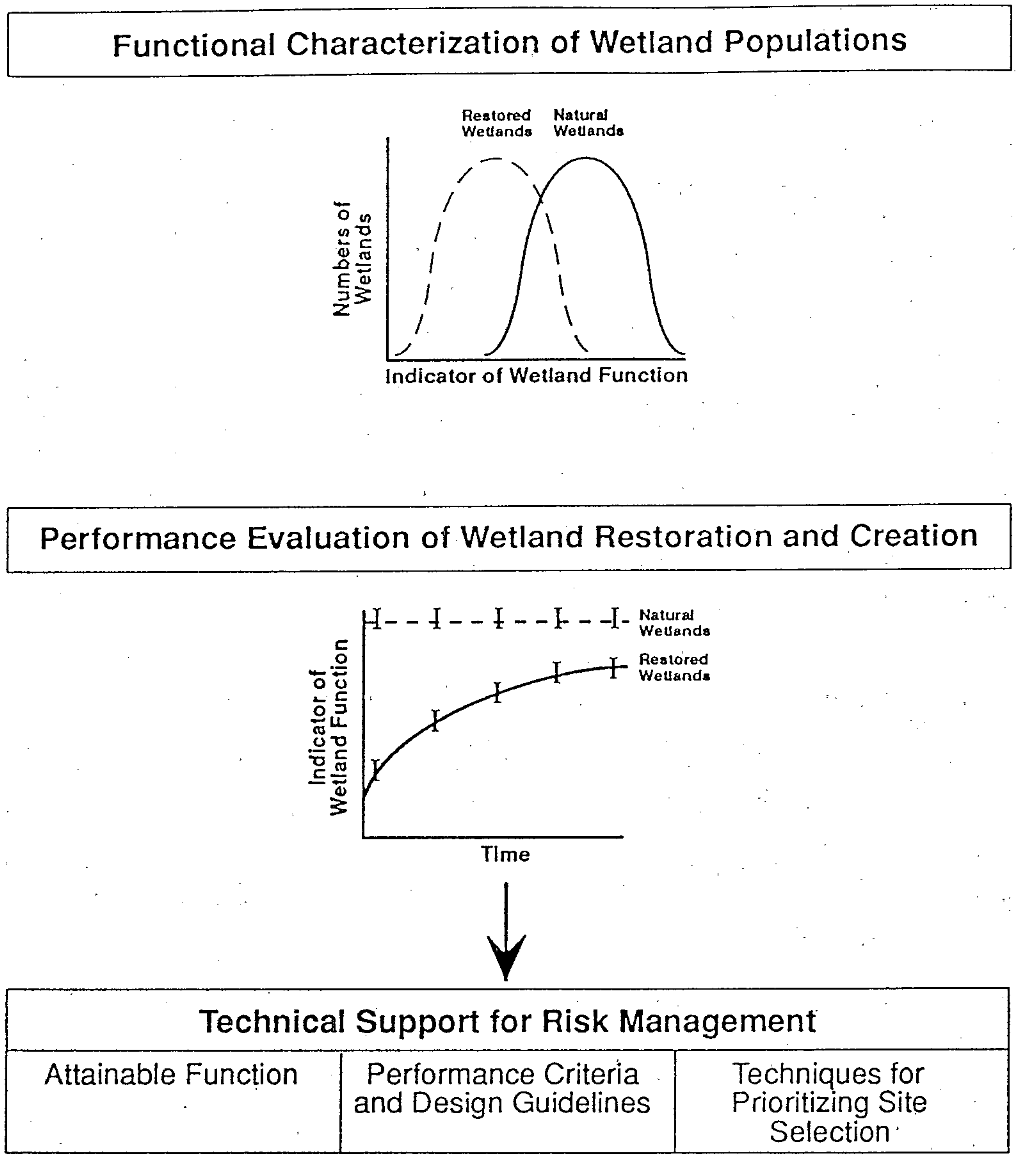

Figure 4. Flow chart for the research strategy for the Characterization and Restoration Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships.

systems and evaluation of approaches for restoring them, and (3) long-term studies of the development of mitigation projects with a major component of freshwater emergent marsh.

LANDSCAPE FUNCTION PROJECT

The Landscape Function Project examines issues at a landscape scale, studying the aggregate of wetlands within a given landscape unit, and comparisons among units, to determine how wetlands contribute to landscape functions (such as regional biodiversity, water quality, and hydrology) and how landscape processes and factors affect wetlands.

For each region/landscape studied, five basic tasks will be conducted:

1. Develop conceptual model(s) and best professional judgment (BPJ) hypotheses regarding the role of wetlands in landscape functions and the influence of landscape processes on wetlands.

2. Refine these hypotheses through simulation analyses with existing models.

3. Conduct empirical landscape analyses for hypothesis testing and indicator development, examining the association between (a) indicators of landscape function and wetland and landscape characteristics and (b) indicators of wetland function and various landscape factors and processes.

4. Calibrate model(s) for specific landscapes, using the results from the empirical landscape analyses as well as from other WRP projects, and conduct model simulations to evaluate management options.

5. Develop low-cost landscape assessment methods (such as the Synoptic Approach, Landscape Development Index, and landscape criteria) that can be readily applied to provide technical support for wetland protection and management in other areas.

The Landscape Function Project will rely primarily on information obtained by compiling and analyzing existing data bases, maps, and other available data sources. Field data collected by the Wetland Function Project, Characterization and Restoration Project, and EMAP-Wetlands also will be incorporated into these landscape-level analyses as appropriate. The overall project strategy is illustrated in Figure 5.

The specific studies to be implemented by the Landscape Function Project are (1) a landscape assessment of prairie potholes; (2) a landscape assessment of bottomland hardwood forests; and (3) an evaluation of the influence of inland wetlands on estuarine water quality.

RISK REDUCTION PROJECT

The Risk Reduction Project will integrate the results from the other three WRP projects to demonstrate the application and utility of the proposed risk-based framework for wetland protection and management. The Risk Reduction Project will conduct no new field work or landscape analyses, but will work directly with the Wetland Function, Characterization and Restoration, and Landscape Function Projects, as well as EMAP-Wetlands, to ensure that these projects provide the types of methods, data, and analyses needed as input to a risk reduction analysis (Figure 6).

Further work is needed to evaluate, refine, and demonstrate the risk-based framework. Therefore, the following five tasks will be completed in sequence:

1. Review and evaluate the conceptual framework (described above), modifying and augmenting it as necessary.

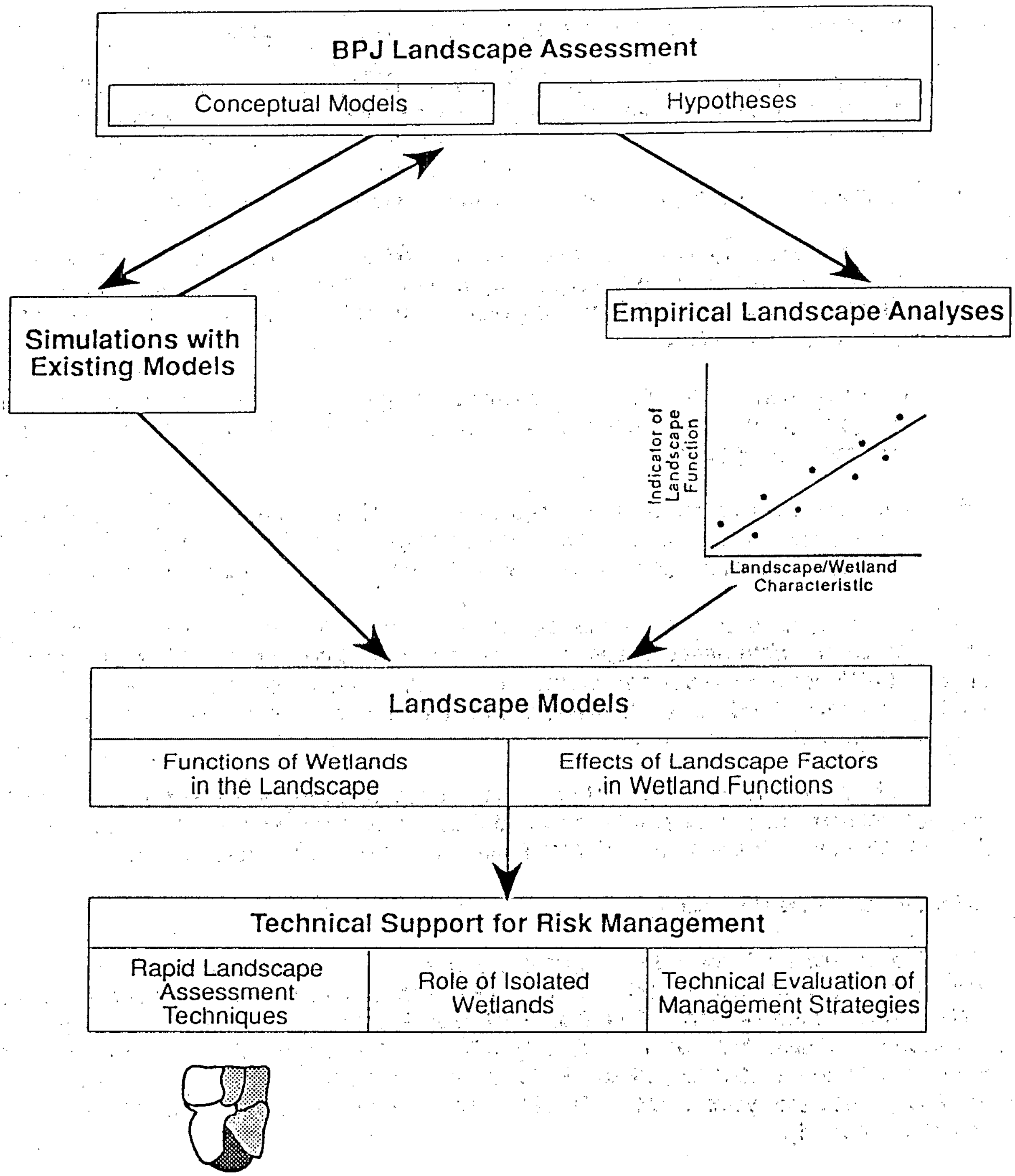

Figure 5. Flow chart for the research strategy for the Landscape Function Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships. The graphic at the bottom of the figure is used to represent the Synoptic Approach and other low-cost landscape assessment methods.

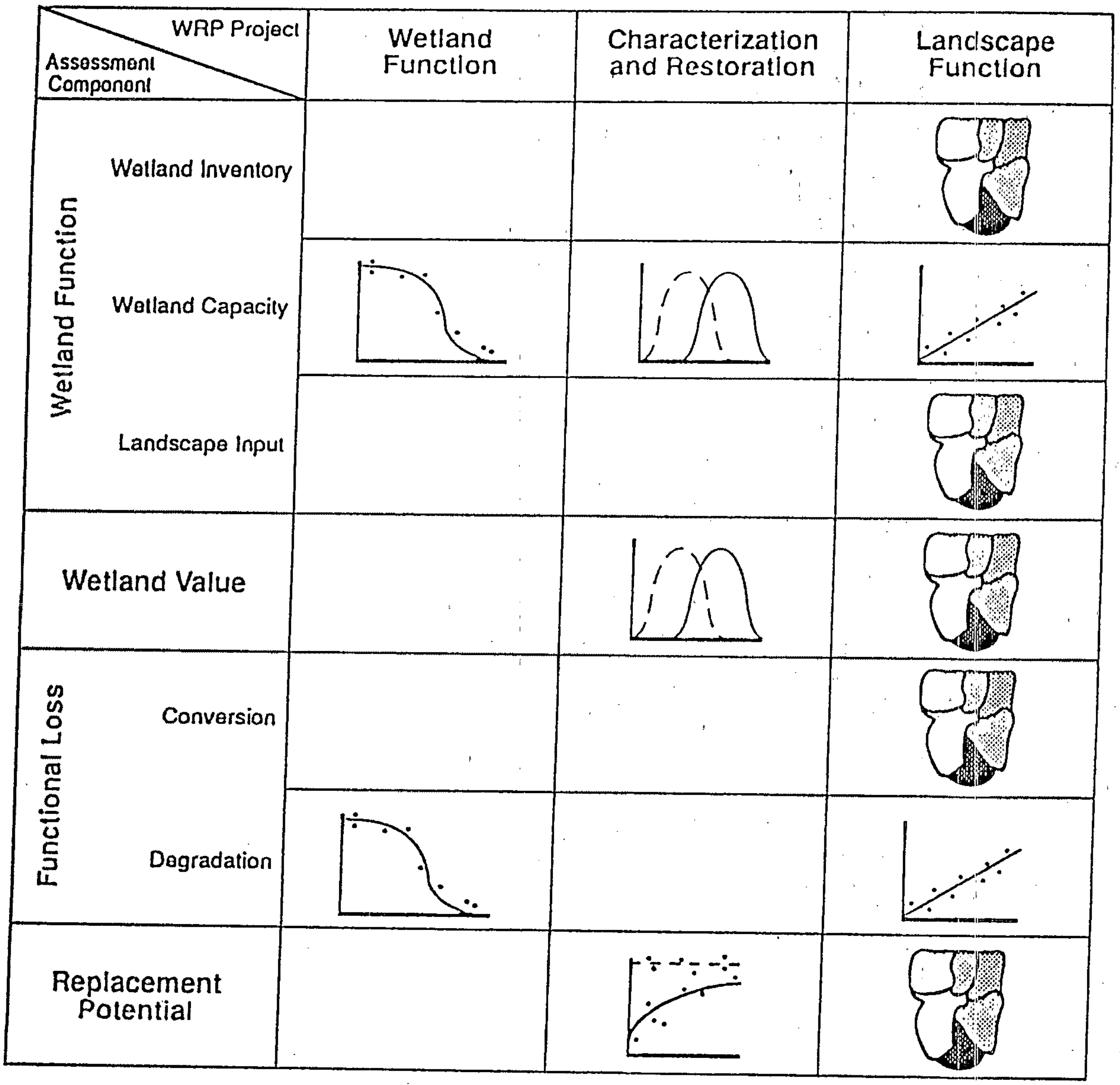

Figure 6. Matrix indicating the major sources of information to be used for each risk assessment component by the Risk Reduction Project. The hypothetical graphics represent the general types of analyses and outputs expected from the other three WRP projects, as illustrated in Figures 3 through 5; they are not meant to convey actual or expected results or relationships.

2. Conduct a BPJ risk assessment, to further evaluate and refine the basic framework, demonstrate the utility of the approach, and provide interim project deliverables.

3. Synthesize the WRP research results into a comprehensive, hierarchical risk assessment for selected regions and issues.

4. Apply the risk assessment to provide technical support for risk management.

5. Develop a monitoring and evaluation protocol.

Consistent with the WRP research priorities and studies proposed by other WRP projects, the Risk Reduction Project will focus on two wetland types: (1) prairie potholes and (2) bottomland hardwood forests. The utility of the risk-based framework will be demonstrated by addressing two major issues: (1) the national policy of no net wetland loss and (2) the role of wetlands in reducing nonpoint source pollution.

QUALITY ASSURANCE

It is essential that data collected by the WRP are scientifically sound, legally defensible, and of known and documented quality. To ensure the collection of high quality data, the WRP will participate in a centrally managed quality assurance (QA) program that complies with the QA policies of EPA and of each of the participating ORD Laboratories.

A member of the WRP staff will serve as WRP's QA Coordinator. The QA Coordinator will prepare a QA Program Plan for the WRP, describing the Program's overall QA goals, methods for achieving these goals, and QA responsibilities within the Program. In addition, individual QA Project Plans will be developed as part of the detailed work plans prepared for each study within the WRP. These QA Project Plans will define specific data quality objectives for the study, along with the research design, sample collection procedures, analytical protocols, data analysis methods, and quality assurance/quality control procedures. Each QA Project Plan will be reviewed and approved by the WRP QA Coordinator and by the appropriate Laboratory QA staff prior to the collection of any project data.

TECHNICAL INFORMATION TRANSFER

Technical information transfer is a Program strategy to ensure that WRP research is relevant to EPA policy and regulatory needs and that innovations developed by the WRP will be adopted and widely used by wetland managers. In 1988, a Regional Liaison Officer position was established within the WRP to foster direct communication between WRP scientists and wetland experts in states and EPA Regional Offices. The responsibilities of the Regional Liaison are to (1) identify and communicate to the WRP the technical support needs of the EPA Regions and states; (2) work to ensure that WRP studies address these priority technical support needs to the degree possible; (3) encourage and coordinate the implementation of cooperative projects, involving shared expertise and/or funding from both the WRP and EPA Regions or states; and (4) distribute information on WRP projects and results to interested agencies, firms, and individuals. WRP results are also presented in scientific journals, workshops, and symposia, and summarized in the "Wetlands Research Update," published at least once per year and distributed widely to all interested parties.

PROGRAM DELIVERABLES

The research plans outlined in this document assume a five-year program with a budget of approximately $2.5 million annually. Major deliverables for the WRP for FY 1992-1996, by project and year, are listed in Table 1.

Table 1. **WRP Deliverables by Project and by Year**

WETLAND FUNCTION PROJECT	
State-of-the-science review of stressors, impacts, and indicators of function for priority wetland types	FY 1993
Risk-based approach to setting water quality criteria, especially biocriteria, for wetlands	FY 1996
Handbook for the protection of wetland functions through the implementation of best management practices	FY 1996
Guidelines for site-specific monitoring of ecological integrity in individual wetlands and wetland complexes	FY 1996
Preliminary technical support on establishment of water quality criteria required for survival, growth, and re-establishment of coastal seagrass systems	FY 1993
CHARACTERIZATION AND RESTORATION PROJECT	
State-of-the-science approach to selecting sites for restoring western riparian wetlands	FY 1994
An approach to selecting sites for wetland restoration	FY 1996
Technical framework for the restoration and creation of wetlands: An evaluation of performance and design	FY 1997
LANDSCAPE FUNCTION PROJECT	
An assessment of the function and value of isolated wetlands, with management recommendations	FY 1995
Rapid techniques for landscape assessment of wetlands	FY 1996
An evaluation of the functions of wetlands in the landscape	FY 1996
RISK REDUCTION PROJECT	
The use of a risk-based framework with best professional judgment for wetland risk assessment	FY 1993
A protocol for monitoring and evaluating the effectiveness of risk management	FY 1995
Application of a risk-based framework to no net loss of wetlands	FY 1996
Application of a risk-based framework to reduction of nonpoint source pollution	FY 1996

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF WATER

MAR 20 1992

MEMORANDUM

SUBJECT: Wetlands Research Program FY 1992-1996 Research Plan

FROM: John W. Meagher, Director
Wetlands Division

TO: Roger Blair, Chief
Watershed Branch
Corvallis Environmental Research Laboratory

I would like to take this opportunity to strongly endorse the Research Plan entitled, "Wetlands Research: An Integrated Risk-Based Research Strategy, FY 1992-1996 Research Plan." The plan reflects the tremendous amount of hard work that went into identifying and exploring the latest needs in wetlands research. I feel the plan is at the forefront of where the Agency is headed with risk-based research efforts, and I commend your continued leadership role in pioneering wetlands research.

The shifts in emphasis within the current projects and the continuing efforts toward integration are timely and will result in a stronger program. I appreciate the opportunities you have provided our Division to influence the directions of the plan. We look forward to continued participation in the implementation of the plan's projects. We also recognize that there are specific projects within the plan that require input from other offices in the Office of Water. Specifically, we look forward to working jointly with the Wetlands Research Program and the Health and Ecological Criteria Division of the Office of Science and Technology to plan the work related to the development of biological criteria for wetlands.

I trust over the next five years our offices will continue this level of cooperation. We appreciate the contributions of the Wetlands Research Program to EPA's wetlands protection goals. Please count us among your strong supporters.

1. INTRODUCTION

This document presents the research strategy developed by the U.S. Environmental Protection Agency's (EPA) Wetlands Research Program (WRP) for Fiscal Years (FY) 1992-1996. The purpose of this research is to address the technical needs that have been identified by the EPA programs within the Office of Water[1] and the EPA Regions having legal authority over wetlands. This research plan is intended, therefore, for two main audiences: the EPA program offices and the wetlands research community. The objectives of the document are to describe the WRP research strategy so that (1) the program offices can evaluate whether their priorities are being met and (2) the wetlands research community can determine whether the proposed research is scientifically sound. Because this is a strategic planning document, specific studies are not described at the level of detail required for actual implementation. Detailed research plans will be prepared and peer reviewed before studies are initiated.

This section presents (1) a brief background on wetlands and the WRP, (2) the priority issues and technical needs identified by the EPA program offices, (3) the priority wetland types for research, and (4) a description of the document format.

1.1 BACKGROUND

As the interface between terrestrial and aquatic ecosystems, wetlands are an integral component of the landscape, contributing in many ways to overall environmental quality. Wetlands comprise only about 5% of the land area in the conterminous United States (Dahl 1990), but they have a significant influence on the landscape because of their roles in regulating watershed hydrology and water quality and in providing habitat for a diverse flora and fauna that includes over one-third of the Nation's endangered species (U.S. Fish and Wildlife Service 1990). During the last 200 years, more than half of all wetlands have been lost in the United States due to human activities, primarily the conversion of wetlands for agricultural uses. Losses in some states have been on the order of 90% (Tiner 1984, Dahl 1990).

The objective of the Clean Water Act (CWA) is to restore and protect the physical, chemical, and biological integrity of waters in the United States. Wetlands are included in the definition of the Nation's waters. Thus, the CWA is the primary legislative basis for federal wetland protection. The EPA is responsible for implementing the CWA and associated regulations.

The WRP was initiated in 1986 within EPA's Office of Research and Development (ORD) to assist the Agency in carrying out its responsibilities under Section 404 of the CWA, which pertains to the disposal of dredge and fill materials within the Nation's waters. Originally, the WRP concentrated on three research areas: Water Quality, Mitigation, and Cumulative Impacts (Zedler and Kentula 1986). Two more projects, Constructed Wetlands and the wetland component of the Environmental Monitoring and Assessment Program (EMAP-Wetlands), were added later. All five projects are described in Appendix A.

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[1] Relevant programs in the Office of Water include the Wetlands Division within the Office of Wetlands, Oceans, and Watersheds; the Standards and Applied Science Division within the Office of Science and Technology; and the Health and Ecological Criteria Division, also within the Office of Science and Technology.

The research strategy presented builds upon the existing research base. Shifts in research emphasis proposed for FY 1992-1996 reflect changes in Agency priorities, emerging environmental issues and research needs, advancements in wetland science, and an expansion of the WRP mandate to provide technical support for administration of other aspects of the CWA that relate to wetlands. It is important to note that the WRP is an applied research program. The research conducted must be scientifically sound and represent a significant contribution to wetland science. At the same time, however, it must serve directly the needs and priorities of the EPA program offices.

1.2 WETLAND RESEARCH PRIORITIES

The EPA program offices identified the following concerns and major technical needs relating to wetlands as priority issues for the period FY 1992-1996:

National Concerns

- Implementation of a comprehensive risk-based approach to wetland protection and management

- Evaluation of the national goal of no net loss of wetland area and function

Programmatic Priorities

Office of Water

- Water quality standards and criteria for wetlands

- Design guidelines and performance criteria for wetland restoration and creation

- The role of wetlands in water quality improvement

- The functions and values of "isolated" wetlands in the landscape

EPA Regions

- Water quality standards and criteria for wetlands

- The role of wetlands in urban stormwater control and associated concerns with wetland protection

- The role of wetlands in reducing nonpoint source pollution in an agricultural setting and the potential effects of agricultural runoff on wetland functions and values

- Guidance for State Wetland Conservation Plans

- The functions and values of "isolated" wetlands in the landscape

- Causes of Louisiana wetland loss

Background information on these and related issues is provided below, grouped into the following categories for ease of discussion: (1) risk assessment and management; (2) the national goal of no net loss of wetland area and function; (3) a general discussion of the major causes of loss of wetland function (background information relating to no net loss as well as water quality standards and criteria); (4) water quality standards for wetlands; (5) wetland restoration and creation; (6) wetland functions in the landscape, including the role of isolated wetlands; (7) the role of wetlands in reducing nonpoint source pollution; (8) State Wetland Conservation Plans; and (9) Louisiana wetland loss.

1.2.1 Risk Assessment and Management

A landmark EPA study conducted in 1987 found that the environmental problems considered by experts as posing the most serious risk were not those targeted most aggressively by Congress or the EPA (U.S. EPA 1987). A follow-up study by EPA's Science Advisory Board (SAB) suggested ways in which the EPA could reduce environmental risk, recommending that environmental protection efforts be focused on areas in which the greatest risk reduction could be achieved. In particular, the SAB recommended that "...EPA should improve the data and analytical methodologies that support the assessment, comparison, and reduction of different environmental risks" (SAB 1990, p. 18). The President's 1992 budget for the first time recommended that funding of programs be reoriented toward the reduction of the greatest environmental risks (Inside EPA, February 9, 1991).

Wetland management must be considered within a risk-based framework to ensure that the most valued wetland functions are protected. Thus, the EPA Administrator has asked for studies "... to identify and develop environmentally sound ways to classify wetlands according to their values and to set priorities for wetlands protection" (Reilly 1991, p. 4).

1.2.2 National Goal of No Net Loss

A national goal of no net loss of wetland area and function was recommended by the National Wetlands Policy Forum in 1988 (The Conservation Foundation 1988). This goal has been endorsed by both the President and the EPA. Such an approach advocates comprehensive resource management instead of regulation on an issue-by-issue basis.

Technical information will be needed for no net loss to be achieved. The concept implies that the loss of wetlands must be reciprocated by replacement of wetlands with equivalent area and function. However, as pointed out by the National Wetlands Policy Forum, "...there is a paucity of information on how to measure the different benefits wetlands provide, how to manage wetlands to support these functions, and how to restore and create wetlands to provide the desired benefits on a sustainable basis" (The Conservation Foundation 1988, p. 5). The development of strategies to achieve no net loss will require, therefore, research to support the evaluation of wetland function, characterization and prioritization of wetlands by function, performance criteria for wetland restoration and creation, and the development of regional assessment methodologies.

1.2.3 Major Causes of the Loss of Wetland Function

The primary reason for wetland loss in the United States has been conversion of wetlands to other uses. The causes of these particular losses are known: 87% of the loss of wetland area between the 1950s and 1970s and 54% of the loss from the mid 1970s to mid 1980s was due to agricultural conversion. An additional 8% of the loss between the 1950s and 1970s and 5% from the mid 1970s to mid 1980s was caused by urban development (Tiner 1984, Dahl and Johnson 1991). Research into this process is not critical, because the cause is understood and regulations have been enacted to limit further loss, e.g., Section 404 of the Clean Water Act and the "swampbuster" provisions of both the 1985 and 1990 Food Securities Act (the "Farm Bill").

Less well understood are the ways in which environmental stressors[2] degrade wetland function. Five important categories of stressors are (1) hydrologic modification, (2) physical alteration, (3) sedimentation, (4) nutrient loading, and (5) toxic contaminants.

1.2.3.1 Hydrologic modification

Hydrology is perhaps the single most important determinant for establishing and sustaining wetlands and their functions (Mitsch and Gosselink 1986). Subtle changes in the hydrologic regime of a site, therefore, can have profound consequences. Examples of hydrologic modification range from extensive flooding or major water withdrawals and diversions to changes in local runoff patterns as a result of construction and increases in impermeable surfaces in the watershed. These alterations can result in outright wetland loss or varying degrees of degradation. Because the effects of small hydrologic changes, and the cumulative effects that result from the many such changes that occur, are seldom assessed, hydrologic modifications may represent the largest unquantified and least understood stressor that affects wetlands.

1.2.3.2 Physical alteration

Physical alterations of wetlands result from dredge and fill operations, changes in land cover type, timber harvesting, and other activities. As with hydrologic modifications, these actions can result in the degradation of wetland function as well as the direct loss of wetland area. The fragmentation of wetland habitat is of particular concern. Both the amount of habitat and its placement on the landscape can have a profound influence on biodiversity and the suitability of the landscape to support various wildlife species. As an example, Gosselink et al. (1990) concluded that maximum wetland patch size was an important criterion for protecting black bear in bottomland hardwood wetlands. Black bears require large, contiguous forested areas to sustain viable populations. Likewise, the distance between wetlands is believed to be an important factor limiting waterfowl success in the prairie pothole region of the central United States and Canada.

1.2.3.3 Sedimentation

Sediment accretion and trapping are characteristic of most wetlands and are an important aspect of wetland biogeochemistry. For coastal wetlands, sediment accretion may be critical to

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[2] We use the term "stressor" to refer to any material or process caused by people that can stress a wetland and thus degrade wetland function(s). This includes the addition of harmful agents, such as pollutants, and the removal of beneficial factors (e.g., stream diversions that alter the hydrology).

countering subsidence or sea level rise and, thus, for maintaining the system above water. The removal of a sediment source can drown the wetland. Conversely, increasing sediment loading rates can decrease the life of a wetland. Therefore, wetlands may be adversely affected by receiving either too much or too little sediment. Additional information is needed on the sedimentation rates necessary for sustaining various types of wetlands and on the quantities of sediments that wetlands can receive and retain without degrading wetland functions.

1.2.3.4 Nutrient loading

Wetlands can be effective at using, retaining, and transforming nutrients and thereby improving water quality. Wetland function can be impaired, however, by either too much or too little nutrients. For example, Langis et al. (1991) found that low levels of nitrogen in a created salt marsh in southern California resulted in low aboveground biomass, as compared with an adjacent natural marsh. Conversely, Giblin (1982) showed that the capacity of freshwater marshes to retain iron, zinc, copper, and cadmium can be reduced by adding nutrients. Information is needed on the total quantity of nutrients that wetlands can retain (i.e., nutrient assimilative capacity) and also the levels of nutrients that can be discharged into wetlands without impairing their condition or functions.

1.2.3.5 Toxic contaminants

Significant bioaccumulation of organic toxics and heavy metals can occur within wetlands as a result of exposure to contaminated sediments, heavy metals in urban runoff, or pesticides in agricultural runoff. For example, Horner et al. (1988) found high levels of lead, zinc, and cadmium in the sediments of wetlands receiving stormwater runoff from urban areas. The concentrations of lead and zinc in these sediments were correlated with toxic responses as determined by the Microtox bioassay, an indicator of toxic effects on several common bacteria (Blum and Speece 1991). Toxic contaminants can affect not only the quality of wetland habitat, but also can interfere with processes critical to the water quality improvement function, such as nitrogen transformations in wetland soils. Commonly used agricultural pesticides have been shown to inhibit nitrification in agricultural soils (Lin et al. 1972), and would likely have similar effects in wetlands. Additional information is needed, however, on the specific effects of toxic contaminants on wetland ecosystems.

1.2.4 Water Quality Standards for Wetlands

The EPA has a legal mandate to ensure that water quality standards are established that prevent the degradation of the Nation's waters. In fulfilling this mandate, EPA is requiring that states develop and implement water quality standards for wetlands (Office of Water Regulations and Standards, OWRS, 1990a), using a two-phased approach. For Phase 1, water quality standards for wetlands must be instituted by the end of 1993 based primarily on existing information and science. In Phase 2, additional research and new approaches will be used to further standards development.

Wetland standards development requires that all wetlands have uses designated that meet the goals of the Clean Water Act, Section 101(a) (2), and that states adopt criteria sufficient to protect these designated uses. States will be responsible for designating uses for wetlands within their states. The Office of Water has requested that ORD and the WRP provide technical support for the development by the states of wetland water quality criteria, particularly biological criteria (biocriteria). Biocriteria are considered a subset of water quality criteria.

Phase 1 requires that states adopt existing criteria for wetlands (including chemical criteria) and adopt new narrative biocriteria. EPA has traditionally emphasized chemical-specific criteria for water column contaminants (OWRS 1990b). In most cases, chemical criteria developed for other surface waters are probably protective of wetland-dependent organisms (Hagley and Taylor 1990). Information needs are limited primarily to field-verifying the adequacy of existing criteria under wetland conditions.

Phase 2 will require that states implement numeric biocriteria. Biocriteria are critical to protect wetlands from stressors such as hydrologic modification, physical alteration, sedimentation, and nutrient loading, as well as from chemical contamination (OWRS 1990 a,b). Biocriteria include not only biological endpoints, but also the habitat and hydrological conditions necessary to sustain designated aquatic life uses. The development of biocriteria, particularly numeric biocriteria, will require a great deal of research and field testing.

1.2.5 Wetland Restoration and Creation

Although wetlands are protected from certain impacts by federal law, economic pressures to develop wetlands remain high. Government agencies will continue, therefore, to decide when and where wetland impacts can be allowed and when and where wetland restoration and creation will be implemented. Wetland restoration and creation projects will undoubtedly remain as options for compensating losses permitted under Section 404 of the Clean Water Act. In addition, as discussed above, the role of wetland restoration and creation was recently highlighted by the National Wetlands Policy Forum as an important element in achieving no net loss of wetlands (The Conservation Foundation 1988). The restoration of thousands of acres of degraded wetlands anticipated under the 1990 reauthorization of the Farm Bill has further focused attention on this practice.

A number of important questions remain to be addressed, however, regarding the success and design of wetland restoration and creation projects, ranging from "What constitutes appropriate compensation?" to "Are ecological functions of natural wetlands replaced by created and restored wetlands?" The amount of information available in the literature on wetland restoration and creation varies by region and topic. In particular, relatively few studies have been conducted on inland freshwater wetlands (Kusler and Kentula 1990a). Additional information is needed on wetland functions to know when and where restoration or creation is appropriate and how to maximize ecological functions in the design and implementation of wetland restoration and creation projects.

1.2.6 Wetland Functions within the Landscape

Wetland research has traditionally examined the characteristics of individual wetland sites or, in some cases, populations of individual wetlands.[3] However, certain regulatory and management issues can only be addressed by considering wetlands within the context of the landscape in which they are located. For example, impacts to individual wetlands that are not considered significant by themselves may cause substantial environmental effects when taken together. Cumulative impacts are the sum of all of the impacts that have occurred over the entire landscape and over time. Cumulative effects refer to the net change in the overall landscape function that results from these impacts. By landscape function, we mean the combination of environmental processes operating within a landscape unit that account for the overall environmental characteristics of that unit. Thus, the term wetland function refers to the functions and benefits provided by individual wetlands, while landscape function refers to the functions and benefits provided by the landscape unit as a whole, including the complex of wetlands and other ecosystems within that landscape unit. Examples of landscape function are regional biodiversity, overall water quality, and the hydrologic integrity of a watershed. Determining the cumulative effects of wetland loss requires an understanding of how wetlands contribute to landscape function, both individually and collectively.

Landscape context also can influence whether management goals, such as the ability to restore a wetland, will be realized. Wetland restoration will be difficult if the environmental processes that maintain wetlands within a landscape have been disrupted. For example, restoring a forested swamp within a floodplain may not be possible if flooding has been reduced by the construction of dams upstream.

One issue of particular interest is the role of isolated wetlands in landscape function. Current regulatory policies assume that small isolated wetlands less than 10 acres in size are not functionally significant. The functions and values of these wetlands, however, are not well understood. In addition, the proportion of the total wetland resource represented by these wetlands is not known. Research is needed to determine how these wetlands function individually and whether the cumulative loss of isolated wetlands has or will lead to a significant decline in landscape function.

1.2.7 The Role of Wetlands In Reducing Nonpoint Source Pollution

Because of internal processes that retain and transform nutrients, heavy metals, and many other pollutants, wetlands often result in a net improvement in water quality. For this reason, there is interest in constructing and restoring wetlands as a means of controlling nonpoint source pollution. In addition, although stormwater cannot be directed into natural wetlands without prior treatment, natural wetlands are being considered as a means of "polishing" urban stormwater and also may serve to mitigate nonpoint source pollution.

Additional quantitative information is needed, however, on the role of natural, restored, and created wetlands in reducing nonpoint source pollution and on the consistency and sustainability of this function over time, on both site-specific and landscape scales. The rate and capacity of wetlands to assimilate different pollutants will determine the magnitude and duration of pollutant

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[3] Unless stated otherwise, we use the phrase "wetland population" in a statistical sense, referring to a collection of individual wetlands, rather than in a biological sense (i.e., species within a wetland).

inputs that a wetland can receive without degrading water quality improvement functions. It is equally important to assess the secondary effects of nonpoint source pollution or urban stormwater on overall wetland functions and characteristics. For example, habitat quality, productivity, and species diversity may be adversely affected as a result of the bioaccumulation of toxic substances.

Because agriculture is a dominant land use over much of the country, the ability of wetlands to retain nutrients in agricultural runoff is a research area of particular interest. The role of wetlands in assimilating nonpoint source pollutants from agricultural sources needs to be determined, as do the effects of agriculture-related stressors on wetland functions and value. Ecological criteria are needed for siting and for the design of wetland restoration projects in agricultural landscapes.

Finally, technical support is needed regarding the role of buffers in protecting wetland water quality and wetland-dependent wildlife. Buffers are vegetated strips of land surrounding a wetland. Established buffers can at least partially filter pollutants and sediments from overland and subsurface flow, thereby decreasing the input of these materials into the wetland. Additional information is needed on the degree to which buffers decrease loading rates and on the characteristics of buffers that influence the efficiency with which they remove sediments and pollutants from overland and subsurface flow.

1.2.8 State Wetland Conservation Plans

The development of State Wetland Conservation Plans was recommended by the National Wetlands Policy Forum (The Conservation Foundation 1988). As part of an increased emphasis on advance planning, the purpose of State Wetland Conservation Plans is to provide a basis for all subsequent acquisition, regulation, and other wetland protection and management activities in the state. Often, the responsibility for wetland protection and management falls within multiple state agencies. A single statewide plan can serve as a vehicle for coordinating the efforts of different wetland authorities and for developing consensus on state wetland protection goals. As envisioned by the National Wetlands Policy Forum, State Wetland Conservation Plans are to (1) set forth a state's goals and objectives with respect to its wetland plans and programs; (2) describe specifically how the state will implement its policies and achieve the goal(s); (3) identify and describe all wetlands in the state in sufficient detail to support the policy framework and define processes for collecting sufficient information for management decisions; and (4) describe the relationship, if any, between the Plan and other local, state, federal, and international plans. Plans should cover both the land and water on which wetlands depend, consider the economic and ecological benefits of wetlands, explore the compatibility of different uses, and integrate wetland protection and management programs with other societal goals (The Conservation Foundation 1989).

1.2.9 Louisiana Wetland Loss

Forty-one percent of the Nation's coastal marshes are found in Louisiana (Turner and Gosselink 1975), primarily as a result of the Mississippi River. The subtropical climate and nutrient-rich sediments of the Mississippi combine to make this coast one of the most productive environments in the Nation. For example, Louisiana's commercial fishery landings in 1984 were the largest in the Nation's history, accounting for 30% of the total U.S. catch (U.S. Department of Commerce 1986). The importance of Louisiana's coastal marshes to maintaining these high fishery yields is evidenced by the spatial correlation between Gulf shrimp yields and the area of intertidal vegetation (Turner 1977). In addition, Louisiana's marshes represent the richest fur-producing region in North America, providing 40-65% of the nation's annual harvest (Larson et al. 1980).

It has been known for decades that Louisiana is experiencing a loss of its coastal wetlands (Russell 1936, Fisk 1944); loss rates as high as 100 km^2/yr have been estimated (Gagliano et al. 1981). Although many factors have been proposed as contributing elements, there is still no consensus on the causes of this loss, nor their relative importance. To obtain further insight, a better understanding is needed of the significance of natural delta switching, compared to the human-related impacts on the river system and on the coastal wetlands. The cause(s) of coastal wetland loss will ultimately determine whether the loss of Louisiana wetlands can be halted and eventually reversed.

1.3 PRIORITY WETLAND TYPES

Based on discussions with the EPA program offices and with wetland scientists participating in a WRP planning workshop held in February 1991, three wetland types were identified as priorities for research in FY 1992-1996: (1) freshwater emergent wetlands, (2) bottomland hardwood forests, and (3) western riparian systems. Selection of these wetland types was based on four criteria: (1) the national significance of the wetland type; (2) the applicability of results to other wetland types; (3) the need for additional research to improve overall wetland protection, as identified by the EPA program offices; and (4) a consideration of research being conducted by other federal agencies, to avoid duplication of efforts and to maximize interagency cooperation. The following subsections provide a brief summary of current conditions, problems, and major research needs for each of these priority wetland types; other wetland resources of interest are also addressed.

1.3.1 Freshwater Emergent Wetlands

Freshwater emergent marshes are shallow wetlands that form in areas such as depressions, lake and stream edges, and in freshwater tidal zones. The hydrologic condition of these communities ranges from intermittently to permanently flooded. Between the 1950s and 1970s, over 4.5 million acres of freshwater emergent wetlands were lost (Tiner 1984). Furthermore, freshwater emergent wetlands accounted for nearly 25% of the Nation's remaining wetland area in the mid 1980s (Dahl and Johnson 1991). Thus, these wetlands are considered high priority for research for two reasons - their wide distribution and high rate of loss.

Prairie potholes are a specific type of freshwater emergent wetland that is of special interest. These wetlands have formed in depressions within glacial deposits of the North American prairie (Winter 1989). The Prairie Pothole Region, an important breeding and stopover habitat for migratory bird species, is considered to be the principal production area for many North American duck species (Batt et al. 1989).

Agriculture is the primary social and economic force in the Prairie Pothole Region, and agronomic conversions have caused significant loss of wetland area through government-sanctioned drainage (Leitch 1989). The prairie pothole wetlands that have not been drained are embedded in a matrix of agricultural land and are frequently exposed to large inputs of sediment, nutrients, and agricultural chemicals. Little is known about the ability of prairie pothole wetlands to maintain their functions under sustained loadings of these stressors (Kantrud et al. 1989). Several factors, such as the loss of buffers between farms and aquatic systems, a dramatic increase in the use of chemical fertilizers, herbicides, and insecticides, and some of the highest soil erosion rates in the Nation, have resulted in poor surface and groundwater quality in the intensively farmed sections of the Prairie Pothole Region (Omernik 1977, Hallberg 1985, Kelley et al. 1986).

Prairie potholes are ideal for studying the effects of nonpoint source pollution sources on emergent wetlands, because they are dominated by plant species that are widespread in North America and they are well-defined in the landscape. Thus, results from research on prairie pothole wetlands can be extrapolated to many similar systems. Additional information on how to improve the local and landscape function of these wetlands could also aid ongoing restoration and research efforts in the area by other federal agencies, such as the U.S. Department of Agriculture's (USDA) Soil Conservation Service and the U.S. Fish and Wildlife Service.

1.3.2 Bottomland Hardwood Forests

Bottomland hardwoods are extensive forested wetlands that occupy the alternating wet and dry hydrologic zone adjacent to many rivers in the southcentral and southeastern United States (Wharton et al. 1982). These forests provide important functions, including flood storage, water quality improvement, and wildlife habitat, and are of direct economic value as sources of harvestable timber (Gosselink and Lee 1989). Nonpoint source pollution is a major contributor to the degradation of surface water quality in agricultural areas in these regions. Bottomland hardwoods are often forested "fingers" in riparian areas along low order streams within an otherwise agricultural landscape. The efficiency of these wetlands in removing nutrients (Lowrance et al. 1984), combined with the high risk to surface waters and riparian wetlands from nonpoint source pollution in this region, make them a logical focus for study.

Cumulative impacts to this resource have included extensive timber clearing (loss rates as high as 80% for the Mississippi River alluvial plain) and the construction of dams and levees that have modified the hydrologic regime (Gosselink and Lee 1989). Such impacts can degrade wetland functions, causing a loss of flood control capacity and ecological structure (e.g., biodiversity) as well as other adverse effects. Through improved management practices, it may be possible to log and farm such wetlands in a manner that lessens the adverse effects (Cairns et al. 1981). Thus, information is needed on the effects of environmental stressors on the functions of bottomland hardwoods and on alternative management techniques that may reduce these effects. Protection of this resource is especially critical because creation of bottomland hardwoods is difficult, and replacement, if it can be accomplished, would take decades (Kusler and Kentula 1990a).

1.3.3 Western Riparian Systems

Western riparian systems contain the principal freshwater wetland type in the arid and semi-arid regions of the western United States. Interest in protecting and restoring these systems is on the rise (e.g., Abell 1989, Baird 1989, Faber et al. 1989). A number of environmental groups, including the National Audubon Society, the Sierra Club, and The Nature Conservancy, have made the protection and restoration of riparian habitat a high priority (Faber et al. 1989). Furthermore, in 1986, the Arizona Riparian Council was formally organized to provide an annual forum for local coordination of management and research (Patten and Hunter 1989).

Even though wetlands are protected under Section 404 of the Clean Water Act, at least three factors have contributed to the continued loss of western riparian systems and their associated wetlands. First, water supply policies have undervalued natural uses of water. As a result, waters have been diverted from natural ecosystems and the availability of water for wetland restoration and creation is limited (Lee and Gross 1988). Because Section 404 regulates the disposal of dredged and fill materials in navigable waters, such water diversion is not prohibited. Second, delineation of the wetlands within western riparian systems under Section 404 is difficult (Lee and Gross 1988). Finally, cattle grazing is common on western arid lands and also not regulated under Section 404. Cattle grazing can eliminate streambank vegetation and cause physical alterations, such as bank erosion (Armour et al. 1991). Other factors contributing to the decline of riparian areas include (1) mining (physical destruction, sediment runoff from tailings, acid mine drainage) and (2) urbanization (direct alteration of flood plains and channelization, plus secondary influences such as gravel mining, etc.).

Because riparian systems in the western United States have been extensively altered and degraded, methods for wetland restoration and creation are of particular interest to states, the EPA regions (Regions 8 and 9), and federal agencies (e.g., Bureau of Reclamation, Bureau of Land Management, Corps of Engineers) with responsibilities for wetland management. Technical guidelines are needed for site selection and project design to improve the success and performance of these restoration programs.

1.3.4 Other Wetland Resources of Concern

Three other types of wetland resources have also been identified as warranting additional research: (1) wetlands in coastal areas, (2) drier wetlands that are saturated with water during only some seasons of the year, and (3) wetlands in urban landscapes.

Coastal wetlands were excluded from past WRP research because more information existed for coastal than inland wetlands (Zedler and Kentula 1986). Furthermore, several federal agencies have research and management responsibilities related to coastal areas and wetlands (e.g., U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration). However, three issues in particular require further research: (1) the effects of stressors, in particular inputs of sediments, nutrients, and toxic contaminants, on the area and quality of coastal wetlands; (2) the role of inland wetlands in moderating the transport of nutrients, sediments, and chemical contaminants from the landscape to estuaries; and (3) the development of water quality criteria for coastal wetlands.

Most wetland research has focused on systems dominated by permanent surface water and/or high groundwater and containing obligate wetland plants. The term "drier" wetlands is used here to refer to wetland areas that are only infrequently saturated or flooded, with facultative wetland vegetation. "Drier" wetlands may occur, therefore, within many wetland types or classes. While the functions and value of "wet" wetlands are widely recognized, the role of drier wetlands remains controversial. Although it is likely that these wetlands also play important roles in flood attenuation, water quality improvement, and habitat, little research has been conducted to confirm and quantify the functions of these systems. Under the proposed changes in federal wetland policy and wetland delineation, large areas of these drier wetlands would no longer be protected and would be opened for development or conversion to agricultural use. Thus, although not a priority wetland type, per se, further information is needed on the role of drier wetland areas within each of the priority wetland types discussed above.

A final area of interest is wetlands in urban settings. Because these systems occur in areas with high human population densities, they are used and valued by relatively large segments of the general public. Yet, wetlands in urban areas are subject to high loss rates and a diversity of impacts. For example, wetlands are increasingly being considered for use in urban stormwater management systems (see Section 1.2.7). Additional information is needed on the ability of wetlands in these landscapes to sustain their functions and value given the level of stressors to which they are exposed. As for the drier wetlands discussed above, many wetland types and classes occur within urban areas; thus, issues relating to wetlands in urban areas are not specific to one or a few wetland types.

1.4 DOCUMENT FORMAT

The research priorities and priority wetland types presented in Sections 1.2 and 1.3 define the major research directions for the WRP. As noted in Section 1.1, research within the WRP is intended to directly serve the needs and priorities of the EPA program offices. The remainder of this document describes the proposed strategy of the WRP to address these needs over the next five years, FY 1992-1996:

- Section 2 provides an overview of the WRP objectives and organization.
- Section 3 introduces the risk-based framework proposed for wetland management and protection.
- Sections 4-7 describe the specific objectives, research approaches, and expected contributions of the four WRP project areas: Wetland Function, Characterization and Restoration, Landscape Function, and Risk Reduction, respectively.
- Section 8 discusses the objectives and approach for technical information transfer, an integral component of the WRP designed to ensure that the research conducted by the Program is relevant to policy and regulatory needs and that the techniques and information developed by the Program are readily available to and adopted by the appropriate EPA program offices and regions.
- Section 9 summarizes the Program deliverables and budgets.
- Section 10 lists the references cited in the text.
- Appendix A provides brief descriptions of the WRP projects pre-1992 and also the Constructed Wetlands project and EMAP-Wetlands.
- Appendix B briefly describes wetland research and technical support programs in other federal agencies.

2. OBJECTIVES AND ORGANIZATION OF THE WETLANDS RESEARCH PROGRAM

This section provides an overview of the WRP: Program goals and objectives for FY 1992-1996 (Section 2.1), Program organization and responsibilities of the participating ORD laboratories (Section 2.2), the approach to quality assurance (Section 2.3), and coordination with other federal agencies (Section 2.4).

2.1 PROGRAM GOALS AND OBJECTIVES

The basic goals of the WRP are as follows:

- Provide the EPA program offices with technical support on issues that they have identified as priorities, thus improving the Agency's ability to carry out its regulatory responsibilities.
- Develop methodologies and, through case studies, illustrate how these methodologies can be used to support program office objectives and to facilitate the incorporation of technical information into management decisions and planning.
- Increase the understanding of wetlands and make significant contributions to wetland science by furthering the development and application of methods for studying wetland functions, wetland characterization, landscape functions, and wetland restoration.

Based on the EPA programmatic priorities delineated in Section 1.2, the following specific research objectives were selected for the WRP for FY 1992-1996:

- Develop and demonstrate a risk-based framework for wetland protection and management.
- Determine the contribution of individual wetlands to water quality improvement, habitat, and hydrologic functions, and develop techniques for enhancing and protecting these functions.
- Evaluate the role of the aggregate of wetlands in the landscape on water quality, habitat, and hydrologic functions at a landscape scale, and the influence of wetland characteristics on these landscape functions.
- Quantify the effects of environmental stressors and landscape factors on wetland functions.
- Describe and compare the functional status of populations of natural, restored, and created wetlands in different landscape settings.
- Provide technical support for the development of biological criteria for wetlands in support of the Office of Water.
- Provide technical support for the development of design guidelines and performance criteria for wetland restoration and creation.

- Using the information and methods listed above, conduct an integrated risk assessment for at least one major wetland type to provide technical support on two major issues:

  -- the national policy of no net loss of wetland area and function, and

  -- the role of wetlands in reducing nonpoint source pollution.

In designing a research program aimed at providing resource managers with information on wetlands, two constraints must be considered. First, because wetlands continue to be lost at high rates, the regulatory process must continue despite the fact that not all issues have been unequivocally resolved. Management decisions must be made using best professional judgment if better information is not available. Second, methods are needed that can be used within the actual regulatory arena, e.g., within the permit review process. As Hirsch (1988) has noted, this effort requires simple protocols, analytical procedures, or "rules of thumb," because time and resources often do not allow extensive data collection. The WRP research results will provide regulators with such tools.

2.2 PROGRAM ORGANIZATION

To achieve the objectives identified in Section 2.1 will require information gathered at three different spatial scales. Detailed studies at **individual wetland sites** are needed to better understand the processes within wetlands that contribute to wetland functions, wetland responses to environmental stressors, and wetland assimilative capacity. Information is also needed on the characteristics of **populations of individual wetlands** to compare the functions of natural, restored, and created wetlands within different landscape settings. Finally, research is needed on the interaction of wetlands with other wetlands and ecosystems within **regional landscapes.** Cumulative impacts within the landscape can degrade individual wetland functions; also wetlands provide off-site benefits and contribute to landscape functions.

The methods and analyses employed in wetlands research tend to vary depending on the spatial scale of interest. For this reason, the WRP has been organized into four major project areas, each of which will emphasize studies at a different spatial scale:

1. **Wetland Function Project** -- focuses on processes within individual wetlands or small groups of wetlands along a gradient of environmental impacts, to quantify wetland functions, stressor/response relationships, and wetland assimilative capacity.

2. **Characterization and Restoration Project** -- develops methods and information to characterize and compare the functional attributes of wetland populations, and also provides technical support for the development of design guidelines and performance criteria for wetland restoration and creation.

3. **Landscape Function Project** -- examines issues at the landscape scale, studying the aggregate of wetlands within a given landscape unit to determine how wetlands contribute to landscape functions (e.g., biodiversity and regional water quality) and how landscape factors (e.g., regional hydrology) affect wetland functions.

4. **Risk Reduction Project** -- integrates findings from the other three projects to address

comprehensive issues (e.g., no net loss) at multiple scales, including the development and demonstration of a risk-based framework for wetland protection and management.

The first three of these projects are modifications of the three original WRP projects: Water Quality, Mitigation, and Cumulative Impacts, respectively (Figure 2-1). The fourth project has been added to emphasize the shift towards program integration and the risk-based framework for wetland protection and management. A major objective over the next five years is the development, demonstration, and implementation of this framework. The Wetland Function, Characterization and Restoration, and Landscape Function Projects are primarily responsible for research; the Risk Reduction Project will synthesize these results into integrated program deliverables (Figure 2-2). To ensure that these integrated deliverables are produced, the Risk Reduction Project will be responsible for coordination among projects.

In addition to the four projects listed above, the WRP includes two other research projects, Constructed Wetlands and EMAP-Wetlands (Figure 2-1; Appendix A), which are funded separately, respond to different program offices, and have separate research plans (Olson 1990 and Leibowitz et al. 1991, respectively). For these reasons, the research to be conducted under these two projects is not included as part of this plan, although important project interactions and cooperative efforts are noted. For the purposes of this document, reference to WRP or the "Program" refers only to the Wetland Function, Characterization and Restoration, Landscape Function, and Risk Reduction Projects.

Original Project	Projects Planned for FY 1992-1996	Scale of Study
Water Quality Constructed Wetlands	Wetland Function Constructed Wetlands	Individual Wetlands and Watersheds
Mitigation	Characterization and Restoration	Populations of Individual Wetlands
Cumulative Impacts	Landscape Function	Regional Landscapes
  EMAP-Wetlands	Risk Reduction EMAP-Wetlands	Multiple Scales

Figure 2-1. Relationship between the original WRP projects and projects planned for FY 1992-1996; the primary spatial scale studied by each project is indicated.

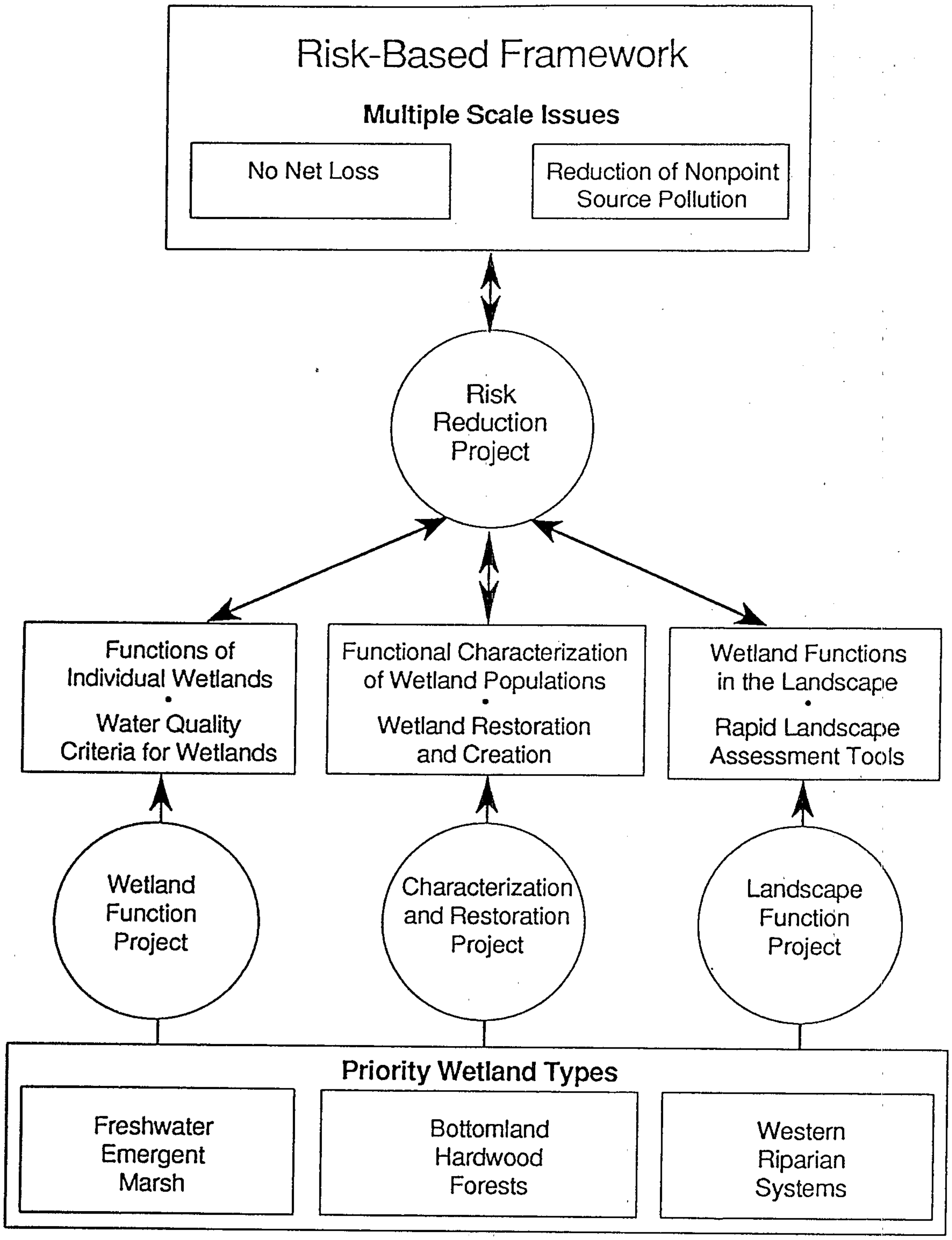

Figure 2-2. Proposed research strategy for the Wetlands Research Program.

Three ORD Laboratories are involved in the WRP. The Characterization and Restoration Project, Landscape Function Project, Risk Reduction Project, Technical Information Transfer (see Section 8), and Quality Assurance (see Section 2.3) will be the responsibility of EPA's Environmental Research Laboratory (ERL) at Corvallis, OR. ERL-Corvallis also will act as matrix manager for the Program as a whole. ERL-Duluth (Minnesota) will be responsible for the inland component of the Wetland Function Project. ERL-Gulf Breeze (Florida) will conduct the pilot study for the proposed coastal component of the Wetland Function Project. This plan and the deliverables contained within it assume a budget of about $2.5 million per year for five years. Further information on project budgets and deliverables is presented in Section 9.

2.3 PROGRAM QUALITY ASSURANCE

Policies initiated by the EPA Administrator in memoranda of May 30 and June 14, 1979, require that all EPA Laboratories, program offices, and regional offices participate in a centrally managed quality assurance (QA) program. This policy extends to those monitoring and measurement efforts supported or mandated through contracts, cooperative agreements, regulations, and other formal agreements. The intent is to develop a unified approach to QA that ensures the collection of data that are scientifically sound, legally defensible, and of known and documented quality. The WRP QA Coordinator will provide 0.5 full-time equivalent (FTE) for the QA support function. Key elements of a QA program include the following:

- **Data Quality Objectives** (DQOs): DQOs must be developed as part of the planning process before data collection. They are intended to help guide the design of sampling and analytical protocols and to ensure that the data collected are adequate for the proposed use. They also provide an objective basis for evaluating the quality of the data actually collected.

- **QA Project Plan**: A QA Project Plan must be based on the data quality requirements and include QA and quality control (QC) procedures. Resources needed to accomplish project objectives must be specified.

- **Audits:** Audits are conducted to evaluate the conformance of data collection, analysis, and management to the DQOs and QA Project Plan.

- **Reporting:** All data must be reported at a quality level adequate for the intended use. Journal articles and reports developed as products must include QC information supporting the data.

To comply with the QA policies of EPA and of each of the participating ORD Laboratories (ERL-Corvallis, ERL-Duluth, and ERL-Gulf Breeze), the WRP will address QA at two different levels:

1. A QA Program Plan will be prepared that describes the Program's overall QA philosophy and approach.

2. Individual QA Project Plans will be developed as part of the detailed work plans prepared for each study.

Both of these QA planning documents will be revised annually.

2.3.1 WRP Quality Assurance Program Plan

The WRP QA Coordinator will prepare the QA Program Plan, in consultation with the WRP Project Leaders and QA staff from each of the three participating Laboratories. The purpose of this document will be to provide overall guidance on QA activities that is consistent with the QA policies of the Agency and each Laboratory. The document will define the QA goals, outline methods for achieving these goals, and describe QA responsibilities within the Program. The QA Program Plan will build upon QA practices developed during the first five years of the WRP. This Plan will be updated and revised annually as experience is gained through implementation and as project objectives change. The QA Program Plan also will identify existing approved QA Project Plans and future planned research that will require QA Project Plans.

As discussed earlier, WRP research activities will be diverse, encompassing three different spatial scales. Chemical, physical, biological, and landscape data will be measured, sampled, collected, and analyzed, both by the WRP staff and by cooperators. The QA Program Plan will address QA issues with respect to each of the kinds of data to be collected and also data management.

2.3.2 Individual QA Project Plans

Individual QA Project Plans will be prepared for each study as part of the detailed work plan developed for that research. These individual QA Project Plans will follow the QA requirements specified in the document "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans" (U.S. EPA 1980). The QA Project Plan will define specific DQOs for the study, along with the research design, sample collection procedures, analytical protocols, and data analysis methods. The purpose of these plans is to ensure that data quality is adequate for the intended use within the budgetary constraints of the particular study. To assure that WRP studies meet the QA requirements of the Agency and each Laboratory, QA Project Plans will be reviewed by the WRP QA Coordinator and by the appropriate Laboratory QA staff. These plans must be approved by an EPA QA Officer prior to the collection of any project data.

2.4 COORDINATION WITH OTHER FEDERAL AGENCIES

Many federal agencies conduct research on wetlands or provide technical support for wetland management. Federal agencies that have a major wetland research role include the Army Corps of Engineers, the U.S. Fish and Wildlife Service, the USDA Soil Conservation Service, the Federal Highway Administration, the Bureau of Reclamation, the USDA Forest Service, and the Tennessee Valley Authority. Appendix B contains a brief summary of the research or technical support objectives for each of these agencies.

The WRP research objectives and priority wetland types (Section 1.3) have been selected to both avoid duplication and foster cooperation with other federal agencies in areas of mutual interest. Coordination of efforts among federal agencies will lead to a better technical base for managing the Nation's wetlands. Specific areas of cooperation are noted in the discussions of WRP implementation within Sections 4-7.

3. A RISK-BASED FRAMEWORK FOR WETLAND PROTECTION

One of the major objectives of the WRP for FY 1992-1996 is to develop and demonstrate a risk-based framework for wetland protection and management. An introduction to this framework is provided here, because the terms, approaches, and issues raised provide context for all aspects of the WRP. Eventually, after the framework has been refined and tested, it can serve two important purposes: (1) providing a basis for management decisions regarding wetland protection that incorporates the best available technical information, and (2) defining future WRP research needs and priorities that focus on those issues of greatest benefit to management decisions. This section describes the basic components of the WRP risk-based framework. Specific plans for developing, demonstrating, and implementing the framework over the next five years are presented in Section 7, as part of the Risk Reduction Project.

3.1 THE CONCEPTS OF RISK REDUCTION

All environmental problems pose some risk - risks to human health, the quality of life, the economy, or ecosystems that provide basic life support. The goal of risk reduction is to focus environmental management and protection efforts on those environmental problems that pose the greatest risk and on those areas and problems in which the greatest risk reduction can be achieved (SAB 1990). Risk reduction includes, therefore, two basic elements:

1. **Risk Assessment** -- the identification and estimation of the risks associated with various stressors and environmental hazards

2. **Risk Management** -- the development and implementation of a specific management strategy to control and manage the most serious risks

Traditionally, risk assessments have involved only technical input and analyses and included four steps (U.S. EPA 1991):

1. **Hazard Identification** -- characterization of the specific stressors of concern for the ecosystem(s), landscape, or region being evaluated as part of the risk assessment

2. **Stressor/Response Relationships** -- quantification of the relationship between the level of stressor and the magnitude of response or probability of adverse effects on one or more important attributes of the ecosystem(s) or landscape, for each stressor of concern

3. **Exposure Assessment** -- quantification of the actual magnitude of stressor exposure, or potential exposure in the future given various management options, for each ecosystem/landscape attribute of interest and each stressor of concern

4. **Risk Characterization** -- integration of the information (and uncertainties) in the three preceding steps to estimate the probability (risk) of occurrence of specific events, such as the loss or degradation of an important ecosystem/landscape attribute

Policy analyses and decisions and the implementation of management actions to reduce risk constitute the risk management component of risk reduction. Under this scenario, the separation between technical and policy input is distinct: technical input and analyses are associated with risk assessment and policy input and analyses occur within risk management.

3. **Hydrology** -- moderating surface and groundwater flows, including flood attenuation, maintenance of base flow, etc.

For example, the process of denitrification (the biochemical reduction of nitrate into gaseous nitrogen) in a wetland may reduce the quantity of nitrogen transported into downstream waters, thereby improving streamwater quality. Thus, the wetland in this example provides a water quality function as a result of the process of denitrification.

Wetland functions depend on two factors: **wetland capacity** and **landscape input**. The capacity of a wetland to perform a given function depends on the characteristics of the particular wetland, for example, wetland type (e.g., marsh or swamp), hydrologic regime, soil and vegetative properties, geomorphological conditions, etc. In the example above, denitrification is dependent on anaerobic soil conditions, which are controlled primarily by the amount of soil moisture.

Capacity alone, however, cannot define wetland functions; these processes also frequently depend on factors originating outside of the wetland. Thus, the actual water quality improvement depends on both the ability of wetlands to transform and retain pollutants **and** the rate and amount of pollutants input from the surrounding landscape. Similarly, flood attenuation assumes an input of floodwater. Many wetland functions depend on input from the surrounding locale. For functions that are linked to water, this "locale" would be the surface water drainage area and the extent of any groundwater aquifer associated with the wetland. For habitat functions, landscape input could be the regional gene pool of organisms that are wetland dependent.

3.2.2 Wetland Value

The identification of wetland functions is a technical endeavor, based on objective criteria and analyses. Wetland values, on the other hand, are determined by subjective choices; different individuals may value the same wetland or wetland function differently. Thus, the assessment of wetland values is the responsibility of wetland managers and policymakers (see Figure 3-1).

Value is determined by the **perceived** benefits of wetland functions that are realized and recognized by society. Values refer to tangible benefits, such as clean water, as well as intangibles, such as aesthetics, and both current and potential future values should be considered.

The value of an individual wetland or group of wetlands may be viewed holistically, considering simultaneously all of the potential benefits that a wetland may provide and the overall value of the wetland(s) as a unit. Alternatively, values may be assigned separately to each distinct wetland function, for example, the value of a wetland for flood control or as habitat for wildlife or for a particular endangered species. The latter approach is easier to implement because it couples value with explicit functions that can be measured. Such an approach also, however, tends to fragment our view of wetlands. As a consequence, important functions may be overlooked or undervalued.

While the assessment of wetland values is the responsibility of policymakers and wetland managers, technical input and objective analyses can still play a critical role. For example, for holistic assessments of wetland values, wetland managers could identify sets of "reference" wetlands considered of overall "high" value and of overall "low" value. Wetland characterization techniques, such as those described in Section 5 for the Characterization and Restoration Project, could be applied to identify specific wetland attributes useful for distinguishing between "high" and "low" value wetlands (Figure 3-2). The results from these objective analyses could then be used to classify other wetlands with similar attributes as high- or low-value wetlands.

As an example of how technical input could be used in the assessment of function-specific values, the value of reduced peak discharge would depend on both how much the average person values a reduction in flooding (a subjective choice) and how many individuals living downstream would benefit from added flood control protection. The latter can be objectively determined.

The process of establishing wetland values is complex and controversial. In particular, societal values are often based on incomplete information and, as a result, society may undervalue important wetland functions. Because of this uncertainty, both societal values and technical information on the ecological importance of wetlands will be included in the prioritization process within the WRP risk-based framework. Furthermore, by explicitly including both function and value in the framework, the resultant dialogue between technical experts and wetland managers may reduce the chance of undervaluing important functions, thereby improving management decisions.

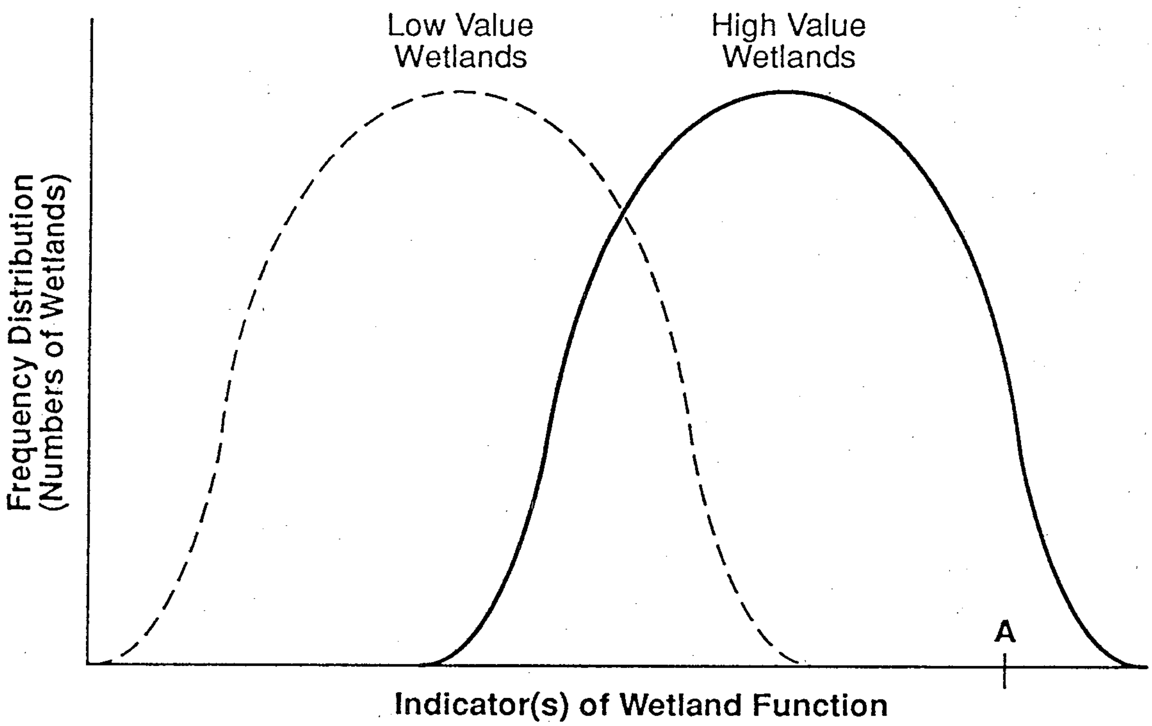

Figure 3-2. Frequency distributions for an indicator of wetland function for wetlands considered of "high" value by policymakers or specific user group (solid line) and wetlands considered to be of "low" value by the same group (dashed line). Based on the measured value for the indicator, wetland "A" would be classified as a high-value wetland. In practice, multiple indicators would be used to distinguish between high- and low-value wetlands.

3.2.3 Functional Loss

The National Wetlands Policy Forum recommended that analyses of wetland loss consider loss of area and loss of wetland function (The Conservation Foundation 1988). Thus, functional loss can result from two factors[4]:

1. **Conversion** -- transforming a wetland into a different land cover or land use (e.g., filling in a wetland for construction)

2. **Degradation** -- loss of function resulting from a stressor. Wetland degradation can be caused by the addition of harmful agents and/or by the removal of beneficial factors (e.g., damage to the environmental infrastructure that maintains a wetland as a result of hydrological modifications caused by dam construction or stream diversion).

With conversion, all or almost all wetland functions are lost. Thus, analyses of functional loss for wetland conversion require only an assessment of the total area of wetland at risk. For wetland degradation, the functional loss element may be qualitative (relative risk) or quantitative. Quantitative analyses would include the four traditional risk assessment activities: (1) identifying the major hazards or stressors of concern, (2) quantifying the relationship between the level of stressor and magnitude of the wetland response, (3) quantifying the actual stressor exposure or the likelihood of stressor exposure given various management scenarios, and finally (4) synthesizing these results into an overall characterization of risk(s). Quantitative techniques for assessing wetland functional loss are discussed further in Section 4.

As mentioned previously, the assessment of functional loss would focus specifically on valued wetland functions. Both losses to date and potential future losses must be considered. Depending on the spatial scale of the assessment (see Section 3.5), functional loss can be evaluated for individual wetlands (wetland function) or for the landscape unit as a whole (landscape function).

3.2.4 Replacement Potential

Replacement potential refers to the ability to replace a wetland and its valued functions through wetland restoration and creation. Replacement potential depends on the type of wetland, the function to be restored, the geographical region, and, in the case of restoration, the type of stressor that altered the original wetland (Kusler and Kentula 1990a). Wetlands with a high replacement potential, by definition, can be restored or created to achieve conditions nearly identical to those in natural wetlands within an acceptable amount of time (Figure 3-3). For some restored wetlands, such as salt marshes, recovery may be rapid because of short turnover times and low ecological complexity. Other wetland types, however, such as bottomland hardwood forests, are complex communities with very long turnover times. Such systems probably require decades to centuries for full functional restoration and, as a result, are likely to have low replacement potential.

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[4] Although loss of wetland function can result from natural processes, this discussion will be limited to environmental impacts caused by people.

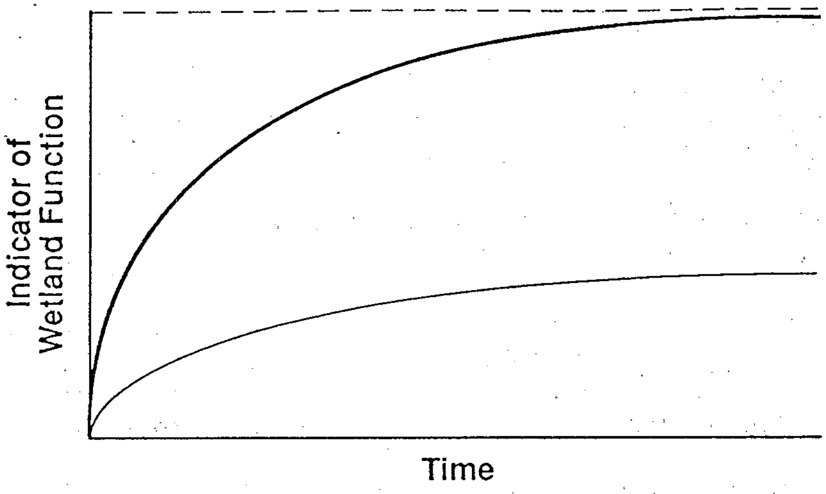


Figure 3-3. Evaluation of restoration potential for wetland functions by comparing the performance of restored or created wetlands with that of natural wetlands in the same landscape setting. The broken line represents the average value of an indicator of wetland function in natural wetlands over time. The heavy curve represents a situation with high restoration potential, because the level of the indicator of wetland function approaches that of the natural wetland within an acceptable amount of time. The situation represented by the lighter line has low restoration potential.

Replacement potential also depends on landscape condition. It is harder to restore or create a wetland if the landscape processes that maintain wetlands have been disrupted. If restoration or creation does take place in such a setting, the wetland will probably not be sustainable.

3.3 RISK MANAGEMENT

Risk assessments estimate risks, identifying those wetlands of greatest value that are at greatest risk of functional loss and also have low replacement potential. Such assessments also determine the major stressor(s) responsible for the risk of functional loss. The results from the risk assessment provide the basis for the selection and implementation of a risk management plan. Other information, such as the financial and societal costs associated with various management options, also plays a role in the selection process.

In practice, risk management plans will be developed by policymakers and regulators and will depend on particular policy objectives. However, technical input is needed to ensure that the selected management options are technically feasible and effective (see Figure 3-1). As previously mentioned, the goal of risk reduction is to focus environmental management and protection efforts where the greatest risk reduction can be achieved (SAB 1990). The WRP risk-based framework provides a conceptual basis for identifying those wetlands and landscapes for which a given unit of management effort will provide the largest marginal return (e.g., increase in function due to wetland restoration and creation or avoidance of future functional loss through wetland protection).

For example, Figure 3-4 provides several hypothetical examples of stressor/response relationships for landscape function. The figure depicts the expected level of landscape function (e.g., the magnitude of flood reduction provided by a given landscape unit) associated with a given level of stressor(s) (e.g., land use changes or wetland drainage) to which the landscape is exposed or subjected. Wetland protection efforts would be most effective (largest reduction in risk) if focused on those landscapes where current conditions are in the area of the curve with the steepest slope. Similar relationships can be developed and applied for decisions regarding individual wetlands and also for wetland restoration and creation (see Figure 3-3).

Curves such as those in Figure 3-4, or, at a minimum, a general understanding of the shape of the curve(s) and positions of the inflection points, also can provide a basis for defining broad categories of landscape condition:

- **Pristine Landscapes** - natural landscapes in which landscape function is at or near maximum. If impacts have occurred, they are small in magnitude and widely dispersed, both over time and space, and the resiliency of the landscape unit has buffered it from functional losses.

- **Transitional Landscapes** - where stressors have resulted in some loss of landscape function(s), although the impacts are mostly localized and have not yet disrupted the fundamental landscape processes that create and maintain wetlands. Generally, these landscapes contain individual wetlands that are still fully functional as well as degraded wetlands.

- **Dysfunctional Landscapes** - where the environmental infrastructure has been damaged to the point where it can no longer provide significant natural landscape functions. The fundamental landscape processes that create and maintain wetlands have been disrupted and/or replaced by human activities and structures. Stressor impacts are extensive and greatly exceed the natural assimilative capacities of these systems. Wetlands in these units are fragmented and degraded, although they may still have significant local (on-site) value, for example, the presence of endangered species.

Depending on the nature of the stressor/response relationship, the greatest marginal returns (increase in function) per unit of management effort often coincide with one category of landscape condition, for instance, in the illustrative curves in Figure 3-4, in transitional landscapes. The nature of the management/restoration effort may vary depending on landscape condition; for example, wetlands in a truly dysfunctional landscape would require extensive off-site mitigation to restore basic landscape processes for restored or created wetlands to be sustainable. Thus, if easy-to-apply protocols can be developed for classifying landscape units, the approach and conceptual tools described above can be used to expedite both risk assessments and risk management decisions.

3.4 MONITORING AND EVALUATION

After a management plan is developed and implemented, two types of monitoring can be employed: evaluative and baseline. **Evaluative monitoring** examines the effectiveness of the management plan. Trends in loss, degree of success of restoration/creation, and compliance with the wetland management plan are evaluated. The specific objective of this type of monitoring is

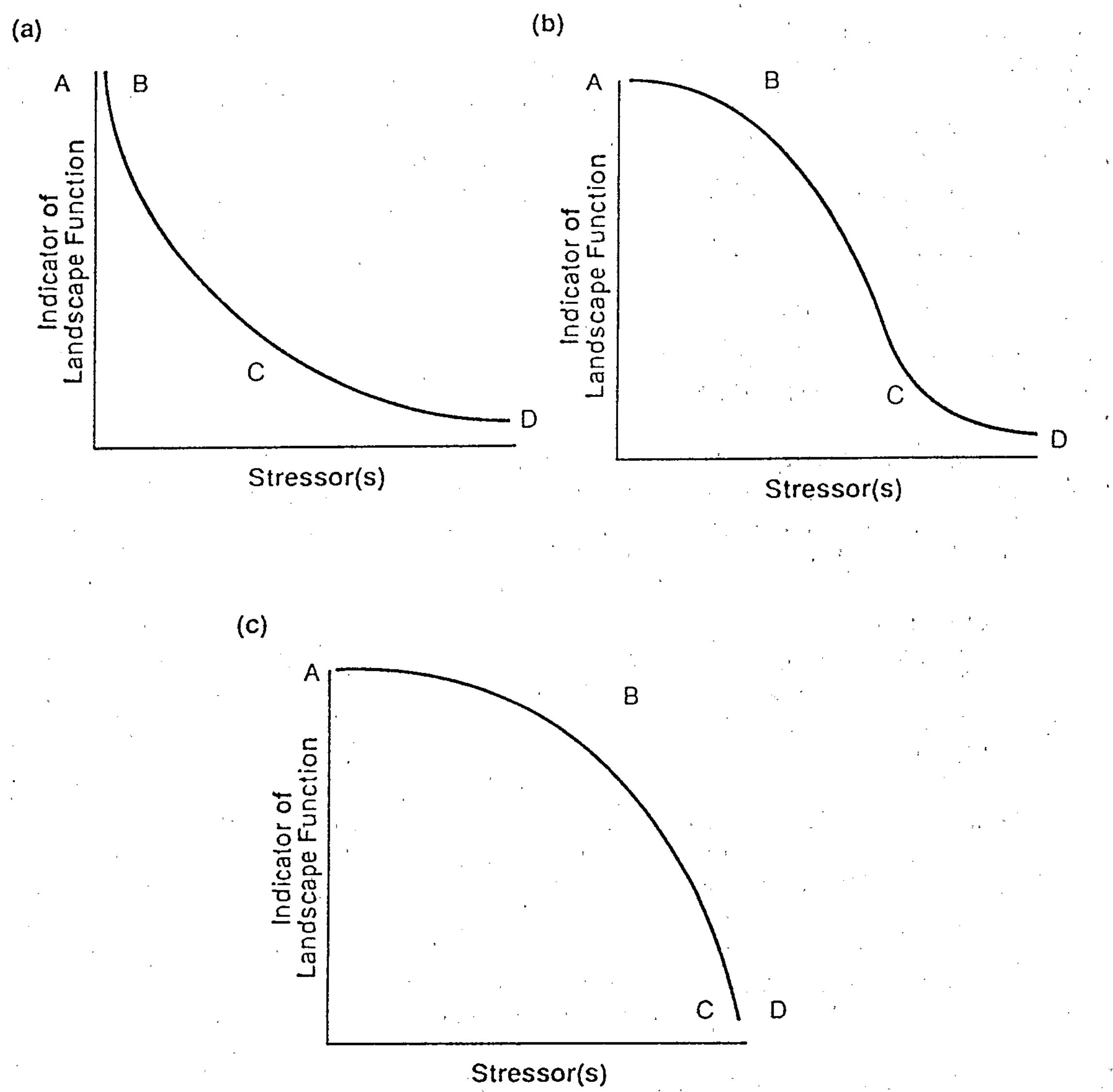


Figure 3-4. Example hypothetical stressor/response curves, illustrating in this case the relationship between landscape function (e.g., biodiversity or overall water quality improvement) and increasing levels of some stressor or multiple stressors (e.g., hydrological modification, toxic contaminants, etc.). In curve (a), landscape function declines sharply even with low levels of stressor(s), while curves (b) and (c) suggest that, because of the system's resiliency, it can initially absorb some level of stressor(s) without a measurable loss of function. The portion of the curve with the steepest slope can be used to identify those landscapes where the greatest return (increase in function) could be achieved per unit of wetland protection effort (reduction of stressor). Labels A-D indicate categories of landscape condition (defined in Section 3.5). Landscapes falling in the zone defined by A to B are considered pristine landscapes; those in the zone defined by B to C are transitional landscapes; and landscapes in the zone defined by C to D are considered dysfunctional.

to determine whether risk reduction goals are being met so that the management plan can be amended if necessary. Thus, this type of monitoring has a relatively narrow focus.

Baseline monitoring is used to determine whether new wetland problems have arisen or whether old problems were overlooked, either of which could result in a change in relative risk. Such monitoring would consider broad trends in the extent and health of the wetland resource, using a variety of indicators. The management plan would be updated periodically to reflect any changes in relative risk, as determined by this type of monitoring. The EMAP-Wetlands project (see Appendix A) will be a major source of information for baseline monitoring of wetland condition.

3.5 IMPLEMENTATION OF THE RISK-BASED FRAMEWORK

To serve the needs of wetland managers and regulators, the risk-based framework must be both technically and programmatically feasible. The framework and risk reduction approach must be consistent with policy objectives and existing laws and regulations. In addition, the types of technical data and analyses required for any given application must not be prohibitive. Thus, to the degree possible, the framework will rely on relatively simple protocols, analytical procedures, and "rules of thumb," to minimize the need for extensive data collection.

All risk management decisions have some accompanying level of uncertainty. Risk assessments need not provide perfectly accurate answers to be successful, since this would require more information than is normally available to the regulator. Rather the framework must simply provide managers with **better** information and approaches than are currently available, thereby improving the effectiveness of environmental protection efforts and reducing risk. Ultimately, the objective is to select the optimal level of technical input required to achieve the desired level of confidence in management decisions at reasonable cost (see Figure 3-5).

For most management applications, the risk-based framework will be implemented hierarchically, increasing the level of effort at each stage and continually focusing on those aspects that will contribute the most to reducing uncertainties and decreasing the chance of making an erroneous management decision. For example, the four elements of a risk assessment generally will be evaluated sequentially to improve the efficiency of the assessment process. By first considering **wetland function,** the assessment of **wetland value** can focus on the subset of functions that are actually present within that region, rather than considering all possible functions. The assessment of **functional loss** is then limited to valued wetland functions. Finally, **replacement potential** is only considered if that valued wetland function is actually undergoing functional loss.

An initial risk assessment may be conducted based solely on best professional judgment (BPJ). Many management decisions currently rely on expert opinion alone. Formulating this expert judgment within the risk-based framework will better define the issues and uncertainties and, as a result, should improve decisionmaking. Depending on the results and desired level of confidence, it may or may not be necessary to proceed with more quantitative analyses. The next phase, if needed, could rely on existing information and data that can be readily obtained from available maps or aerial photography. Finally, if additional information is needed to further reduce uncertainties, a site visit or even field sampling could be conducted. Again, data would be collected specifically for those sites that previous analyses (based on BPJ or existing data) suggest are at greatest risk or of most uncertain status. Thus, fewer wetlands need to be evaluated at each step.

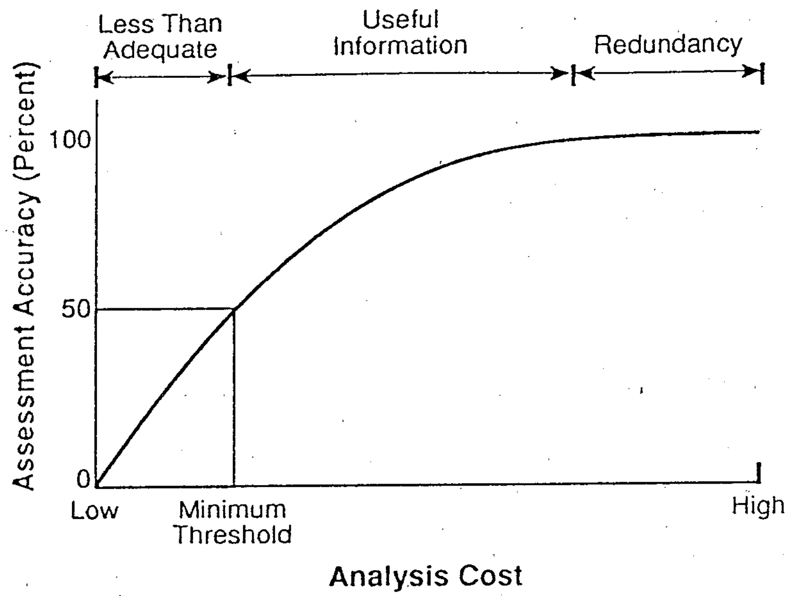


Figure 3-5. The benefits of a risk assessment, measured in terms of the accuracy of the results, as a function of the assessment costs. At the very minimum, the risk assessment must provide results that are better than chance alone, e.g., greater than 50:50 for binary decisions.

Frequently, it may also be effective to implement the framework hierarchically on a spatial scale. Assessments would focus first on landscape functions and landscape units, for example, ranking watersheds or ecoregions within a state. For some management objectives, landscape-level assessments may be sufficient, especially in areas that are relatively homogeneous. Analyses of smaller scale units (e.g., subbasins or wetland complexes) or individual wetlands within these landscape units may be necessary, however, in some cases. For instance, such analyses would be conducted in areas that are heterogeneous or where site-specific information is desired to reduce the chance of wetland misclassification or of errors in decisionmaking. If funds are limited, it may be appropriate for individual wetland assessments to be limited to or conducted first in those landscape units considered at greatest risk (for example, based on an assessment of landscape condition as discussed in Section 3.3).

In all cases, risk assessments for wetland protection and management must consider the condition of the surrounding landscape (in addition to on-site wetland condition) for two reasons: (1) ignoring landscape considerations will omit important environmental factors that contribute to wetland function and value, thereby reducing the likelihood of achieving policy objectives; and (2) including landscape information can expedite the assessment process, as it is generally not feasible to evaluate every wetland individually.

The specifics of how best to implement the risk-based framework will vary depending on the management context and management objective being evaluated. The framework could be applied, for example, to assist with the development of State Wetland Conservation Plans, with the implementation of Section 404 of the Clean Water Act, or with decisions regarding wetland acquisition. As part of the Risk Reduction Project, the results from the other three WRP projects will be combined to demonstrate the application and usefulness of this framework for two major issues: the national policy of no net loss and the role of wetlands in water quality improvement. In addition, components of the risk-based framework will be applied to provide technical support for the development of water quality criteria for wetlands, as part of the Wetland Function Project. Further details on these applications are provided in Sections 7 and 4, respectively.

4. WETLAND FUNCTION PROJECT

The Wetland Function Project focuses on those tasks and information needs best provided through relatively detailed studies of processes and responses in individual wetlands or small groups of wetlands. Work within this project will contribute primarily to three of the WRP research objectives:

1. Determine the contribution of individual wetlands to water quality improvement, habitat, and hydrologic functions, and develop techniques for enhancing and protecting these functions (e.g., best management practices).

2. Quantify the effects of environmental stressors and landscape factors on wetland functions.

3. Provide technical support for the development of biological criteria for wetlands in support of the Office of Water.

This section presents background information on the Wetland Function Project and the research issues to be addressed (Section 4.1); an overview of the basic approach to be used to achieve the research objectives (Section 4.2); brief descriptions of the proposed studies for project implementation (Section 4.3); and a summary of the major expected contributions of the project relative to the overall goals and objectives of the WRP (Section 4.4).

4.1 BACKGROUND

The Wetland Function Project is an outgrowth of the original WRP Water Quality Project (see Appendix A). Research within the Water Quality Project focused on the role of wetlands in water quality improvement. This research direction was emphasized because water quality functions were (1) more poorly quantified than other wetland functions; (2) a logical research focus for EPA, given the Agency's responsibilities under the Clean Water Act and its historic research strengths in the area of water quality; and (3) not a primary focus of research by other federal agencies (Zedler and Kentula 1986, Adamus 1989).

During FY 1992-1996, the Wetland Function Project will broaden its research to encompass all three major categories of wetland functions (hydrologic, habitat, and water quality improvement) and also address the full suite of major environmental stressors: hydrologic modification, physical alteration, sedimentation, nutrient loading, and toxic contaminants. This expansion of the project scope is necessitated by both the shift to a risk-based framework and the need for innovative biological criteria fo wetlands covering the full range of potential stressors. Biocriteria include hydrological and habitat conditions necessary to sustain designated aquatic life uses, as well as biological endpoints.

The Wetland Function Project will provide information on (1) wetland functions, emphasizing the role of individual wetlands in reducing nonpoint source pollution and urban stormwater management consistent with the priorities of the EPA program offices (see Section 1.2); (2) the effects of environmental stressors on wetland functions; (3) management techniques that may be used to mitigate the effects of stressors on wetland functions; and (4) technical guidance on site-specific wetland monitoring and indicators of wetland condition and function.

The overall goal of the project is to provide the technical support needed to develop and evaluate management strategies for protecting the ecological integrity of individual wetlands and wetland complexes. In particular, one important objective of the project is to demonstrate how both the traditional risk assessment approach (U.S. EPA 1991) and the the WRP risk-based framework can be used to aid state wetland regulators in the selection of water quality criteria and best management practices for wetland protection.

The nature, rates, and levels of wetland functions often vary both spatially, within a given wetland, and temporally (e.g., Nixon and Lee 1986, Johnston et al. 1990a). For example, a wetland may be a sink for excess phosphorus during the growing season, thus improving downstream water quality; that same wetland, however, could become a phosphorus source in the autumn during plant senescence. In addition, specific wetland characteristics may influence the nature and magnitude of wetland functions, for example, the degree to which a given wetland may serve as a phosphorus sink and thus the utility of the wetland for nonpoint source pollution control. An understanding of these factors and within-wetland variability is needed to better interpret the patterns and responses observed at the population and landscape level. Thus, the detailed studies of individual wetlands conducted as part of the Wetland Function Project are an essential component of the WRP for interpretation of the results from the Characterization and Restoration and Landscape Function Projects, as well as the extensive monitoring data collected by EMAP-Wetlands (see Appendix A).

The Wetland Function Project also will be the primary source of quantitative information on wetland responses to stressors. Comprehensive studies are needed to (1) identify which structural or functional attributes of wetlands are most sensitive to particular stressors, (2) distinguish natural variability in wetland functions from changes caused by anthropogenic stressors, (3) quantify wetland assimilative capacity and threshold levels for response to stressors, and (4) assess the combined effects of multiple stressors (Adamus and Brandt 1990).

Best management practices provide a means for preventing or reversing wetland degradation. In particular, as noted in Section 1.2.7, buffers (i.e., vegetated strips of land) around wetlands may filter pollutants and sediments from overland and subsurface flow, thereby decreasing the input of these materials into the wetland. Under conditions where point source (e.g., stormwater) discharges or hydrological modifications are of concern, the use of buffers may not be sufficient to moderate effects. Best management practices, such as upland source reductions through shifts in tillage practices or in usage patterns to less hazardous pesticides or herbicides, maintenance of historical watershed/wetland area ratios, or upstream treatment or control of runoff quantity/quality, may be required. Information is needed on (1) the effectiveness of buffers and other best management practices at mitigating the effects of stressors on wetland functions; (2) the critical features of buffers (e.g., size and structure) that may influence their effectiveness; and (3) the types of stressors and impacts for which the implementation of best management practices may be most appropriate. The development of technical guidance for best management practices will rely on and complement the approaches being developed by the Landscape Function Project (see Section 6).

Finally, as discussed in Section 1.2.4, EPA's Office of Water will be providing guidance to states for developing biological criteria for wetlands. The Wetland Function Project will provide technical expertise in support of this effort. Major technical needs include (1) quantification of stressor/response relationships, as discussed above; (2) an improved understanding of exposure pathways in wetlands and the influence of the wetland environment on chemical availability and toxicity; and (3) the identification of suitable indicators of wetland condition and functions, and information on the range of indicator values in natural and impacted wetlands, as a basis for defining biocriteria. This information can be integrated through the traditional risk assessment approach to provide support for developing water quality criteria and best management plans, with known uncertainties and an appropriate margin of safety. In addition, incorporation of results into the functional loss element of the WRP risk-based framework (Section 3.2.3) will facilitate the integration of water quality criteria and best management practices into large-scale (e.g., ecoregions, landscapes) wetland protection and management strategies. Use of the risk-based framework for criteria development also will facilitate the integration of water quality criteria into the broader context of risk management and the selection of optimal management strategies for wetland protection.

4.2 APPROACH

To address the objectives and data needs outlined above, the Wetland Function Project will conduct four major types of activities: (1) literature synthesis and development of conceptual models, (2) empirical field studies, (3) manipulative experiments, and (4) development of management strategies within the risk-based framework for protecting individual wetlands and wetland complexes. Each of these efforts is described in greater detail below. The overall research strategy is presented diagrammatically in Figure 4-1.

4.2.1 Literature Synthesis and Conceptual Models

For each of the regions and wetland types studied (see Section 4.3), the relevant literature will be reviewed and synthesized; wetland experts will be consulted; and conceptual models, such as the model of the Des Plaines River wetland presented in Figure 4-2, will be developed. The following will be identified:

- the major stressors of concern for the particular system being studied, that is, the stressor(s) considered to have the most critical or severe effects on the wetland type of interest (e.g., excessive sedimentation caused by high erosion and the loss of buffer strips might be considered critical for prairie pothole wetlands);
- the most important wetland functions that are threatened by each stressor (e.g., loss of habitat and depletion of food resources for waterfowl that rely on the prairie pothole wetlands);
- major ecosystem components and processes, in particular those components or processes that may serve as indicators of impaired function caused by different stressors (e.g., seed bank viability of critical plant species, macroinvertebrate dynamics, etc.); and
- linkages among these stressors, ecosystem components, processes, and wetland functions.

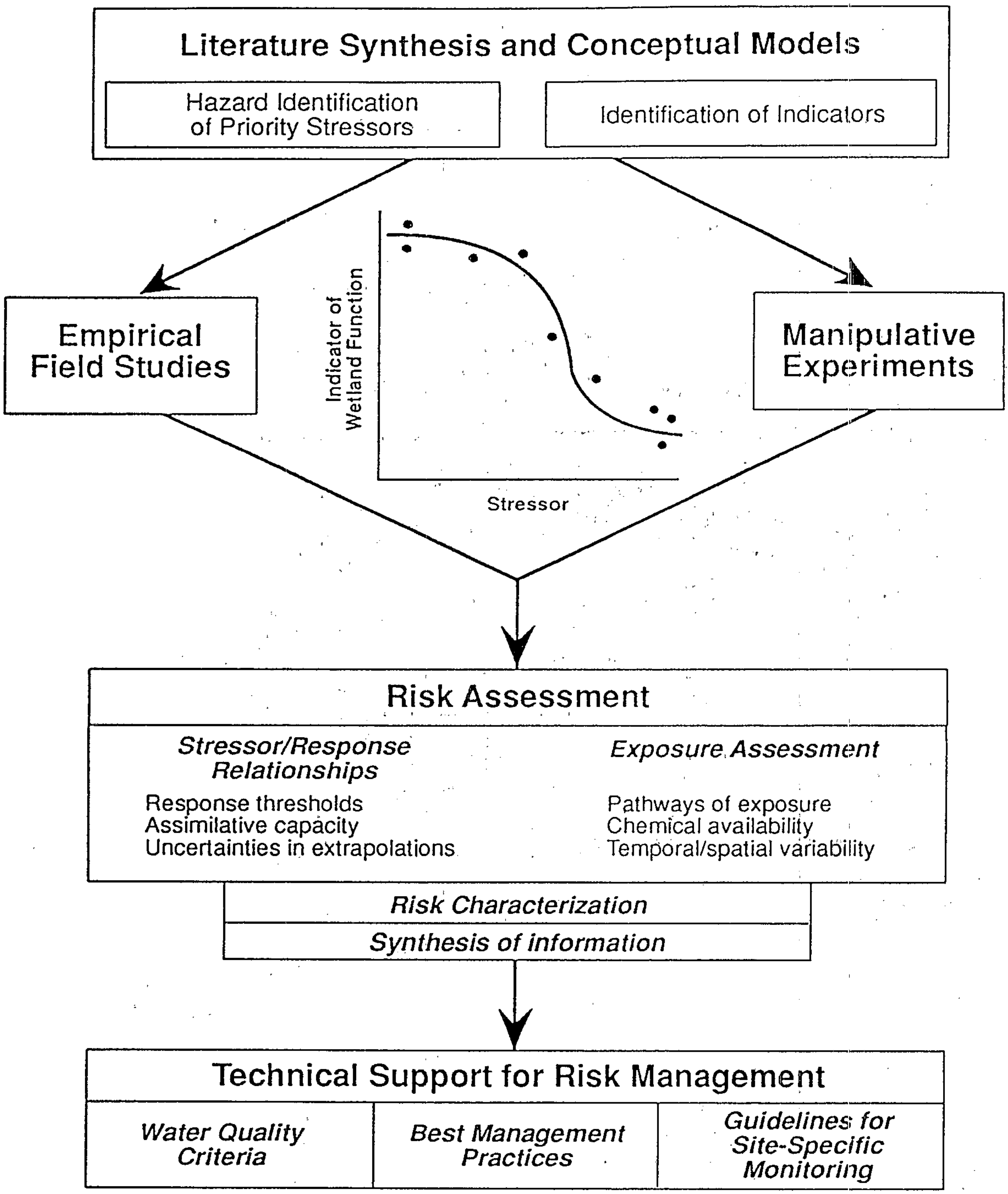


Figure 4-1. Flow chart for the research strategy for the Wetland Function Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships.

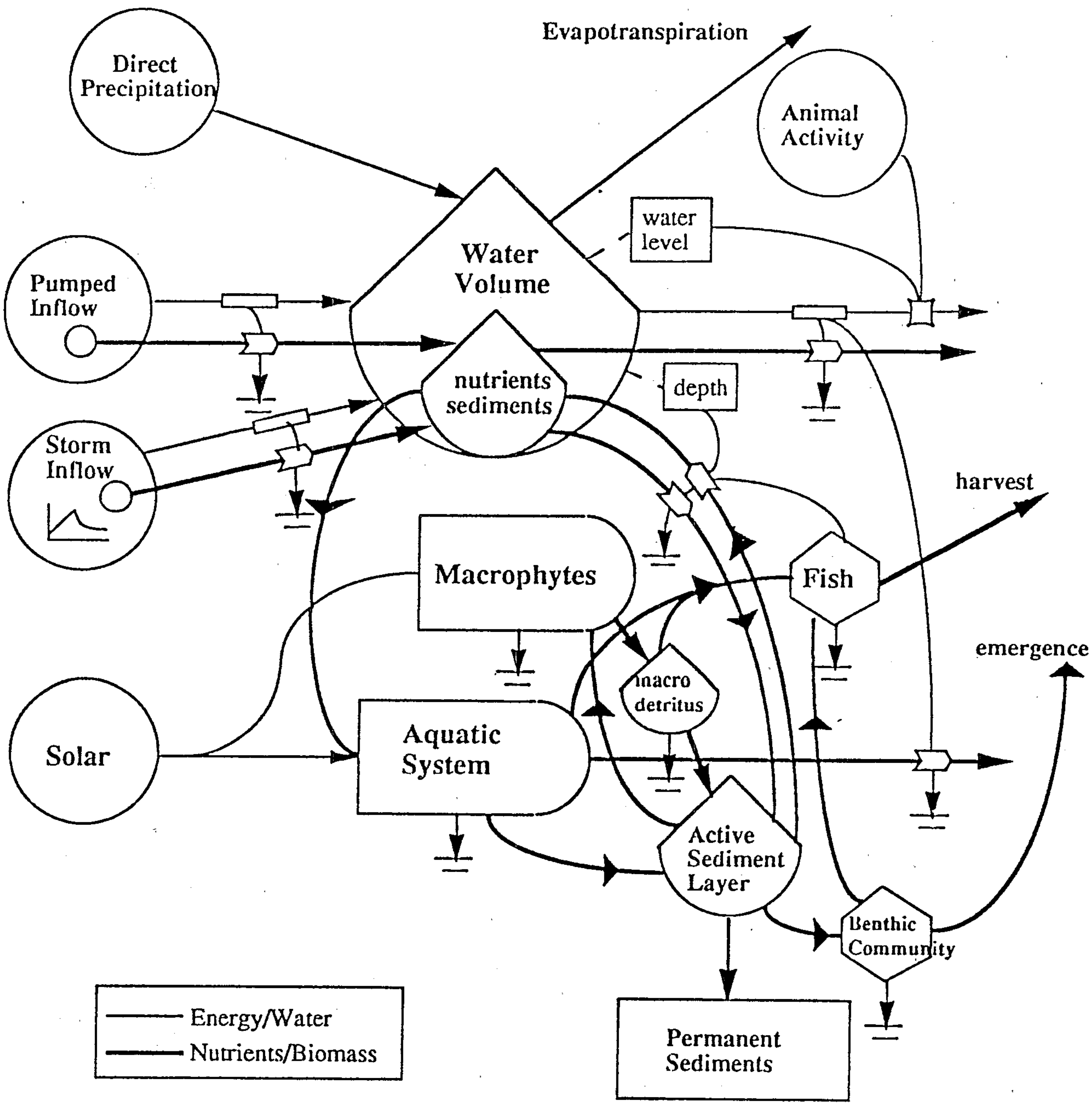


Figure 4-2. Conceptual model of the Des Plaines River Wetlands, developed by William Mitsch and others for the Des Plaines River Wetlands Demonstration Project examining the response of constructed wetlands receiving stormwater runoff from the City of Chicago. This project was funded through the WRP Water Quality Project.

The results from the literature review, expert consultation, and conceptual models will be used for several purposes:

- to limit the scope of study by focusing on those functional and structural attributes considered most sensitive to particular stressors of concern;
- to develop specific research hypotheses to be tested during the empirical and manipulative studies;
- to define hypothetical or preliminary stressor/response relationships based on the best available data;
- to aid in the design of experiments that will verify stressor/response relationships and separate natural variability from stress-induced responses;
- to identify potentially useful indicators of wetland functions and responses to stressors that can then be evaluated in the empirical and manipulative studies; and
- ultimately, to assist in the interpretation of study results, which may be complicated by system interactions and the indirect effects of stressors on wetland functions.

The conceptual models will be revised and enhanced as needed as additional information is obtained through the field and laboratory studies conducted by the Wetland Function Project.

4.2.2 Empirical Field Studies

Detailed studies of individual wetlands or small groups of wetlands will be conducted to characterize wetland conditions (1) along a gradient of an environmental stressor or disturbance, (2) before and after the occurrence of a disturbance or stressor, and/or (3) in wetlands with varying wetland or watershed management strategies, such as buffers, that may be used to mitigate the effect of stressors on wetland functions. Indicators of wetland function will be measured in each wetland and the correlation between indicator values and stressor levels will be examined to help define exposure pathways and stressor/response relationships.

The recently completed two-year study of Minnesota wetlands by Detenbeck et al. (1991) for the Water Quality Project provides an example of the type of study envisioned. The objective was to evaluate the effects of stressors associated with urbanization on wetland water quality, as well as the ability of these wetlands to improve downstream water quality. Within the 8-county Minneapolis/St. Paul metropolitan area, 31 wetlands were identified that would be disturbed during the time frame of the study (September 1988 to September 1990). Disturbances included dredging, fill, impoundment, drainage, and inputs of urban stormwater or pumped groundwater. Water quality and hydrologic data were collected seasonally at the inflow to, mid-wetland, and outflow from each site before, during, and after disturbances. Relationships between wetland response (e.g., the change in total phosphorus pre- and post-disturbance) and indicators of the disturbance intensity (e.g., the change in wetland type or water depth) were examined using stepwise multiple regression (see Figure 4-3). Stormwater or pumped groundwater inputs, construction, dredging and/or impoundment, wetland fill, and an increase in the watershed area or urban/residential land use relative to wetland area all had a significant effect on wetland water quality.

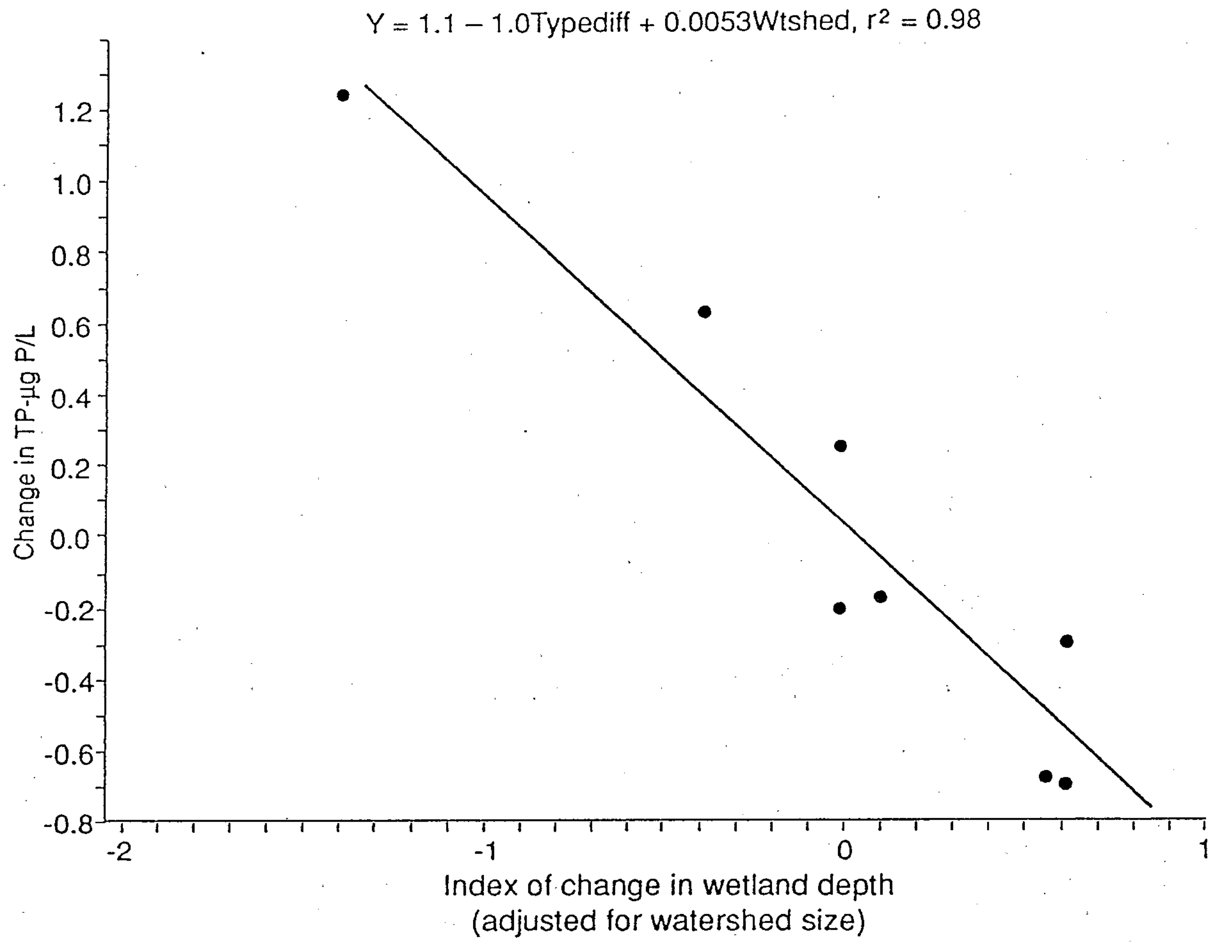


Figure 4-3. Example of the type of results expected from empirical field studies relating a gradient of stressors to the response of individual wetlands. In this study, changes in wetland depth (TYPEDIFF) were used as an indicator of hydrologic disturbance to urban wetlands in the Minneapolis/St. Paul area. Springtime concentrations of total phosphorus (TP) decreased following disturbance as wetlands were deepened by dredging and/or impoundment (Detenbeck et al. 1991). The relationship illustrated in the plot has been adjusted for correlations between watershed size (Wtshed) and the change in total phosphorus or in wetland depth.

For studies involving spatial gradients, land use, topography, soils, groundwater quality, and other existing data will be used to select wetlands with varying degrees of stressor exposure, from non-impacted reference sites to severely impacted sites. Studies will also examine the role of buffers and other wetland or watershed characteristics (e.g., wetland morphology, hydrologic regime, watershed/wetland area ratios) that may influence wetland responses to stressors.

4.2.3 Manipulative Experiments

Selected stressor/response relationships will be evaluated under controlled conditions using experimental manipulations of portions of natural wetlands (mesocosms) in the field or of artificial experimental units (microcosms) in the field or laboratory. Changes in wetland functions and processes will be quantified in response to a controlled range of levels of specific stressor(s). Sufficient levels of each stressor will be included in the experimental design to allow for development of a stressor-response curve or response surface (for exposures to multiple stressors). In addition, a range of modifying factors (e.g., salinity, redox potential, sediment organic carbon content) will be incorporated into a factorial design to assess exposure pathways and so that results can be extrapolated to a wider range of wetland conditions. When possible, experiments will be run for several years so that stressor effects over time and/or recovery times can be assessed directly. Based on the results from these experiments, threshold levels for adverse effects can be identified, that is, the level of stressor beyond which a detectable and ecologically significant loss of function occurs.

An ongoing study by R.D. Delaune, W.H. Patrick, and others at Louisiana State University, initiated as part of the Water Quality Project, provides an example of the type of work planned. The effects of waterborne contaminants on important functions and characteristics of bottomland hardwood forests and *Panicum* marsh in Louisiana, wetland types with predominately mineral and organic sediments, respectively, are being examined. Experimental microcosms are being used to evaluate assimilation processes and rates for toxic organics and metals that are known problems in this region (see Figure 4-4). Assimilation rates are being measured along a gradient of sediment redox potentials. Mesocosm experiments are being used to define indicator responses at a range of contaminant levels. Such process-level experimentation provides rate measurements that may be incorporated into predictive models to estimate the risks associated with continued or increased contaminant loading (e.g., as part of risk characterization; see Section 4.2.4).

4.2.4 Development of Management Strategies for Protecting Individual Wetlands and Wetland Complexes

The Wetland Function Project will demonstrate how a traditional risk assessment approach (introduced in Section 3.2.3) can facilitate and improve the development of management strategies for protecting individual wetlands and wetland complexes. The goal is to provide state regulatory agencies responsible for implementing standards and best management practices with an approach that they can use to develop a comprehensive, well integrated combination of protective strategies to protect their wetland resources. Results from the empirical and manipulative studies conducted by the Wetland Function Project will be used to demonstrate and test the usefulness of this approach and, ultimately, to contribute to the functional loss element of the risk-based framework.

The four steps of a traditional risk assessment (hazard identification, quantification of stressor/response relationships, exposure assessments, and risk characterization) provide a basis for characterizing the most critical risks to wetlands. Using this information, wetland managers can then manage those risks through wetland standards, including an appropriate combination of narrative and numeric biological, physical, and chemical criteria and best management practices.

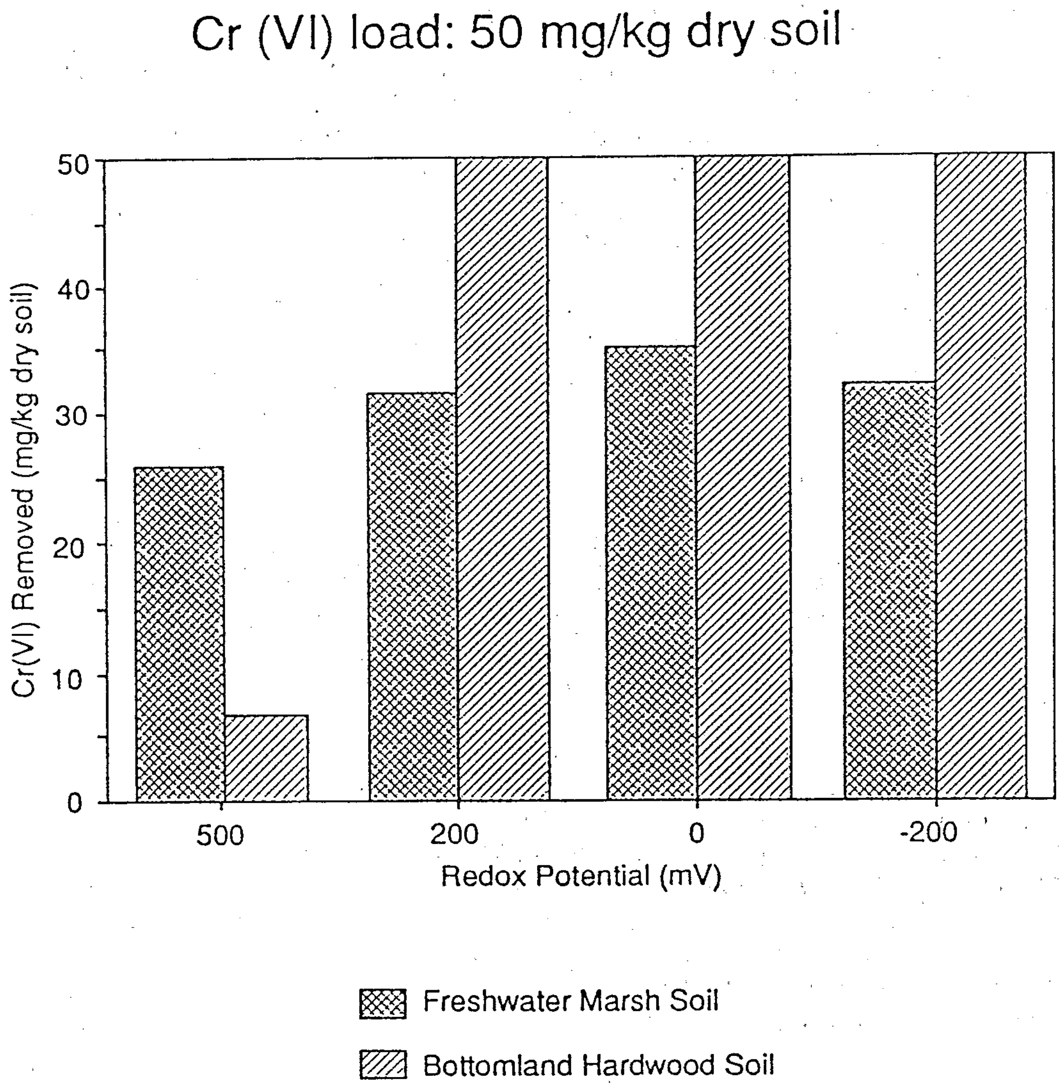


Figure 4-4. Chromium assimilation within microcosms containing a heavily organic freshwater marsh soil or a predominately mineral bottomland hardwood forest soil as a function of redox potential, under a loading rate of 50 mg Cr/kg dry soil (Delaune et al., unpublished data, Louisiana State University; project funded through the WRP Water Quality Project).

Hazard identification involves a qualitative, preliminary assessment of risks and the identification of appropriate endpoints and indicators, so that subsequent efforts can be focused on the priority stressors and responses of greatest concern. In most cases, this step can rely on existing information, and the Wetland Function Project will demonstrate how the literature syntheses and conceptual models described in Section 4.2.1 can serve as the primary basis for hazard identification.

Knowledge of stressor/response relationships, exposure pathways, and natural variability is critical to the development of criteria with known levels of uncertainty and sensitivities. The Wetland Function Project will rely on both the empirical studies and manipulative experiments to quantify stressor/response relationships and conduct exposure assessments. Experimental manipulations demonstrate cause-and-effect and can be used to quantify the effects of individual stressors in a controlled environment. By including modifying factors in the experimental design, information will also be provided on chemical availability and exposure pathways. The empirical field studies examine wetland responses to real-world conditions that cannot be adequately simulated in small-scale experiments. The two approaches together are complementary and necessary to determine with confidence how important wetland functions and characteristics respond to stressors.

Through risk characterization, the information described above can be synthesized and presented to wetland managers in a manner that can facilitate decisions regarding appropriate water quality criteria, especially numeric biocriteria, to protect the ecological integrity of wetlands. Uncertainties can be explicitly recognized and accounted for through margins of safety or other means. Many wetland mosaics have already been seriously degraded by a complex of anthropogenic stressors, from point and nonpoint sources. In such cases, the implementation of best management practices, along with water quality criteria, may be an appropriate management strategy to arrest and reverse wetland degradation. The risk-based approach described in this section provides an objective basis for selecting the most appropriate combination of protective measures and also for extrapolating the assessment results to other regions or wetland types. To apply these recommendations to larger management scales (e.g., ecoregions, landscapes), the Wetland Function Project will provide information to the Landscape Function and Risk Reduction Projects.

The risk-based approach described above for the development of water quality criteria and best management practices will be demonstrated for one wetland type and region, specifically the Prairie Pothole Region (see Section 4.3.1). Because this will be a demonstration project, no attempt will be made to provide **all** of the data needed to develop a **full set** of criteria; efforts will concentrate on (1) developing and refining the approach itself and (2) providing technical support for criteria and best management practices relevant to excess sediments and sediment-associated contaminants. Data from the other primary studies (bottomland hardwoods and freshwater emergent wetlands in urban areas; see Section 4.3) also will be used to provide technical support for water quality criteria, focusing primarily on the development of biocriteria and best management practices relevant to the primary stressors being considered in each system.

The sequence of tasks to be completed is as follows:

1. Through the hazard identification process, a proposed set of biological, physical, and chemical criteria appropriate to the chemical and nonchemical stressors of greatest concern will be developed.

2. The degree to which existing stressor/response data and criteria (primarily chemical criteria, developed for lakes and streams) may be relevant to the wetlands of interest will be evaluated.

   Substantial information already exists on the toxic effects of chemical stressors and conventional pollutants on aquatic and terrestrial biota, and many chemical-specific criteria are already available for lakes and streams. Furthermore, the collection of data for quantifying stressor/response relationships and exposure is expensive. Thus, states will need to make efforts to reduce the need for additional chemical-specific toxicity testing, while still ensuring that the final criteria are adequately protective of wetlands. For criteria relevant to prairie pothole wetlands, the Wetland Function Project will test a simple procedure, based on available data, to determine whether existing criteria are sufficient to protect wetland-dependent organisms under wetland conditions (Hagley and Taylor 1991).

3. Empirical and manipulative studies will be used to (1) field verify the relevance of existing criteria and (2) develop new stressor/response relationships and exposure data, focusing primarily on developing and testing biological indicators of chemical and nonchemical stressors, from which both narrative and numeric biocriteria can be developed.

   States may find that site-specific adjustments are needed in select cases. Limited additional testing may be warranted for classes of chemical contaminants (e.g., heavy metals) expected to have altered toxicity under wetland conditions of low and/or variable dissolved oxygen or pH. The Wetland Function Project will conduct actual toxicity tests only in the context of research already planned for prairie potholes and southeastern bottomland hardwoods (see Sections 4.3.1 and 4.3.2); all tests will be conducted under conditions appropriate for wetland ecosystems.

   For nonchemical stressors, such as a change in hydrologic regime or physical alteration, both the direct and indirect effects on wetland ecosystems can be significant and must be evaluated. In some cases, the effects may be nonlinear or may involve an irreversible shift to an alternate state (Niemi et al. 1990). Information will be collected on the level and range of critical driving factors, such as hydrologic regime and physical structure, within which wetland functions can be maintained at the levels expected for natural, unaltered wetlands.

   Data collected within the Wetland Function and other WRP Projects on indicators of wetland functions in natural and impacted wetlands will provide the basis for developing biocriteria. Biocriteria can be used to indicate when the cumulative effects of both chemical and nonchemical stressors have induced significant changes in community structure or other important wetland attributes. To date, biocriteria have been developed and applied only for lotic systems in some states (e.g., Ohio EPA 1988). Data suitable for biocriteria development will be collected in each of the wetland types studied by the Wetland Function Project (see Section 4.3).

4. Seriously degraded wetlands and wetland complexes will be identified for which development of best management practices might be especially appropriate.

   Retrospective functional loss assessments will be used to determine when best management practices are most appropriate. Literature reviews as well as the empirical and manipulative studies will provide information on the best methods for implementing best management practices.

5. The information described above will be synthesized in such a way that it can be extrapolated to the ecosystem level or to other similar systems through empirical or mechanistic models or the development of expert systems.

The results from this work will contribute directly to the major deliverables proposed for the Wetland Function Project (Section 9) and also the integrated program deliverables for the Risk Reduction Project (see Sections 7 and 9). Research efforts by the Wetland Function Project concerning water quality criteria and best management practices will be closely coordinated with programs ongoing within EPA's Office of Science and Technology and the Office of Wetlands, Oceans, and Watersheds dealing with the development of sediment criteria, new water quality and biological criteria, and wildlife criteria; nonpoint source pollution; and coastal zone management.

4.3 IMPLEMENTATION

Consistent with the EPA program priorities identified in Sections 1.2 and 1.3, the Wetland Function Project has selected four areas of emphasis for FY 1992-1996: (1) the functional responses of prairie pothole wetlands to sediments and sediment-associated pollutants, (2) the effects of management practices and nonpoint source pollution on the water quality and habitat functions of bottomland hardwood forests in agricultural landscapes of the southeastern United States, (3) the effects of hydrologic modification on the water quality and habitat functions of freshwater emergent marsh in an urban setting, and (4) a pilot study of the effects of stressors on coastal seagrass communities. Brief descriptions of these four studies are provided below.

4.3.1 Functional Responses of Prairie Pothole Wetlands to Sedimentation

Work conducted on prairie pothole wetlands will provide technical support for (1) developing water quality criteria to protect freshwater emergent marshes from the effects of sediment and sediment-associated pollutants, (2) developing guidelines for buffer widths of nonagricultural land to protect these wetlands from nonpoint source pollution, and (3) determining the role of isolated wetlands in performing habitat, water quality, and hydrologic functions (see Section 1.2.6). Tasks will be coordinated with concurrent efforts in these wetlands conducted by the Characterization and Restoration (Section 5.3.1) and Landscape Function (Section 6.3.1) Projects and EMAP-Wetlands, and the results will be integrated by the Risk Reduction Project into the risk-based framework (Section 7.2). Results from the prairie pothole studies also will be used to demonstrate a risk-based approach for setting water quality criteria, as described in Section 4.2.4.

The general hypotheses to be tested include the following:

> *The habitat function and water quality improvement capacity of wetlands in agricultural landscapes have been degraded by nonpoint source pollution.*
>
> *Sediment from agricultural watersheds is a major cause of habitat degradation and declines in the water quality improvement capacity of prairie pothole wetlands.*
>
> *Buffers surrounding wetlands in agricultural watersheds can reduce sediment input and preserve the wetland water quality improvement and habitat functions.*
>
> *Isolated wetlands in agricultural landscapes function as sinks and/or transformers of contaminants associated with nonpoint source pollution.*

The study will be initiated by conducting a literature review and assessing expert opinion to define the state of the science on the effects of sedimentation and associated nutrients and toxics on the habitat and water quality improvement functions of prairie pothole wetlands. Conceptual model(s) will be developed and potential indicators of deleterious effects identified. Specific hypotheses regarding stressor/response relationships will be developed, focusing on the relationship between sedimentation and wetland habitat functions. Degradation of hydrologic functions will also be considered in the state-of-the-science review, though to a lesser degree.

Both empirical and manipulative studies will be conducted. Wetlands with a range of adjacent upland buffer widths and upland agricultural practices will be selected for field sampling. Indicators of wetland function, identified through the literature review, will be measured in each wetland. Wetland condition will be examined as a function of surrounding land uses (as an index of nonpoint source pollutant loadings) and buffer widths. Concurrently, wetland mesocosm experiments will be conducted to evaluate the effects of increased loads of sediment and associated contaminants on important wetland components and processes (e.g., the growth and survival of plants and invertebrates, seed bank viability, rates of litter decomposition). The results from the empirical and manipulative studies will provide information on (1) the effects of sediment and sediment-associated contaminants on the wetland habitat function, (2) stressor/response relationships for the development of water quality criteria, (3) the development of best management practices (e.g., guidelines for tillage practices or buffer widths), and (4) uncertainties associated with monitoring strategies for detecting the effects of stressors on prairie potholes.

4.3.2 Effects of Best Management Practices and Nonpoint Source Pollution on Bottomland Hardwoods

Both the Wetland Function and Landscape Function Projects (see Section 6.3.2) will be conducting research on bottomland hardwoods; the results from these studies will be integrated into the risk-based framework by the Risk Reduction Project (Section 7.2).

Studies by the Wetland Function Project will focus on (1) the effects of nonpoint source pollution and buffer management on the functions of bottomland hardwood wetlands and (2) the effectiveness of these riparian wetlands at reducing nonpoint source loadings to downstream surface waters. Technical guidance will be developed for riparian buffer widths needed to protect the water quality of low order streams (i.e., upstream tributaries having low discharge relative to the main stem) and buffer widths of nontilled land needed to protect the riparian forest habitat functions from upland inputs. The general hypotheses to be evaluated include the following:

> *The width and structure of riparian bottomland hardwood forests are important determinants of the water quality improvement functions of these wetlands, reducing pollutant loadings to low order streams.*
>
> *Nontilled buffers adjacent to bottomland hardwood wetlands will protect the habitat function of these riparian forests from upland inputs of nonpoint source pollutants.*
>
> *The relationships between wetland condition, land use, and buffer widths provide useful management guidelines for protecting low order streams and riparian forests from nonpoint source pollution.*

A literature review will be conducted and expert opinion assessed to (1) identify and evaluate existing conceptual and quantitative models of riparian forest wetland structure and function;

(2) summarize existing information characterizing baseline sediment, nutrient, and pesticide assimilation curves and buffer widths for undisturbed riparian forests under different nonpoint source loading scenarios; (3) select indicators of riparian forest water quality and habitat functions; and (4) generate preliminary stressor/response curves for two major stressors of these systems, physical alteration and sedimentation.

Empirical and manipulative studies will be conducted. Bottomland hardwood stands with a range of upland buffer widths and upland disturbance regimes will be selected for field sampling. Experimental bottomland hardwood stands will be evaluated after being subjected to several different management regimes that represent a range of severity of effects. Overland and groundwater flows of materials will be monitored to develop assimilation curves for the various management practices and to determine riparian buffer widths required to protect stream water quality. Management practices, both best management practices and current detrimental management practices, also will be correlated with changes in indicators of wetland habitat functions.

The relationships between buffer widths, the surrounding land use, wetland condition, and stream water quality, from both the empirical and manipulative studies, will provide the basis for management guidelines. Response thresholds identified from stressor/response curves will support the development of criteria for wetland water quality standards.

4.3.3 Hydrologic Modification in Urban Wetlands

The objective of this study is to determine the effects of hydrologic modification caused by urbanization on the water quality and habitat functions of freshwater emergent wetlands. Given the current budget for FY 1992-1996, efforts will be limited to a literature review, synthesis and expansion of ongoing projects funded through the Water Quality Project, and potential research on the effects of stormwater on urban wetlands funded jointly by the EPA Regions and the WRP. The literature review will focus on the types, levels, and mechanisms of effects generally associated with urban hydrologic modification. Ongoing research includes (1) the study by Detenbeck et al. (1991) evaluating the effects of physical and chemical disturbances on urban wetland water quality functions, (2) the development of macroinvertebrate indices of wetland integrity along a gradient of urban stormwater effects, and (3) a study being conducted in King County (Seattle metropolitan area), WA, examining the response of vegetation and amphibian indicators to hydrological stressors in urban wetlands. Follow-up surveys of wetland water quality and habitat functions will be conducted at disturbance sites in the Minneapolis/St. Paul metropolitan area to evaluate the rate of recovery of wetlands following physical disturbances. A regional workshop on urban wetlands to be held in early 1992 in New York City will provide the framework for planning additional studies of urban wetlands to address regional issues (e.g., stormwater inputs).

4.3.4 Effects of Stressors on Coastal Seagrass Communities

Coastal seagrass communities, one of the major categories of coastal wetland habitat, are highly productive ecosystems that furnish food and shelter to ecologically and commercially important fisheries (Thayer et al. 1984). Significant declines in both the area and quality of seagrass communities have been documented in many coastal areas of the United States. However, the nature of seagrass responses to important stressors is not well understood, nor have the tolerance limits of seagrass communities to individual and combined stressors been defined. Empirical field studies and microcosm and mesocosm experiments are needed to characterize stressor/response relationships and to determine the effects of known quantities of stressors on the structure and function of seagrass communities.

During FY 1992, a pilot study will be initiated on the effects of stressors on seagrass communities along the Gulf Coast. A workshop was held in January 1992, including representatives from the National Oceanic and Atmospheric Administration, the U.S. Fish and Wildlife Service, the Corps of Engineers, and state agencies. Based on the information and research discussed at this workshop, a detailed plan of study is being developed to examine the effects of land use and watershed management practices on seagrass systems. The results from the pilot study, together with long-term data sets for estuaries in Texas and Florida, will be used to identify variables and conditions associated with the absence or loss of seagrass communities. Field studies by EMAP-Wetlands and the EMAP-Near Coastal monitoring programs also will aid in generation of testable hypotheses and in field verification.

If additional funding is obtained, research will continue in FY 1993 and beyond, studying seagrass communities in the Atlantic and Pacific as well as in the Gulf of Mexico. In addition to field studies, laboratory mesocosm experiments will be conducted, manipulating variables singly and in combination, to measure the effects of stressors on seagrass survival, growth, and community structure. Major stressors of concern include nutrients, toxics, light levels, and sediment loads. An important objective is to determine the optimal water quality conditions for the establishment and growth of seagrasses. This information will be used to support the development of water quality criteria for the protection of seagrass communities.

4.4 MAJOR CONTRIBUTIONS

The major contributions of the Wetland Function Project to the WRP will include the following:

- quantification of wetland stressor/response relationships and changes in wetland functions and attributes over time in response to important environmental stressors;
- quantification of wetland assimilative capacities and response thresholds for selected stressors;
- development and application of a risk-based approach to setting water quality criteria for wetlands;
- technical guidelines for wetland protection, including the role of buffers and best management practices;
- technical guidance on the role of individual wetlands for water quality improvement, in particular for nonpoint source pollution control or urban stormwater management; and
- technical guidance on wetland monitoring and indicators of wetland condition and functions.

The specific program deliverables for the Wetland Function Project are listed in Section 9.

5. CHARACTERIZATION AND RESTORATION PROJECT

The Characterization and Restoration Project focuses on those information needs and objectives best achieved through field studies of wetland populations. Work within this project will contribute primarily to two of the WRP research objectives:

1. Describe and compare the functional status of populations of natural, restored, and created wetlands in different landscape settings.

2. Provide technical support for the development of design guidelines and performance criteria for wetland restoration and creation.

This section presents background information on the project and the research issues addressed (Section 5.1); an overview of the basic approach to be used to achieve the research objectives (Section 5.2); brief descriptions of the specific studies to be implemented (Section 5.3); and a summary of the major expected contributions of the project relative to the overall goals and objectives of the WRP (Section 5.4).

5.1 BACKGROUND

A cohesive management and regulatory program requires information not only on the ecological functions of wetlands, both individually and in the landscape, but also on the ability to create and restore those functions. Over the past five years, the WRP Mitigation Project focused on research to evaluate how well restored and created wetlands replace the functions of natural wetlands (Zedler and Kentula 1986). Based on this research, an approach was developed for establishing regional performance criteria and design guidelines for mitigation projects with open water and emergent marsh (Appendix A). The Characterization and Restoration Project, an outgrowth of the original Mitigation Project, will continue this research. In addition, the scope of the project has been expanded to include the development of methods and data for characterizing wetland populations. Characterizations can then be used to (1) test and refine the approach developed to assess the success of wetland restoration and creation projects of additional wetland types and (2) provide basic information on attainable wetland functions and among-wetland variability needed for regional-scale wetland management and implementation of the risk-based framework.

The strategy of the Mitigation Project always centered on wetland populations, comparing the characteristics of a sample of restored or created wetlands to an analogous population of natural wetlands[5] of the same type, occurring in similar landscape settings. This approach is in contrast to most wetland studies that have considered only a single site or paired sites (natural versus restored or created). Case studies of individual sites or comparisons of pairs of sites do not provide information that can be extrapolated with known confidence to the wetland population as a whole. Variations among natural wetlands, and among restored or created wetlands, must be

[5] We use the term "natural" to refer to wetlands that occur naturally in the landscape, that is, excluding created, restored, enhanced, rehabilitated, constructed, and other types of wetlands that have been manipulated by humans. Natural wetlands are not, however, necessarily minimally impacted, but may be subject to a range of impacts and stressors.

considered when evaluating the success of wetland restoration or creation efforts, especially for setting design and performance criteria. The population frame used in the Characterization and Restoration Project is not only an outgrowth of historical and ongoing activities of the project, but is regarded as an effective approach for evaluating the overall success of mitigation projects.

The characterization of wetland populations is also a primary objective of EMAP-Wetlands. It is essential, therefore, that the Characterization and Restoration Project and EMAP-Wetlands work closely together to avoid duplication and ensure comparability of results. EMAP-Wetlands is charged with characterizing wetlands over large spatial and temporal scales, implementing a long-term monitoring network that will eventually cover the entire United States and all major wetland types. The Characterization and Restoration Project, by contrast, will sample only certain regions and wetland types to address specific WRP research objectives. The types of measurements and sampling methods in the two projects will be similar, although additional project-specific indicators will likely be measured within the Characterization and Restoration Project. Appendix A provides further discussion of the interactions between EMAP-Wetlands and the WRP projects.

The evaluation of wetland restoration and creation projects will remain an important component of the research in the Characterization and Restoration Project. The amount of existing literature on this issue varies by region and topic. Much of the research has been based on case studies, with no natural sites for comparison (Quammen 1986). If reference sites were used, typically a paired approach was taken. Consequently, the majority of research to date has been site specific.

To determine the adequacy of current information, the Mitigation Project assembled a team of experts to compile and document the status of science on wetland restoration and creation (Kusler and Kentula 1990b). The major findings of this group follow:

- Practical experience and available information vary by wetland type, ecological function, and region. The most extensive and best documented data are available for Atlantic coastal wetlands. Much less is known about restoring and creating inland wetlands.

- Most restoration and creation projects do not have specific goals, complicating efforts to evaluate "success." Success is often evaluated only in terms of compliance with permit requirements or establishment of vegetation. Such measurements are not indicative of the occurrence or level of function, nor the persistence of those functions over time.

- Monitoring of restoration and creation projects has been uncommon. Monitoring of sites and quantitative comparisons with natural wetlands over time would provide a variety of information, including how projects develop and how they compare with natural wetlands in the region (Kusler and Kentula 1990a).

The research to be conducted as part of the Characterization and Restoration Project will address these major data gaps by (1) studying the restoration and creation of inland wetlands; (2) developing approaches for establishing performance criteria and for evaluating project success, especially success in terms of establishing or restoring important wetland functions; (3) evaluating regional patterns and long-term trends in the performance of mitigation projects; and (4) developing an approach for prioritizing sites for wetland restoration and creation.

5.2 APPROACH

Four major tasks will be conducted as part of the Characterization and Restoration Project:

1. Describe (characterize) wetland populations, including natural, restored, and created wetlands, to quantify wetland functions and among-wetland variability within specific geographic and land use settings.

2. Evaluate the performance of wetland restoration and creation projects and the attainable levels of wetland functions in various landscape settings.

3. Provide technical support for the development of specific performance criteria and technical design guidelines to enhance performance and accelerate project development.

4. Develop and test an approach for prioritizing sites for wetland restoration and creation.

The approach to be employed for each of these tasks is described in the subsections that follow. The overall project strategy is presented diagrammatically in Figure 5-1.

5.2.1 Wetland Characterization

To characterize wetland populations requires three subtasks: (1) selecting the specific sites to be sampled, (2) deciding which wetland attributes to measure and how and when to sample, and (3) analyzing the sample results to provide an effective characterization of the population of interest. Each of these subtasks is described in turn.

5.2.1.1 <u>Site selection</u>

Data will be collected on a representative sample of natural, restored and/or created wetlands within specific region and land use setting(s) of interest. Ecological and landscape settings are considered important determinants of wetland characteristics and attainable levels of wetland functions. It is important that restored and created wetlands be compared to natural wetlands occupying similar landscapes, and thus exposed to similar stressors, to ensure that the expected attributes of a wetland restoration or creation project are within the bounds of possible performance given the setting (Brown 1991). For this reason, the sites sampled will be stratified by ecoregion and land use. Brooks and Hughes (1988) suggested Omernik's (1987) ecoregions as a framework for wetland selection because the ecoregion boundaries were selected to reflect regional patterns of land surface form, potential natural vegetation, and soils. In addition, the effects of land use and landscape position will be accounted for by grouping wetlands in similar land use settings (e.g., urban, agricultural).

For each study region, a list of all restored and created wetlands in the area will be compiled or obtained (e.g., using a listing of Section 404 permits that required compensatory mitigation). This list will define the population of restored and created wetlands. Depending on the study objectives and size of the population (i.e., total number of mitigation projects in the area), either all or a random subset of these wetlands will be sampled. If projects within the area are of varying age (i.e., time since completion of the wetland restoration or creation activities), then the sample may be stratified by age to provide a basis for evaluating how projects develop over time.

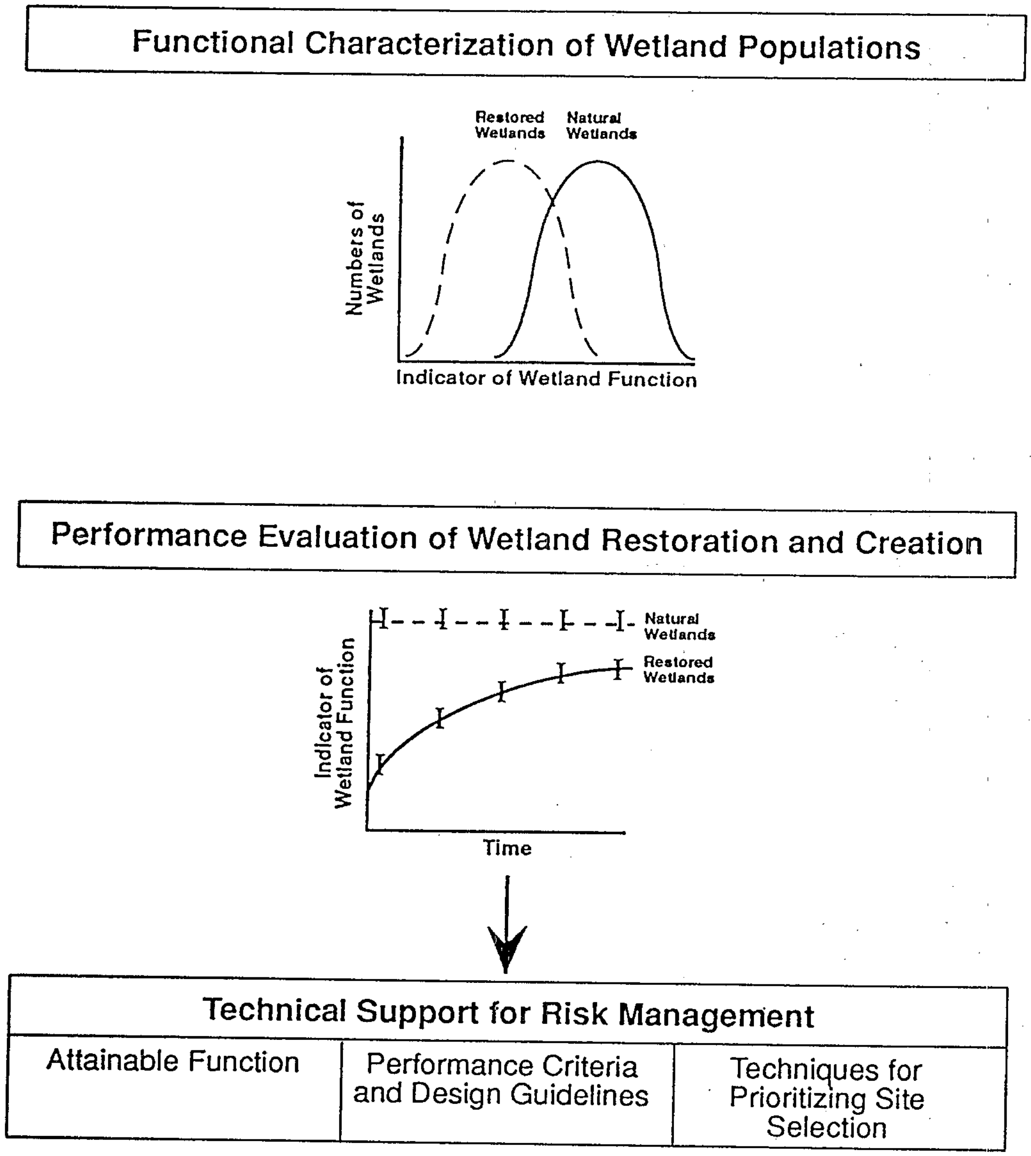


Figure 5-1. Flow chart for the research strategy for the Characterization and Restoration Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships.

Analysis of the list of sites also can be used to describe patterns and trends in wetland restoration and creation (e.g., acreage of impacted or created wetlands, wetland type(s) affected, mitigation ratios, etc.), as illustrated in Figure 5-2 (Kentula et al., in press; Holland and Kentula, in press; Sifneos et al., in press).

The next step is to select the natural wetlands that will be used to establish the level of wetland function(s) that is attainable for a given region and land use setting. For example, a landscape quadrat may be established along a gradient of interest, such as the urbanization gradient shown in Figure 5-3. The total population of wetlands within the quadrat can be identified using either National Wetland Inventory maps or aerial photography. The population may then be stratified according to land use, degree of impact, or major stressor using a procedure such as the Landscape Development Index (Brown 1991), which is discussed further in Section 6. As is the case for restored and created wetlands, either all or a random sample of natural wetlands can be surveyed, depending on the size of the wetland population and desired sample size and stratification.

Finally, the suitability of the sites needs to be verified in the field, and the list of sites to be sampled finalized. Sites will be rejected if they are the wrong wetland type or size, if conditions at or adjacent to the site would be hazardous to the field team, or if access is denied. Contingencies for site rejection will be factored into the preliminary site lists, to ensure that the final sample size is adequate.

5.2.1.2 <u>Site characterization</u>

At each of the sites selected, field measurements will be collected to assess wetland characteristics. Indicators of wetland functions are of particular interest, because an important objective of wetland restoration/creation is to replace losses of wetland area or function. At present, there are no universally accepted indicators of wetland function. Indicators of potential utility have been identified, however, by consulting wetland scientists and the literature. Adamus and Brandt (1990) completed such a review for the WRP. In addition, a list of potential indicators for use in regional wetland monitoring has been developed for EMAP-Wetlands (Leibowitz et al. 1991). Finally, studies conducted over the last five years as part of the Mitigation Project have resulted in the identification of useful indicators, especially for comparing natural and restored/created wetlands (e.g., Confer and Niering, in press; Sherman 1991; Sherman et al. 1991).

To the extent possible and to ensure comparability/exchangeability of data, the indicators and sampling methods employed will be consistent with those used for EMAP-Wetlands. In some cases, additional indicators and more intensive sampling may be needed to satisfy specific objectives of the Characterization and Restoration Project. In general, wetlands will be described through measurements of important biological, physical, and chemical parameters. Sites will be mapped to scale, and the maps will be annotated with features of the site and the surrounding area. Basin morphology will be described; other measured variables (e.g., vegetation patterns) will then be related to relative elevations within the site. Surveys of vegetation and animals will be conducted. Site hydrology, soils, and water quality will be described.

The Characterization and Restoration Project will contribute to indicator development, testing, and improvement by evaluating the utility of proposed indicators in extensive surveys in different

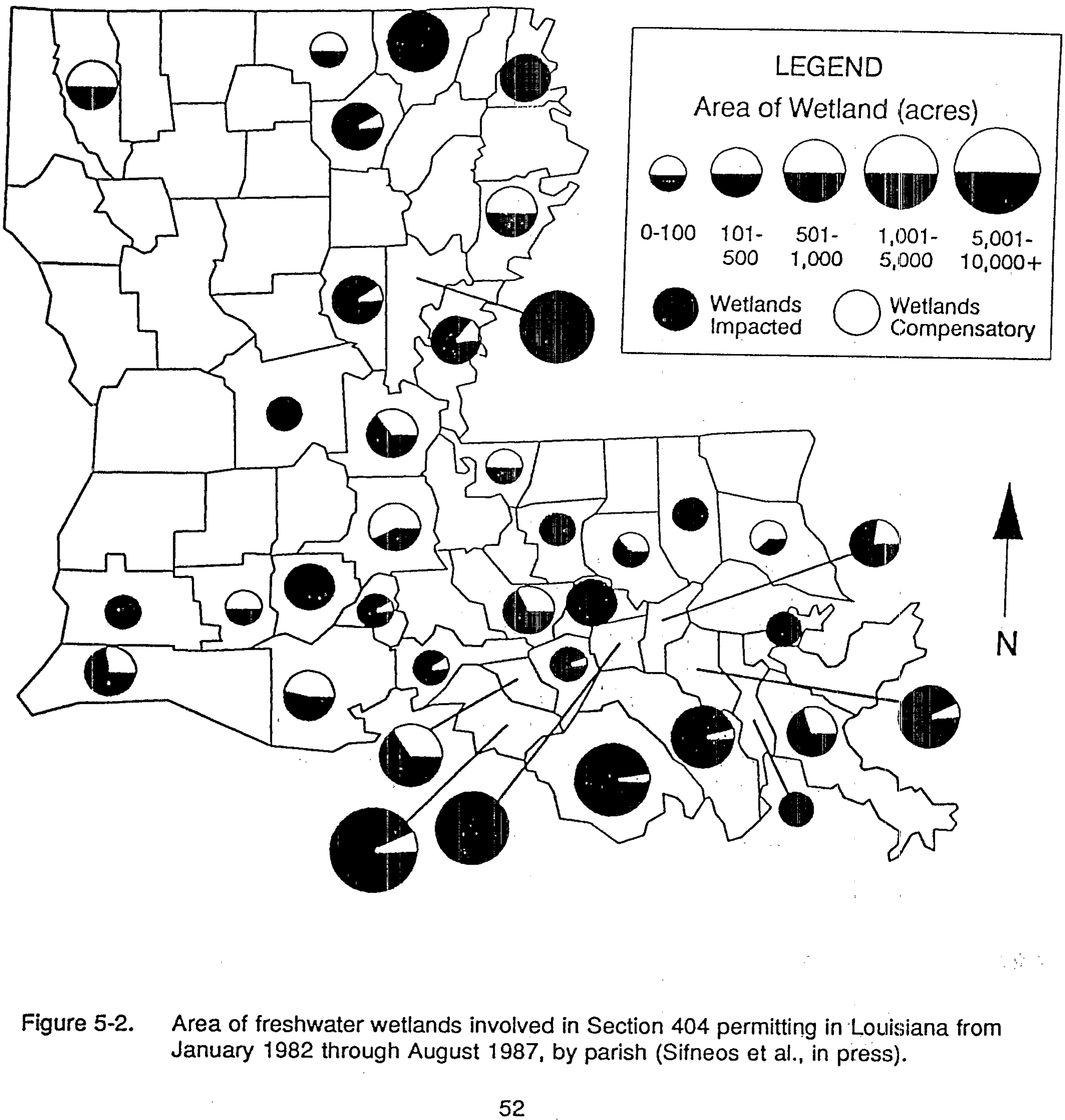
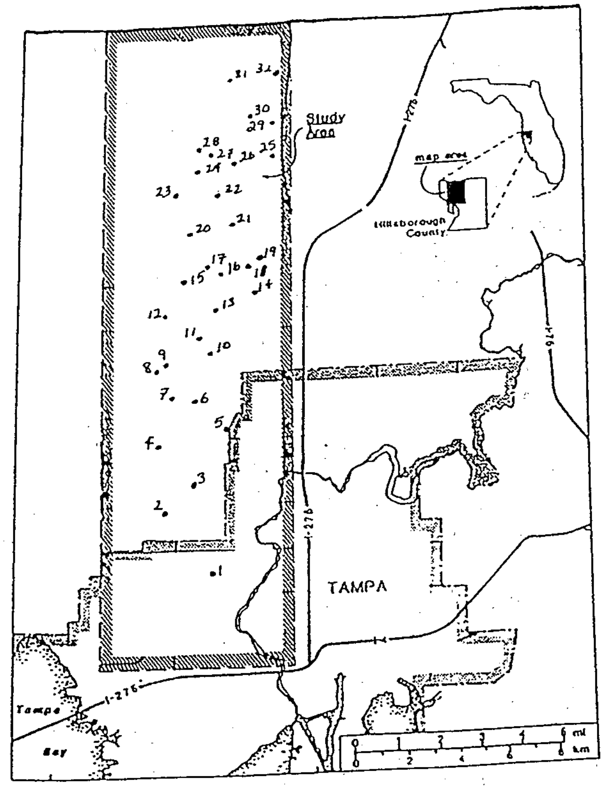


Figure 5-2. Area of freshwater wetlands involved in Section 404 permitting in Louisiana from January 1982 through August 1987, by parish (Sifneos et al., in press).

(a)



(b)

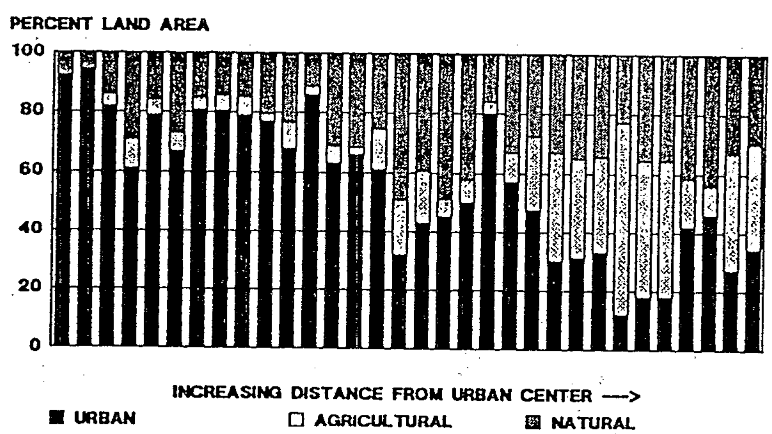


Figure 5-3. Illustration of a land use gradient showing (a) the locations of 32 candidate wetlands in a landscape quadrat that extends out from the urban area of Tampa, FL, and (b) a comparison of land uses surrounding each candidate wetland showing the change from predominately urban to increased agricultural and natural land uses with increasing distance from the urban center (adapted from Brown 1991).

wetland types and regions. The results will complement, and provide a population context for, the intensive field studies and mesocosm and microcosm experiments conducted as part of the Wetland Function Project (see Section 4.2.2).

5.2.1.3 Population characterization

The major output from this task will be **characterization curves**, describing the frequency distributions of functional indicators (or a multivariate, integrated index of wetland function) for the wetland populations of interest. Separate curves will be developed and compared for natural and restored or created wetlands (top of Figure 5-1), for wetlands in different landscape settings, and, where possible, for mitigation projects (restored or created wetlands) of different ages.

5.2.2 Performance of Wetland Restoration and Creation Projects

Data collected in the field studies described above also will be used to document the ecological performance of restored and created wetland projects. The two main analytical tools used to assess the success of wetland restoration and creation efforts within a region will be (1) snapshot comparisons of the characterization curves for functional indicators in natural and restored or created wetlands (top of Figure 5-1) and (2) **performance curves**, which track the development of ecological functions of restored or created wetlands over time relative to natural wetlands (middle of Figure 5-1; also Figure 5-4). As noted above, it is important that wetlands be compared within the same landscape setting; natural wetlands provide the basis for defining the level of function that can be attained by restored or created wetlands within a specific landscape setting. Questions to be addressed by these analyses include the following:

- What is the achievable level of wetland function in a particular environmental/land use setting? (What is the time-averaged mean for natural sites?)

- How long does it take for restored or created wetlands to achieve their maximum level of function? (What is the slope of the performance curve during the period of establishment?)

- Do restored and created wetlands achieve, on average, the same level of function as natural wetlands? (Is the average value for any specific functional indicator, at some time after establishment of the mitigation project, equal to the mean value of that functional indicator in natural sites in the same landscape setting?)

- How can natural and degraded wetlands best be distinguished? (What indicator(s) of wetland function have the least overlap between the characterization curves for the two groups of wetlands and what is the value of this indicator(s) where the two characterization curves intersect?)

Figure 5-5 illustrates the type of results expected from these analyses using recently completed Mitigation Project studies. Measurements of an index of plant diversity in created freshwater wetlands of different ages in Connecticut, Florida, and Oregon are compared to the mean and standard error for the diversity index for comparable populations of natural wetlands. Note that most of the wetlands studied during this project were less than five years old. Furthermore, very few studies have evaluated changes in restored or created wetlands over time (Kusler and

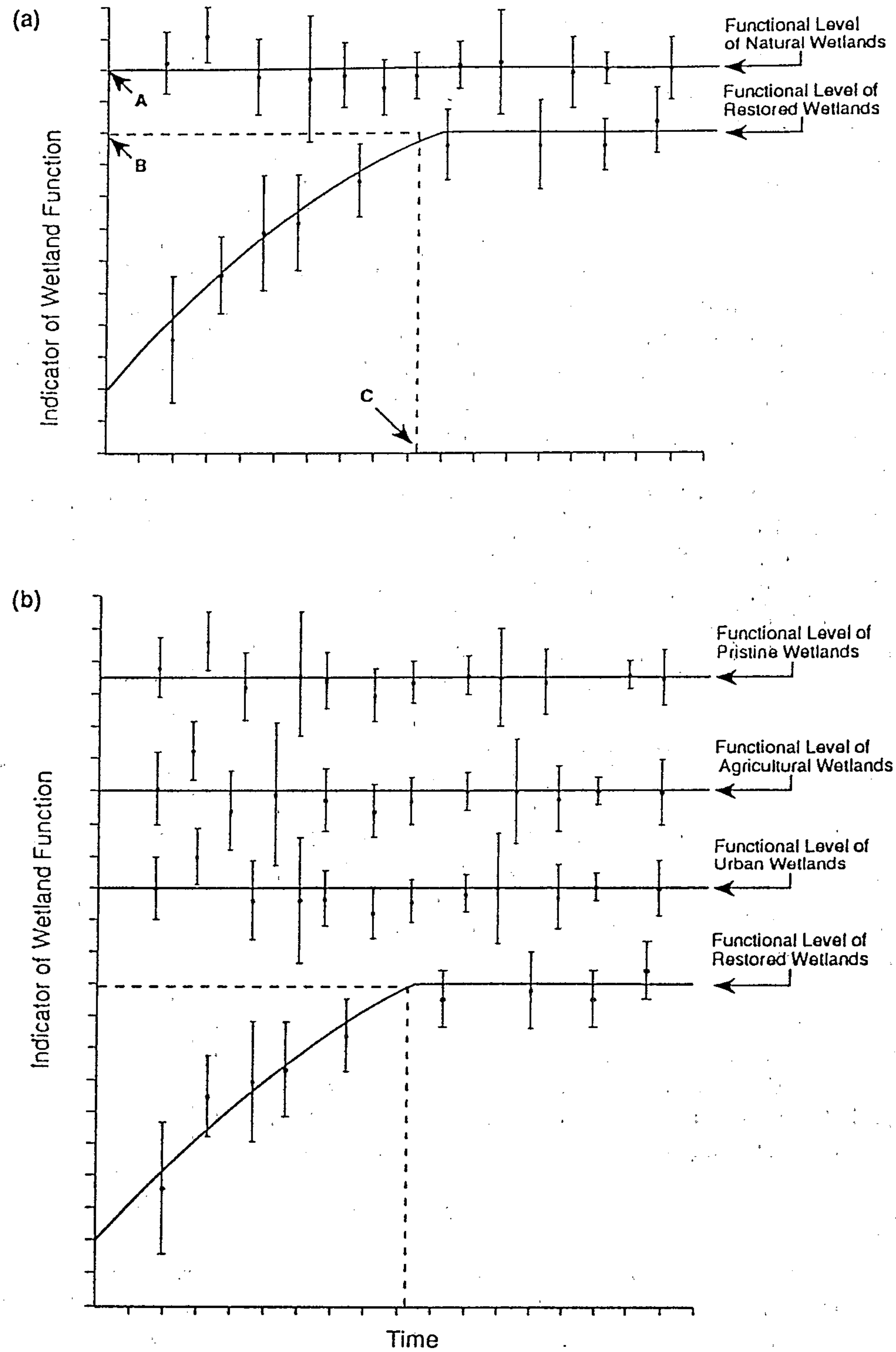


Figure 5-4. Hypothetical performance curves illustrating (a) the comparison of a sample of populations of restored and natural wetlands in the same land use setting and (b) in different land use settings. In figure (a), "A" minus "B" is equal to the difference in the level of function between the restored and natural wetlands. "C" is the time needed to develop the maximum level of function on the restored sites.

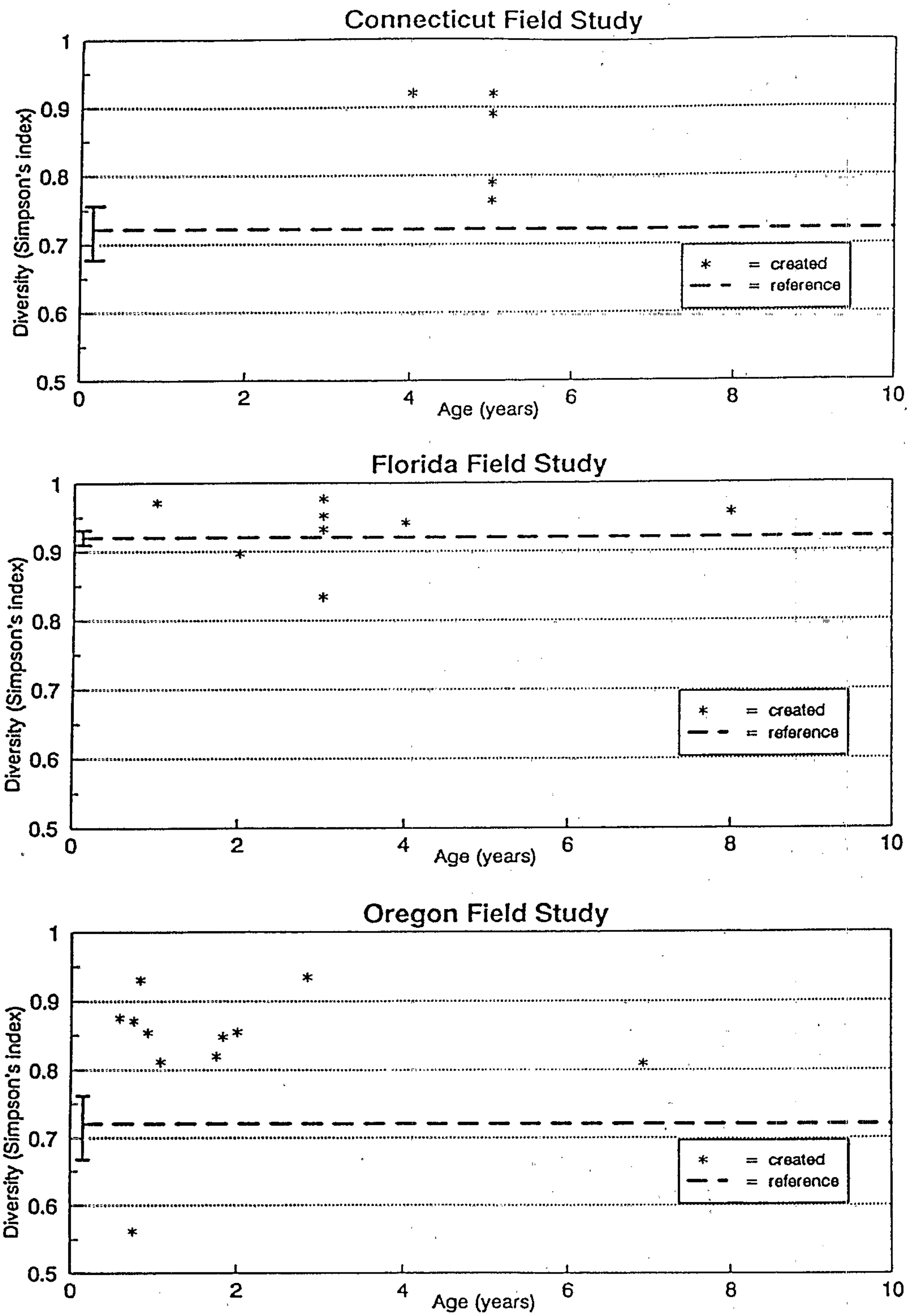


Figure 5-5. Performance curves illustrating the level of plant diversity in the emergent marsh component of created and natural wetlands of different ages in Connecticut, Florida, and Oregon. The dashed line represents the mean plant diversity of the population of natural wetlands; the errors bars indicate one standard error. An asterisk indicates the value for an individual created wetland.

Kentula 1990b). For this reason, during FY 1992-1996 the sites from one or more of the earlier studies will be re-examined to track their development five years later and further characterize the apparent temporal trends identified (Figure 5-5). In addition, mitigation projects constructed since the last study will be included in the sample to see if their pattern of development repeats that of the projects studied earlier (see Section 5.3.3).

The field data collected as part of the wetland characterization studies described in Section 5.2.1 also provide documentation on the "as-built" conditions of restored or created wetlands. These data will be compared to the original planning documents, such as the construction plans and Section 404 permit conditions, to determine if the project was constructed as planned and permitted (e.g., Gwin and Kentula 1990).

5.2.3 Performance Criteria and Design Guidelines

Based on the data and results described in Sections 5.2.1 and 5.2.2, specific technical guidelines will be developed to aid in the design and evaluation of wetland restoration and creation projects. Performance and characterization curves will be produced for each indicator measured and will be used to suggest **performance criteria**. For example, based on the information in Figure 5-5, we can suggest a check on the status of the plant community development at a created site. Within five years after construction, the plant diversity of the site is expected to be greater than or equal to that of natural wetlands within comparable settings. Sites having plant diversities more than one standard error **less than** the average value for natural wetlands may need a correction in design.

Information on the structural features of restored or created wetlands, relative to the functional level attained, will suggest design guidelines and generate testable hypotheses concerning critical design features that influence the likelihood of a successful wetland restoration or creation project. For example, Figure 5-6 illustrates, from the same Mitigation Project study discussed in Section 5.2.2, the concentration of soil organic matter in created wetlands of varying ages in Oregon, relative to the mean soil organic matter content in a comparable population of natural wetlands. Site 'A' has more soil organic matter than both the other created wetlands and the vast majority of natural wetlands. Examination of this site could suggest insights into how to design a created wetland to accelerate the accumulation of organic matter. This accumulation should concurrently increase wetland functions related to soil organic matter content, such as water quality improvement. The validity of such hypotheses will be evaluated by (1) looking for similar patterns and relationships in other groups of restored, created, and natural wetlands; and/or (2) conducting field experiments (e.g., mesocosm studies) that evaluate specific cause-and-effect relationships. Studies and analyses will be carried out to identify design features that are critical to wetland functions and can be manipulated to accelerate the development of these functions over time.

The objectives of the Characterization and Restoration Project are not only to develop technical guidelines for the specific wetland types and areas studied, but also to demonstrate a general process that can be applied by wetland managers in other regions and other wetland types. This approach, proposed initially as part of the Mitigation Project, will provide a framework for the development of ecologically defensible mitigation strategies that are tailored to local and regional needs. The major features of this approach include the following:

- Existing information in project files on wetland restoration and creation activities in the area is used to guide planning and decisionmaking.

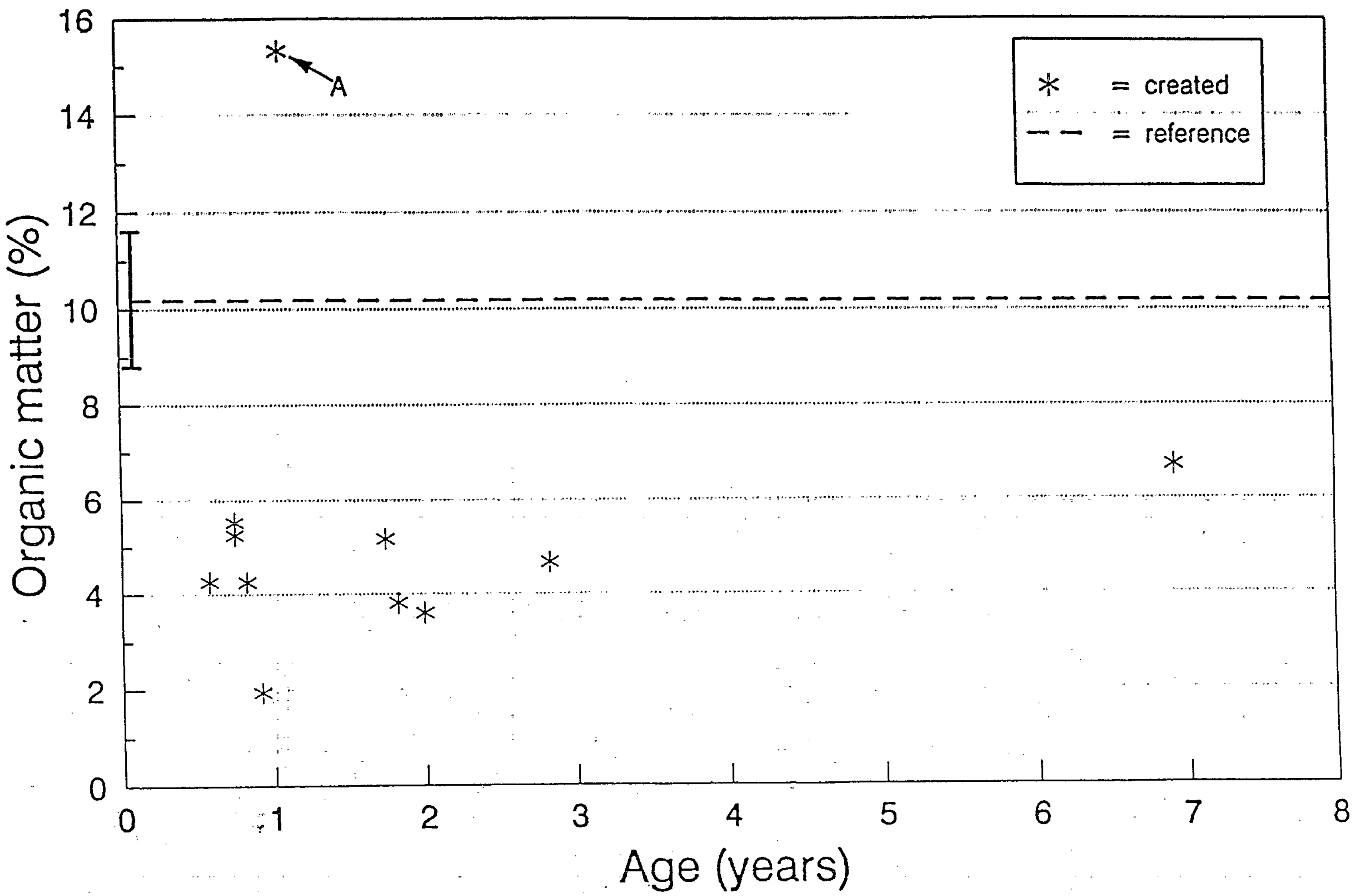


Figure 5-6. Performance curve illustrating the accumulation of soil organic matter in created and natural freshwater wetlands of different ages in Oregon. The dashed line represents the mean soil organic matter content for the population of natural wetlands; the error bar indicates one standard error. An asterisk indicates the value for an individual created wetland. Site "A" is discussed in the text.

- Areas at greatest risk are identified and targeted for monitoring efforts to evaluate the performance of wetland restoration and creation projects.

- Ecological (ecoregion) and land use settings are considered in the selection of sites for monitoring.

- The characteristics of natural wetlands, of the same type and in the same landscape setting, are used to define the attainable conditions for restored and created wetlands.

- Characterization and performance curves are used to set objective, realistic performance criteria, develop design guidelines for maximizing function, and identify critical checkpoints in project development.

- The process of developing design guidelines and setting performance criteria is iterative.

During the next five years, this framework will be tested and refined as needed to ensure that the approach and specific techniques are broadly applicable to a variety of wetland types, regions, and management concerns.

5.2.4 Prioritization of Sites for Wetland Restoration and Creation

Another important management need is the development of objective guidelines and techniques for identifying and prioritizing sites for wetland restoration and creation. Critical issues for project siting include (1) identifying locations where wetlands are needed to improve the ecological functions of the landscape, (2) selecting those sites that are most suitable for wetland restoration or creation, and (3) protecting restored and created wetlands from further impacts associated with surrounding land uses and stressors.

Four subtasks are proposed to develop an approach for prioritization:

1. Identify target locales where wetland restoration and creation projects are planned.

2. Conduct a literature review to (a) determine the wetland types that occur in that area, (b) identify experts on restoring and creating those wetland types, and (c) assess the available information on wetland functions and factors that may influence the success of wetland restoration.

3. Commission a group of experts to develop a state-of-the-science approach for prioritizing sites for restoration and creation.

4. Test the proposed approach by conducting field studies to evaluate the success of wetland restoration and creation projects implemented at the recommended sites, and refine the approach as needed. The ability to complete this final step may be constrained, however, by the timing of these follow-on mitigation projects.

As part of the state-of-the-science approach for site selection, landscape-level assessment tools will be developed. The utility of the Landscape Development Index (Brown 1991) and the Synoptic Approach (Abbruzzese et al. 1990a,b) will be examined as a first step in developing a decision support system for selecting sites for restoration and creation. This work will be coordinated with the Landscape Function Project (Section 6).

5.3 IMPLEMENTATION

The components of the approach described above can be combined in different ways to assess a diversity of wetland types in different parts of the country. In general, the goal of the project is to demonstrate the approach in typical wetlands and regions, so that the techniques can be adopted and applied by others. Research on wetland restoration and creation is dependent on the existence of completed or soon to be constructed projects. Thus, to some degree, the Characterization and Restoration Project must focus on opportunities for research that currently exist or have a high probability of occurring. Sites with existing monitoring data, for which temporal trends information can be obtained, are of particular interest. Cooperative effort with other WRP projects, to provide a basis for conducting an integrated risk assessment and demonstrating the risk-based framework, is an additional consideration in selecting areas and wetland types for study.

Under the Characterization and Restoration Project, three priority studies have been targeted for implementation during FY 1992-1996: (1) the characterization of agriculturally converted wetlands in the Prairie Pothole Region, which will be conducted as part of an integrated study with the other WRP projects and EMAP-Wetlands; (2) the development of objective protocols for selecting sites for restoring western riparian systems and evaluation of approaches for restoring them; and (3) long-term studies of the development of mitigation projects with a major component of freshwater marsh. Brief descriptions of each of these studies are presented below.

5.3.1 Agriculturally Converted Wetlands in the Prairie Pothole Region

Research by the Characterization and Restoration Project on prairie pothole wetlands will focus on those data and studies required by the Risk Reduction Project to demonstrate the risk-based framework (see Section 7.2). The objectives are twofold: (1) to characterize populations of natural and restored wetlands in the Prairie Pothole Region and (2) to evaluate the recovery of function in restored wetlands previously converted to agriculture. The first of these objectives will be conducted in cooperation with EMAP-Wetlands, which is currently planning a pilot study in the Prairie Pothole Region in 1992 and 1993 (see Appendix A). The Characterization and Restoration Project will conduct additional field sampling for characterization of natural and restored wetlands, supplementing the EMAP sampling and analyses as needed.

Hundreds of agriculturally converted wetlands, primarily prairie potholes, have been restored in the Midwest and represent a source of information that could be tapped on the effectiveness of wetland restoration and creation. An examination of the success of prairie pothole restorations, in terms of specific wetland functions, is particularly important because the 1990 Farm Bill has a provision for farmers to restore and enroll up to 600,000 acres of degraded wetlands in the Wetlands Reserve Program. The USDA Soil Conservation Service (SCS), which has responsibility for implementing the Farm Bill, is interested in cooperating with the WRP in the evaluation of existing restoration projects to refine and, where possible, improve the design of new projects.

The methods described in Sections 5.2.1 to 5.2.3 will be used to evaluate the performance of restoration and creation projects in the Prairie Pothole Region and to develop performance criteria and design guidelines. The underlying hypothesis is as follows:

> *Restored agriculturally converted wetlands have the same level of ecological function as natural wetlands in the same landscape setting.*

If funding allows, at least two ecologically different areas will be studied to test whether the approach and results can be generalized to other landscape settings. If possible, sites will be stratified by different agricultural stressors to (1) evaluate differences in attainable function and (2) test hypotheses such as the following:

> *Wetlands in landscapes dominated by the cultivation of a certain commodity have a lower level of ecological function than wetlands in landscapes dominated by natural systems.*

Studies of projects of various ages and monitoring data over time, if available, will provide information on rates of revegetation, repopulation by animals, and redevelopment of soil profiles; patterns of succession; and wetland persistence.

A potential secondary project, if funding allows, will be to compile and summarize SCS records to report on patterns and trends in wetland restoration and preservation in the Prairie Pothole Region.

5.3.2 Restoration of Western Riparian Systems

As discussed in Section 1.3.3, interest in protecting and restoring riparian systems in the arid and semi-arid west has been on the rise (Abell 1989, Baird 1989, Faber et al. 1989). Several agencies (e.g., Bureau of Reclamation, Bureau of Land Management, Federal Highways Administration) are involved in the restoration of these systems, and all of these agencies have expressed an interest in cooperative studies with the WRP. In addition, EPA Regions 8 and 9 have asked the WRP to provide technical support for the restoration and management of western riparian systems.

The principal focus of the Characterization and Restoration Project will be the development of a methodology for selecting and prioritizing sites for restoring or creating western riparian systems. One or more watersheds will be selected for a demonstration study. The basic approach will be as described in Section 5.2.4. To the degree possible, the proposed guidelines and protocols for site selection will rely on existing or easy to obtain information on watershed characteristics, to facilitate management applications. Several of the low-cost landscape assessment methods described in Section 6.2.5 will be included in these assessments of landscape factors that influence the sustainability and functions of restored wetlands.

The Characterization and Restoration Project also will evaluate the performance and design of existing restoration projects. By sampling and characterizing populations of restored and natural riparian systems, the following hypothesis will be tested:

> *Restored western riparian systems have the same level of function as similar natural systems in the same landscape setting.*

If funding allows, at least two ecologically different areas will be studied and/or sites will be stratified by land use, to (1) evaluate the relationship between attainable function and the landscape setting and (2) test hypotheses such as the following:

> *Western riparian systems in landscapes dominated by a particular land use (e.g., urban, agricultural) have a lower ecological function than do western riparian systems in landscapes dominated by natural systems.*

In addition, information on project siting in relationship to project success will contribute to the development of the guidelines and protocols discussed above for selecting priority sites for restoration.

Finally, if an appropriate opportunity arises and funding allows, manipulative experiments (see Section 5.2.3) will be conducted to evaluate ways for improving project design and performance.

5.3.3 Creation of Freshwater Marsh

As part of the Mitigation Project, the performance of created wetland mitigation projects with a major component of freshwater marsh was assessed in studies in Connecticut, Florida, and Oregon. At least one of these studies will be repeated during FY 1992-1996 to provide additional data on the development of created wetlands as they mature over time (see Section 5.2.2). If possible, more recently constructed mitigation projects and additional natural sites will be sampled, stratified by land use or other important stressors, to examine differences in attainable function in relationship to the landscape setting.

If funding allows, manipulative studies also will be conducted to evaluate design features or construction techniques that may enhance the success of wetland restoration or creation projects (see Section 5.2.3). Specifically, substrate development is an emerging issue of importance. Research in salt marshes has shown that low soil organic matter in created marshes impairs nutrient cycling and may have effects throughout the food chain (Langis et al. 1991). Approaches to accelerate substrate development through additions of organic matter are being investigated for saltwater marshes (J.B. Zedler, San Diego State University, personal communication). Parallel studies in freshwater marshes may be appropriate to test hypotheses such as the following:

> *A created freshwater marsh with at least X% of the average soil organic matter content of similar natural freshwater marshes sustains a level of nutrient cycling comparable to that in natural marshes.*

5.4 MAJOR CONTRIBUTIONS

The Characterization and Restoration Project will make several important contributions to the goals and objectives of the WRP and the priority needs of the EPA program offices, including the following:

- a characterization of wetland populations in different landscape settings, including information on among-wetland variability in wetland characteristics and functions;

- an assessment of the utility of indicators of wetland functions in extensive surveys of different wetland types in different regions and landscape settings;

- an approach for selecting and prioritizing sites for wetland restoration and creation;

- performance criteria and technical design guidelines that can be used to evaluate and improve the success of wetland restoration and creation projects; and

- a general framework that can be broadly applied for collecting and using information on wetlands to guide management decisions regarding wetland restoration and creation.

The specific program deliverables for the Characterization and Restoration Project are listed in Section 9.

6. LANDSCAPE FUNCTION PROJECT

The Landscape Function Project examines issues at a landscape scale, studying the aggregate of wetlands within a given landscape unit. Research focuses on how wetlands contribute to landscape functions (such as regional biodiversity, water quality, and hydrology) and how landscape processes and factors affect wetlands. The incorporation of landscape-level research into the WRP is essential because (1) the formation and maintenance of wetlands are highly dependent on landscape processes and (2) the functions that wetlands provide often arise from complexes of wetlands and the interactions between wetlands and other ecosystems in the landscape.

Work within the Landscape Function Project will contribute primarily to two of the WRP research objectives (Section 2.1):

1. Evaluate the role of the aggregate of wetlands in the landscape on water quality, habitat, and hydrologic functions at a landscape scale, and the influence of wetland characteristics on these landscape functions.

2. Quantify the effects of environmental stressors and landscape factors on wetland functions.

The first of these two objectives will be the major focus of the Landscape Function Project. Relative to Objective 2, of particular interest to the Landscape Function Project are (1) landscape factors, such as regional hydrology and geomorphology, that are critical to creating and maintaining wetlands, and (2) the effects of cumulative impacts on wetland and landscape functions (see Section 1.2.6). The Landscape Function and Wetland Function (Section 4) Projects will work together on the second objective to assess how landscape factors and environmental stressors affect wetlands.

The remainder of this section presents (1) background information on the Landscape Function Project (Section 6.1); (2) an overview of the basic approach to be used to achieve the research objectives (Section 6.2); (3) brief descriptions of the specific studies to be implemented (Section 6.3); and (4) a summary of the major expected contributions of the project relative to the overall goals and objectives of the WRP (Section 6.4).

6.1 BACKGROUND

The Landscape Function Project is an outgrowth of the Cumulative Impacts Project conducted during the first five years of the WRP (see Appendix A). To evaluate cumulative impacts requires studies at temporal and spatial scales beyond those of an individual disturbance, specific project, or individual wetland. The role of component wetlands in the functioning of the entire landscape system must be determined (Preston and Bedford 1988). Furthermore, the importance of wetlands may depend not just on their area or individual characteristics, but on the mosaic of wetland types and conditions in the landscape (Whigham et al. 1988). For these reasons, the study of cumulative impacts requires analyses at the watershed or regional landscape level. Thus, the Landscape Function Project is a natural extension of the Cumulative Impacts Project.

Three basic approaches have been used to study landscape functions: (1) empirical analyses, (2) case studies, and (3) modeling. Empirical analyses examine the relationship between the level of function achieved by individual landscape units and the characteristics of those units. The number of landscape units involved must be sufficient to identify statistically valid relationships. Because controlled landscape-scale experiments are typically not feasible, this approach is the most rigorous alternative for the study of landscape processes. The boundaries of the landscape units and total study area are defined relative to the landscape function of interest and study objectives. For example, for water quality improvement functions, landscape boundaries are generally delineated by watersheds. For habitat functions, landscape boundaries could be defined by the range and distribution of the biota of interest. Examples of results from empirical analyses include the following:

- An analysis of 33 Minnesota watersheds found that stream water quality (including nitrates and inorganic suspended solids) was related to wetland characteristics within the watershed (Johnston et al. 1990b).

- Dissolved organic carbon levels in 42 streams in southern Quebec were correlated with the percentage of each catchment that was wetland (Eckhardt and Moore 1990).

- Smith and Higgins (1990) found that areas with avian cholera epizootics had a significantly lower density of semipermanent wetlands, compared to areas without epizootics.

Case studies, by contrast, involve too few sites for statistical testing of hypotheses. Such studies do, however, provide a first-order assessment of whether the findings are consistent with proposed hypotheses and relationships. For example, Childers and Gosselink (1990) found that downstream levels of total phosphorus, total suspended solids, and turbidity were significantly related to water level at three sites in the Tensas Basin in northern Louisiana. Noting that elevated levels of nutrients and suspended solids were characteristic of cleared watersheds, the authors concluded that stream enrichment in the Tensas could have been caused by the logging of bottomland hardwood. The number of streams was not large enough to test whether other factors might have caused these water quality trends. When considered with other findings (e.g., Gosselink et al. 1990), however, a reasonable conclusion is that the landscape function of the Tensas had declined as a result of the loss of forested wetlands. Case studies such as this and others (e.g., Brooks et al. 1989) can be used to refine hypotheses about important landscape processes and functions when a more rigorous study is not possible.

Modeling, a third approach to landscape analysis, is often the only way to study complex systems that would require extensive and costly field sampling programs to characterize landscape conditions and functions adequately. The validation of model results with empirical data can be a form of hypothesis testing. Furthermore, once developed, calibrated, and tested, models provide a means of exploring management options before implementation. For example, the CELSS model, developed for coastal Louisiana (Costanza et al. 1990), simulates land loss and marsh succession based on factors such as river discharge, sedimentation, subsidence, and ecosystem productivity. The model has been used to examine various management scenarios, such as the construction of a levee extension. In some cases, relatively simple models may also be useful. For example, Rhoads and Miller (1990) developed an input/output stream channel model to study the effects of created wetlands on channel stability.

Work within the Landscape Function Project will focus on empirical analyses and modeling as the primary approaches to assessing landscape functions. Results from case studies conducted by other research programs also will be used to aid in model development and calibration.

6.2 APPROACH

For each region/landscape studied, five basic tasks will be conducted:

1. Conceptual models and best professional judgment (BPJ) hypotheses regarding the role of wetlands in landscape functions and the influence of landscape processes on wetlands will be developed.

2. These hypotheses will be refined through simulation analyses with existing models.

3. Empirical landscape analyses will be performed for hypothesis testing and indicator development.

4. Models will be calibrated for specific landscapes, and simulations will be used to evaluate various management options.

5. Low-cost assessment methods will be developed that can be readily applied to provide technical support for wetland protection and management.

The approach for each of these tasks is described in the subsections that follow. The overall project strategy is illustrated in Figure 6-1.

The Landscape Function Project will rely primarily on information on wetland and landscape characteristics obtained by compiling and analyzing existing data bases, maps, and other available data sources. Field data collected by the Wetland Function and Characterization and Restoration Projects and EMAP-Wetlands also will be incorporated into these landscape-level analyses as appropriate.

6.2.1 Conceptual Models and BPJ Hypotheses

As part of the Cumulative Impacts Project, a generic model of landscape processes was developed that considers individual ecosystems as sources or sinks[6] of materials linked within a larger landscape unit. Consistent with the discussion of wetland functions in Section 3.2.1, the amount of material removed by a sink is determined by both the sink's capacity to remove material and the landscape input of material received by the sink. The effect of any individual ecosystem component on the overall landscape function depends, therefore, on three factors: (1) the magnitude of the ecosystem as a source or sink; (2) the transport mechanism for the material (e.g., diffusion, gravity, channelized flow, or migration); and (3) the spatial relationship

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[6] An ecosystem can reduce the amount of material passing through it in several ways, for example, chemical transformation, filtration, etc. The term "sink" is used here in a generic sense to refer to any reduction in material transport resulting from an ecosystem process. The model also recognizes neutral ecosystems, which neither add to nor remove the particular material.

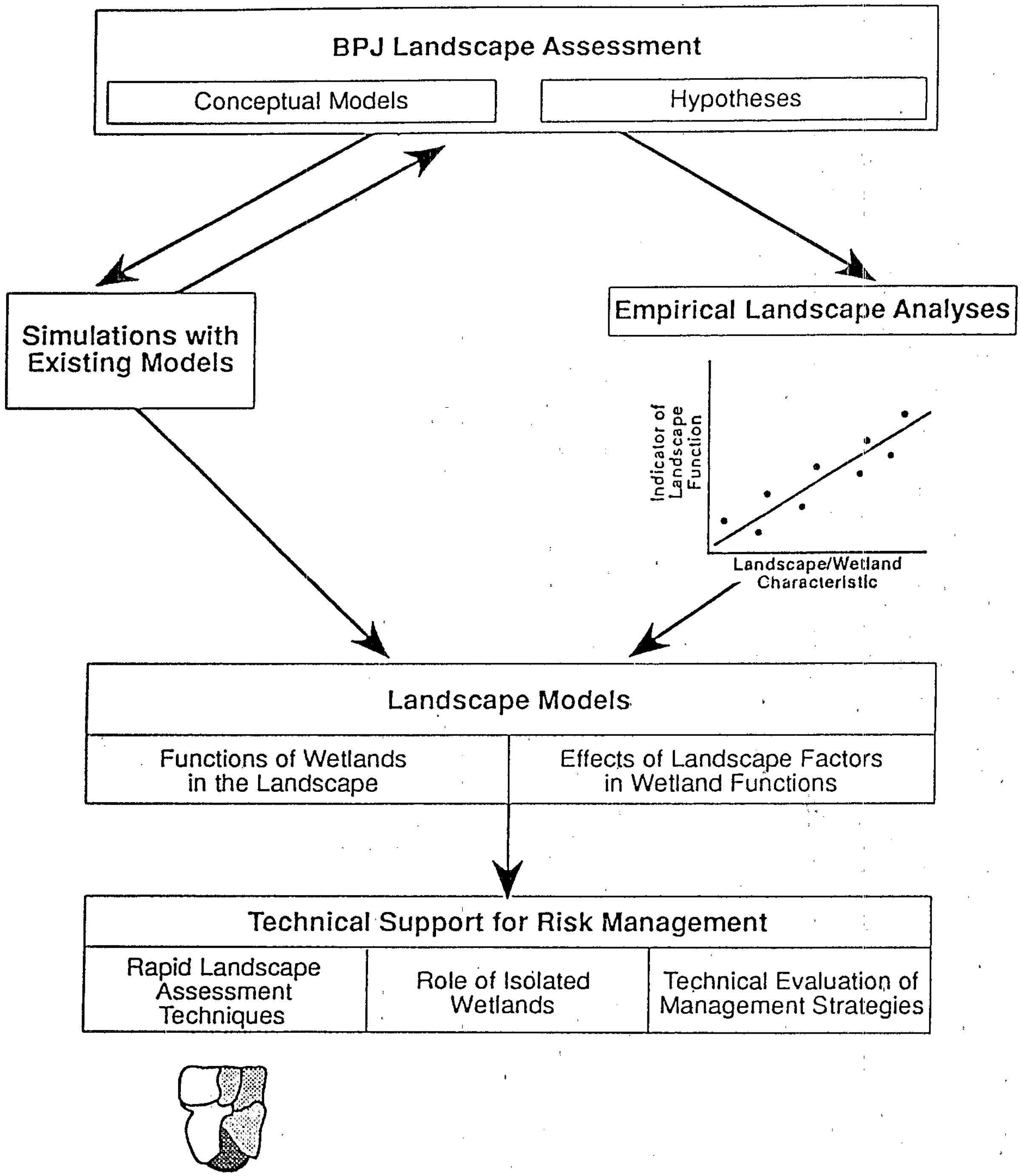

Figure 6-1. Flow chart for the research strategy for the Landscape Function Project. The hypothetical graphics are provided to illustrate how findings will be integrated into the project; they are not meant to convey actual or expected results or relationships. The graphic at the bottom of the figure is used to represent the Synoptic Approach and other low-cost landscape assessment methods.

between the sources and sinks in the landscape. The model also provides a theoretical basis for assessing values, by incorporating utility functions that represent the usefulness of the material to end users (e.g., the importance of flood control for downstream population centers).

This generic model provides a framework for evaluating ecosystem interactions, landscape processes, and the role of wetlands in landscape functions. It will be used as a frame for defining formal hypotheses and associated conceptual model(s) for each of the wetland landscapes to be studied as part of the Landscape Function Project (see Section 6.3). A literature review will be conducted, and experts familiar with the specific landscape will be consulted. The purpose of this review will be to identify the major environmental factors that contribute to the formation and sustainability of wetlands within the particular landscape (e.g., hydrology, geology, and soils) as well as stressors that may affect these landscape processes or the wetland directly. Based on these results, BPJ conceptual models and hypotheses will be developed. Regional workshops will then be held to review and further refine these hypotheses and models. Synthesis documents summarizing management recommendations, derived from the workshop discussions, and BPJ hypotheses will be produced as interim deliverables.

6.2.2 Simulation Studies

Several models already exist for evaluating the effects of land use (including the occurrence and extent of wetlands) on selected landscape functions. For example, the Soil Conservation Service's TR-55 (SCS 1986), and the USDA Agricultural Research Service's AGNPS model (Young et al. 1987) can be used to examine how land use and wetland location affect peak discharge and agricultural nonpoint source pollution, respectively. Model simulations could examine, for example, whether adding a unit of headwater wetland is more effective at lowering peak discharge than is a unit of isolated (basin) wetland. Although these models include relatively simple representations of complex processes, their application is considered worthwhile for exploring alternative hypotheses regarding landscape processes because (1) they are general enough to be applied over a wide geographic range; (2) they are available and can be used with minimal start-up time, compared to more complex models or models developed from scratch; and (3) they can aid in the definition and refinement of specific hypotheses to be examined in the empirical landscape analyses.

A literature review will be conducted to identify environmental models that include land use as a variable and that may be used to evaluate the role of wetlands in landscape functions. A subset of these models will then be adapted to conduct simulation studies of the particular landscapes being researched. The results from these simulations will be used to refine the BPJ hypotheses and conceptual model(s) and will assist in the design and interpretation of the empirical landscape analyses.

6.2.3 Empirical Landscape Analyses

As discussed in Section 6.1, empirical analyses evaluate the relationship(s) between landscape function(s) and the characteristics of wetlands and other ecosystems within each landscape unit (see Figure 6-1). These studies will be used to (1) test hypotheses regarding how wetlands function within the landscape and (2) evaluate the utility of various indicators of landscape function.

In most analyses, the emphasis will be on how wetlands affect landscape function. Thus, the dependent variable in statistical analyses will be indicator(s) of landscape function(s). For example, downstream water quality (e.g., nitrate or phosphorus concentrations) may serve as an indicator of the water quality function of a watershed, or peak discharge as an indicator of a landscape's hydrologic function. The independent variables will be one or more indicators of the characteristics of wetlands (and perhaps other types of ecosystems) within each landscape unit. Examples of potentially useful indicators include total wetland area, average wetland patch size, wetland type (e.g., swamp or marsh), wetland position (e.g., distance from stream), or an indicator of wetland shape.

In some cases, empirical analyses may also be conducted to examine how landscape factors affect wetlands. In this instance, indicators of wetland function would be the dependent variables, while the characteristics of the landscape outside of the wetland become the independent variables. The optimal landscape unit for these analyses would be the drainage area of an individual wetland. It may not be feasible to use such a unit, however, because watershed delineations for individual wetlands are typically not available; completion of these delineations for the large number of sites required for an empirical landscape analysis would be extremely time consuming. Thus, analyses will generally be conducted using a watershed or ecoregion containing a population(s) of wetlands as the landscape unit. Landscape factors that could be used as independent variables include land use, hydrologic modifications, and point and nonpoint source pollutant estimates. Wetland attributes that could be used as dependent variables (indicators of wetland function and condition) include plant biomass, biodiversity indices, measures of primary and secondary productivity, and others.

The relationships between dependent and independent variables will be explored using a variety of statistical techniques, including multiple regression and principal components analysis (for example, see Johnston et al. 1990b).

Data sources for landscape analyses will vary depending on the specific areas being studied. Wetland and land use data are needed in a spatial format so that a Geographic Information System (GIS) can be used to derive the various landscape parameters. U.S. Geological Survey (USGS) Land Use/Land Cover (LULC) data are available in digital format for much of the country. Most wetland areas have been mapped by the National Wetlands Inventory (NWI), but these maps have been digitized for a limited number of states. The Soil Conservation Service's STATSGO digital soils maps will soon be available for most of the United States. In addition, many states have their own GIS data that could be used for landscape analyses. County census data from the U.S. Census or the Agricultural Census can also be applied to these analyses. Sources of information that can be used to summarize landscape function include the USGS Water Resources data (includes stream discharge and water quality parameters); U.S. Fish and Wildlife Service (FWS) Breeding Bird Surveys; and rare, threatened, and endangered species lists compiled by the FWS or State Heritage programs. Although data on wetland condition (e.g., biomass or biodiversity) are available for many wetlands, a statistical characterization of specific wetland populations is not readily available and would be expensive to collect. The Landscape Function Project will make use of such data when available from the Characterization and Restoration Project, EMAP-Wetlands, and other sources.

In addition to evaluating various hypotheses about the relationship between wetlands and the surrounding landscape, the empirical analyses will assist in the identification and evaluation of indicators of landscape function. Cost-effective indicators are needed so that scientific findings can be applied in daily management decisions. Thus, analyses will be conducted to evaluate the relative utility of alternative indicators that are simpler and/or require less effort and cost to obtain. For example, landscape analyses based on a 1:24,000-scale NWI map may indicate a significant relationship between certain landscape and wetland characteristics. These analyses could then be repeated, substituting similar information obtained using a 1:250,000-scale USGS LULC map. If the latter also describes a significant relationship and similar results, indicators based on the USGS LULC maps may be preferable for wetland management because the labor requirements and computer costs for obtaining these data are lower and the USGS LULC maps are more widely available.

The EMAP-Wetlands project also will conduct landscape characterizations and develop and use landscape-level indicators (see Appendix A). Thus, the development and testing of indicators of landscape function as part of the Landscape Function Project will be carefully coordinated with efforts conducted by EMAP-Wetlands. For EMAP-Wetlands, a subset of the sites analyzed using remote sensing and mapped data will be sampled in the field, providing partial field verification of the landscape assessments.

6.2.4 Model Calibration and Applications

Once the hypotheses developed as part of the tasks described in Sections 6.2.1 and 6.2.2 have been tested and revised, the generic landscape model will be adapted and calibrated for the specific landscape being studied. Two sources of information will be used to parameterize these models: (1) regression coefficients from the empirical landscape analyses and, where available, (2) data from the Wetland Function Project on wetland assimilative capacity and stressor/response relationships (Section 4.2).

After parameterization, the models can be used to rank wetlands based on their relative contribution to landscape function. Potential candidate sites for wetland restoration or creation could also be similarly evaluated, leading to recommendations for siting wetlands in the landscape. A set of management maps, showing the locations of these ranked wetlands and candidate sites for wetland restoration and creation, could also be prepared. This work will contribute to the effort of the Characterization and Restoration Project to develop method(s) for prioritizing sites for restoration (Section 5.2.4). Finally, the models could also be used to evaluate different management scenarios and to support the development of specific management guidelines. Many of these simulations and applications will be conducted in conjunction with the Risk Reduction Project (Section 7).

6.2.5 Low-Cost Landscape Assessment Methods

The landscape models described in Section 6.2.4 will give wetland managers a powerful management tool. Unfortunately, because of the intensive efforts and costs required to develop these models, it will not be possible to repeat these analyses in all areas where needed. Therefore, the final task of the Landscape Function Project will be to develop low-cost landscape assessment methods, which can be easily applied to other regions and management needs. Three types of landscape assessment tools will be used: (1) synoptic landscape assessments, (2) general landscape criteria, and (3) the Landscape Development Index (LDI). The Synoptic Approach and LDI were developed initially as part of the Cumulative Impacts and Mitigation

Projects, respectively. Over the next five years, these methods will be further tested, improved, and modified as needed for broader applicability.

6.2.5.1 Synoptic landscape assessment

The Synoptic Approach was developed by the WRP for assessing cumulative impacts to wetlands. Case studies have been applied in Louisiana (Abbruzzese et al. 1990a) and Washington (Abbruzzese et al. 1990b), and a first version is to be released in 1992. It involves the mapping, at large scales, of indicators of wetland function, wetland value, functional loss, and replacement potential. Based on these maps, areas within a state or region can be prioritized for protection or further study. For example, Figures 6-2 and 6-3 illustrate two maps developed for the state of Washington. The initial distribution of wetlands in the state was estimated by the occurrence of hydric soils. The difference between the total area with hydric soils and current wetland acreage (mapped in Figure 6-2) provides an indicator of the wetland loss rate. In the United States as a whole, 95% of the historical wetland loss (from the 1950s to 1970s) has been due to conversion to agricultural and urban land uses (Tiner 1984; 59% from the mid 1970s to mid 1980s, Dahl and Johnson 1991). Therefore, recent trends in agricultural and urban growth (in Figure 6-3) can be used as an indicator of potential future stressors related to land use changes. Other stressor indicators could also be mapped, e.g., the percent of channelized stream as an indicator of hydrological modification. For the Synoptic Approach, mapping at larger scales, such as regions or the statewide maps illustrated in Figures 6-2 and 6-3, is most appropriate.

Over the next five years, the Synoptic Approach will be updated, focusing on the risk-based framework, the needs of the Risk Reduction Project, and priority regional issues. The development and testing of landscape indicators, discussed in Section 6.2.3, will result in more accurate assessments of landscape and wetland functions. The parameterized landscape model (Section 6.2.4) will allow functional weighting factors to be developed for different wetland types.

6.2.5.2 General landscape criteria

Forman and Godron (1986) described several structural components of landscapes, including patches, corridors, and the background matrix, many or all of which may influence landscape functions. Indices, such as patch size, connectivity, and porosity, can be used to quantify and characterize these landscape components and may provide useful landscape criteria for wetland protection. For example, the black bear requires large forested areas as habitat. The Tensas Basin in northern Louisiana initially consisted of extensive bottomland hardwood swamps. Much of this wetland area has been logged and converted to agricultural land, however, leaving small fragmented patches in the center of the unit and only a few larger patches. An appropriate landscape criterion for protecting the black bear would be to maximize wetland patch size. Given such a criterion, wetlands within the landscape unit could be evaluated according to how their loss (or gain) would affect the maximum patch size (see Figure 6-4).

In developing these criteria, the objective is to identify fairly simple and easily measured landscape characteristics that can be used to prioritize wetlands for protection or to rank sites for wetland restoration and creation. As part of developing the BPJ hypotheses (Section 6.2.1), consideration will be give to landscape characteristics that are critical to maintaining important landscape and wetland functions (e.g., what is the optimal distance between ponds or the optimal

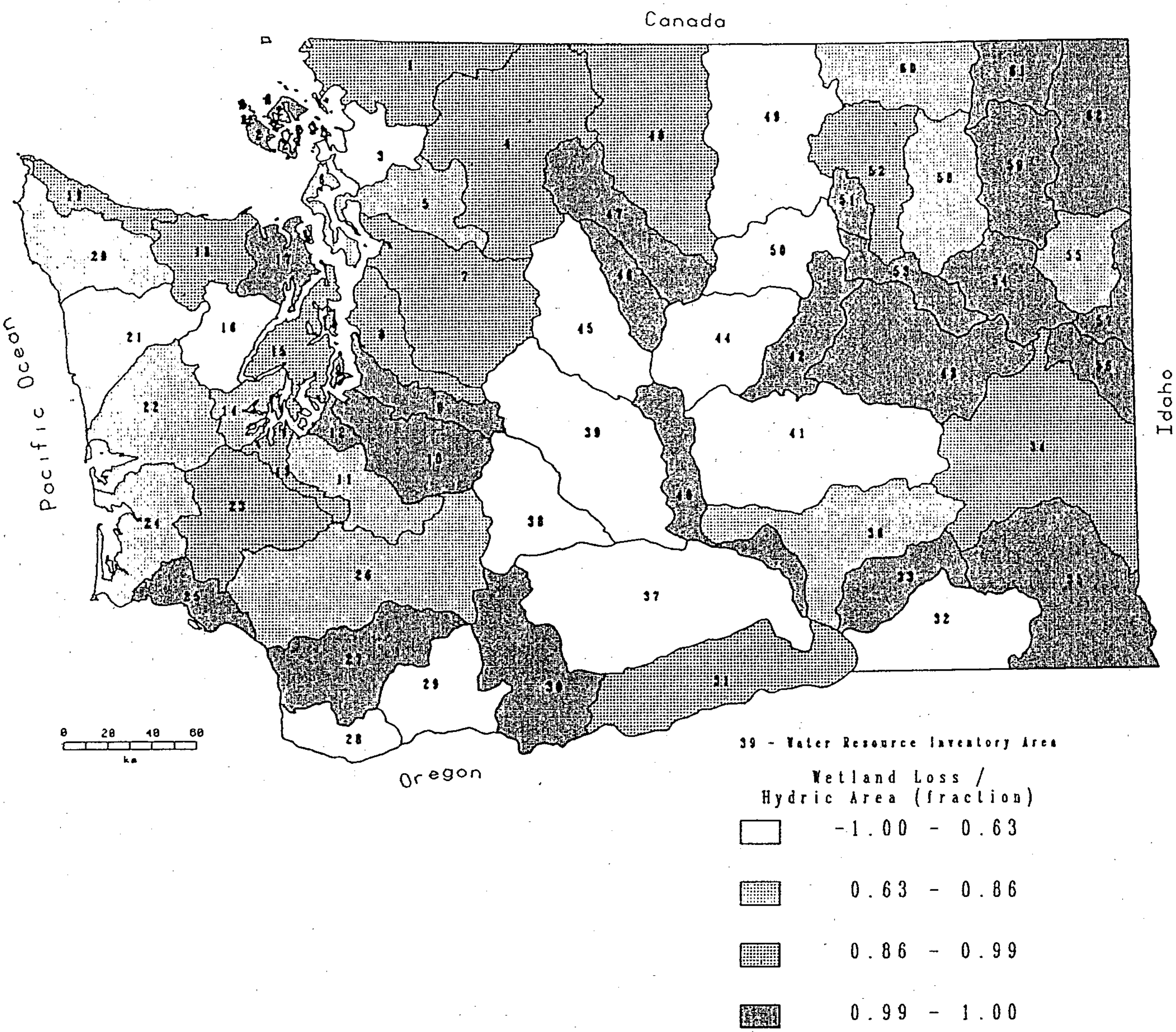

Figure 6-2. Estimated wetland loss rates (percent loss) for landscape units in the state of Washington. Initial wetland area was estimated from the area with hydric soils; current wetland area estimated from the U.S. Geological Survey Land Use/Land Cover maps (Source: Abbruzzese et al. 1990b).

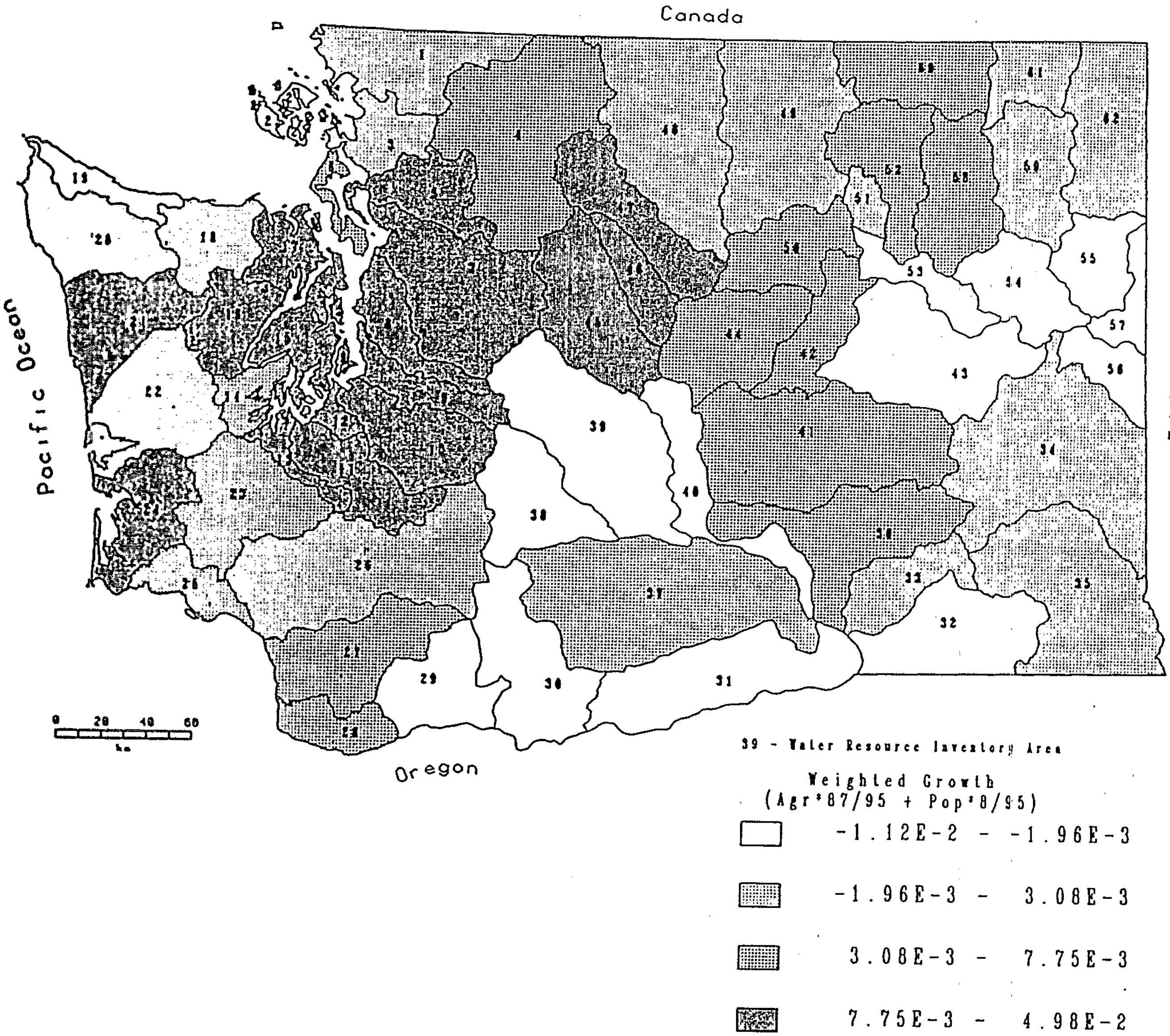

Figure 6-3. Weighted annual rate of growth in agricultural and urban land uses for landscape units in the state of Washington. Historically, agricultural and urban land uses accounted for 87% and 8% of wetland loss, respectively. Therefore, recent trends in agricultural and urban growth were weighted by 87 and 8, respectively, to provide a first-order indicator of potential future stressors on wetlands related to land use changes (adapted from Abbruzzese et al. 1990b).

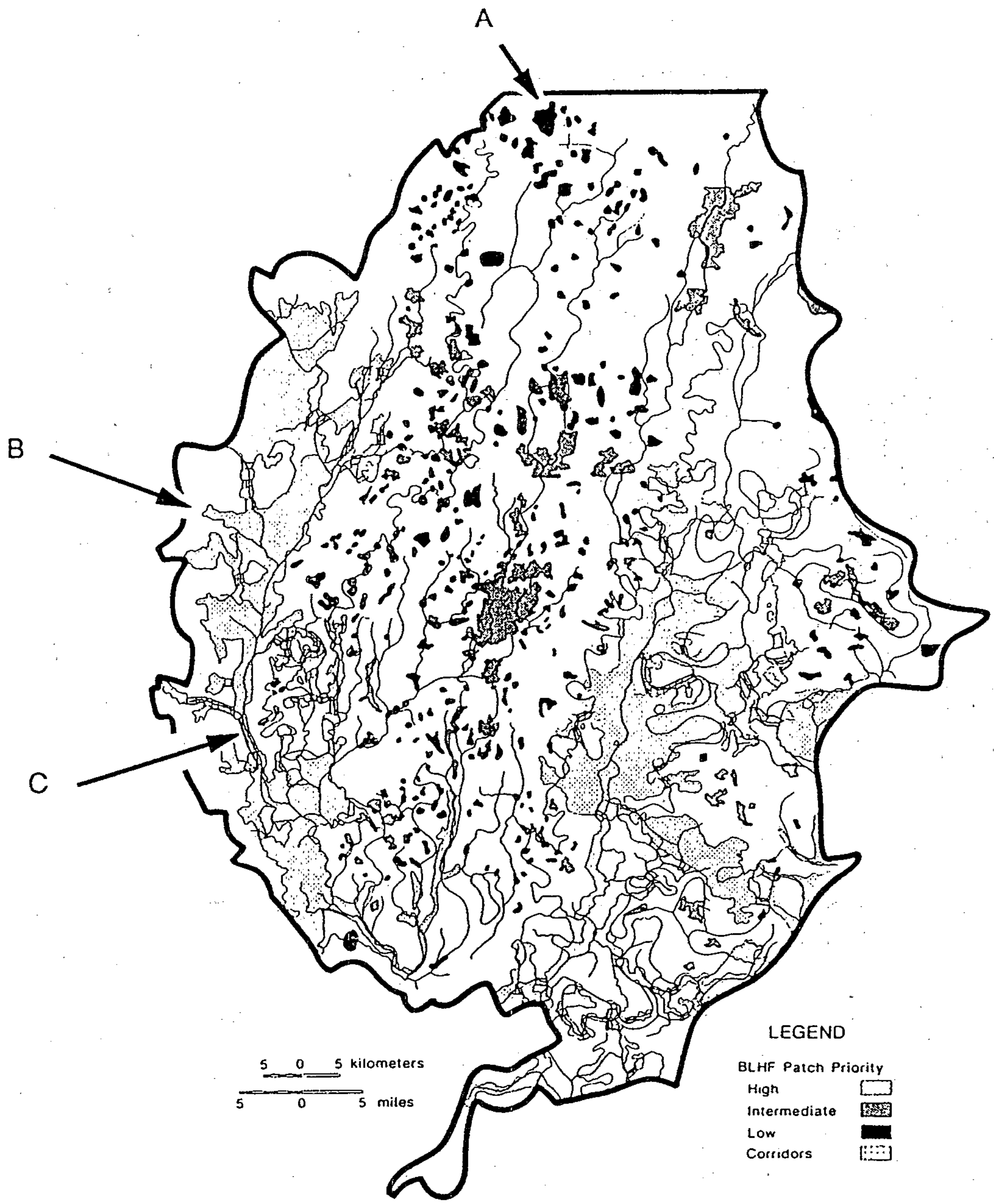

Figure 6-4. Wetland site prioritization for wetlands in the Tensas Basin, Louisiana, based on a management objective of maximizing patch size (modified from Gosselink et al. 1990). Loss of wetland area from patch "A," which is not the largest patch in the basin, would have no effect on the maximum patch size and thus is given a low priority for protection (dark shading). On the other hand, loss of wetland area from the largest patch, "B," would have a proportionate effect on the maximum patch size. Patch "B," therefore, is ranked as high priority for protection. Finally, loss of wetland area could have a disproportionately large effect if the area affected was a corridor that linked two large patches ("C"). Patch "C," therefore, is ranked as the highest priority for protection.

frequency distribution for pond depths for waterfowl production in prairie potholes?). These hypotheses will be tested with the empirical landscape analyses and the results used to select general landscape criteria.

Wetlands are typically found in one of three landscape configurations: (1) extensive (e.g., the Atchafalaya Basin or the Everglades), (2) patchy (e.g., prairie potholes), and (3) dendritic or branched (e.g., the Pearl River Basin in Mississippi or Georgia's Savannah River). Studies to develop landscape criteria will be conducted for patchy and dendritic landscapes. Little work will be conducted for extensive wetlands, because the study by Gosselink et al. (1990) provides initial guidance for these systems.

6.2.5.3 Landscape Development Index

The LDI is an indicator of the intensity of landscape stressors that may degrade wetlands, based on land uses in the surrounding area (Brown 1991). For each land use type (urban, agricultural, natural), a land use intensity factor (weight) is defined that reflects the expected severity of the impacts on wetlands associated with that land use. The LDI was first developed for use in Florida, where urban land use was given greater weight than agricultural or natural land uses, because groundwater withdrawal for urban populations was considered the most important factor causing wetland degradation.

Over the next five years, the LDI will be adapted for other regions by adjusting the land use types included and the relative weighting factors for each land use. Weighting factors can be derived from the empirical landscape analyses and applied to other similar landscapes outside of the study area. Where limited information exists, BPJ could be used to determine which land uses to include and how they should be weighted.

The LDI can be used for both small- and large-scale landscape assessments. LDI values for areas around individual wetlands may be useful for permit evaluations or in selecting reference wetlands. Because the LDI weights more heavily those land uses that are expected to impact and degrade wetlands, the LDI could also be used as an indicator of functional loss within the risk-based framework.

6.3 IMPLEMENTATION

Consistent with the priority wetland types identified in Section 1.3, the Landscape Function Project will focus on studies in freshwater emergent marshes in the Prairie Pothole Region and bottomland hardwood forests. A third study also is planned to evaluate the effect of inland wetlands on estuarine water quality. Brief descriptions of these studies are provided below.

6.3.1 Landscape Assessment of Prairie Pothole Wetlands

All five of the tasks described in Section 6.2 will be conducted in the Prairie Pothole Region. The work will be coordinated with concurrent efforts by the Wetland Function Project (Section 4.3.1), Characterization and Restoration Project (Section 5.3.1), and EMAP-Wetlands (Appendix A), and will contribute directly to the risk assessment and management analyses for the Risk Reduction Project (Section 7.2).

The Prairie Pothole Region is a patchy landscape, with many isolated wetlands. Analyses will focus on two important landscape functions: (1) prairie potholes as habitat for waterfowl and other biota and (2) the potential for prairie pothole wetlands to improve regional surface water quality. The general hypothesis to be tested is as follows:

> *Within the Prairie Pothole Region, these landscape functions (habitat and water quality improvement) depend on the characteristics of wetlands in that landscape, such as the distance between wetlands, the frequency distribution of pond depths, or percent open water.*

The Landscape Function Project also will work with the Wetland Function and Characterization and Restoration Projects to address the following hypotheses:

> *Prairie pothole wetlands are being degraded by landscape factors, such as sedimentation and nonpoint source pollution, and the severity of these impacts is influenced by landscape characteristics, in particular the occurrence of buffers.*

> *The ability to restore wetland functions is dependent on the condition of the landscape unit.*

Specific research hypotheses will be developed based on a literature review and conceptual model(s) (Section 6.2.1). Simulation studies will be used to further refine these hypotheses (Section 6.2.2), which will then be tested through empirical landscape analyses (section 6.2.3). The final calibrated and tested landscape model(s) (Section 6.2.4) will be used to evaluate various management options for protecting and restoring wetlands to maximize the water quality and habitat support functions of these wetlands. The synoptic landscape assessment and other landscape assessment approaches (Section 6.2.5) will be evaluated and applied. Using these models and landscape assessment techniques, it may be possible to extrapolate the results for prairie potholes to other patchy landscapes.

6.3.2 Landscape Assessment of Bottomland Hardwoods

All five of the tasks described in Section 6.2 also will be completed for the study of bottomland hardwoods. These efforts will be coordinated with complementary research being conducted by the Wetland Function Project (Section 4.3.2) and integrated into the risk-based framework as part of the Risk Reduction Project (Section 7.2). Two issues, in particular, will be addressed: (1) the effect of riparian buffers on stream water quality and (2) the effects of habitat alteration (e.g., logging) on the habitat functions of bottomland hardwoods. Both of these issues also will be evaluated by the Wetland Function Project, although at a different spatial scale (individual wetland versus landscape-level responses and analyses).

Bottomland hardwoods occur in both extensive and dendritic configurations. The Landscape Function Project will be evaluating dendritic landscapes, including three major wetland types: headwater wetlands, riverine wetlands, and isolated (basin) wetlands. Analyses will examine the roles of these three different wetland types in landscape functions (water quality, habitat, and hydrology), and will provide an opportunity for improved understanding of the importance of small, isolated wetlands (see Section 1.2.6). General hypotheses include the following:

Within a dendritic landscape setting, the contribution of wetlands to different landscape functions depends on the type of wetland (headwater, riverine, or isolated).

Riverine wetlands are effective sinks of nonpoint source pollution and, therefore, can improve stream water quality.

6.3.3 Effect of Inland Wetlands on Estuarine Water Quality

As noted in Section 1.3.4, research is needed on the effects of inland watersheds on estuarine water quality and how this is moderated by wetlands. This study will examine the effects of different types of wetlands on agricultural nonpoint source pollution of estuarine waters. In particular, analyses will focus on comparisons among riverine wetlands, temporarily flooded wetland forests, and agricultural wetlands (wetlands that have been converted to agriculture, but still retain hydric soil conditions) and their relative effectiveness at reducing nonpoint source pollution. The latter two wetland types are examples of drier wetlands, as discussed in Section 1.3.4. This research will build upon a nutrient study to be implemented in early FY 1992 with funding from the Cumulative Impacts Project. Because funding for this study will be limited, only the empirical analysis and synoptic landscape assessment components of the Landscape Function Project will be included.

6.4 MAJOR CONTRIBUTIONS

The major contributions of the Landscape Function Project to the WRP and EPA program office priorities will include the following:

- techniques for rapid landscape-level assessments of wetlands;
- an improved understanding of the role of wetlands in the landscape, including methods for ranking wetlands according to their relative contribution to landscape functions;
- an evaluation of the functions of isolated wetlands in the landscape;
- an improved understanding of landscape processes and characteristics that are critical to establishing and maintaining wetlands and of how stressors affect these processes, which will assist the Characterization and Restoration Project in developing methods for prioritizing sites for wetland restoration and creation;
- landscape-level methods and data on wetland and landscape functions in the Prairie Pothole Region and bottomland hardwood forests required for estimating risks and conducting the Risk Reduction Project; and
- an evaluation of the effectiveness of different wetland types at reducing the impact of nonpoint source pollution on estuarine water quality.

The specific program deliverables for the Landscape Function Project are listed in Section 9.

7. RISK REDUCTION PROJECT

In Section 3, we proposed a general risk-based framework for wetland protection and management. The Risk Reduction Project will integrate the results of the other three projects to demonstrate the application and utility of this framework (see Figure 2-1). Thus, the Risk Reduction Project will address two of the WRP objectives:

- Develop and demonstrate a risk-based framework for wetland protection and management.

- Conduct an integrated risk assessment for at least one major wetland type to provide technical support on two major issues:

  -- the national policy of no net loss of wetland area and function, and

  -- the role of wetlands in reducing nonpoint source pollution.

The Risk Reduction Project will conduct no new field work or landscape analyses, but instead will work directly with the Wetland Function, Characterization and Restoration, and Landscape Function Projects to ensure that these projects provide the types of data and analyses needed as input for a risk reduction analysis. Therefore, within the WRP, the Risk Reduction Project is responsible for inter-project coordination and for producing integrated program deliverables. The project approach is described in Section 7.1, plans for project implementation in Section 7.2, and the major expected contributions of the Risk Reduction Project in Section 7.3.

7.1 APPROACH

The components of the risk-based framework and major elements of a wetland risk assessment were described in Section 3 (see Figure 3-1). Although this discussion outlines a general framework for a risk reduction analysis, further work is needed to evaluate, refine, and demonstrate these techniques and the overall usefulness of the approach. Therefore, the following tasks will be completed in sequence:

- Review and evaluate the conceptual framework, modifying and augmenting it as necessary.

- Conduct a best professional judgement (BPJ) risk assessment, to further evaluate and refine the basic framework, demonstrate the utility of the approach, and provide interim project deliverables.

- Synthesize the WRP research results into a comprehensive, hierarchial risk assessment.

- Apply the risk assessment to provide technical support for risk management.

- Develop a monitoring and evaluation protocol.

These tasks are described in the subsections that follow.

7.1.1 Framework Development and Review

The proposed risk-based framework will be thoroughly reviewed and evaluated early on during the five-year research program. The objectives of this effort are to ensure that the framework (1) has not omitted important factors, (2) is workable and efficient, and (3) considers other EPA programs and risk assessment guidelines. A comprehensive review of the risk assessment literature will be completed. Workshops and interagency work group meetings will be held to discuss the proposed framework and its application to the types of issues and problems that arise in wetland protection and management. Representatives from other EPA programs involved in the development of risk assessment protocols (e.g., the Risk Assessment Forum) will be invited to participate actively in these discussions. Finally, journal articles describing the framework will be prepared and peer reviewed.

7.1.2 BPJ Risk Assessment

For one or more selected regions and priority issues (see Section 7.2), the risk assessment process will be completed using BPJ to define the four elements of a risk assessment (wetland functions, values, functional loss, and replacement potential). The objectives are (1) to test the framework and refine it as necessary, (2) to identify high priority data and research needs to reduce uncertainties in the assessment results, and (3) to demonstrate the utility of the risk-based framework and approach even when applied using strictly BPJ without extensive data collection and analysis. A BPJ assessment can provide management with preliminary information until a more rigorous, data-based analysis can be completed. A report summarizing this case study will be prepared as an interim deliverable.

The BPJ risk assessment will be based on a literature review and consultation with regional wetland experts. In addition, indicators that could be used to measure and assess each of the four risk assessment elements and regional data sources will be identified. The regional experts also will be asked to propose general landscape criteria (see Section 6.2.5.2).

7.1.3 Hierarchical Risk Assessment

The field sampling, experiments, and analyses to be conducted as part of the Wetland Function, Characterization and Restoration, and Landscape Function Projects (Sections 4-6) will provide the basic technical information needed to evaluate wetland functions, values, functional loss, and replacement potential (Figure 7-1). The Risk Reduction Project will integrate and synthesize this technical information, together with subjective input on wetland values from wetland managers and policymakers, to address two major management issues: (1) the national goal of no net loss of wetland area and function and (2) the role of wetlands in reducing nonpoint source pollution (see Section 7.2). The following discussion outlines briefly the major sources and types of information required for each element of a risk assessment.

7.1.3.1 <u>Wetland function</u>

In Section 3.2.1, the functions of wetlands were grouped into three major categories: (1) habitat, (2) water quality improvement, and (3) hydrology. For an assessment of no net loss, all three of these major functions are of concern, while analyses relating to nonpoint source pollution control will focus primarily on the water quality improvement function.

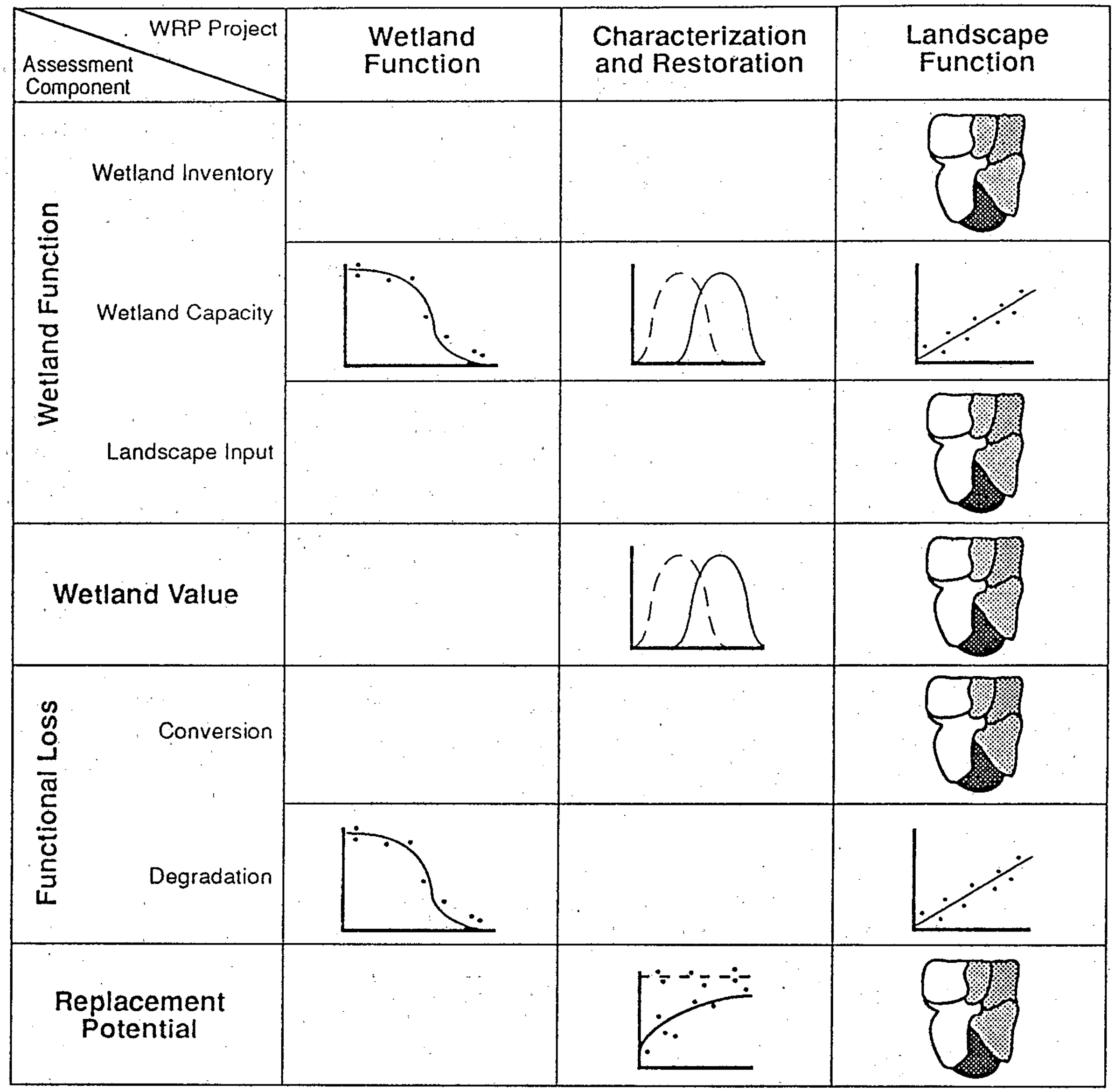

Figure 7-1. Matrix indicating the major sources of information to be used for each risk assessment component by the Risk Reduction Project. The hypothetical graphics represent the general types of analyses and outputs expected from the three other WRP projects, as illustrated in Figures 4-1, 5-1, and 6-1; they are not meant to convey actual or expected results or relationships.

Wetland functions, as discussed in Section 3.2.1, depend on both the wetland capacity and landscape input. Wetland capacity depends on the wetland type. Thus, to evaluate wetland functions requires information on (1) the numbers and types of wetlands present in the landscape (i.e., a wetlands inventory), (2) the capacity of each wetland type, and (3) landscape inputs to each type or group.

Wetland Inventory. The Landscape Function Project, as part of the synoptic landscape assessment (Section 6.2.5.1), will determine the extent of the wetland resource and the types of wetland communities present for each landscape unit in the region(s) of interest. Various sources of data will be used, depending upon availability, including National Wetlands Inventory maps, USGS LULC maps, and State resource inventories. The types of wetland communities present in the region will be determined from existing inventories or by consulting state or federal resource agencies, State Heritage programs, and regional wetland experts.

Wetland Capacity. Quantitative information on wetland capacity will be provided by the Wetland Function, Characterization and Restoration, and Landscape Function Projects for individual wetlands, wetland populations, and landscape units, respectively. The stressor/response relationships and temporal response curves developed by the Wetland Function Project will be used to quantify wetland assimilative capacity and also differences in assimilative capacity among different wetland types (e.g., wetlands of type "A" or with characteristics "A" may, on average, be able to assimilate more nitrate than wetlands of type "B"). The empirical landscape analyses conducted by the Landscape Function Project will relate general wetland characteristics to landscape functions (e.g., reductions in stream nitrate concentrations).

Landscape Input. Information on land use and landscape conditions collected by the Landscape Function Project, in particular the synoptic landscape assessments, will be used to estimate landscape inputs. Analyses will be conducted for all three categories of wetland function. For example, the models described in Section 6.2.2 can provide estimates of nonpoint source pollutant loadings and peak discharge.

7.1.3.2 Wetland value

The risk-based framework incorporates information on wetland values to help focus subsequent analyses in the risk assessment on those wetland components and functions considered of greatest importance. These values, however, will be defined by others, specifically wetland managers and regulators, not the WRP or the Risk Reduction Project.

As discussed in Section 3.2.2, wetland values can be assessed holistically (i.e., the overall value of the wetland as a unit) or assessed separately for each distinct wetland function. Given an explicit listing of valued wetland functions within a particular area, the Landscape Function Project can provide an analysis of the numbers of individuals who may benefit from these functions. For example, based on census data from the Bureau of Statistics, human population densities can be determined for areas downstream that may benefit from flood attenuation. Beneficiaries of wetland functions will be broadly defined to include people, fish, wildlife, and/or other significant organisms. Thus, indicators of ecological benefits could include lists of rare, threatened, and endangered species; numbers of drinking wells; and sales of hunting and fishing licenses.

A holistic evaluation of wetland values requires wetland managers or regulators to select examples of "high" and "low" value wetlands that, as a group, are representative of the full range of values and benefits that wetlands provide. Characterization curves, as developed by the Characterization and Restoration Project, can then be used to identify specific wetland characteristics indicative of high or low value for one or more possible wetland functions (see Figure 3-2).

The specific approach to be applied over the next five years will be determined by the wetland managers and regulators involved in the risk assessment and risk management process, working together with the staff of the WRP and Risk Reduction Project.

7.1.3.3 Functional loss

Risk assessments must consider losses of wetland area and function, through conversion and degradation, respectively. Declines in landscape function may result from both a loss of wetland area and a decline in individual wetland functions within the landscape unit. Cumulative loss of these functions will also be considered.

Conversion. The loss of wetland area to date will be estimated as part of the synoptic landscape assessment (Section 6.2.5.1). Figure 6-3 illustrates such an analysis for the state of Washington based on the difference between areas with hydric soils (estimate of historic wetland area) and current wetland areas from USGS LULC maps. The particular methods employed will depend upon data availability. For example, Figure 5-2 illustrates trends in wetland losses based primarily on Corps of Engineers Section 404 permit data (e.g., Holland and Kentula, in press; Sifneos et al., in press). When such information is available, it can be incorporated into the assessment. If data are available in GIS format, loss trends will be examined by wetland type, geographic area, and land use or stressor type.

Degradation. The extent and degree of wetland degradation may be determined by (1) statistical field surveys to determine the current status and health of wetland populations, as planned by EMAP-Wetlands, and/or (2) assessing the types and levels of stressors impacting wetlands within the region (hazard identification and exposure assessment) and the sensitivity of wetland functions to these stressors (stressor/response relationships). The Wetland Function Project will quantify the effects of stressors on important wetland processes and functions (Section 4.2). Empirical landscape analyses conducted by the Landscape Function Project will be used to quantify the relationship between landscape function and wetland and landscape characteristics (Section 6.2.3). The Wetland Function and Landscape Function Projects will evaluate data to estimate the levels of wetland stressors locally and regionally, respectively. Finally, the simulation models developed by the Landscape Function Project (Section 6.2.4) will provide a basis for identifying those wetlands and wetland characteristics most important to landscape functions and the specific wetlands and landscape units at greatest risk of degradation (loss of function) from specific stressors.

7.1.3.4 Replacement potential

The Characterization and Restoration Project will develop performance curves (Figure 5-5) that can be used to evaluate the replacement potential of different wetland types and/or specific wetland functions. In addition, the Landscape Function Project will provide information on landscape processes (e.g., regional hydrology) that can be used to determine how replacement potential is affected by landscape condition (Section 6.2).

7.1.4 Technical Support for Risk Management

A risk assessment quantifies the probability that the loss or decline of valued wetland functions has or will occur. Using this information, wetland regulators and managers can then develop a plan for managing that risk. Two complementary approaches can be applied for risk management:

1. **Avoidance** -- Minimize the functional loss of those wetlands with the highest value by protecting them from conversion and degradation.

2. **Restoration/creation** -- Increase functional values within high risk areas by replacing lost function through wetland restoration or creation.

The Risk Reduction Project will provide technical support for the development of risk management plans by EPA Regional personnel within the study areas. Results from the risk assessment will identify the most significant cause(s) of functional loss and the areas and wetland types at greatest risk. The Landscape Function Project simulation model(s) can be used to explore alternative management options (Section 6.2.4). The replacement potential of high risk wetland types, as determined from performance curves (Section 5.2.2), will influence whether the management strategy emphasizes avoidance or restoration/creation. For wetlands with a high replacement potential, technical support for design guidelines (Section 5.2.3) and methods for site selection and prioritization (Section 5.2.4; also Section 6.2.4) will be available from the Characterization and Restoration Project to increase the probability of achieving a successful and sustainable replacement of wetland function.

7.1.5 Monitoring and Evaluation Protocols

As discussed in Section 3.4, two types of monitoring are needed: (1) evaluative monitoring to determine the effectiveness of a specific management program and (2) baseline monitoring to detect new wetland problems that may arise and general trends in wetland status. As part of the WRP, over the next five years the time frame and budget will not be adequate to implement a monitoring and evaluation sampling program. It will be possible, however, to develop a monitoring and evaluation protocol that illustrates these two monitoring schemes using components of the Characterization and Restoration Project and EMAP-Wetlands as examples. Empirical studies conducted by the Wetland Function and Landscape Function Projects (Sections 4.2.2 and 6.2.3) will aid in the selection of useful indicators of wetland and landscape function for both evaluative and baseline monitoring.

7.2 IMPLEMENTATION

The Wetland Function, Characterization and Restoration, and Landscape Function Projects, as well as EMAP-Wetlands, all will be conducting research in the Prairie Pothole Region during FY 1992-1996 (see Sections 4.3.1, 5.3.1, 6.3.1, and Appendix A). Results from this research will serve as the basis for an integrated case study by the Risk Reduction Project to demonstrate the hierarchial implementation of the risk-based framework. The Risk Reduction Project also will coordinate with the U.S. Fish and Wildlife Service, the Soil Conservation Service, the Bureau of Reclamation, the Corps of Engineers, and other agencies and universities working in this area to determine whether research studies funded by these organizations can contribute to and be integrated into the Prairie Pothole risk reduction case study.

Information from other WRP research also will be used, as appropriate, by the Risk Reduction Project to illustrate how differences in regional processes and management goals may influence the application of a risk-based framework. Both the Wetland Function and Landscape Function Projects will be working in bottomland hardwood wetlands (Sections 4.3.2 and 6.3.2). The results from these studies will be integrated into the risk-based framework as a second risk reduction case study.

As mentioned previously, the Risk Reduction Project will use the risk-based framework to provide technical support for two major issues: no net loss (Section 1.2.2) and the role of wetlands in reducing nonpoint source pollution (Section 1.2.7). The framework will be implemented hierarchically as described in Section 3.5. The subsections that follow provide preliminary research hypotheses that will guide the design and development of these proposed risk assessments.

7.2.1 No Net Loss

Two case studies will be conducted to illustrate how the risk-based framework can be applied to support the development of risk management plans for no net loss, one in the Prairie Pothole Region and the other for bottomland hardwood wetlands. The hypotheses for the Prairie Pothole Region are as follows:

> *The most important functions of prairie pothole wetlands are waterfowl habitat and reduction of nonpoint source pollution.*
>
> *The habitat function of prairie potholes is dependent on both the condition of individual wetlands and the characteristics of wetland assemblages (for example, the statistical distribution of basin depths).*
>
> *The most significant causes of functional loss in prairie potholes are agricultural conversion, habitat alteration, and sediment and nutrient loading from nonpoint source pollution.*

The following hypotheses apply to bottomland hardwoods:

> *The most important functions of bottomland hardwoods are water quality improvement, wildlife habitat, and flood attenuation.*
>
> *Fragmentation of the dendritic system would result in the degradation of these wetland functions.*
>
> *The most significant causes of functional loss have been floodplain conversion, hydrologic modification, and habitat alteration.*

Risk-based analyses can provide information relevant to the goal of no net loss by assessing (1) which valued functions are being lost through conversion or degradation and (2) whether these functions can and are being replaced. The results from these analyses could be applied through a number of different mechanisms, for example, by the Office of Water to provide guidelines for State grants; by EPA Regions to establish regional goals and to prioritize permit activities; and by States to develop State Wetland Conservation Plans (see Section 1.2.8).

7.2.2 Reduction of Nonpoint Source Pollution

Technical information is needed on the sustainable use of natural, restored, and created wetlands for water quality improvement (see Section 1.2.7). In particular, the WRP will focus on the use of wetlands as buffers to reduce nonpoint source pollution loadings to downstream waters. The specific hypotheses to be examined, in addition to those listed in Section 7.2.1 relating to the water quality improvement function, are as follows:

Restoration of agricultural wetlands is an effective way to reduce nonpoint source pollution.

Riparian buffers are effective for water quality improvement.

Optimal siting of restored, created, or constructed wetlands will maximize the level of water quality improvement.

Wetland habitat function can be degraded by assimilation of nonpoint source pollution.

The Risk Reduction Project will provide technical support aimed at developing approaches to maximize the water quality function of wetlands, while minimizing the loss of other valued functions. Research on the secondary effects of pollution will suggest guidelines and water quality criteria to avoid wetland degradation (e.g., Section 4.2.4). Simulation studies, as described in Sections 6.2.2 and 6.2.4, will help identify areas with a high landscape input of nonpoint source pollution where the water quality improvement function of wetlands may be especially important.

7.3 MAJOR CONTRIBUTIONS

The Risk Reduction Project will produce integrated program deliverables that synthesize the results of the other WRP projects into reports, guidelines, and management tools useful to wetland managers and regulators. The major contributions of the project will include the following:

- a risk-based framework for wetland protection and management, that has been tested and finalized and can be applied to a range of management issues and needs;
- a methodology, and case study, for risk assessments based on BPJ that can provide for improved decisionmaking without extensive data collection or new analyses;
- technical support for management plans to implement the policy of no net wetland loss;

- technical support for maximizing the role of wetlands in reducing nonpoint source pollution while also avoiding the degradation of other valued wetland functions; and

- protocols for wetland monitoring and evaluation of the success of wetland management programs.

The specific deliverables for the Risk Reduction Project are listed in Section 9.

8. TECHNICAL INFORMATION TRANSFER

Technical information transfer is a program strategy to ensure that WRP research is relevant to policy and regulatory needs and that innovations developed by the WRP will be adopted and widely used by wetland managers at the regional and state levels. Only by actively involving regional and state wetland managers and regulators in the process of research planning and demonstration will the WRP research have the impact necessary to reduce environmental threats to wetlands. For these reasons, technical information transfer is an important and integrated component of the WRP.

8.1 APPROACH

Technical information will spread within an organization only if it is first transmitted from its innovator to a receptive "expert" in an identified user group (Muth and Hendee 1980). While traditional approaches to technical information transfer, such as publications and symposia, can successfully generate awareness of and interest in a particular innovation, they do not often lead to its trial and adoption.

Accordingly, in 1988 a Regional Liaison Officer position was established within the WRP to foster more direct communication between WRP scientists and wetland experts in states and EPA Regional Offices. The Regional Liaison is an EPA Regional wetland manager assigned to the WRP. The responsibilities of the Regional Liaison include the following:

- Identify and communicate to the WRP the technical support needs of the EPA Regions and states that are consistent with the goals and objectives of the WRP, such as the listing of priority research needs presented in Section 1.2.
- Work to ensure that WRP studies address these priority technical support needs to the degree possible within the constraints of the mandate and budget of the WRP.
- Encourage and coordinate the implementation of cooperative projects, involving shared expertise and/or funding from both the WRP and EPA Regions or states.
- Involve the EPA Regions from the beginning of the research process to the end, to ensure ownership and further technology transfer through direct participation in the research process.
- Identify Region and State staff who are interested in innovation and piloting research.
- Distribute information on WRP projects and results to interested agencies, firms, and individuals.

Collaborative research studies, in which wetland managers work directly with WRP scientists on research projects (sharing expertise and/or funding), are an important feature of the WRP strategy for technical information transfer. Thus, one of the primary responsibilities of the Regional Liaison is to identify opportunities for WRP scientists to conduct studies that are both relevant to the WRP Five-Year Research Plan and also support the more immediate needs of the EPA Regions and states. Besides offering technical assistance to the Regions and states, these collaborative studies serve two important purposes. First, collaborative efforts provide a forum for WRP scientists to receive feedback from wetland managers on the relevance of their proposed research. Second, collaborative studies directly involve Regional and state wetland experts in the development of new wetland science and innovations, increasing the likelihood that these new innovations will be adopted and used for wetland management. The WRP can then encourage further technology transfer with offers of additional technical consultation, as resources allow.

Over the next five years, the Regional Liaison will implement a plan, developed in July 1990 and endorsed by both the WRP and EPA Regions, for identifying opportunities for collaborative studies. The plan includes a formal set of provisions for (1) establishing an EPA Regional research committee; (2) developing collaborative study selection criteria; (3) soliciting proposals for regional studies from the EPA Regions; and finally (4) ranking, selecting, and implementing these studies. The Regional Liaison will have an annual budget of about $250,000 (see Section 9) that will be used to provide incentives for WRP participation in collaborative studies that may not be directly related to project objectives. A series of collaborative reports will result from these studies.

No formal training programs by the WRP are planned at this time, but opportunities for such training may arise as results from the WRP research become available. The Regional Liaison will, however, on occasion organize informal workshops at the EPA Regional Offices.

Copies of all WRP reports and publications will be transmitted by the Regional Liaison to the EPA Regions, who will in turn notify the states of their availability. The Regional Liaison also will develop a separate mailing list for the states to ensure that the information generated by the WRP is widely distributed.

8.2 ADDITIONAL ACTIVITIES

The WRP recognizes its responsibility to provide visible and technically credible information to the scientific community, to other federal agencies involved in wetland research, and to the public. The WRP scientists will continue, therefore, to pursue peer-reviewed publication of their findings in scientific journals. WRP scientists also will serve as organizers and contributors to national and regional wetland workshops and symposia, such as those organized by the Society of Wetlands Scientists.

Another aspect of technology transfer that must be considered is the coordination of WRP research with wetland research conducted by other federal agencies. This task is the responsibility of the WRP Manager, in cooperation with the Wetlands Division within the Office of Water. The WRP Manager, or her delegate, currently serves on a number of interagency committees and work groups (e.g., with the Army Corps of Engineers, Soil Conservation Service, and Federal Highways Administration). Additional coordination between the WRP and wetland research activities in other agencies is achieved through review of major project plans and reports, and participation in peer review and coordination workshops.

The WRP prepares an informal "Wetlands Research Update" at least once per year. This report provides a summary of WRP's ongoing research activities, the names of project scientists, and the conclusions of recently completed studies to any interested individual or group. The WRP maintains a large, open mailing list for distribution of the Update. Representatives from states, the EPA, other federal agencies, and many private individuals and consulting firms are included on the mailing list.

9. PROGRAM DELIVERABLES AND BUDGET

This planning document assumes a five-year program funded at $2.552 million annually. Major deliverables from the WRP for FY 1992-1996 will directly address the priority EPA programmatic needs identified in Section 1 and will include the following:

- a risk-based approach to setting water quality criteria, including biocriteria, for wetlands;
- a technical handbook on the protection of wetland functions through the implementation of best management practices;
- a technical framework for the restoration and creation of wetlands, focusing on an evaluation of performance and design;
- rapid techniques for landscape assessments of wetlands;
- an assessment of the role and functions of isolated wetlands, with management recommendations;
- application of the risk-based framework to the national policy of no net loss of wetlands; and
- application of the risk-based framework to an evaluation of the role of wetlands for reducing nonpoint source pollution.

Table 9-1 provides a full list of the WRP major deliverables by project and year. The total Program budget, assumed for FY 1992-1996, is summarized by year and WRP project in Table 9-2. Individual project budgets, by deliverable and year, are presented in Tables 9-3 to 9-6 for the Wetland Function, Characterization and Restoration, Landscape Function, and Risk Reduction Projects, respectively. The budget for Technical Information Transfer is included in Table 9-2. The outputs from this program element will be collaborative research reports, not major program deliverables. Therefore, no separate budget table by deliverable is provided for Technical Information Transfer.

Table 9-1. WRP Deliverables by Project and by Year

WETLAND FUNCTION PROJECT	
State-of-the-science review of stressors, impacts, and indicators of function for priority wetland types	FY 1993
Risk-based approach to setting water quality criteria, especially biocriteria, for wetlands	FY 1996
Handbook for the protection of wetland functions through the implementation of best management practices	FY 1996
Guidelines for site-specific monitoring of ecological integrity in individual wetlands and wetland complexes	FY 1996
Preliminary technical support on establishment of water quality criteria required for survival, growth, and re-establishment of coastal seagrass systems	FY 1993
CHARACTERIZATION AND RESTORATION PROJECT	
State-of-the-science approach to selecting sites for restoring western riparian wetlands	FY 1994
An approach to selecting sites for wetland restoration	FY 1996
Technical framework for the restoration and creation of wetlands: An evaluation of performance and design	FY 1997
LANDSCAPE FUNCTION PROJECT	
An assessment of the function and value of isolated wetlands, with management recommendations	FY 1995
Rapid techniques for landscape assessment of wetlands	FY 1996
An evaluation of the functions of wetlands in the landscape	FY 1996
RISK REDUCTION PROJECT	
The use of a risk-based framework with best professional judgment for wetland risk assessment	FY 1993
A protocol for monitoring and evaluating the effectiveness of risk management	FY 1995
Application of a risk-based framework to no net loss of wetlands	FY 1996
Application of a risk-based framework to reduction of nonpoint source pollution	FY 1996

Table 9-2. **Budget Summary for WRP Projects by Year (thousands of dollars, $K)**

Project	FY 92	FY 93	FY 94	FY 95	FY 96	TOTALS
Wetland Function	765.6	595.5	595.5	595.5	595.5	3147.6
Characterization and Restoration	595.5	595.5	595.5	595.5	595.5	2977.5
Landscape Function	595.5	595.5	595.5	595.5	595.5	2977.5
Risk Reduction	340.3	510.4	510.4	510.4	510.4	2381.9
Technical Information Transfer	255.1	255.1	255.1	255.1	255.1	1275.5
TOTALS	2552.0	2552.0	2552.0	2552.0	2552.0	12760.0

Note: A one-year pilot study on coastal seagrass communities is funded for FY 92 within the Wetland Function Project at $170.1K; these funds are allocated to the Risk Reduction Project during all other years.

Table 9-3. Wetland Function Project: Timelines and Budgets ($K)

Deliverable	FY 92	FY 93	FY 94	FY 95	FY 96	TOTALS
State-of-the-science review of stressors, impacts, and indicators of function for priority wetland types	150.0	175.0				325.0
Risk-based approach to setting water quality criteria, especially biocriteria, for wetlands	75.0	75.0	100.0	100.0	150.0	500.0
Handbook for the protection of wetland functions through the implementation of best management practices	170.5	170.5	250.0	245.5	225.0	1061.5
Guidelines for site-specific monitoring of ecological integrity in individual wetlands and wetland complexes	200.0	175.0	245.5	250.0	220.5	1091.0
Preliminary technical support on establishment of water quality criteria required for survival, growth, and re-establishment of coastal seagrass systems	170.1					170.1
TOTALS	765.6	595.5	595.5	595.5	595.5	3147.6

Table 9-4. Characterization and Restoration Project: Timelines and Budgets ($K)

Deliverable	FY 92	FY 93	FY 94	FY 95	FY 96	TOTALS
State-of-the-science approach to selecting sites for restoring western riparian wetlands	100.0	25.0				125.0
An approach to selecting sites for wetland restoration	75.0	200.0	100.0	100.0	100.0	575.0
Technical framework for the restoration and creation of wetlands: An evaluation of performance and design	420.5	370.5	495.5	495.5	495.5	2277.5
TOTALS	595.5	595.5	595.5	595.5	595.5	2977.5

Table 9-5. Landscape Function Project: Timelines and Budgets ($K)

Deliverable	FY 92	FY 93	FY 94	FY 95	FY 96	TOTALS
An assessment of the function and value of isolated wetlands, with management recommendations			100.0	100.0		200.0
Rapid techniques for landscape assessment of wetlands	300.0	150.0	100.0	100.0	200.0	850.0
An evaluation of the functions of wetlands in the landscape	295.5	445.5	395.5	395.5	395.5	1927.5
TOTALS	595.5	595.5	595.5	595.5	595.5	2977.5

Table 9-6. Risk Reduction Project: Timelines and Budgets ($K)

Deliverable	FY 92	FY 93	FY 94	FY 95	FY 96	TOTALS
The use of a risk-based framework with best professional judgment for wetland risk assessment	240.3	100.0				340.3
A protocol for monitoring and evaluating the effectiveness of risk management			100.0	100.0		200.0
Application of a risk-based framework to no net loss of wetlands	50.0	205.2	205.2	205.2	255.2	920.8
Application of a risk-based framework to reduction of nonpoint source pollution	50.0	205.2	205.2	205.2	255.2	920.8
TOTALS	340.3	510.4	510.4	510.4	510.4	2381.9

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APPENDIX A: OVERVIEW OF ORIGINAL WETLANDS RESEARCH PROGRAM

The original Wetlands Research Program (WRP) developed in 1986 consisted of three semi-autonomous projects (Zedler and Kentula 1986): (1) Water Quality, (2) Mitigation, and (3) Cumulative Impacts. During the past five years, these three WRP projects have developed the basic research methods required to support a risk reduction strategy. Water Quality has developed techniques to quantify the response of wetlands to environmental stressors. Mitigation has developed methods for characterizing various wetland populations and assessing the performance of mitigation projects. Cumulative Impacts has developed techniques for ranking and mapping landscape units according to function and risk.

These methods contain the basic elements for the more comprehensive research approach needed to address the FY 1992-1996 research priorities. The WRP objectives are being met through two basic organizational changes: (1) the missions of the individual projects have been broadened to address a wider range of issues, and (2) a fourth project has been added whose specific mission will be to integrate results from the other three projects into synthesis deliverables on risk reduction. Brief descriptions of the three original WRP projects are provided in the subsections below.

More recently, two additional research areas have been added to the WRP to address emerging national priorities: Constructed Wetlands and the wetland component of the Environmental Monitoring and Assessment Program (EMAP-Wetlands). The Constructed Wetlands and EMAP-Wetlands projects are not included as a part of this plan, because they were funded separately and have developed their own research plans (Olson 1990 and Leibowitz et al. 1991, respectively).[1] The Constructed Wetlands project also responds to a different program office. The research activities described in this document will, however, be closely coordinated with and mutually supportive of the Constructed Wetlands and EMAP-Wetlands projects, to assure that all studies are designed to provide maximum benefit to both individual projects and the Program as a whole. Brief descriptions of the Constructed Wetlands and EMAP-Wetlands projects are also provided below.

A.1 WATER QUALITY

Wetlands provide three primary functions in the landscape: water quality, hydrology, and habitat functions. Of these three, the role of wetlands in regulating or modifying water quality is the most poorly understood. To increase our understanding of this function, the original Water Quality Project was developed with two goals:

1. Ensure that water quality criteria protect the chemical, hydrological, and biological integrity of wetland resources adequately by determining the effects of contaminants on wetland structure and function.

2. Determine quantitative limits for waste assimilation to maintain the long-term structural and functional integrity of wetlands of different types.

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[1] For the purposes of this document, reference to the WRP or to the "Program" refers only to the projects described as a part of this plan. Constructed Wetlands and EMAP-Wetlands are not included unless stated otherwise.

Field surveys and experiments have been conducted as part of this project to determine the effects of anthropogenic stressors on wetland water quality functions and the capacities of priority wetland types to assimilate common contaminants.

A.2 MITIGATION

Since the 1970s, thousands of wetlands have been created to compensate for wetland losses permitted under Section 404 of the Clean Water Act (CWA). Few follow-up studies have been conducted, however, to determine whether created wetlands adequately replaced the valued wetland functions that were lost. The goal of the Mitigation Project in the last five years has been to assess the success of mitigation projects both in terms of compliance with permit specifications and the ecological performance of wetland restoration and creation projects. To what degree has wetland mitigation successfully compensated for wetland losses? To accomplish this goal, restored and created wetlands have been treated as experiments in progress. Measurements of ecological condition made on restored and created wetlands have been compared with measurements from a set of "reference" wetlands (i.e., natural wetlands of the same type and in the same landscape setting as the restored and created sites). Such comparisons have resulted in both an evaluation of the performance of current mitigation efforts as well as recommendations for improving wetland designs in future mitigation projects.

A.3 CUMULATIVE IMPACTS

Wetland losses are permitted under Section 404 of the CWA only after measures have been taken to avoid, minimize, and compensate for impacts to wetlands. However, impacts considered insignificant by themselves may cause substantial environmental effects when their combined consequences are considered. Cumulative impacts are the sum of all of the impacts that have occurred over the entire landscape and over time. Cumulative effects refer to the total change in landscape function resulting from these impacts. The goal of the Cumulative Impacts Project in the past five years has been to provide technical support to wetland regulators in assessing both cumulative impacts to wetlands and the consequent cumulative effects on landscape function. The Cumulative Impacts Project has been developing the theory, landscape indicators, and methods for such assessments.

A.4 CONSTRUCTED WETLANDS

The Constructed Wetlands project receives funding from outside the WRP base budget to (1) provide technical support on the role of constructed wetlands in wastewater treatment and water quality improvement, and (2) evaluate the relationship between water quality and ecological condition. A constructed wetland[2] treatment system is a wetland that has been created or restored to treat either point or nonpoint source wastewater. Current applications of wetland treatment systems include treatment of municipal and home wastewater, acid mine drainage,

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[2] The term "constructed wetlands" is used to distinguish these wetlands from "created or restored wetlands" that might be required as compensation for wetland impacts permitted under Section 404 of the CWA. Constructed wetlands are developed specifically for water quality improvement; permits are required under Section 404 only if constructed wetlands involve or will impact jurisdictional wetlands.

landfill and industrial wastewater, nonpoint source pollution, and urban stormwater. Program objectives are to evaluate the following:

- the relationships between the design and structure of wetland treatment systems and water quality improvement;
- the relationship between water quality in wetland treatment systems and ecological condition, including bioaccumulation of toxic substances, productivity, species diversity, and habitat quality (secondary ecological effects); and
- the relationship between the placement of wetland treatment systems and landscape water quality functions.

The Constructed Wetlands Project recently produced a document outlining its five-year research plan (Olson 1990). Coordination with this project will improve the WRP deliverable on the role of wetlands for reducing nonpoint source pollution.

A.5 EMAP-WETLANDS

EMAP was initiated in 1988 to provide information on the health of the Nation's ecological resources. Wetlands are one of seven resource categories that will be studied in EMAP. The goal of EMAP-Wetlands is to provide a quantitative assessment of the current status and long-term trends in wetland condition at regional and national scales. This goal will be achieved through estimates of condition based on probabilistic samples of wetlands within regional wetland populations; health will be assessed by the use of field and remote indicators. The objectives, statistical design, and approach for EMAP-Wetlands are described in greater detail in the recently completed and peer-reviewed research and monitoring plan for the project (Leibowitz et al. 1991).

Several opportunities exist for cooperative efforts between the WRP Projects and EMAP-Wetlands and are currently being pursued. All of these projects will be evaluating and applying indicators of wetland and/or landscape condition. Thus, current plans call for extensive sharing of information among projects as well as the coordination of indicator selection and testing activities. For example, the literature review on indicators prepared by the WRP (Adamus and Brandt 1990) played an important role in the selection of potential indicators for use in EMAP-Wetlands. Furthermore, recent efforts and workshops conducted by EMAP-Wetlands on wetland indicators will be used to help guide future WRP research and indicator development.

The WRP Characterization and Restoration Project will be conducting surveys of wetland populations, similar in scope to (although with different objectives than) the surveys and monitoring planned for EMAP-Wetlands. To the degree possible, the indicators and sampling methods employed in the Characterization and Restoration Project will be consistent with those used for EMAP-Wetlands (see Section 5.2.1.2).

The Wetland Function Project will be conducting intensive studies of individual wetlands or small groups of wetlands (see Section 4.2.2). The resulting information on within-wetland indicator variability and on changes in wetland indicators in response to stressors will be of value to both EMAP-Wetlands and other WRP projects, both for indicator selection and for interpreting the indicator data collected in these more extensive surveys and landscape assessments. Pilot studies planned by EMAP-Wetlands also will involve some evaluation of within-wetland indicator variability. Results from these efforts will aid both the Wetland Function Project and Characterization and Restoration Project with indicator selection.

Current plans also call for a joint project on prairie pothole wetlands. EMAP-Wetlands is in the advance stages of planning a pilot study in this region in 1992-1993. As a result, the WRP will "piggy-back" its proposed studies of prairie potholes (see Sections 4.3.1, 5.3.1, and 6.3.1) onto the EMAP-Wetlands pilot. WRP will benefit, therefore, from EMAP-Wetlands planning and Interagency contacts. Data collected by EMAP-Wetlands on the status of wetland populations in the area will be used directly by the Characterization and Restoration Project and the Risk Reduction Project. Additional population-level sampling by the Characterization and Restoration Project will be designed specifically to supplement, as needed, the EMAP-Wetlands pilot study (see Section 5.3.1). In addition, the development of a working relationship between the WRP and EMAP-Wetlands through the prairie pothole study will establish a protocol for formal coordination of joint future activities.

APPENDIX B: WETLAND RESEARCH BY OTHER FEDERAL AGENCIES

Many federal agencies conduct wetland research or provide technical support on wetland management. The nature of these activities is dictated by agency mandate. In general, federal wetland responsibilities fall into three categories: (1) regulatory, (2) resource management, and (3) public works. In addition, an important factor that controls the kind of research or technical support activities conducted by an agency is whether that agency's primary involvement with wetlands is conservational (e.g., management or protection) or compensatory (i.e., the pursuit of agency objectives causes deleterious effects on wetlands that must be mitigated).

For each federal agency with a major wetland role, the following subsections provide a brief overview of their overall responsibilities with respect to wetlands and major research or technical support objectives and strategy. In particular, these discussions focus on three key areas: wetland function and value, restoration and creation, and the effects of anthropogenic stressors. Major wetland types of concern to the agency also are identified. The purpose of this appendix is to demonstrate that the planned research by the Wetlands Research Program (WRP) avoids duplication and, even more important, will foster cooperation between the WRP and other federal agencies in areas of mutual interest.

B.1 ARMY CORPS OF ENGINEERS

The Army Corps of Engineers (COE) has wetland responsibilities within all three management categories: (1) under Section 404 of the Clean Water Act, the Corps has the primary responsibility for issuance of wetland dredge and fill permits; (2) the COE manages 9 million acres of federal land as part of its water resources projects, and wetland management is a part of the Corps' overall land stewardship; and (3) the COE causes adverse effects on wetlands through dredging operations and must mitigate, therefore, for wetland loss.

The Corps has committed $22 million during FY 1991-1993 for wetland research. A recent draft planning document describes six technical task areas for planned research (COE 1990): (1) critical processes, (2) delineation and evaluation, (3) restoration and development, (4) predicting and minimizing impacts, (5) change assessment, and (6) stewardship and management. The primary focus of the Corps' wetland research activities is the development of techniques for conserving, establishing, and managing the Nation's wetlands. The Corps' expanded research program for FY 1991-1993 will emphasize field research and demonstrations aimed at restoring, establishing, and managing numerous wetland types, including wooded wetlands, freshwater marshes, and coastal intertidal wetlands. The work will involve interdisciplinary undertakings in environmental engineering, hydrology, hydric soils, biological techniques, structures, and design criteria. Considerable effort also will be expended on improving the accuracy and range of wetland delineation and evaluation techniques, with major emphasis on wetland functions and values. The application of remote sensing for wetland change assessment will be evaluated, as well as techniques to predict and avoid wetland impacts. The three-year program is responding to the Administration's challenge of no net loss of wetlands. The WRP is working with the Corps to assure coordination of the two research programs.

B.2 U.S. FISH AND WILDLIFE SERVICE

The U.S. Fish and Wildlife Service's (FWS) mission is to conserve, protect, and enhance fish and wildlife along with their habitat. Although it is mostly a resource management agency, with over half of the Service's funding directed towards wetland conservation, it also has regulatory responsibilities (for example, under the Endangered Species Act). The FWS manages 90 million acres of wildlife refuges throughout the nation, 37% of which are wetlands (U.S. FWS 1990). The FWS is responsible for restoring and enhancing wetlands under programs such as the North American Waterfowl Management Plan and as a part of the Conservation Reserve Program. The Service also is responsible for evaluating wetland status and trends through its National Wetlands Inventory (NWI) program.

A 1990 FWS Wetlands Action Plan lists several key research areas (U.S. FWS 1990), including (1) the ecological consequences of management practices; (2) habitat requirements of wetland-dependent species; (3) evaluation of assessment methods for management and restoration; (4) assessment of the function, wildlife value, and stability of wetland ecosystems; (5) the effects of large-scale environmental change (e.g., global warming) on wetlands; (6) assessment of the effectiveness of alternative mitigation strategies; (7) assessment of the long-term impacts of chemical contamination; and (8) evaluation of the role of hydrology in habitat maintenance. The FWS has been involved in evaluating wetland functions and values at both site-specific and landscape scales. Wetland restoration and creation research has similarly occurred at both of these spatial scales. Priority stressors have included chemical contaminants and global climate change. Research has been conducted on several wetland types, including bottomland hardwoods, prairie potholes, and coastal/estuarine systems such as seagrass communities. The experience of the FWS in these areas, especially regarding the use of the Prairie Pothole Region by waterfowl, can complement planned WRP studies.

B.3 SOIL CONSERVATION SERVICE

The U.S. Department of Agriculture's (USDA) Soil Conservation Service (SCS) has both resource management and public works responsibilities. Under the 1990 Farm Bill, SCS provides technical assistance for the Wetlands Reserve Program; the objective of this program is to restore up to 600,000 acres of degraded wetlands. The SCS also makes wetland determinations for the "swampbuster" provisions of both the 1985 and 1990 Farm Bills. The Service's major responsibility in the area of public works is flood prevention. Main areas of interest to the SCS include (1) the value of prior converted cropland and cropped wetlands; (2) improved wetland delineation; (3) an evaluation of the functions and value of wetland restorations, along with methods for improvement; and (4) the environmental factors that cause anaerobic soil conditions.

While the SCS is not involved directly with research, it has a need to provide personnel in state offices with technical support for meeting SCS responsibilities. In addition, the SCS has considerable experience in restoring wetlands on agricultural lands, mostly focusing on engineering requirements and the management of vegetation for waterfowl production. The plant materials used for increasing the function and success of restored and created wetlands are selected at SCS plant materials centers. The effects of nonpoint source pollution on wetlands (both nutrients and sediments) is another area that the SCS has investigated.

The importance of working closely with SCS is illustrated by the fact that 87% of the historical wetland losses from the 1950s to 1970s and 54% from the mid 1970s to mid 1980s resulted from agricultural conversion (Tiner 1984, Dahl and Johnson 1991). The technical assistance provided by the SCS for the Wetlands Reserve Program offers a major avenue for redressing these losses. WRP's proposed research on prioritization of restoration sites could help ensure that the ecological benefits of this program are maximized.

B.4 FEDERAL HIGHWAYS ADMINISTRATION

The Federal Highways Administration (FHWA) is a public works agency. FHWA policy is to mitigate for the adverse effects on wetlands occurring as a result of highway construction (Isaacson 1988). Thus, FHWA research has focused on two areas: (1) evaluating the effects of highway projects on wetlands, including both direct losses of wetland area as a result of highway construction and wetland degradation caused by runoff from highway projects, and (2) developing guidance on site-specific mitigation, including minimization and compensation (restoration or creation). The FHWA is funding an FY 1992 research initiative which includes wetland research. Priority research areas will include (1) functional assessments of wetlands, (2) cost-effectiveness of wetland creation, (3) identification of hydric soils, and (4) short-term impacts from construction in wetlands.

The assessment of the functions and value of individual wetland sites has been a major interest of the FHWA. In fact, the FHWA was responsible for the original development of the Wetland Evaluation Technique (WET; Adamus 1983, Adamus and Stockwell 1983). Restoration and creation activities have focused on engineering approaches to successful mitigation. The construction of highways itself has been the major impact considered by this agency. The FHWA has expressed particular interest in the mitigation of western riparian wetlands.

B.5 BUREAU OF RECLAMATION

The Bureau of Reclamation (BOR) is primarily a public water resources agency, serving the western United States. BOR water projects provide irrigation water for over 10 million acres of farmland and drinking water for more than 25 million people (Crossman 1990). BOR dams also provide hydroelectric power. The BOR owns over 8 million acres of land and, therefore, also has resource management responsibilities.

Because BOR water projects have impacted wetlands, the BOR has had a policy of avoidance, minimization, and wetland mitigation. In 1987, however, the BOR announced an expanded emphasis on its role as a resource management agency (Crossman 1990). To fully realize the water resource benefits of wetlands, wetland protection and management have been integrated into the Bureau's water resource management initiatives. The BOR recognizes that wetlands can serve as integrators and indicators of overall basin conditions. Thus, four major research needs have been identified: (1) siting of wetlands to realize water resource and fish and wildlife benefits, (2) design criteria for different wetland functions, (3) the hydrologic regime required to support different wetland functions, and (4) operating and maintenance requirements for sustaining wetland systems.

The BOR initiated a five year multi-million dollar wetland program in FY 1991 that emphasizes three activities: (1) inventorying wetlands on BOR lands, (2) developing projects to support the North American Waterfowl Management Plan, and (3) specific research and demonstration projects. Short-term research priorities are to develop scientific and engineering guidelines and procedures for wetland restoration and creation.

BOR's main interests in wetlands relate to wetland functions for flood storage, reducing nonpoint source pollution, and habitat. Restoration and creation activities have focused on engineering design criteria, including hydrologic requirements of wetlands. Likewise, hydrologic modification is the major wetland stressor of concern to the BOR.

The BOR also has a major interest in western riparian systems. Research by the Characterization and Restoration Project could assist the BOR in their efforts to increase the ecological functions of their wetland restoration and creation projects. BOR's experience with western riparian systems also could benefit the study planned by the WRP on these systems (see Section 5.3.2).

B.6 USDA FOREST SERVICE

The USDA Forest Service is responsible for the management of 191 million acres of forest and range lands, of which 12 million acres are classified as wetlands. National Forest System land is managed to achieve multiple objectives, including timber and mining production, enhancement of water quality and quantity through watershed protection, and other goals such as fish and wildlife habitat preservation. The mission of Forest Service research is to serve society by developing and communicating the scientific information and technology needed to protect, manage, and use the natural resources of forest and range lands. Forest Service research has the authority to address information needs on private and public lands, including industrial and non-industrial land owners. Research is carried out through a network of eight Experiment Stations and the Forest Products Laboratory, encompassing 74 locations and $170 million in FY 1991.

Wetland and water quality research in the Forest Service has been underway for decades in many parts of the country. In the North Central region, long-term, process-based studies in peatland ecosystems have been conducted since the 1950s. Bottomland hardwood management in the South, especially in Mississippi and Louisiana, has been studied since 1937. Techniques to manage riparian areas in the western United States have been an essential part of Forest Service research for 20 years, including increased emphasis on the fundamental functions of these systems. Under the Center for Forested Wetlands in Charleston, SC, environmental controls on the growth and productivity of major wetland species are being studied, with some emphasis on soil chemistry and plant physiology. Projects in Louisiana and North Carolina are examining the legislative, regulatory, and economic controls on forest wetland management practices. Studies of wetland ecosystems as wildlife and fish habitat and as areas to maintain and enhance biological diversity are underway in all Stations.

To meet the management challenges of wetland ecosystems, "Wetlands" has been identified as a National Research Problem Area for FY 1993; a staff specialist will coordinate research efforts across the country. The program will continue to cover the full range of research needs previously described, and will focus on areas of critical uncertainties (e.g., best management practices). Research categories that will be emphasized include fundamental understanding of ecosystem dynamics in disturbed and undisturbed landscapes; development of methods and evaluation of the success of wetland restoration and rehabilitation; management of the wetland resource; socioeconomic values of wetlands and legislative/regulatory controls on management decisions; and landscape-scale linkages of wetlands to upland and adjoining ecosystems.

The WRP will contact the Forest Service to coordinate studies on bottomland hardwood forests (Sections 4.3.2 and 6.3.2) and western riparian systems (Section 5.3.2).

B.7 TENNESSEE VALLEY AUTHORITY

As described in its enabling legislation, the Tennessee Valley Authority (TVA) is both a public works and resource management agency. Historically, its widely publicized flood control, navigation, and power generation programs have greatly overshadowed its natural resources management and development activities. Recent organizational and policy changes have, however, prompted many new initiatives for improved stewardship of public lands and natural resources under its control. Research areas of interest to TVA include classification, delineation, mapping, and inventory; restoration and creation for water quality improvements and habitat development; effects of flooding on ecological function; and habitat value of wetlands.

TVA's major interests in wetland functions are the role of constructed and natural wetlands for restoring and maintaining water quality and the habitat values associated with such systems. Restoration and creation has centered on the role of constructed wetlands for treating wastewater, acid drainage, and agricultural and industrial waste. Hydrologic modification has been the major stressor of concern. Because of its geographic location, bottomland hardwood forests are of particular interest to TVA. The WRP will contact TVA to coordinate their studies on bottomland hardwood forests (Sections 4.3.2 and 6.3.2).

GLOSSARY[1]

Assimilative capacity - the total quantity of a material (such as sediments, nutrients, or toxic contaminants) that a wetland (or other ecosystem) can remove through filtration, transformation, retention, etc.

Avoidance - when used in the context of wetland management, the prevention of the loss of wetland area or function by implementing regulations or management strategies to protect wetlands.

Baseline monitoring - periodic measurements or observations of ecosystem attributes over time used to assess trends in ecosystem condition and to identify new environmental problems as they arise.

Bioaccumulation - the process by which a compound is taken up and concentrated by an organism, both from the surrounding media (water, soil, or air) and through the food chain.

Biocriteria - numerical values or narrative expressions that describe the reference biological integrity of aquatic communities inhabiting or relying on wetlands of a given designated use, and the habitat and hydrological conditions necessary to sustain that use. Biological criteria are considered to be a subset of water quality criteria.

Buffer - vegetated strips of land surrounding ecosystems. Established buffers can at least partially filter pollutants and sediments from overland and subsurface flow, thereby decreasing the input of these materials into the ecosystem. Buffers can occur around wetlands, protecting the wetland from external loading, or a wetland can serve as a buffer to protect other ecosystems, such as streams.

Characterization curve - a histogram or curve representing the frequency distribution of a wetland attribute (e.g., an **indicator** of **wetland function**) for a wetland **population** within a given landscape setting.

Conceptual model - a simplified or symbolic representation of a system's behavior and responses, identifying important **stressors**, major ecosystem components, **processes**, and **functions**, and the linkages among these stressors, components, processes, and functions.

Constructed wetland - a wetland that has been created or restored specifically to treat either point or **nonpoint source pollution** wastewater.

Conversion - the transformation of a wetland into a different land cover or land use (e.g., filling in a wetland for building construction), resulting in the complete or near complete loss of the original wetland functions.

[1] Terms are defined specifically as they are used in this document.

Created wetland - a wetland that has been constructed on a non-wetland site specifically to compensate for wetland losses permitted under Section 404 of the Clean Water Act.

Cumulative effects - the net change in the overall **landscape function** that results from **cumulative impacts.**

Cumulative impacts - the sum of all of the **impacts** that have occurred over the entire landscape of interest and over time.

Data quality objectives - the desired level or standard of data quality (e.g., minimum acceptable levels of precision and accuracy) established during the project planning process and used to (1) help guide the sampling design and selection of analytical protocols and (2) provide an objective basis for evaluating the adequacy of the data collected.

Degradation - the loss of function (in this case, wetland or landscape functions) resulting from exposure to a **stressor.** Wetland degradation would include direct and indirect **effects** resulting from the addition of harmful agents and/or the removal of beneficial factors (e.g., damage to the environmental infrastructure that maintains a wetland as a result of **hydrological modifications** caused by dam construction or stream diversion).

Denitrification - biologically mediated reduction of nitrate to gaseous forms of nitrogen (NO, N_2O, and N_2). Nitrate is used as an electron acceptor in the absence of free oxygen (e.g., in wetland soils and sediments); denitrification occurs in association with the decomposition of organic matter.

Ecoregion - a mapped classification of ecosystem regions. Ecoregions are geographic areas that have relatively homogeneous ecological systems and homogeneous relationships between organisms and their environment.

Ecosystem - a complex of biological communities and the physical and chemical environment forming a functioning whole in nature. Wetlands, upland forests, lakes, and streams are examples of types of ecosystems.

Effect - a change in wetland structure and/or function in response to some causal agent (i.e., some **impact** or **stressor**).

Empirical study - relying on experience or observation alone (as opposed to a controlled experiment). In this document, an empirical study refers to field observations and measurements collected for wetlands along a gradient of **stressor(s)** or surrounding management practices.

Environmental stressors - see **stressor.**

Evaluative monitoring - measurements or observations of ecosystem attributes collected specifically to determine the effectiveness of a **risk management** plan.

Exposure assessment - a component of a traditional risk assessment, involving the quantification of the magnitude of one or more **stressors** to which the organism, biological population, or ecosystem is exposed or may be exposed to in the future given various management scenarios.

Function - see **wetland function** and **landscape function.**

Functional loss - the loss or decline of a valued **wetland function** as a result of wetland **conversion** or **degradation.**

Hazard identification - a component of a traditional **risk assessment**, involving the characterization of the specific **stressors** of concern for the ecosystem(s), landscape, or region being evaluated as part of the risk assessment.

Hydrologic modification - a change in the timing, duration, frequency, quantity, location, or distribution of water flows as a result of human activities. Hydrologic modifications may result from dam or levee construction, water withdrawals, stream diversions, changes in local runoff patterns due to construction activities or increases in impermeable surfaces in the watershed, etc.

Hydrology - the study of waters of the earth: the properties, circulation, and distribution of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere. Hydrology is a major determinant of the occurrence and condition of wetlands.

Impact - an action that adversely affects a wetland or other ecosystem, for example, dam construction, timber clearing, agricultural activities that result in wetland conversion or degradation.

Indicator - one of the specific environmental attributes measured or quantified through field sampling, remote sensing, or, in some cases, compilation of existing data (e.g., existing maps or land use information) to assess ecosystem condition or functions, or exposure to environmental stressors.

Isolated wetlands - wetlands that are small (e.g., less than 10 acres) and have no connection to other surface water bodies. The term "isolated wetlands" is used in this document to refer specifically to those small, isolated wetlands that are covered under Nationwide Permit 26.

Landscape Development Index - an index of the intensity of landscape stressors that may degrade wetlands, based on land uses in the surrounding area and their known or suspected effects on wetlands.

Landscape function - the combination of environmental **processes** operating within a **landscape unit** that account for the overall environmental characteristics of that unit. The term **wetland function** refers to the functions and benefits provided by individual wetlands, while landscape function refers to the functions and benefits provided by the landscape unit as a whole, including the complex of wetlands and other ecosystems within that landscape unit. Examples of landscape function are regional biodiversity and the overall water quality and hydrologic integrity of a watershed.

Landscape unit - a contiguous area of land used in landscape-level analyses. The scale and boundaries of landscape units can vary depending on the **landscape function** of interest and study objectives. Often, watersheds or ecoregions are used as landscape units.

Loading rate - the amount of material received by a wetland or other ecosystem per unit of time.

Manipulative studies - controlled experiments in which a wetland/ecosystem component of interest is exposed to a controlled set of conditions or levels of some **stressor.**

Mesocosm - a portion of a wetland or other ecosystem enclosed in the field for the purpose of a **manipulative study.**

Microcosm - an artificial experimental unit including one or more wetland/ecosystem components used in a **manipulative study** in either the laboratory or field.

Mitigation project - wetland enhancement, **restoration**, or **creation** activities required to compensate for wetland losses permitted under Section 404 of the Clean Water Act.

Natural wetland - a wetland that occurs naturally in the landscape and has not been manipulated to recover or increase wetland functions.

Nitrification - the oxidation of ammonium to nitrite or nitrate by microorganisms.

Nonpoint source pollution - impurities or contaminants derived from diffuse origins (e.g., agricultural runoff), as opposed to pollutants that are introduced into a wetland or ecosystem at one or more discrete locations (point source pollution).

Nutrients - chemicals required for biological maintenance. Nitrogen and phosphorus are examples of plant nutrients.

Nutrient loading - the input of **nutrients** into a wetland or other ecosystem from external sources.

Performance curve - a curve tracking the change in an **indicator** of **wetland function** over time in a **population** of **restored** or **created wetlands** compared to trends through time of the same indicator in **natural wetlands** in similar landscape settings.

Physical alteration - a change in the physical structure or characteristics of a wetland or other ecosystem as a result of human activities, for example, as a result of dredge and fill operations, changes in land cover type, timber harvesting, etc.

Population - the entire group of wetlands of a given **wetland type** occurring within a geographically defined area. Unless otherwise stated, the phrase "wetland population" is used in this document to refer to statistical populations, rather than biological populations (i.e., an assemblage of organisms of the same species inhabiting a given wetland or other ecosystem).

Process(es) - a natural phenomenon involving the biological, chemical, or physical conversion or transfer of some material. For example, **nitrification** and **denitrification** are processes within wetlands that contribute to the water quality **function**.

Replacement potential - the ability to recover a wetland and its valued **functions** through **wetland restoration** or **creation**.

Response threshold - the level of **stressor** above which a significant change will occur in some wetland/ecosystem attribute of interest (see **stressor/response relationship**).

Restored wetland - a wetland that has been returned from a disturbed or altered condition to a previously existing natural or altered condition by some action of man.

Riparian system - ecosystems occurring in the interface between aquatic and terrestrial systems, in floodplains and adjacent to rivers and streams. Riparian systems are subject to direct influences of ground and/or surface waters (e.g., occasional flooding, root zones extending into the groundwater table). Riparian systems are valued for diverse functions, such as flood attenuation, groundwater supply, streambank stabilization, habitat and migration corridors for wildlife (including many endangered species), and modification of surface water habitats (e.g., shading, or organic matter inputs).

Risk - the possibility of some loss or adverse **effect**.

Risk assessment - the identification and estimation of the **risks** associated with various **stressors** and environmental hazards.

Risk-based framework - an organized approach for identifying and quantifying **risks** (**risk assessment**), developing management strategies to reduce risks (**risk management**), and monitoring the effectiveness of these management actions and identifying new problems and risks that may arise (monitoring and evaluation).

Risk characterization - the final component of a traditional **risk assessment**, involving the integration of the information (and uncertainties) resulting from the three steps of **hazard identification**, **stressor/response relationships**, and **exposure assessment**, to estimate the probability of occurrence of specific events, such as the loss or degradation of an important ecosystem/landscape attribute.

Risk management - the development and implementation of a specific environmental management strategy to control the most serious environmental problems, thereby reducing **risks**.

Risk reduction - a policy goal or process to focus environmental protection activities on those problems or areas where the greatest decrease can be achieved in the potential for adverse environmental **effects**.

Sediment accretion - the net accumulation of particulate material deposited within a wetland or other ecosystem.

Sediment trapping - the reduction in the quantity of particulate material carried by surface or groundwater as it passes through a wetland.

Sedimentation - the process by which particulate material settles to the bottom of the water column of a wetland, lake, stream, or other water body.

Stressor - any material or process (physical, chemical, or biological) caused by man that can adversely affect a wetland (or other ecosystem) and thus degrade wetland (or other ecological) **function(s)**. Stressors include the addition of harmful agents, such as pollutants, and the removal of beneficial factors (e.g., stream diversions).

Stressor/response relationship - the quantitative association between the level of some **stressor** to which an organism, biological population, or ecosystem is exposed and the magnitude of response or probability of an adverse **effect** on one or more important attributes of the ecosystem(s) or landscape.

Synoptic landscape assessment - the ranking and mapping, at large scales (e.g., ecoregions or states) of **indicators** of **wetland function**, wetland **value**, **functional loss**, or **replacement potential**.

Technical information transfer - a program strategy to ensure that the technical information collected and methods developed in a research program, such as the Wetlands Research Program, are relevant to policy and regulatory needs and that the innovations developed through research will be adopted and widely used by environmental managers at regional and state levels.

Toxic contaminant - impurities that enter wetlands or other ecosystems as a result of human activities (either point or **nonpoint source pollution**), potentially causing an increase in mortality or sublethal adverse effects on organisms exposed to these materials.

Value - the benefits of a wetland or other ecosystem that are realized or recognized by society.

Water quality criteria - as defined by the U.S. Environmental Protection Agency, the recommended levels of various water quality parameters (including **biocriteria**) that should not be exceeded (or in some cases, minimum recommended levels) to protect aquatic life and human health.

Water quality standards - a law or regulation that consists of the beneficial designated use or uses for a waterbody, the **water quality criteria** (including **biocriteria**) that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

Watershed - the geographic area from which all of the surface water that drains into a particular wetland or other aquatic ecosystem is derived.

Wetland - a type of **ecosystem** that occurs at the interface between terrestrial and aquatic systems. In the Clean Water Act, wetlands are defined as "those areas inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

Wetland creation - see **created wetland.**

Wetland function - the benefits derived from or role served by an individual wetland (cf. landscape function). Wetland functions are generally grouped into three categories: (1) habitat (providing the factors and conditions necessary to support wetland-dependent species); (2) water quality (improving the quality of "downstream" surface and groundwaters through the uptake of contaminants, sediment retention, nutrient retention or supply, etc.); and (3) hydrology (moderating surface and groundwater flows, including flood attenuation, maintenance of base flow, etc.).

Wetland mosaic - the complex or group of often interconnected **wetlands**, often of different types and/or sizes, within a given geographic area.

Wetland restoration - see **restored wetland.**

Wetland type - a group of wetlands with common qualities and characteristics that distinguish them as an identifiable class. Several formal wetland classification schemes have been developed. The term wetland type is used in this document, however, in a general sense and does not refer to any of these formal or standard wetland classifications. The wetland types discussed include freshwater emergent wetlands, bottomland hardwood forests, and wetlands within western riparian systems.

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