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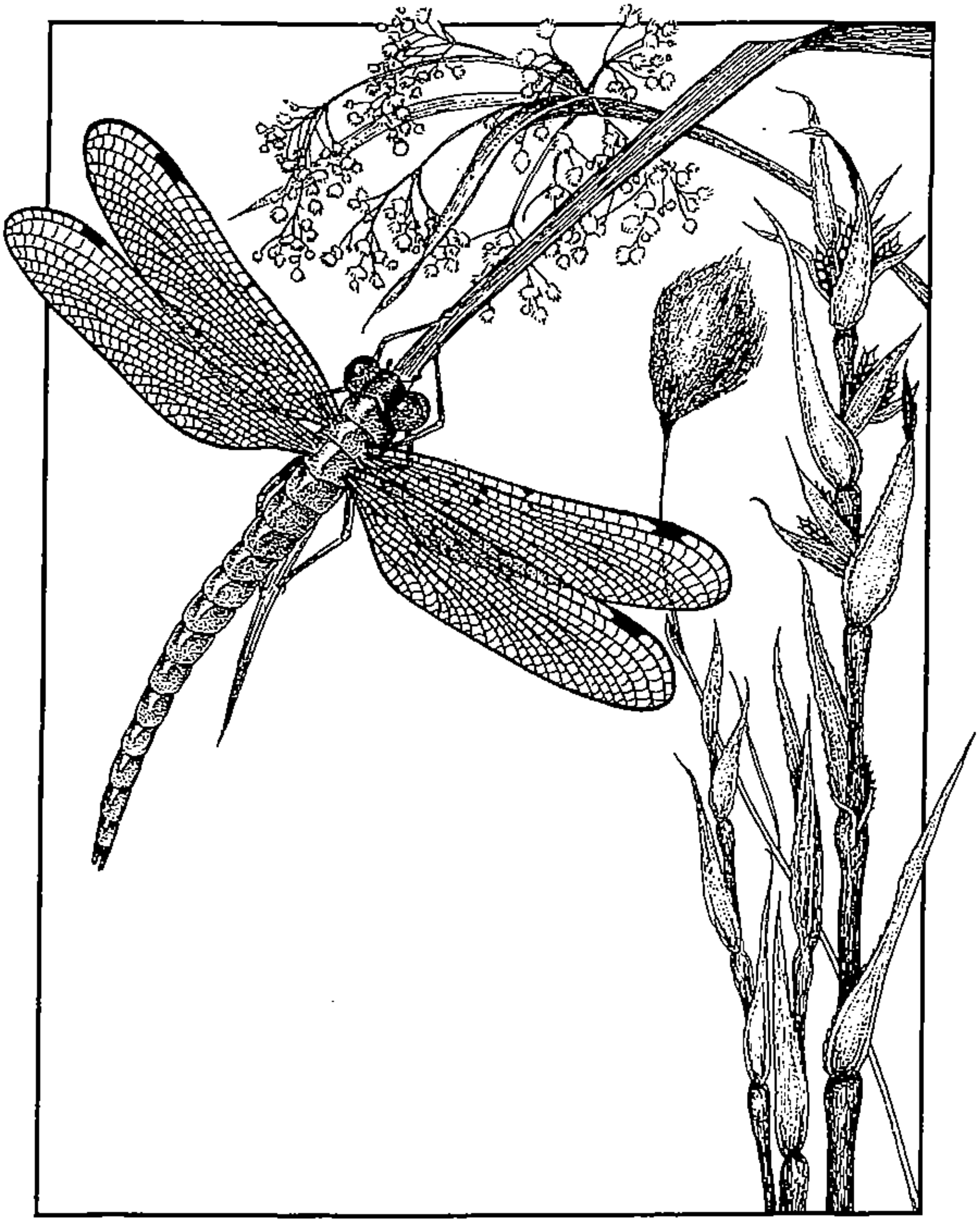
A SYNOPTIC APPROACH TO CUMULATIVE IMPACT ASSESSMENT: A PROPOSED METHODOLOGY



A Synoptic Approach to Cumulative Impact Assessment

A Proposed Methodology

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OFFICE OF
WATER

Dear Reader:

The following document is a product of the Environmental Protection Agency Office of Research and Development's (ORD) Wetlands Research Program developed at the request of our office in response to the need for more information on cumulative impact assessment. The proposed methodology was designed to assist wetland regulators in assessing the cumulative effect of individual wetland impacts within the landscape. Other potential applications of the approach include prioritizing areas for restoration and protection as part of nonpoint source abatement efforts implementing the Coastal Zone Act Reauthorization Amendments guidance, supporting the development of State Wetland Conservation Plans and wetland water quality standards, including designating uses and identifying Outstanding National Resource Waters, prioritizing acquisition and restoration efforts for other water quality or habitat benefits, and conducting regional risk assessments and watershed planning efforts such as Advance Identifications or Special Area Management Plans.

The synoptic approach allows wetland managers to produce statewide maps that rank portions of the landscape according to a set of landscape variables, or synoptic indices. These maps and indices should enable permit reviewers to consider the landscape condition of the area in which a particular permit is proposed, and, in so doing, allow them to better consider the cumulative impact of a proposed activity.

The synoptic approach was specifically designed for situations in which time, resources, and information are limited. It is practical within this context because an assessment is prepared for an entire state or region, and not on a case-by-case basis. In addition, the approach is intended to augment the best professional judgement used daily by wetland managers and regulators. It is not intended to provide a precise, quantitative assessment of the cumulative effects within a particular area. Rather, it provides a mechanism to compare potential cumulative impacts between areas.

The report describes the steps of conducting a synoptic assessment, and illustrates the use of synoptic information through four case studies. In the Pearl River, Louisiana case study, the potential use of the synoptic approach for assessing cumulative impacts under the Clean Water Act Section 404 regulatory program is illustrated. In the Illinois case study, subwatersheds are ranked for restoration according to their potential for water quality improvement. In the Washington State case studies, the approach is used for regional comparisons to support the development of a State Wetland Conservation Plan and to demonstrate the feasibility of introducing the concepts of value and future risk into the synoptic assessments.

The report does not provide a specific, detailed procedure for choosing the synoptic indices, nor does it supply a scientifically tested list of landscape indicators with confidence limits. This is not possible, given the strong dependency of the synoptic indices and landscape indicators on the specific management goals and the actual environmental conditions of the assessment.

ORD has issued this report as a proposed, rather than operational methodology to allow testing of the approach in Regional and State applications. We ask anyone conducting a synoptic assessment to provide the Wetlands Research Program or our office with feedback so that EPA can evaluate the suitability of the method and refine the approach.

Sincerely,

Suzanne E. Schwartz

for John W. Meagher, Director
Wetlands Division
Office of Wetlands, Oceans
and Watersheds

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DISCLAIMER

The research described in this report has been funded by the U.S. Environmental Protection Agency. This document has been prepared at the EPA Environmental Research Laboratory in Corvallis, Oregon, through Contract No. 68-C8-0006 to ManTech Environmental Technology, Inc., and Contract No. 2B0245NTSA to Word Design. This document has been subjected to the Agency's peer and administrative review process and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Two earlier reports (Abbruzzese et al. 1990a, 1990b) were produced during the development of the synoptic approach. Although these reports are useful in illustrating applications of the approach, the procedures contained in this document supersede those earlier versions and should be used in conducting a synoptic assessment. As the approach is further tested and evaluated, it may become necessary to update this method again. A mail-in form is provided in the back of the report for those wanting future updates or related products.

ACKNOWLEDGMENTS

This report is the culmination of a five-year effort on cumulative impact assessment and involved many individuals over the years. We would like to acknowledge all those who collected information, analyzed data, or otherwise helped with the case studies, including Jack Davis, Robert Hipple, JoEllen Honea, Colleen Johnson, Harbans Lal, Daren Moore, Frances Morris, Barbara Peniston, and Susan Ross. Debby Sundbaum-Somers produced Figures 2.1, 6.1, 6.2, and 6.4-6.6, and Linda Haygarth prepared Figures 4.1 and 5.1. Kristina Miller generated the computer graphics for Figures 1.2, 3.1, 3.2, 6.3, 7.1, and G.3. Brenda Huntley assisted in producing the synoptic maps, Figures 4.2-4.19. Thanks to Robert Crumb for allowing use of his cartoon, "A Short History of America" (Figure 1.1).

Susan Christie assisted in some of the initial editing of this document. Special thanks to Myrna Branam, Janet Converse, Kelly Davis, and the rest of those at Word Design for making the extra effort and sacrifices without complaint and for their high quality work. We would especially like to thank and recognize our technical editors, Ann Hairston, for her energy and support, and for showing us the light at the end of the tunnel; and Scott McCannell, for his creative contribution to the document's layout, his attention to the details, his dedication to the project, and for bearing the brunt of it all.

We thank the individuals and agencies that supplied us with data for the case studies, including the Louisiana Department of Environmental Quality, the Washington Department of Ecology, the Illinois Natural History Survey, and the State Heritage Programs of Mississippi, Louisiana, Washington and Illinois. We also thank EPA Regions 4, 5, 6, and 10 for their cooperation and input.

Drs. Louis Iverson (Illinois Natural History Survey), Joseph Larson (University of Massachusetts-Amherst), Arnold O'Brien (University of Massachusetts-Lowell), and Paul Risser (University of New Mexico) served as official reviewers and provided many useful comments that improved this document. We also want to thank all those others who read through the draft manuscript and provided useful feedback. Of course, final responsibility for this document and its contents lies with the authors.

We would especially like to thank our colleagues in the Wetlands Division within the Office of Water for their early and enthusiastic support of the synoptic approach. John Maxted, now with the State of Delaware, was an early believer in the method and provided additional funding for the Louisiana and Illinois case studies. Doreen Robb has served as Wetlands Division liaison to the Wetlands Research Program (WRP), coordinating review and comments from the Office of Water and providing us with her own useful feedback and vision. We especially appreciate the support we have received on our landscape concepts from John Meagher, Wetlands Division Director, and David Davis, Deputy Director of the Office of Wetlands, Oceans and Watersheds.

Dr. Mary E. Kentula, acting WRP Program Leader, has been kind enough to provide administrative cover, allowing us to focus on completing this document. We appreciate her patience during this period.

Richard Sumner, WRP regional liaison, deserves special mention for his enthusiastic and tireless campaigning to promote the synoptic approach among the Regions. He has been responsible for acting as a "reality check" to make sure this work would be useful to the program. Also, he has been the motivating force behind our ideas on the use of best professional judgment.

Finally, we would like to acknowledge the earlier work and contributions of Dr. Eric M. Preston, Assistant Chief of the Watershed Branch and former WRP Program Leader, who started it all. In spite of the growth and evolution of the synoptic approach, it still includes many of his original ideas. Although we miss his direct involvement in this area, we look forward to his continuing influence through his work on biodiversity and habitat.

We were deeply saddened to learn of the death of Dr. Allan Hirsch as we were completing this document. Allan Hirsch was a visionary and leader in the field of environmental management, excelling in both science and policy arenas. He served as the first Director of Fish and Wildlife Service's Office of Biological Services, where his leadership established that office. He was subsequently Director of EPA's Office of Federal Activities, where he led the EPA Wetlands Program during an important period in its growth and maturation, and later was instrumental in establishing the Office of Wetlands Protection. Dr. Hirsch contributed to the Wetlands Research Program and to this report both directly and indirectly through his published ideas, by participating in an early WRP workshop on cumulative impacts, by serving as chairman of a Science Advisory Board review of WRP's five year research plan, and most recently by reviewing and commenting on the draft of this report. This document is dedicated to Allan's vision and legacy.

PREFACE

A 1987 study conducted by the Environmental Protection Agency (EPA) found that problems considered by experts to pose the most serious threat to the environment were not those targeted most aggressively by Congress or EPA (EPA 1987). A follow-up study by EPA's Science Advisory Board suggested ways in which EPA could reduce environmental risk, including a recommendation that EPA develop methods to improve our ability to assess and compare environmental risks (SAB 1990).

Given this challenge, the Wetlands Research Program (WRP) within EPA's Office of Research and Development has proposed a hierarchical, risk-based approach to wetland assessment that would allow evaluation at three different scales (Leibowitz et al. 1992): a site-specific scale, at which the function of individual wetlands is assessed; an intraregional scale, at which relative comparisons are made between wetlands within the same watershed (or similar landscape subunit); and an interregional scale, at which relative comparisons are made between landscape subunits by considering the aggregate characteristics of wetlands within those subunits. WRP's Wetland Function Project and Characterization and Restoration Project are primarily responsible for developing the site-specific and intraregional approaches, respectively. The Landscape Function Project is developing a method for making assessments at the interregional scale. The latter, known as the synoptic approach, is the subject of this document.

WRP originally developed the synoptic approach so that regulators could include information on cumulative impacts of wetland loss during review of permits for proposed discharges under Section 404 of the Clean Water Act. However, the approach also fits into the larger framework of risk assessment by providing managers a broad view of wetlands within a landscape context, and it can be used to assign priority to wetland protection or replacement efforts as part of a comprehensive wetland management program. Because the synoptic approach has not been tested in real management applications, it should be viewed as a proposed, rather than operational, methodology.

GLOSSARY

Active pool
The materials (including biota) or energy within a landscape that are actively being transferred between component ecosystems as opposed to materials or energy that are cycled or stored within an individual ecosystem.

Barrier
An ecosystem that inhibits material movement by excluding imports.

Best professional judgement
Making decisions based on personal experience when better information is unavailable. Best professional judgement is often used in day-to-day management decisions.

Capacity
The maximum amount of a particular material that an ecosystem can remove from the active pool were the material not limiting; also referred to as "assimilative capacity." Could be used more specifically, e.g., decomposition capacity. Also refers to one of the components of the function index.

Combination rule
A rule that specifies how two or more components of a synoptic index will be mathematically or logically combined.

Conduit
An ecosystem that assists the movement of materials through different parts of the landscape by transferring imports between ecosystems without altering the amount of material.

Conversion
Transformation of an ecosystem into a different ecosystem type or land use (e.g., conversion of a wetland for construction of a mall). Causes complete functional loss of the original ecosystem functions.

Creation
Building a wetland on an upland site, i.e., in a location where wetlands did not previously exist (compare with restoration).

Cumulative effects
The sum of all environmental effects resulting from cumulative impacts.

Cumulative impacts
The sum of all individual impacts occurring over time and space, including those of the foreseeable future.

Degradation
Partial functional loss caused by impacts that act on an ecosystem without causing conversion (e.g., reductions in productivity because of inputs of pesticides through nonpoint source pollution).

Disturbance
The action that causes ecosystem stress; includes actions caused by natural agents (e.g., hurricanes) and human impacts.

Drainage area
See "Watershed."

Ecological function
An aggregate behavior that arises from one or more physical, chemical, or biological processes.

Effect
A physical, chemical, or biological change in an ecosystem that results from an impact. The effect can be an immediate consequence of the impact (direct effect) or it can be removed in time and space (indirect effect).

Excess capacity
The difference between a sink ecosystem's capacity (the maximum amount of a material that the ecosystem can remove if the material is not limiting) and the actual amount of material removed. Excess capacity represents additional material that could be removed and is a form of redundancy that buffers an ecosystem from impacts.

Existing data
Data that were previously collected, usually for purposes unrelated to the current objective. Existing data must be used when time or money preclude the collection of new data. Also referred to as "available data."

Forcing functions

Materials and energy that drive an ecosystem. These materials and energy originate outside the ecosystem boundary, but over the long run drive most ecosystem processes. In the broadest sense, forcing functions can be natural or anthropogenic in origin. Also referred to as "driving factors."

Function

One of the four synoptic indices; refers to the total amount of some function provided by one or more ecosystems within a landscape without consideration of benefits. Capacity and input are components of function.

Functional loss

One of the four synoptic indices; refers to the complete or partial loss of one or more ecological functions as a result of impacts.

Fragmentation

The break-up of an extensive ecosystem into a number of smaller patches.

Habitat function

Ecological processes that, when taken together, provide support (food, shelter, breeding sites, etc.) for different species.

Home range

The area around an organism's home typically used for feeding.

Hydrologic function

Ecological processes that, when taken together, somehow moderate hydrology; e.g., reduce flood peaks, recharge aquifers, etc.

Impact

A human-generated action or activity that either by design or by oversight alters the characteristics of one or more ecosystems.

Index

See "Synoptic Index."

Indicator

See "Landscape Indicator."

Input

The total amount of material imported into sink ecosystems from one or more sources. Also referred to as "landscape input." Can also refer to one of the components of the function index.

Landscape ecology

The study of interactions between ecosystems.

Landscape indicator

The actual data or measurements used to estimate a synoptic index; in the synoptic approach, a landscape indicator is usually a first-order approximation based on existing data.

Landscape subunit

The basic subdivision of a landscape for which synoptic indices are calculated; a synoptic assessment provides a comparison of landscape subunits. Landscape subunits could be defined environmentally (e.g., watersheds or ecoregions), politically (e.g., counties or conservation districts), or by other criteria.

Landscape

"A heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout" (Forman and Godron 1986). A landscape is normally defined by geomorphology or climate. The study boundary for a synoptic assessment need not include the entire landscape.

Landscape unit

The specific landscape or portion of a landscape for which a synoptic assessment is conducted. The landscape unit can be larger than the study unit because it can contain forcing functions that are outside of the study unit.

Metapopulation

The combined population of all ecosystem patches that are connected by movement of individuals. The metapopulation contributes to the redundancy of a landscape.

Patch

An irregularly shaped ecosystem embedded within a larger "matrix" ecosystem.

Patch distance

The distance between two patches or, more generally, the average distance between patches in an area.

Process

A basic physical, chemical, or biological transformation within an ecosystem which, in aggregate, defines ecosystem functions.

Project-specific application

The use of a synoptic assessment to provide a landscape context for a subunit that has been preselected based on independent criteria (compare with regional comparison).

Redundancy

The ability of an ecosystem to perform functions in more than one way, or an excess capacity or structure beyond what is normally needed. Redundancy buffers an ecosystem from impacts.

Regional comparison

The use of a synoptic assessment to determine which subunits within a region best meet some specific criteria (compare with project-specific application).

Replacement potential

One of the four synoptic indices; refers to the degree to which a wetland and its valued functions can be replaced by creation or restoration. Specifically refers to the landscape characteristics as opposed to on-site characteristics that control replacement.

Resilience

The ability of an ecosystem to return to predisturbance levels of function.

Resistance

The ability of an ecosystem to resist loss of function as a result of a disturbance.

Response

The long-term physical, chemical, and biological changes that result indirectly from stress.

Restoration

Building a wetland on a non-upland site in a location where a wetland previously existed (compare with creation).

Risk assessment

An evaluation of environmental risks associated with human actions.

Section 404

The portion of the Clean Water Act that specifies that a permit must be obtained to discharge dredged or fill materials into waters of the United States.

Sink ecosystem

An ecosystem that causes a net decrease in the total amount of a material being transferred within the landscape; this occurs if exports are less than imports (compare with source ecosystem). The status of an ecosystem as a source or sink depends upon the particular material.

Source ecosystem

An ecosystem that causes a net increase in the total amount of a material being transferred within the landscape; this occurs if exports are greater than imports (compare with sink ecosystem). The status of an ecosystem as a source or sink depends upon the particular material.

Stress

The immediate physical, chemical, and biological changes that result from a disturbance.

Stressor

Same as a disturbance.

Structure

The collection of an ecosystem's physical, chemical, and biological characteristics. Structure is built from energy and raw materials.

Study unit

The actual geographic boundary of a synoptic assessment. May be based on political (e.g., a state) or environmental (e.g., a geological province) criteria.

Synoptic approach

A five step approach to assessing cumulative impacts or environmental risk, as described in this document, that provides a broad overview of environmental and landscape factors.

Synoptic assessment

The process of following the five steps of the synoptic approach in order to produce a set of maps, data, and reports that can be used to assess cumulative impacts or environmental risk.

Synoptic index

A landscape variable that is used in a synoptic assessment as a basis for comparing landscape subunits. There are four general synoptic indices (function, value, functional loss, and replacement potential); in an actual assessment, a specific index would be defined for one or more of the general indices.

Systems ecology

The study of ecological systems (ecosystems), including their response to stress.

Travel distance

The maximum distance an organism can travel in order to reach suitable habitat. An organism cannot travel to a different patch if the patch distance is greater than the travel distance.

Value

One of the four synoptic indices; refers to the benefits obtained by individuals or society from an ecological function. Could include benefits received indirectly, i.e., when the function acts on something of value (e.g., flood reduction is valuable because it reduces loss of life and loss of valued property).

Water quality function

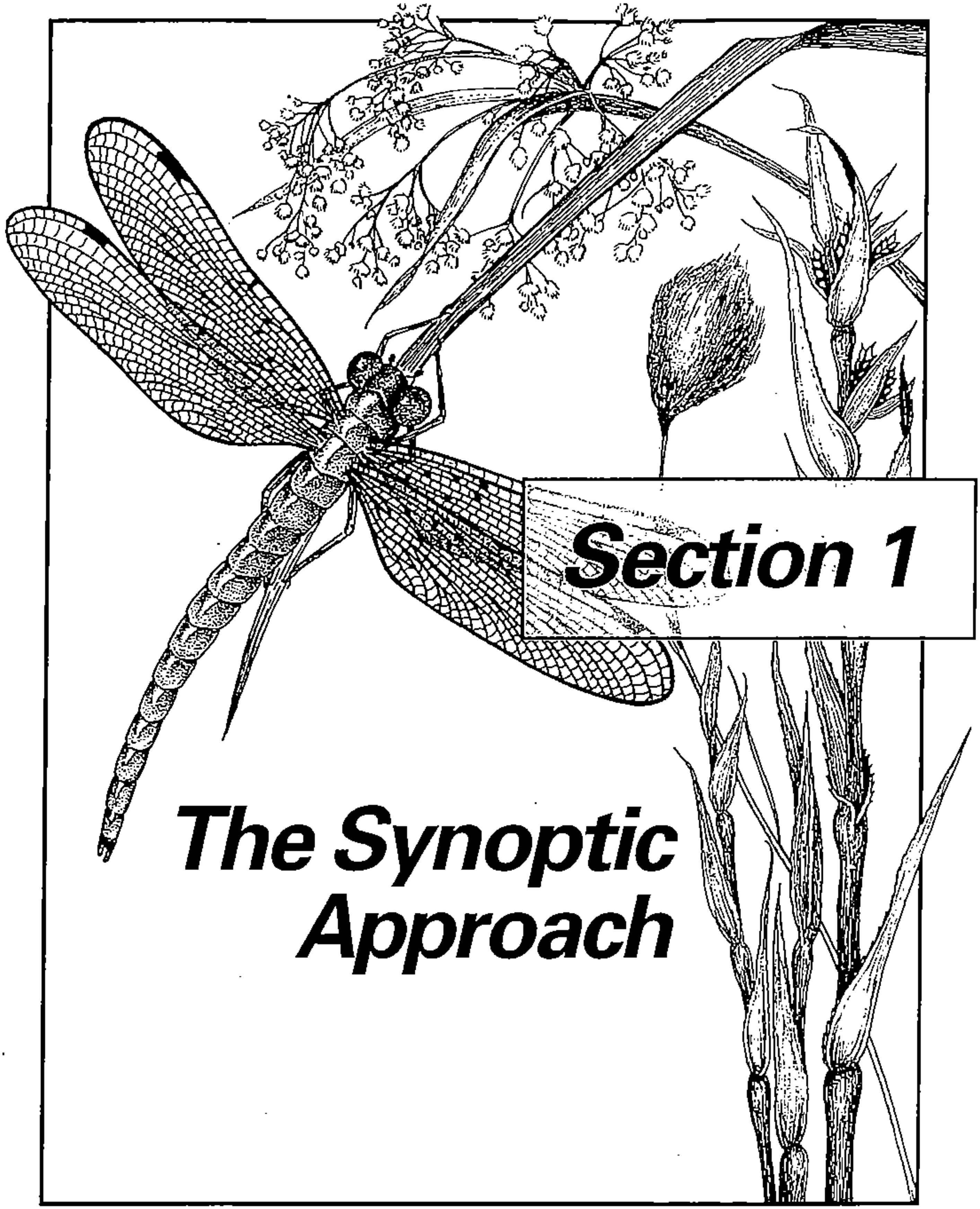
Ecological processes that, when taken together, improve water quality; e.g., reduce pollutant concentrations, contribute to nutrient cycling, etc.

Watershed

A natural drainage unit defined by topographic high points within which the only input of water is precipitation. Used analogously with drainage area, although the latter is more properly defined relative to some specific point; e.g., the drainage area for some particular point on a river includes all the area that collects precipitation that is ultimately routed through that point on the river.

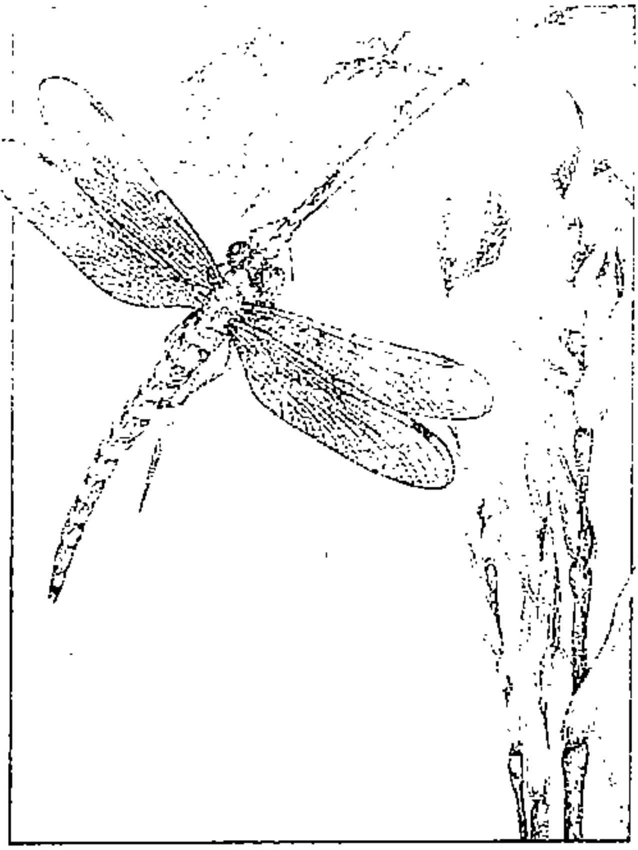
Wetland

Any ecosystem characterized by the presence of water; unique soils compared with adjacent uplands; the presence of vegetation adapted to wet conditions; and the absence of flood-intolerant vegetation (Mitsch and Gosselink 1986). In a more limited sense, used to specifically refer to those wetlands that are included under Section 404 of the Clean Water Act ("jurisdictional wetlands").



Section 1

The Synoptic Approach



Chapter 1
Introduction

This report provides resource managers and technical staff with an approach for evaluating the cumulative environmental effects of individual human impacts on the environment, particularly with respect to wetlands. This document is intended to give the reader a general understanding of cumulative impacts and to describe how a synoptic assessment is produced. Although specifically designed for use in wetland permit evaluation under the Clean Water Act (CWA), this method can be applied to cumulative impact assessment in general[1]. A second objective of this report is to encourage resource managers responsible for wetland protection to consider and view wetlands within a landscape context.

The synoptic approach, so named because it provides a broad overview of the environment, was developed specifically for cases in which time, resources, and information are limited. The method is not intended to provide a precise, quantitative assessment of cumulative impacts *within* an area, nor can it be used to assess the cumulative effects of specific impacts. Rather, it provides a relative rating of cumulative impacts *between* areas. The approach is intended to be easily applied so it can augment the best professional judgment used daily by wetland managers and regulators.

This report is divided into two sections. Section 1 describes the method and illustrates its use. It defines cumulative impacts, reviews the regulatory basis for cumulative impact assessment, and introduces the Wetland Research Program's (WRP's) synoptic approach (Chapter 1). It also provides the ecological basis for the synoptic indices (Chapter 2), describes in detail how to conduct a synoptic assessment (Chapter 3), illustrates the method's use and several possible applications through four case studies (Chapter 4), and contains a summary that discusses future directions (Chapter 5). Section 2 contains detailed background material for readers interested in additional information. It includes a discussion of environmental stress (Chapter 6) and a review of wetland functions and the effects of impacts on these functions (Chapter 7).

Cumulative Impacts

Traditionally, impact assessment has evaluated the likely effects of a single action on the environment. There has been concern, however, that numerous activities considered insignificant by themselves could, when taken together, cause significant degradation and damage to

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[1] Because of its general nature, the synoptic approach is not limited to legally defined (i.e., "jurisdictional") wetlands. We therefore define wetlands in the broadest sense, as those ecosystems that are characterized by: the presence of water; unique soils, compared to adjacent uplands; the presence of vegetation adapted to wet conditions; and an absence of flood-intolerant vegetation (Mitsch and Gosselink 1986).

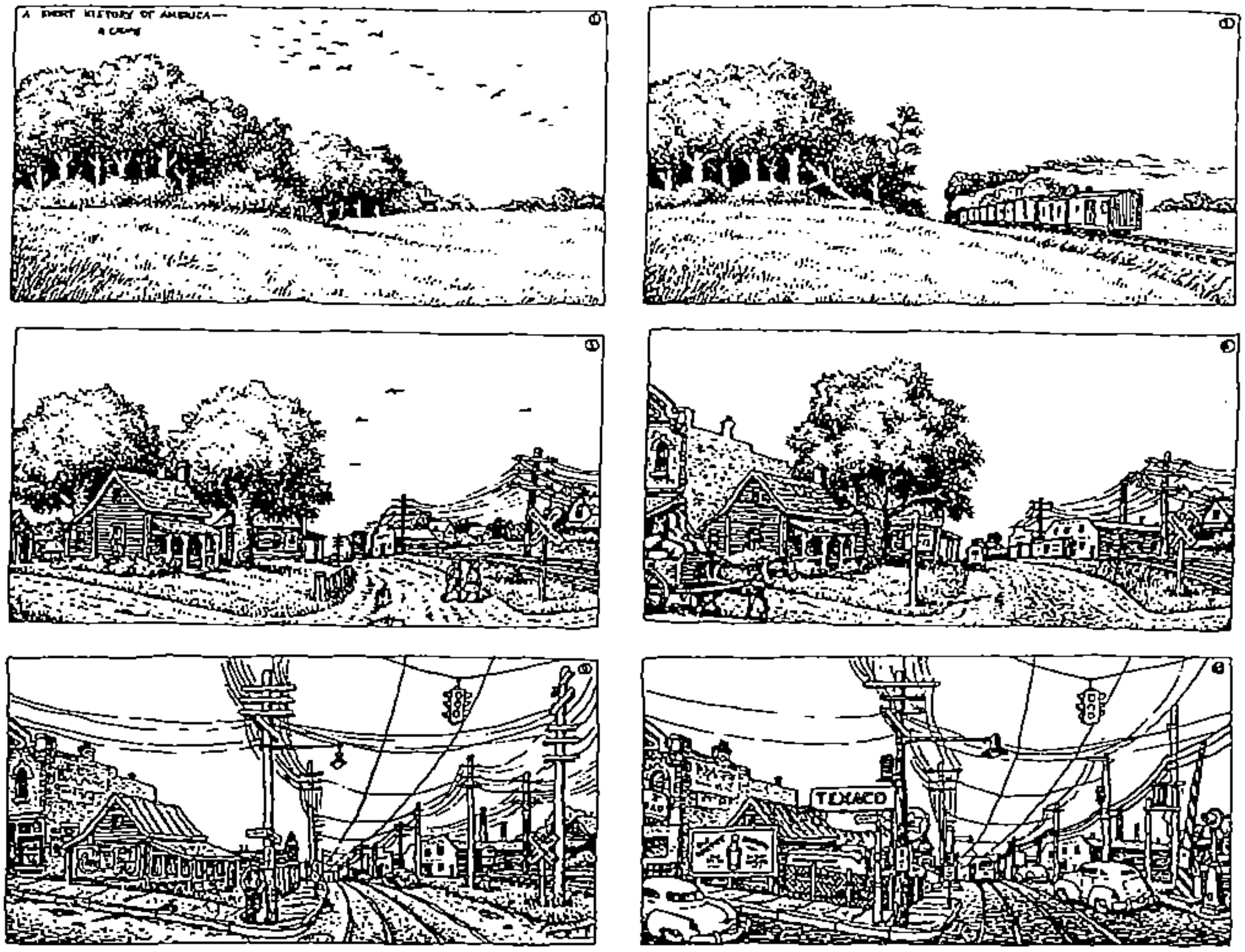
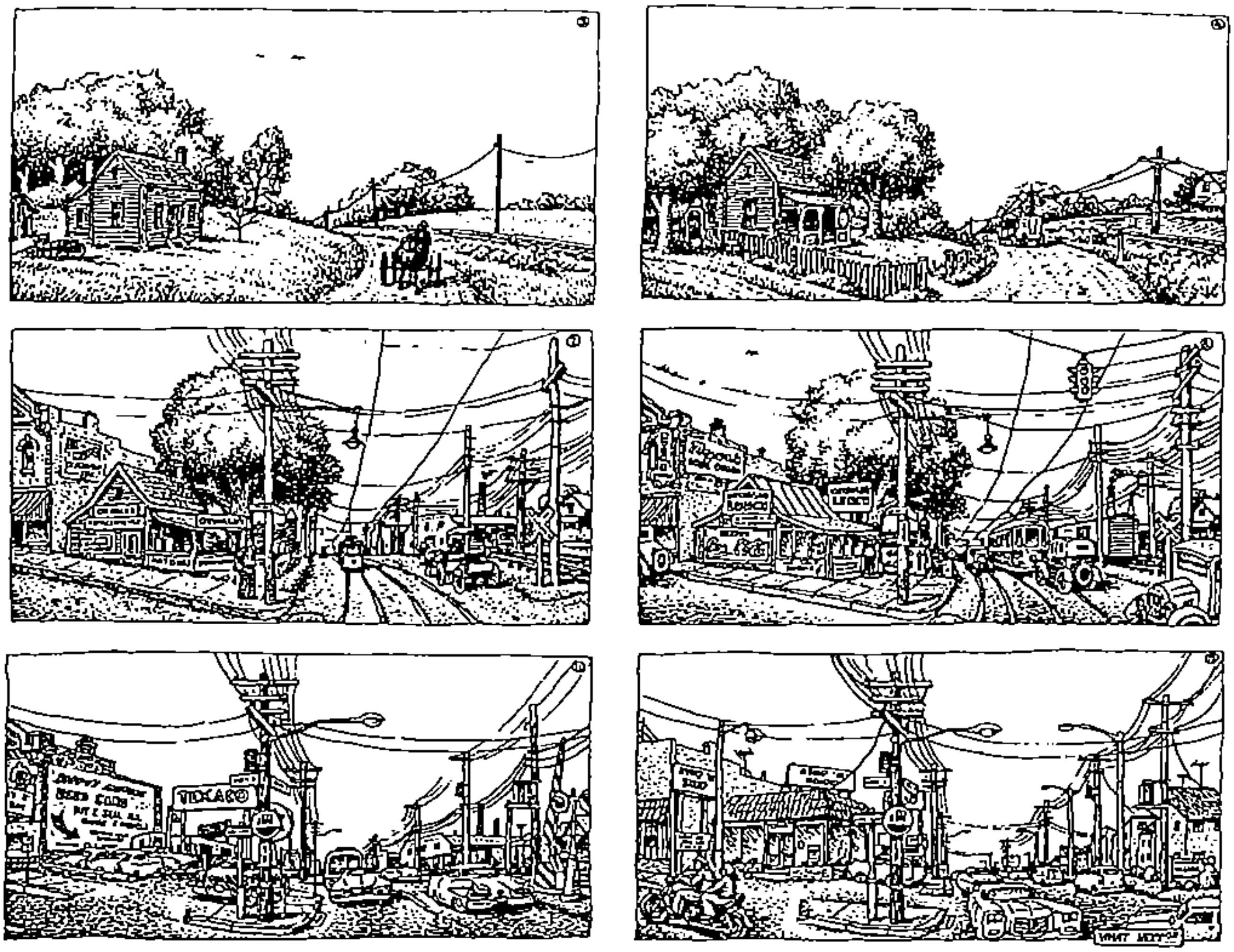


Figure 1.1. "A Short History of America," by the cartoonist R. Crumb, graphically illustrates cumulative impacts over time. Although none of the individual impacts would have been expected to significantly damage the environment, the cumulative result is a major loss of environmental functions (from CoEvolution Quarterly No. 23, Fall 1979, © R. Crumb 1992).

the environment (Kahn 1966; Odum 1982). An analogy provided by Ehrlich and Ehrlich (1981) illustrates this concept. If a single rivet pops out of a jet's wing, no serious threat exists, because no one rivet contributes significantly to the plane's airworthiness. But if enough rivets are lost, the integrity of the plane's structure gradually weakens until a failure occurs. In this analogy, the cumulative effect of the individually minor impacts would be catastrophic. In the same manner, a conventional impact analysis might conclude that a single discharge into a wetland would not amount to significant impact and would therefore be acceptable. However, an assessment that ignores the combined effect of these cumulative impacts could seriously underestimate the extent of environmental damage (Figure 1.1), thereby frustrating policy and management goals (Irwin and Rodes 1992).

A major difference between traditional impact assessment and cumulative impact assessment is that the former is performed with respect to the proposed *disturbance*. Cumulative impact assessment is performed with respect to valued environmental *functions* (Beanlands and Duinker 1983; Preston and Bedford 1988). Cumulative impact assessment must therefore take a holistic view of the environment. An excellent overview of cumulative impacts and wetlands is given in a special volume edited by Bedford and Preston (1988a) that includes a review of regulatory issues and the status of scientific understanding of cumulative impacts with respect to hydrology, water quality, and wildlife. This volume is highly recommended for readers interested in a more in-depth treatment of the subject.



Regulatory Mandate

Regulations prepared by the Council on Environmental Quality under the National Environmental Policy Act require environmental impact statements to "anticipate a cumulatively significant impact on the environment from Federal action"[2] (38 CFR Sect. 1500.6). A cumulative impact is defined as:

> "...the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." (40 CFR Sect. 1508.7)

Under CWA Section 404, permits must be obtained to discharge dredged or fill material into waters of the United States, which include most wetlands. The CWA Section 404(b)(1) guidelines contain the criteria that are used in evaluating a permit for a proposed discharge. These regulations, promulgated by the Environmental Protection Agency (EPA) in conjunction with the Army Corps of Engineers, call for consideration of cumulative impacts (40 CFR 230.11):

> "[1] Cumulative impacts are the changes in an aquatic ecosystem that are attributable to the collective effect of a number of individual discharges of dredged or fill material. Although the impact of a particular discharge may constitute a minor change in itself, the

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[2] "Federal action" has been interpreted to include any action regulated by the federal government.

cumulative effect of numerous such piecemeal changes can result in a major impairment of the water resources and interfere with the productivity and water quality of existing aquatic ecosystems.

[2] Cumulative effects attributable to the discharge of dredged or fill material in waters of the United States should be predicted to the extent reasonable and practical. The permitting authority shall collect information and solicit information from other sources about the cumulative impacts on the aquatic ecosystem. This information shall be documented and considered during the decision-making process concerning the evaluation of individual permit applications, the issuance of a General Permit, and monitoring and enforcement of existing permits."

Regulatory Context

If a proposed discharge involves a major or controversial action, permit evaluation requires extensive information and may include collection of field data and even an Environmental Impact Statement (Hirsch 1988). However, most of the permit requests received each year are for minor, routine actions. Because of the large number of requests and the limited amount of time and staff, a simpler environmental assessment must be conducted, based upon existing information.

There are a number of methods for evaluating cumulative impacts (Appendix A); however, none of these are practical within the regulatory constraints of Section 404. Although the concept of cumulative impacts is intuitive enough to have influenced the guidelines for permit evaluation, the lack of an easily applied method makes it difficult to consider cumulative impacts as part of routine permit decisions (Preston and Bedford 1988). Therefore, regulators must often rely on best professional judgment in order to comply with the 404(b)(1) guidelines. A major goal of EPA's Wetlands Research Program has been to provide permit reviewers with an easily applied technical approach for assessing cumulative impacts.

Our current understanding of the environment and our lack of data make it impossible to provide a precise, quantitative evaluation of the effects that cumulative wetland losses will have in a specific region or to predict how additional wetland losses will add to those effects. However, our understanding of ecological processes in general, and wetlands in particular, should be sufficient for us to make qualitative comparisons of these effects between different areas. For example, we may not be able to say that the cumulative loss of 100 hectares of wetland within a particular area caused a 10% reduction in water quality; however, we should be able to say that a 100 hectare loss of wetland in area "A" will more likely cause a reduction in water quality than a similar loss in area "B". The synoptic approach is a response to Hirsch's (1988) call for "simple protocols, analytical procedures, or logic flows, and some *do's and don'ts* or rules of thumb" that can augment the site-specific permit review process and improve in best professional judgment (Figure 1.2). Managers can use this approach to evaluate cumulative impacts until more rigorous research provides better alternatives.

The Synoptic Approach

The synoptic approach is an inexpensive, rapid assessment method that can assist managers and regulators in evaluating cumulative impacts within the regulatory constraints of tight schedules and budgets. Although research on the loss of wetland function is far from complete, the synoptic approach can support development of the best possible management strategies based on current knowledge.

Using the synoptic approach, wetland managers will be able to produce regional or statewide maps[3] that rank portions of the landscape according to synoptic indices. These maps and indices will enable permit reviewers to consider the landscape condition of the area in which a particular permit is proposed compared with other areas within their jurisdiction. By providing the environmental context in which wetlands occur, the maps also will allow wetland managers to examine wetland issues more comprehensively. Further, because the assessment is prepared at the same time for an entire state or region and not on a permit-by-permit basis, using this method will save time and money.

The synoptic approach consists of five steps (Table 1.1). Two major steps are definition of synoptic indices and selection of landscape indicators. The synoptic indices represent the actual functions and values within the particular environmental setting of interest. The landscape indicators are the actual data used to represent these indices. Choosing indicators often requires making simplifying assumptions because of limited information, time, and money. For example, agricultural area as measured from a land-use map could be a landscape indicator for agricultural nonpoint source nutrient loading, which would be the synoptic index for that particular management concern. The synoptic index and landscape indicator are defined separately to

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[3] The end product of a synoptic assessment need not be a set of maps, but could consist solely of tabular data summaries. However, we believe that presentation as maps is more appropriate for the intended use, and gives a "big picture" overview that tables cannot provide.

keep them distinct, so we remember that agricultural area is not the management concern; it is only useful to the extent to which it represents nonpoint source nutrient loading.

The synoptic approach is flexible enough to cover a broad spectrum of management objectives and constraints. The specific synoptic indices and landscape indicators used in an application depend on the particular goals and constraints of the assessment. They also depend on the actual environmental setting. However, *this handbook does not provide a specific, detailed procedure for choosing the synoptic indices, nor does it supply a scientifically-tested list of landscape indicators having known confidence limits.* This is not possible, given our current state of knowledge and the strong dependency of the synoptic indices and landscape indicators on the particulars of the assessment. Instead, *the approach relies on the assessment team to make decisions, since they are best qualified to know their particular needs and constraints.* The synoptic approach provides the user with an ecologically-based framework in which local information and best professional judgment can be combined to address cumulative impacts and other landscape issues.

The synoptic approach is not a fixed procedure that always uses the same data sources and provides a standard end product. Rather, a synoptic assessment is a creative process that requires the manager to weigh the need for precision—as determined by management objectives—against the constraints: limited time, money, and information. An initial synoptic assessment could be conducted using the best available information and then updated as better data become available.

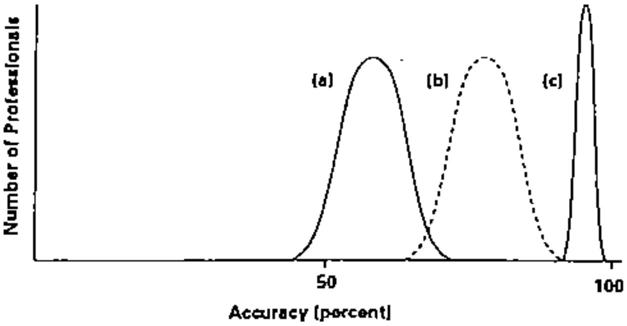
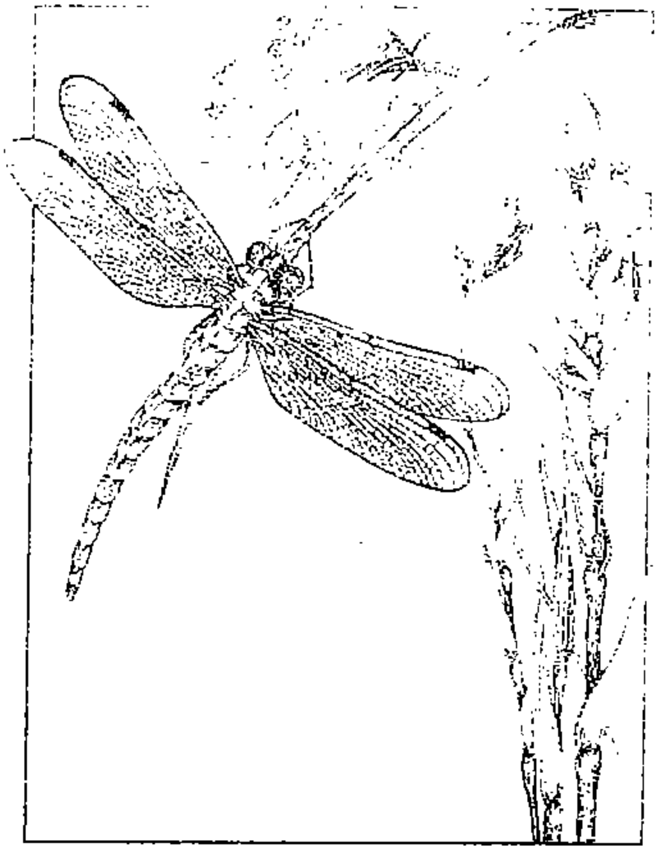


Figure 1.2. Improving best professional judgment (BPJ). "a" represents the hypothesized accuracy of BPJ under current conditions; most professionals probably give correct answers more than 50% of the time, and the most experienced professionals may be fairly accurate. However, the least experienced professionals may do worse than the flip of a coin, i.e., their answers may be wrong more often than right. A precise, quantitative assessment would greatly improve the accuracy of BPJ ("c") and reduce variability. However, such an assessment could be impractical within a regulatory context. The synoptic approach is a compromise that can be implemented within regulatory constraints and yet still improve the accuracy of BPJ ("b").

Table 1.1. Major steps in conducting a synoptic assessment.

Step 1.	Define Goals and Criteria
Step 2.	Define Synoptic Indices
Step 3.	Select Landscape Indicators
Step 4.	Conduct Assessment
Step 5.	Prepare Synoptic Reports



Chapter 2

Ecological Basis for the Synoptic Indices

The synoptic approach provides a framework for making comparisons between landscape subunits[1] so cumulative impacts can be considered in management decisions. Comparisons are made by evaluating one or more landscape variables, or ***synoptic indices***, for each subunit. Defining the proper synoptic indices for a particular assessment is a critical step and depends on the environmental setting and the specific goals of the assessment. In this chapter, we provide an overview and rationale for the synoptic indices, drawing on concepts from three disciplines: ***systems ecology***, or the study of ecological systems (ecosystems), including their response to stress; ***landscape ecology***, which examines the interactions between ecosystems; and ***risk assessment***, which evaluates environmental risks associated with human actions.

Rationale for a Landscape Approach

The purpose of a cumulative impact assessment is to evaluate the cumulative environmental response to various impacts. Because no standard usage exists for the term, we define ***impact*** as a human-generated action or activity that either by design or by oversight alters the characteristics of one or more ecosystems; ***cumulative impacts*** are the sum of all individual impacts occurring over time and space, including those of the foreseeable future. We define ***effects*** as the physical, chemical, and biological changes that result from an impact, including direct and indirect changes that can be removed in time and space. ***Cumulative effects***, then, are the sum of all these changes resulting from cumulative impacts.

In conducting a cumulative impact assessment, we are particularly concerned with the loss of valued functions. These ***ecological functions*** are aggregate behaviors that arise from the many physical, chemical, and biological processes that take place in the environment. For example, whether a wetland reduces flood peaks depends on the processes that determine the wetland's hydrologic budget, e.g., precipitation, evapotranspiration, surface and groundwater inflows and outflows, and tidal input (Mitsch and Gosselink 1986).

Because an impact can affect more than one ecosystem and because an ecosystem can be affected by activities outside its boundaries, an assessment of cumulative impacts cannot be limited to a single ecosystem. Also, many ecological functions valued by society depend on interactions between ecosystems; they are more properly viewed as landscape functions, rather than ecosystem functions. For example, the water quality of a river is not determined by any one ecosystem but by

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[1] Examples of possible subunits are counties, watersheds, and ecoregions; selection of subunits as part of a synoptic assessment is discussed in Chapter 3.

the aggregate effect and interaction of all ecosystems within its drainage area. The landscape is an appropriate unit for considering cumulative impacts, especially since landscape factors partially determine an ecosystem's response to cumulative impacts. For example, the survival of organisms following disturbance can depend on landscape characteristics such as corridor quality (Henein and Merriam 1990) and the degree of habitat fragmentation (Merriam and Wegner 1992; Stacey and Taper 1992).

Synoptic indices allow us to evaluate overall wetland condition for a particular landscape subunit through comparison with other subunits. Because the approach is not intended to provide a detailed landscape assessment, we must simplify and generalize our view of the landscape to ensure that relevant factors are included. The synoptic indices are therefore based on a simple model that describes ecosystem functions within the landscape and includes the effect of impacts on these functions. Because the focus of an assessment is *valued* ecological functions, concepts of risk assessment are also incorporated.

Landscape Model of Ecosystem Function

Forman and Godron (1986) have defined a landscape as "a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout." Wetlands, forests, lakes, and streams are examples of such ecosystems. Interactions occur through transfers of energy and material — including nutrients, minerals, and organisms — between ecosystems. A landscape can be viewed as a portion of the environment composed of ecosystems within which materials and energy are transferred as a result of various ecological processes. To further simplify this view, we will consider these ecosystems only as they affect the transfer of materials within and through the landscape.

At any time, a landscape contains a pool of materials[2] and energy being transferred between component ecosystems (as opposed to being cycled or stored *within* individual ecosystems). This dynamic state can be described by the aggregate flow of these materials within and through the landscape; it also includes the processes that drive or are controlled by these flows. Landscape functions result from these interactions, as in the earlier discussion of the effect of drainage area on river water quality. Ecosystems contribute to landscape functions by affecting (1) the quantity of transferred material, i.e., either increasing or decreasing the active pool; (2) the quality of the material, i.e., transforming it into different forms; or (3) the timing of material transfers, e.g., introducing a temporal lag in transfers or altering transfer rates.

From the simplest perspective, each component ecosystem can be considered to function as either a source or a sink for a given material. An ecosystem is a *source* if it causes a net increase in the total amount of material being transferred within the landscape (i.e., exports from the ecosystem are greater than imports into it); it is considered a *sink* if it causes a net reduction in the material flux[3]. We define these terms in the broadest sense, without regard to the specific processes responsible for the functions. For example, an ecosystem could function as a sink through biochemical conversion, filtration (e.g., removal of suspended materials from water as it passes through clays), or trapping (e.g., settling out of particulates from water). In the case of biological materials, an ecosystem would be a sink if emigration were less than immigration, which could occur if the death rate exceeded the birth rate (MacArthur and Wilson 1967; Pulliam 1988).

Because our definition of a sink is independent of causative processes, an ecosystem that induces a net transfer of materials to on-site storage would also be considered a sink since this would lead to a net reduction in the pool of materials. Conversely, an ecosystem that removes material from storage and returns it to the pool acts as a source. For example, a riparian forest acts as a sink where stream velocities are low and sediment storage increases through deposition; however, it acts as a source if high current velocities cause bank erosion, thereby removing sediment from storage (Pinay et al. 1992).

A landscape model that describes an ecosystem as either a source or a sink can easily account for the effect ecosystems can have on the quantity of transferred materials. When the status of the ecosystem as source or sink is dynamic, the model can also account for qualitative and timing effects. For example, an ecosystem that converts nitrate to molecular nitrogen through denitrification (a qualitative effect) would be described as a sink for nitrate and a source for molecular nitrogen. An ecosystem that stores water below ground during spring runoff functions as a sink at that time of year, then as a source during summer and fall, when it slowly releases the water from storage.

The ability and degree to which an ecosystem functions as a source or a sink is controlled by on-site conditions, such as local hydrology and geomorphology, soil and vegetative characteristics, nutrient availability, and population densities. However, an ecosystem with the potential to reduce material flows could not function as a sink if the particular material was unavailable. In

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[2] We define materials broadly to include biotic and abiotic materials.

[3] An ecosystem could be neither a source nor a sink if exports are equal to imports. Such an ecosystem would be neutral with respect to changes in the magnitude of landscape flows. However, such an ecosystem could still affect the distribution of materials; see Chapter 6.

other words, an ecosystem can reduce the pool of active landscape materials only if it is connected to at least one source. Thus the ability of an ecosystem to function as a sink depends on two factors: the ***assimilative capacity***, which is the amount of material the ecosystem could remove, assuming it was available; and ***landscape input***, which is the amount of material imported into the ecosystem from source ecosystems[4]. While capacity is controlled by characteristics *within* the ecosystem, landscape input is determined by interactions *between* ecosystems and depends on (1) the magnitude of the various sources, (2) where these sources are located relative to the target ecosystem, (3) the transport mechanism of the particular material (e.g., passive diffusion, wind-borne dispersion, gravity flow, or migratory movement in animals), and (4) the occurrence of any sinks along the transfer pathway.

Phosphorus retention by a wetland is one example of how capacity and landscape input control sink functions. A wetland's capacity to retain phosphorus depends on factors such as plant uptake; the concentrations of minerals that precipitate phosphorus (e.g., ferric iron and aluminum); soil pH, which affects phosphorus solubility; and adsorption to soil constituents such as clays and organic matter (Mitsch and Gosselink 1986). The landscape input of phosphorus into the wetland depends on the types of neighboring ecosystems, land-use practices outside the wetland (e.g., fertilizer application rates), and landscape characteristics that control sedimentation rates into the wetland, such as slope.

According to the model we have been describing, the landscape is a collection of source and sink ecosystems embedded within a matrix of neutral ecosystems. Although this is somewhat simplistic and ignores actual processes, simplifying the overwhelming complexity of a real landscape is necessary if overall function is to become understandable. This model allows us to visualize the landscape as a dynamic network of interacting ecosystems, each of which can affect the quantity, quality, and timing of the materials transferred within the landscape. It also provides a framework that allows us to consider the effect of impacts on landscape function.

Effect of Impacts on Landscape Function

It is important to differentiate between an activity (the impact) and the ecological response to it (the effect), because many environmental regulations target activities (e.g., discharge of dredge and fill materials under CWA Section 404). Numerous ecosystem characteristics could be altered by an impact. Lugo (1978) developed a generic model that described five ways in which an ecosystem could be stressed. We further aggregate these to define three general types of impact based on the type of characteristic being altered (Figure 2.1):

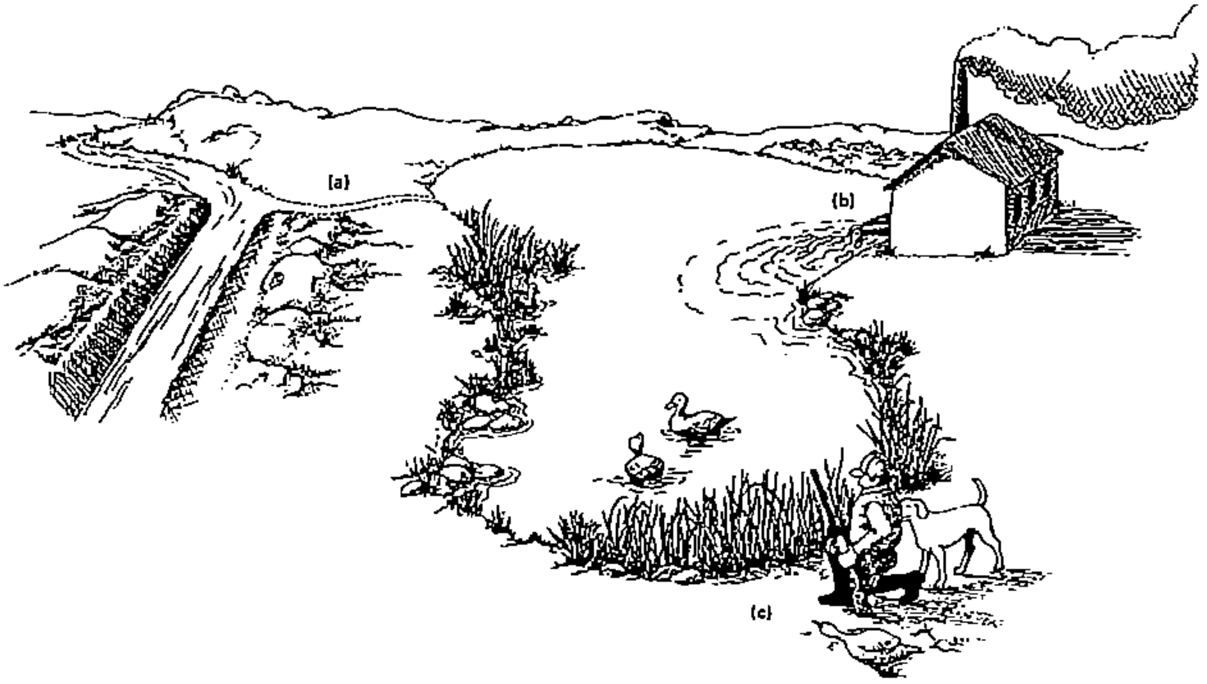

Figure 2.1 Generic model of ecosystem impacts. An impact can affect external driving factors (forcing functions) before they cross the ecosystem boundary, e.g., hydrologic diversion (a); an impact can affect ecosystem processes, e.g., discharge of industrial pollutants that alter productivity (b); and an impact can alter ecosystem structure, e.g., harvesting wildlife through hunting (c).

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[4] As defined here, the capacity is the net amount of material that can be removed, after accounting for removal of on-site material. If gross capacity is preferred, landscape input would have to include on-site production.

- Changes in forcing functions — Ecosystems are ultimately driven by material and energy flows that originate outside their boundaries. These driving factors are referred to as *forcing functions*. For example, sunlight is the ultimate forcing function for most ecosystems, and hydrologic input (in the form of surface water, groundwater, or tides) is an important driving factor for wetlands. Forcing functions can be diverted or reduced in magnitude, or the timing can be changed. New forcing functions to which the system is not adapted can be introduced, or the magnitude of an existing factor can be increased beyond its natural range.
- Changes in ecosystem process — Processes such as production or respiration can be stimulated or depressed, and material or energy distribution within the ecosystem can be altered.
- Changes in structure — *Structure*, built from energy and raw materials, is the collection of an ecosystem's physical, chemical, and biological characteristics. Biological examples of ecosystem structure include the various organisms, their complex behaviors, trophic relationships between organisms, seed banks that maintain biodiversity, and even dead matter. Physical structure includes concentrations of raw materials, such as lake water. Examples of structural impacts include harvesting of organisms by hunting or farming, introduction of domestic species not naturally present, reductions in water level through drainage, and destruction of soil structure by compaction.

In general, ecosystems affected by stress exhibit the following properties (Odum 1985): (1) internal material cycling is reduced, (2) the community reverts to earlier successional stages, (3) efficiency of resource use declines, and (4) parasitism increases. In stressed ecosystems, native species can be replaced by opportunistic species; this is especially significant in wetlands, where invasion by weedy species such as purple loosestrife can alter community structure (Wilcox 1989).

Not only does the environment respond to individual impacts, it also responds to them cumulatively. Examples of cumulative impacts and cumulative effects appear in Table 2.1. Bormann (1987) described seven stages of ecosystem stress, ranging from insignificant effects at low levels of pollution to complete ecosystem collapse under continued, severe pollution (Table 2.2). Although based on air pollution, these seven stages could represent a general model of ecosystem response to cumulative impacts. From a landscape perspective, the ultimate consequence of these changes is a loss of ecosystem function. This translates into a change in the ability of an ecosystem to act as a source or a sink either quantitatively (an increase or a decrease in the existing level of function) or qualitatively (e.g., a change from source to sink or vice versa).

The boundaries for cumulative impacts and cumulative effects need not coincide. Some cumulative effects could occur outside a cumulative impact boundary; conversely, cumulative effects within an area could partially result from impacts occurring outside the boundary. If the objective is to determine the cumulative effects within a specific area, a larger boundary must be defined that includes impacts to external forcing functions.

Synoptic Indices

Based on these principles, we define four synoptic indices for assessing cumulative impacts and relative risk: function, value, functional loss, and replacement potential. These indices are landscape-level measures, so each is evaluated for an entire landscape subunit, rather than for an individual component ecosystem. Although the indices are generic and could be applied to any ecosystem type, we discuss each as it applies specifically to wetlands. The hierarchical evaluation of these indices as part of a risk assessment can be found in Leibowitz et al. (1992).

Table 2.1. Typology of cumulative impacts and cumulative effects (after Beanlands et al. 1986).

Cumulative Impact	Description
Time-crowded Perturbations	Disturbances that are so frequent in time that the ecosystem does not have the chance to recover between disturbances
Space-crowded Perturbations	Disturbances that are so close in space that their effects overlap
Cumulative Effect	**Description**
Synergisms	Interaction of different types of disturbance to produce a response that is qualitatively and quantitatively different than the separate effects combined
Indirect Effects	Effects that are produced through a complex pathway and that are removed in time and/or distance from the initial disturbance
Nibbling	Simple additive effects that result from cumulative impacts

Table 2.2. Model of ecosystem response to increasing stress (adapted from Bormann 1987).

Stress Level	Ecosystem Response
Insignificant	Insignificant
Low levels	Relatively unaffected; ecosystem may function as a sink
Levels inimical to some species	Changes in competitive ability of sensitive species; selection of resistant genotypes; little effect on biotic regulation
Increased stress	Resistant species substitute for sensitive ones; some niches opened for lack of substitutes; biotic regulation may be disrupted, but may return as system becomes wholly populated by resistant species
Severe levels	Large plants, trees, shrubs of all species die off; ecosystem converted to open-small shrubs, weedy herb system; biotic regulation severely diminished; increased runoff, erosion, nutrient loss
Continued severe stress	Ecosystem collapse; completely degraded ecosystem; ecosystem seeks lower level of stability with much less control over energy flow and little biotic regulation

Function

Wetlands are capable of performing various functions as a result of physical, chemical, and biological processes. These functions can be divided into three general categories:

- Habitat functions—Providing support for wetland-dependent species, including food, shelter, and breeding sites;
- Water quality functions — Water quality improvement, nutrient cycling and supply; and
- Hydrologic functions—Flood attenuation and moderation of hydrologic flow.

The *function* index refers to the total amount of a particular function a wetland provides within a landscape subunit *without consideration of benefits*. The index is the rate at which material or energy is added to or removed from the active landscape pool. In the case of a sink function, the index is separated into two components[5]: *capacity*, which is the maximum net amount of material that could be removed by a subunit's wetlands if the supply of material were unlimited; and *landscape input*, or the total amount of the material imported into wetlands from contributing sources.

Value

Environmental regulations such as the Clean Water Act consider both ecosystem functions and their impact on public welfare (Preston and Bedford 1988; Westman 1985); thus we identified *valued* ecological functions as the target of a cumulative impact assessment. Wetlands can be valued for the tangible benefits they provide, such as clean water or hunting, or for intangible benefits such as aesthetics. However, values are highly subjective, and a wetland characteristic valued by one individual could be perceived as a liability to another. Even when the wetland provides a service that benefits the individual (such as improved water quality), the service could be undervalued because of poor information or conflicting goals.

Whether a particular ecological function is considered valuable is not a technical issue, but must be determined by the policy maker initiating the synoptic assessment. Such a decision might be based on law or on agency mandate. For example, by enacting the Endangered Species Act, Congress has determined that endangered species are valuable; similarly, an agency mandated with protection of drinking water would value functions that improve water quality. Policy makers could determine values through public input, interagency consensus or both. Gosselink and Lee discuss policy considerations and the importance of goal-setting as part of a cumulative impact assessment (Gosselink and Lee 1989; Lee and Gosselink 1988). A framework for including the effects of cumulative impacts on programmatic decisions is given in Irwin and Rodes (1992).

Once it is decided that a particular function is important, the *value* index can be used to determine the relative value of that function within each landscape subunit. This ranking depends on two factors. First, value is related to overall level of function, although this need not be a linear relationship (e.g., there could be diminishing returns at higher functional levels). Second, a function may be considered valuable not because of its inherent value, but because it acts upon something else valued by society. In such instances, the overall value also depends on the occurrence of this valued object. For example, flood reduction has no inherent value; it is

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[5] These two sub-components are similar to the terms "effectiveness" and "opportunity" used in the Wetland Evaluation Technique (Adamus 1983). However, the synoptic terms and their meaning are derived from the previously described landscape model.

valued because it reduces property damage and human injuries and deaths. Dams are not necessarily built where the largest floods occur, but where floods threaten human populations, valuable property, or both. Valued objects can also include plants and animals; the value of wetlands for habitat could increase with the number of rare and endangered species supported by that habitat. This index can also include future values by considering the future benefits of these functions. Finally, we note that this index does not represent economic value, since it does not consider market factors, etc. Instead, it provides an estimate of the value provided by a function within a landscape subunit, relative to other subunits.

Functional Loss

Functional loss represents the cumulative effects on a particular valued function that have occurred within a subunit. Functional loss caused by changes in forcing functions, processes, and structure should all be considered. The index should include complete loss of function from *conversion*, where the ecosystem is changed into a different ecosystem or land use (e.g., filling in a wetland to build a home), and partial loss through *degradation*, where the impact does not change the ecosystem type but alters function (e.g., reduced production through pesticide contamination). Future loss should also be considered as called for by Council on Environmental Quality regulations (40 CFR Sect. 1508.7).

Functional loss depends on the characteristics of the impact, including the type of impact, its magnitude, timing, and duration; and ecosystem *resistance*, or the relative sensitivity of the ecosystem to the impact, based on its robustness and overall health (see Chapter 6).

Replacement Potential

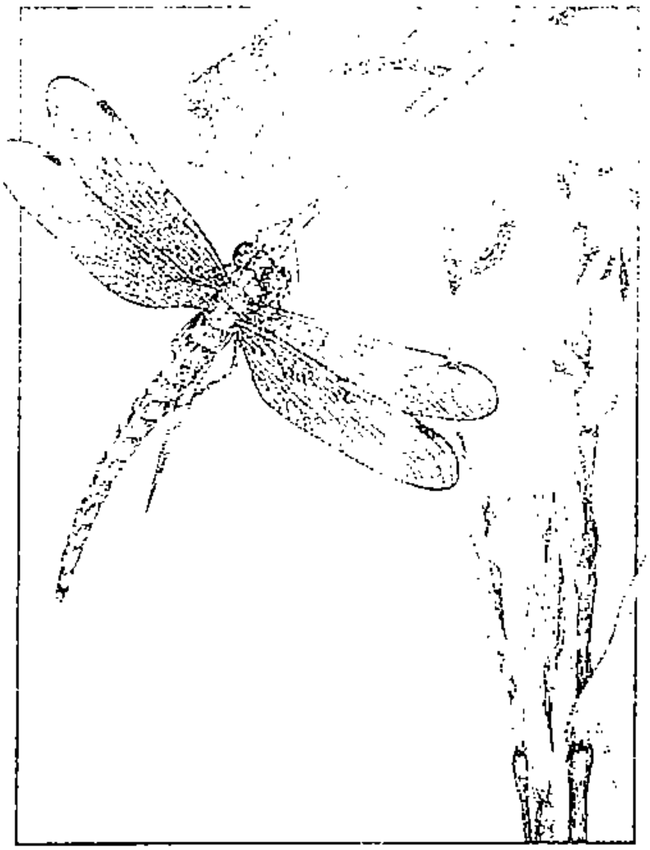
Replacement potential refers to the ability to replace a wetland and its valued functions. In this case, we are referring to functional replacement carried out by people; however, natural recovery could also be considered. Although not a component of a cumulative impact assessment *per se*, replacement potential is included as a synoptic index because it is a consideration within the 404 permit process and is also an important component of risk assessment (Leibowitz et al. 1992). The ability to offset the loss of valued functions and reduce ecological risk is greater if replacement potential is high; conversely, protection is more critical for risk reduction if replacement potential is low.

Replacement potential depends on many factors specific to the particular wetland, such as the type of wetland, the function to be restored, and, in the case of restoration, the kind of impact that altered the original wetland (Kentula et al. 1992; Kusler and Kentula 1990). In a synoptic assessment, however, we are more concerned with the landscape factors that contribute to replacement potential. Because it is more difficult to replace a wetland if critical driving factors have been disrupted, this index depends on the overall environmental condition of the subunit. For example, it would be difficult to restore a swamp within a historical flood plain if a levee had been constructed on the river. If restoration did take place, the wetland probably would not be sustainable because natural overbank flooding, which was a driving factor for the original swamp, would be disrupted.

Synoptic Index Evaluation

In conducting a synoptic assessment, it is necessary to refine the general synoptic indices into a specific set of indices that are most relevant to management concerns within a particular landscape setting. For example, in an application concerned with nonpoint source nitrogen pollution within an agricultural region, the specific indices for capacity and landscape input might be the maximum denitrification rate and the nitrate loading rate, respectively. However, quantifying the specific indices accurately for large landscape subunits would be difficult if not impossible. In order to evaluate the indices, the synoptic approach uses landscape *indicators* of actual functions, values, and effects. The indicators are first-order approximations that represent some particular index, given certain assumptions (see discussion in Chapter 3, Step 3.5). For example, data on agricultural nonpoint source nitrate loadings might not be available, in which case agricultural area could be used as a first-order landscape indicator.

In addition, we often take a risk-based approach to estimate specific indices. For example, we may not be able to quantify the actual loss of hydrologic function due to cumulative impacts, but we could assume that the risk of actual loss is greater in areas with high function and high cumulative impacts, compared with areas having low function and low impacts. Such an approach will undoubtedly make errors in assigning a relative ranking to each landscape subunit. However, a synoptic assessment need not provide a perfect evaluation of cumulative effects. The goal is to provide information that will improve permit evaluation and management decisions overall.



Chapter 3

Conducting a Synoptic Assessment

The process of producing a synoptic assessment involves five steps (Table 3.1). Although presented and discussed sequentially, it might be necessary in an actual application to follow these steps iteratively. We suggest that information resulting from this process not be viewed as the ultimate end product, but that synoptic assessments be updated periodically to reflect changing objectives and environmental conditions or to incorporate better data. Further, it may not be possible to achieve the desired management objectives in a one- or two-year period. By producing an initial assessment and improving it over time, an agency can obtain the desired results over the long run while gaining useful short-run results. A synoptic assessment should be an iterative process.

Preparation of a synoptic assessment requires the efforts of a team of individuals having different backgrounds and responsibilities (in an actual assessment, these roles need not literally be performed separately by three individuals):

- The manager, who is in charge of the resource management program and who makes the decision to conduct a synoptic assessment, is the individual with primary responsibility for defining the overall goals of the assessment.
- The resource specialist, who is the ultimate user of the final maps (e.g., a permit reviewer) and who is familiar with the area's wetland resources and their ecological functions, has the primary responsibility for defining the ecological relationships relevant to the particular management objectives.
- The technical analyst, who assembles the data, makes measurements, calculates the index values, and then maps them, should be familiar with database management and geographic information systems (GIS) or computerized mapping.

Step 1: Define Goals and Criteria

The purpose of this step is to identify explicitly the assessment objectives, intended use, required accuracy level, and the constraints within which the assessment will be conducted. Often the objectives call for more accuracy and detail than constraints allow. This step may require repetition until an acceptable combination of objectives, accuracy, and resource allocation is agreed upon.

Step 1.1 – Define Assessment Objectives

The general objectives of the assessment depend on the overall mission and goals of the particular agency or organization conducting it. If the manager works within a Department of Environmental Quality, the focus could be wetland water quality functions. A manager

Table 3.1. Steps in conducting a synoptic assessment.

Steps	Procedures
1. Define Goals and Criteria	1.1 Define Assessment Objectives 1.2 Define Intended Use 1.3 Assess Accuracy Needs 1.4 Identify Assessment Constraints
2. Define Synoptic Indices	2.1 Identify Wetland Types 2.2 Describe Natural Setting 2.3 Define Landscape Boundary 2.4 Define Wetland Functions 2.5 Define Wetland Values 2.6 Identify Significant Impacts 2.7 Select Landscape Subunits 2.8 Define Combination Rules
3. Select Landscape Indicators	3.1 Survey Data and Existing Methods 3.2 Assess Data Adequacy 3.3 Evaluate Costs of Better Data 3.4 Compare and Select Indicators 3.5 Describe Indicator Assumptions 3.6 Finalize Subunit Selection 3.7 Conduct Pre-Analysis Review
4. Conduct Assessment	4.1 Plan Quality Assurance/Quality Control 4.2 Perform Map Measurements 4.3 Analyze Data 4.4 Produce Maps 4.5 Assess Accuracy 4.6 Conduct Post-Analysis Review
5. Prepare Synoptic Reports	5.1 Prepare User's Guide 5.2 Prepare Assessment Documentation

for the Fish and Game Division might be particularly interested in wetland habitat functions. A manager of a wetland protection program, however, might be interested in not just one particular function but in several functions or in wetland restoration. The management objectives could be very specific, e.g., determination of wetland degradation caused by superfund sites, protection of wetland habitat for sport fish, protection of floodplain wetlands, etc.

During this step, the boundary for the study unit needs to be defined explicitly. This would typically be either a political boundary, based on the agency's jurisdiction (a state or multi-county region) or a natural boundary, e.g., a natural watershed or geomorphological province. The study area could be of special interest to management (one for which a special area management plan is being developed). It may be necessary to get input from other agencies or interested parties before finalizing the boundary.

Step 1.2 – Define Intended Use

The manager should define how assessment results will be applied. The assessment could be used to support very specific decisions, e.g., to support cumulative impact assessment as part of Section 404 permit review, or it could be used for general planning, e.g., to help identify areas sensitive to future impacts as part of a State Wetland Conservation Plan. The particular use affects the level of accuracy required and the degree of review the final products must undergo. In addition, an assessment used as part of a regulatory program might need to meet specific legal tests or require public comment or interagency consensus. The manager should also determine whether the assessment is to be purely technical or whether political considerations need to be included.

Step 1.3 – Assess Accuracy Needs

The overall management objectives and intended use of the information determine the level of uncertainty the manager is willing to accept in decisions that make use of a synoptic assessment. EPA guidelines on data quality assurance refer to the process of selecting the level of accuracy needed as defining the data quality objectives. This process includes five steps (EPA 1989):

- Define the decision;
- Describe the information needed for the decision;
- Define the use of environmental data;
- Define the consequences of an incorrect decision attributable to inadequate environmental data; and
- Estimate available resources.

The previous sections covered the first three steps of this process. Since any analysis has a level of uncertainty, and thus the chance of erroneous conclusions, the manager must consider the repercussions of incorrect decisions based on the level of uncertainty. If it could lead to litigation, for example, an assessment developed for regulatory applications might require a high confidence level. If the assessment is being conducted for broad-scale planning using best professional judgment, results might be sufficient as long as they are "more right than wrong." In other words, results need not be completely accurate; rather, the data must be adequate for the stated purposes of the assessment. The manager, in consultation with other team members, must define the level of accuracy needed for an assessment so the benefits outweigh the liabilities. Estimating available resources is discussed in the following section.

Step 1.4 – Identify Assessment Constraints

The manager must estimate the amount of time, money, and personnel hours that can be committed to the project. Regardless of the objectives and needs for accuracy, the effort will be limited by available resources.

As an example of possible assessment costs, the Louisiana and Washington pilot projects that are discussed in Chapter 4 each took a year and a half for completion and required a half-time senior scientist and both a full-time and half-time technical analyst (i.e., two full-time equivalents per year for each project). Much of the technical analysts' time was spent collecting data from various agencies, conducting quality control checks, performing map calculations, digitizing, and creating various databases. Other costs included approximately $20,000 for supplies and materials (excluding data, which mostly were obtained from cooperating agencies), plus access to a GIS. Although the purpose of the pilots was methods and development, and not an actual application, costs for a similar statewide analysis should be comparable. At the opposite extreme, an application requiring high precision and field verification could easily require several years of effort and cost hundreds of thousands of dollars for data collection, analysis, and labor. Project costs depend on study area extent and whether adequate data already exist (Steps 3.1-3.3).

The team should also consider other constraints that influence the outcome of an assessment, such as legal requirements, agency mandates, institutional constraints, and the need for public comment or interagency coordination.

If the resources available for an assessment are much less than what is deemed necessary based on best professional judgment (Steps 1.1-1.3), then management can change the objectives (e.g., assess a smaller area or accept less accurate results), relax the constraints (find a source of extra funding), or conclude that the assessment is not feasible at that time.

Step 2: Define Synoptic Indices

Once the objectives have been determined, the resource specialist must define a specific set of synoptic indices that will meet the objectives and intended use of the assessment. This involves replacing the four generic indices (function, value, functional loss, and replacement potential) with a set of indices specific to the objectives.

Defining the specific indices and the factors they include requires an understanding of the interactions between wetlands and regional landscapes. To summarize this understanding, the resource specialist can provide a landscape description that includes wetland types, functions and related societal values, natural factors sustaining the wetlands and major impacts (Table 3.2).

The resource specialist can consult with regional experts for assistance in determining these interactions, for example:

- University or state Soil Conservation Service (SCS) soil scientists are familiar with regional factors affecting denitrification capacity and adsorption potential (e.g., percent of organic matter);

Table 3.2. Examples of landscape descriptions that can be used in selecting indices.

Category	Example 1
Management Objective	Develop risk assessment guidance for county planners to protect sparse wetland populations of central Washington for waterfowl and other wildlife habitat.
Wetland Type	Palustrine (emergent, scrub-scrub and forested) on floodplains; saline (scrub-scrub) in playas and wind created depressions (Canning and Stevens 1989).
Natural Setting	Basin, characterized by loess deposits and deep dry channels cut into basalt, surrounded by mountain ranges which provide hydrologic inputs; arid climate (23-64 cm average annual precipitation); streams predominantly influent, many go dry in dry years (Omernik and Gallant 1988).
Landscape Boundary	Columbia Basin in Central Washington.
Significant Impacts	Water withdrawal for irrigation; altered water quality and stream morphology from grazing; high nutrient and suspended sediments from agriculture and mining.
Specific Indices	Habitat support, low stream flow and hydrologic modification (water withdrawal); non-point source pollution.
Landscape Subunits	Subwatersheds and county boundaries.

Category	Example 2
Management Objective	Include cumulative impacts as part of 404 permit review in Southern California.
Wetland Type	Intertidal salt marshes.
Natural Setting	Mediterranean climate, accretion and erosion of sediments, warm ocean current from Mexico, tidal flushing. Natural perturbations include storm events and catastrophic sedimentation; drought; lagoon closure (Zedler 1982).
Landscape Boundary	Southern California coast including intertidal slopes in river valleys, from Point Conception to the international border with Mexico.
Significant Impacts	Urban development (dredge and fill disposal); reduced circulation from anthropogenic sedimentation; altered watershed hydrology (Zedler 1982).
Specific Indices	Cumulative wetland loss, suspended sediment loading, peak discharge, hydrologic modification.
Landscape Subunits	Coastal watersheds.

- Hydrologists with universities or the state office of the U.S. Geological Survey (USGS) can provide insight into the hydrologic factors that form wetlands, and can also provide information on hydrologic modifications that may affect wetland functions;
- Biologists with the U.S. Fish and Wildlife Service (USFWS), state agencies, or the Nature Conservancy/Natural Heritage Program can provide expertise on wetland habitat and wetland-dependent species; and
- Biologists with the SCS and other agencies will be familiar with wetlands in agricultural settings, as well as with opportunities for restoration.

Other valuable resources are USFWS "Community Profile" reports. Each of these reports provides a wealth of information on a regional wetland type and often includes discussions of geological/climatic setting, natural forcing functions, ecological functions, ecosystem structure, and degradation by human impacts.

Step 2.1 – Identify Wetland Types

The first step in developing synoptic indices is to compile a list of the major wetland types found in the assessment area, e.g., specific wetland communities. This list can be limited to a particular type of wetland if management objectives are narrow, or it can include all of the area's wetlands if objectives are broad. The identification of these wetland types can be based on popular classifications (e.g., marsh, bog, or pothole), a functional classification (e.g., Novitzki 1979; O'Brien and Motts 1980), or the more detailed system developed by USFWS (Cowardin et al. 1979). The choice of classification should match the assessment objectives and constraints. For example, if protection of wetlands for flood control is the primary objective, the analyst could focus on palustrine or floodplain wetlands as defined by the Cowardin system or floodplain/river lower perennial wetlands as defined by a hydrogeomorphic classification (personal communication, M. Brinson, East Carolina University, Greenville, North Carolina). If, however, the objective is protection of wetlands for environmental education, then unique or rare wetlands near urban areas could be classified using a popular system or one defined by the State Heritage Program. Where the objective is to assess cumulative impacts, it will be important to select a classification that is broad and synthetic.

Selection of a particular wetland classification scheme also depends upon the availability of information. For example, if National Wetland Inventory (NWI) maps are available for the region, the Cowardin classification is a logical choice. At the minimum, the classification should include or be cross-referenced with information on geomorphic setting and source of water because both are important components of the natural setting (Step 2.2) and are useful for identifying significant impacts (Step 2.6).

Step 2.2 – Describe Natural Setting

The analyst should understand the landscape driving factors or forcing functions responsible for the formation and maintenance of wetlands because this information is important for defining landscape boundaries (Step 2.3) and for evaluating the significance of impacts (Step 2.6). The natural factors include natural stresses, such as drought, and structural components, such as soil and seed banks (see Chapter 6). The classification used to identify wetland types (Step 2.1) should provide relevant information. A broad-scale or detailed description of natural factors can be developed around a series of questions such as those listed in Table 3.3.

Step 2.3 – Define Landscape Boundary

In Chapter 2 we noted that the boundaries for cumulative impacts and cumulative effects need not be the same; the cumulative effects occurring within a given area could result partially from impacts that take place outside the boundary. The resource specialist must define the landscape boundary to include the appropriate natural setting (Step 2.2) and impacts (Step 2.6) that could be operating outside the study area. Even if the actual analysis ignores this larger boundary, the boundary must be defined so the resource specialist can determine the degree to which the assessment might be ignoring important factors.

Because hydrology is the single most important determinant of wetland type and function, the landscape boundary should include at least the entire drainage area in which the study is located. For example, an assessment of the state of Louisiana cannot stop at the state boundary but must consider hydrologic input from upstream segments of the Mississippi, Red, Sabine, Ouachita, and Pearl rivers. The landscape boundary for groundwater discharge wetlands might include recharge areas hundreds of miles outside the study area; likewise, the boundary for coastal wetlands will probably include estuarine, nearshore, and even offshore waters. These hydrologic boundaries also delimit many water quality processes, such as transport of nutrients, sediments, and pollutants.

Defining the boundary for habitat processes is more problematic than for the other functions. Biotic factors operate on scales defined by the ranges of wetland-dependent species. Given the diversity of species, no single spatial unit can encompass all species' ranges for a particular study area. Many times, ecoregions provide useful landscape units for habitat support (Omernik 1987); research by Inkley and Anderson (1982) and Larsen et al. (1986) demonstrates a correspondence between ecoregions and wildlife and fish communities, respectively. If habitat of wide-ranging migratory species is an important element of the assessment, a broader landscape boundary must be defined.

Table 3.3. Examples of technical questions that could be used to describe the natural factors determining wetland function.

	Technical Questions
Describing natural wetland setting related to forcing functions, ecosystem processes, and structure:	What are the geological processes responsible for the wetlands' formation, e.g., deposition of marine or riverine sediments, glaciation?
	What are the physiographic characteristics associated with the wetlands, e.g., large depressions, river valleys, karst topography?
	What are the hydrologic influences, e.g., tidal, riverine or lacustrine energy, or groundwater influence?
	What are the climatic influences, e.g., timing, type and amount of precipitation, length of growing season?
	What are the chemical characteristics and fluxes of the wetlands, e.g., salinity, organic content, nutrient and mineral availability?
	What are the natural perturbations that wetlands are either adapted to or dependent on, e.g., fire dependent species, periodic inundation, seasonal drought?

Step 2.4 – Define Wetland Functions

The resource specialist next defines the particular wetland functions to be addressed. Depending on management objectives, the functions of interest could be either specific or broad. Because it is impossible to assess all functions, even when the objectives are general, the specialist must determine a subset of functions that best represents the broader class. For example, consideration of hydrologic function in regions where small, non-tidal wetlands prevail might include wetland influence on peak flow but not on storm surges, which occur mainly in larger, tidal wetlands.

Habitat functions can be defined by determining the various species (including birds, fish, and mammals) that are dependent on or utilize the wetland communities identified in Step 2.1. For hydrologic and water quality functions, wetlands often function as sinks. Therefore it is useful to consider the hydrologic and water quality sources that are found within the particular landscape setting, since the source is a component of sink functions (Chapter 2). Natural and anthropogenic sources should both be included. Chapter 7 provides a detailed discussion of wetland functions that have been reported in the literature and can serve as a source of candidate functions that should be considered during this step.

Step 2.5 – Define Wetland Values

As discussed in Chapter 2, whether a function is valued is a policy decision rather than a technical consideration. These valued functions could be a given, based on the objectives. However, the manager might choose to map the relative magnitude of many functions first, then use this information to determine which wetland functions are most valuable. If so, the manager has deferred the valuation until after analysis. In either instance, the value may also depend on the co-occurrence of the function and "valued objects" such as property.

To define a synoptic index for value, the team must determine who ultimately benefits from the various wetland functions and whether other valued objects are involved (see discussion on value, Chapter 2). For example, they might decide that the value of flood protection is low if it occurs mostly in uninhabited regions or that the value of water quality improvement is very high if it occurs in areas that supply drinking water to large urban centers.

Functions and values are kept distinct by defining them in separate steps. This allows the team to consider whether important ecological functions, based on technical information, are being undervalued in terms of social perceptions.

Step 2.6 – Identify Significant Impacts

In this step, the resource specialist determines the most significant impacts on the functions of interest. If the proportion of recent wetland conversion within a particular region is high, it may be the dominant cause of functional loss, in which case other factors may be assigned lower priority. In this case, the index for functional loss would be loss of wetland area.

If conversion in the region is insignificant or if the specialist thinks conversion is not the dominant cause of functional loss, then the impacts most likely to cause wetland degradation must be identified. Tables 3.4 and 3.5 are examples of how best professional judgment could be organized to guide this process. Table 3.4 contains a list of impacts associated with agriculture along with the type of degradation each is expected to produce. Similar tables for other major classes of wetland impacts (resource extraction, urbanization, and water management) appear in Appendix B. Using Table 3.4 or a modification, the specialist can identify significant types of degradation that would result from commonly occurring impacts. Then the specialist could use Table 3.5 to determine which hydrologic functions would most likely be affected by these impacts (similar tables for water quality and habitat functions appear in Appendix C). The tables can be used in reverse order to determine which impacts would most likely degrade a given function.

As an example, in a state where livestock ranching is a major agricultural activity, possible impacts include fertilizers, harvesting, pesticides, species introduction, trampling, and water consumption (Table 3.4). Based on familiarity with the region, the specialist might decide that harvesting and trampling are the two most common impacts. Both have a high likelihood of causing degradation through changes in behavior or habits of wetland animals resulting from habitat alteration, and both have a medium likelihood of causing denudation (Table 3.4). If the overall function of interest is hydrology, Table 3.5 indicates that functional loss from changes in animal behavior is not likely.

These tables represent hypotheses about the mechanistic linkages between impacts, degradation, and functions; they are an example of how best professional judgment could be used to guide the selection process. The resource specialist should consult regional experts to ascertain whether these relationships hold true in the specific study area.

Step 2.7 – Select Landscape Subunits

At this time the resource specialist defines the landscape subunits that will be the basis for making relative comparisons and reporting results. For now, the decision

Table 3.4. Typical relationships expected between agricultural impacts and wetland degradation based on best professional judgment. Letter indicates degree of expected association and not the intensity or duration of impact (H = high, M = medium, L = low).

Impact	Acidification	Altered Animal Behavior	Compaction	Contamination/Toxicity	Denudation
Channelization[3]					H
Drainage[3,4]	L	H	L	M	
Fertilizers[1-5]	L			M	M
Fill[2,3]	L	H	H	L	H
Harvesting or Burning[1-5]	M	H[1-3]			M[2]
Impoundment[1]		H		M	
Irrigation/Flooding[3]	L	M		M	
Pesticides[1-5]				H	M
Species Introduction[1-5]		H			
Tillage[3]	L	L			H
Trampling[1-5]		H	L		M
Vehicles/Boats/Planes[1-4]		M	M	L	L
Water Consumption[1-5]				M	

Impact	Dehydration	Eutrophication/Enrichment	Erosion	Inundation	Light Reduction
Channelization[3]	M	M	M		L
Drainage[3,4]	H	M	M		M
Fertilizers[1-5]		H			L
Fill[2,3]	H	M	L		H
Harvesting and Burning[1-5]				M[2]	
Impoundment[1]		M	L	H	M
Irrigation/Flooding[3]		M	M	H	M
Pesticides[1-5]					
Species Introduction[1-5]	L				L
Tillage[3]		M	H		
Trampling[1-5]			L		L
Vehicles/Boats/Planes[1-4]			M		L
Water Consumption[1-5]	H	M			

Impact	Salinization	Sedimentation	Surface Runoff Timing	Thermal Warming
Channelization[3]	L	L	H	M
Drainage[3,4]	L	M	H	
Fertilizers[1-5]	M			
Fill[2,3]	L	H	M	
Harvesting and Burning[1-5]		M[2]	M[2]	H[2]
Impoundment[1]	M	M	H	L
Irrigation/Flooding[3]	H	M	M	
Pesticides[1-5]				
Species Introduction[1-5]				
Tillage[3]	L	H	M	
Trampling[1-5]				
Vehicles/Boats/Planes[1-4]				
Water Consumption[1-5]	M		H	L

[1] Aquaculture (e.g., cranberries, rice, crayfish)
[2] Crops – No Till
[3] Crops – Till
[4] Forestry
[5] Livestock

Table 3.5. Effect of wetland degradation on hydrologic functions and degree of expected association based on best professional judgment (H = high, M = medium, L = low).

Type of Degradation	Peak Flow Reduction	Storm Surge Reduction	Water Conservation	Groundwater Exchange	Hydrologic Input
Acidification					
Animal Behavior					
Compaction	L	L		M	M
Contamination/Toxicity					
Denudation	M	M	M	H	M
Dehydration	H	H	H	H	H
Eutrophication/Enrichment			L	L	
Erosion		M			
Habitat Fragmentation				M	
Inundation	H	H	H	H	H
Light Reduction			L	L	
Salinization					
Sedimentation	M	L	M	M	
Surface Runoff	H	H	H	H	H
Thermal Warming			L	L	

should be based on management objectives and ecological considerations; data availability will be considered in Step 3. For assessments at the state or regional level, the USGS cataloging unit or a similar state unit might be most appropriate because it functions as a natural drainage area. Ecoregion subunits (see the previous section) or finer-resolution subunits, e.g., soil-vegetation associations, may also be useful. Selection of landscape subunits might also be based on political criteria, e.g., county boundaries.

Step 2.8 – Define Combination Rules

A specific synoptic index is typically a mathematical expression that includes several factors. Factors that may be combined in an index include components of an index (for example, capacity and landscape input could be components of function, and degradation and conversion could be components of functional loss) or other indices (e.g., an index of value would include function). Although a separate index could be defined for each of these factors (e.g., separate indices of functional loss through stormwater runoff and agricultural conversion), it is often desirable to mathematically combine them into a single index, in which case a set of combination rules needs to be defined. These combination rules must address the following questions:

- Will the factors be combined by addition, multiplication, or some other operation?
- Will the data be normalized, that is, adjusted to a common ordinal scale, prior to combination? If so, by what procedure?
- Will all factors be considered to contribute equally, or should weighting factors be applied to some?
- Will the same combination rules apply to all wetland types and across the entire range of conditions within the study area?

Decisions concerning combination rules are difficult and often subjective, but deserve careful attention to reduce error. Mathematical relationships between factors may be available from the literature or regional models. It is often necessary, however, to assume that factors have equal weight (i.e., are added without weighting factors) or that there is a first-order proportionality between factors, i.e., that the factors are multiplicatively combined. At the minimum, the resource specialist should explicitly describe the combination rules and any assumptions as part of the review (Step 3.7) and documentation (Step 5.2). Combination rules are further discussed in Hopkins (1977), O'Banion (1980), Skutch and Flowerdew (1976), Smith and Theberge (1987), and USFWS (1981).

Step 3: Select Landscape Indicators

Landscape indicators are the actual measures used to estimate the synoptic indices; either a single indicator or combination of indicators can be used. Selecting indicators requires balance between accuracy and cost. Major considerations are discussed below.

Selection of landscape indicators, which depends on data availability, should not begin until goals are defined (Step 1) and the relevant environmental variables are identified (Step 2). In order to evaluate the adequacy of an assessment (Step 4.5), it is important to keep the goals and environmental variables distinct from the trade-offs that occur because of data limitations. If data availability is considered too early on, real-world limitations begin to dominate the process before the goals and environmental variables are articulated. Goal setting, defining synoptic indices, and selecting landscape indicators should occur iteratively and not simultaneously.

Step 3.1 – Survey Data and Existing Methods

Contact various federal and state agencies having jurisdiction over the study area to determine what kind of environmental data are available; for smaller study areas, include county agencies. Other sources could be university experts and state and university libraries. The survey should include both mapped and tabular information available for the entire assessment area. (Examples of data that can be used for the various synoptic indices appear in Appendix D; sources for the data appear in Appendix E). As part of the survey, the technical analyst should also note the following types of information, which will be necessary for assessing data adequacy (Step 3.2):

- The purpose of the database and the type of information it contains;
- The methods used in collecting, measuring, and analyzing the data;
- Examples of how the data have been used, especially if reported as case studies;
- Known problems or limitations;
- Data format, e.g., hard copy or computer compatible;
- Availability of documentation, both for data collection and quality assurance procedures and, if appropriate, file formats for computerized databases;
- Procedure needed to acquire data, including cost.

The survey need not be limited to databases. Various existing methods and techniques can also be used to estimate indices. For example, the USGS collects discharge data at various sampling locations on many streams and rivers. Annual water resources data reports for each state provide summaries of these data; they are also entered into the WATSTORE database (see Appendix E). Unfortunately, monitoring stations are not typically at the locations needed for the synoptic assessment, e.g., at the lowest downstream point of the subunit. The technical analyst would have to select an indicator appropriate for estimating discharge at that location.

One possibility is to use regression equations published by most state USGS offices for estimating discharge using watershed characteristics. For example, variables for regression equations developed for eastern Mississippi include watershed area, channel slope, and mainstem channel length (Landers and Wilson 1991). Alternatively, mathematical models can estimate many variables; e.g., SCS's TR-55 (SCS 1986) and the USDA Agricultural Research Service's AGNPS model (Young et al. 1987) estimate peak discharge and agricultural nonpoint source pollution, respectively, from factors such as topography, precipitation, land use, and soils. The technical analyst can determine whether appropriate methods are available through a literature review, by conferring with regional experts, or both.

Step 3.2 – Assess Data Adequacy

Adequacy of existing data depends on several factors, including the degree to which an indicator based on the data represents the index and the quality of the data relative to the management objectives (Table 3.6). The following example illustrates the difference between these factors: For a synoptic index of peak discharge, two possible indicators are runoff volume as calculated by the "curve number" technique (SCS 1986) and discharge estimates produced by the USGS regression methods, discussed above. For the former, the physical quantity being estimated (volume) is different from the variable of interest (peak rate of discharge or volume/time). There is a relationship between runoff and peak discharge, but the two variables are not identical. However, the estimate of runoff could be accurate if based on high quality data. Conversely, an indicator based on the USGS regression represents the same physical quantity defined by the index, yet it could be unacceptable if calculated using poor quality data. Both of these issues must be taken into account. If an indicator that is physically different from the index is being considered, the resource specialist or technical analyst must determine whether the indicator represents a reasonable first-order approximation to the actual index and whether the use of that indicator is contingent upon any unreasonable assumptions (Step 3.5).

Potential indicator data should be evaluated according to a set of criteria (e.g., Table 3.6). The technical analyst must also consider extra effort required to translate the data into the format needed for the assessment. For example, data found in reports might require entry into a database. It is especially important to consider the extra effort required for processing mapped data. Do not assume that more detail is better until you consider the additional cost. For example, the use of 1:250,000 scale STATSGO soil maps, if available, may be much more appropriate for statewide synoptic assessments than 1:20,000 scale county soil survey maps because greater effort would be required to analyze the more detailed maps.

Step 3.3 – Evaluate Costs of Better Data

The technical analyst should assess the time and cost of obtaining better data. Identifying the types of data needed and the associated costs for producing results of various confidence levels is useful. For example, how much would the highest quality, most up-to-date information cost? What would be the gain in accuracy if the budget were increased by $10,000 or if two extra months were available for the assessment? These considerations would allow existing information to be compared.

Table 3.6. Example of objectives and related questions for defining landscape indicators for synoptic indices.

Objectives	Technical Questions
Determine how well the indicator represents the index:	Do comparable data exist for the entire study area or are there gaps that would limit intraregional comparison?
	Do standardized data exist for the appropriate time period, e.g., the past ten years, the entire year, or by season?
	Are data at the appropriate spatial scale or are there major scale differences between data sources?
	Are the classification systems used for wetlands and other landscape variables compatible? For example, the USFWS National Wetland Inventory maps, SCS soils maps and USGS Land Use/Land Cover maps classify wetlands according to different criteria.
Assess the quality of existing data:	What is the source of the data, e.g., agency or university?
	Can the originator (person or agency responsible for data collection) be contacted?
	When, where and how often were the data collected?
	What methods were used for the data collection?
	Was the data collection associated with a Quality Assurance program? If so, what information is available on the precision, accuracy, representativeness, comparability and completeness of the data?
	Are there assumptions, limitations or caveats to consider in using the database?
	What are the time, personnel and cost constraints of obtaining better data?
Determine level of confidence in the data:	What are the common assumptions between indicators and indices?
	What evidence would violate these assumptions?
	How should the weighing of variables be adjusted to compensate?

Step 3.4 – Compare and Select Indicators

Given the adequacy of available data (Step 3.2) and the cost of obtaining better information (Step 3.3), the resource specialist and technical analyst can select a suite of indicators that best balances the level of accuracy needed to satisfy management objectives (Step 1.3) within existing constraints (Step 1.4). These choices are an optimal solution, given the existing opportunities and constraints.

Step 3.5 – Describe Indicator Assumptions

Once indicators have been selected, the resource specialist and the technical analyst should carefully determine which assumptions must hold if the indicator is to represent the synoptic index adequately (in this case, "adequately" is defined relative to the need for accuracy, as stated in Step 1.3). It is important for these assumptions to be stated explicitly, so they can be revisited later in the assessment to determine whether the assumptions were violated (Step 4.5). This information will also be included as part of the assessment documentation (Step 5.2). Examples of assumptions that can affect the outcome of an analysis are:

- The USGS regression estimates for peak discharge are often developed using data from watersheds that are not heavily urbanized, channelized, or dammed (e.g., Landers and Wilson 1991); in other words, these regressions are meant to represent "pristine" conditions. Use of regressions developed in this manner would include the implicit assumption that none of the watersheds has undergone significant hydrologic modification.
- Use of area as an indicator for wetland function assumes that function or capacity per unit area is similar for all wetlands or, if it varies, that wetlands having different unit area responses are similarly distributed between landscape subunits. The use of area as an indicator of a sink function further assumes that all wetlands receive import from a source or, if not, that the spatial relationship between wetlands and sources is similar between landscape subunits.
- The use of hydric soil area as an indicator of historical wetland area assumes that (a) wetland soil retains its hydric characteristics after drainage or conversion, (b) hydric soils are properly mapped, and (c) more permanently flooded wetlands, which could appear on SCS maps as water and not hydric soils, are either insignificant in an area or are distributed in such a way that bias is uniform across all subunits.

Step 3.6 – Finalize Subunit Selection

After selecting the final indicators, the resource analyst should reconsider subunits in light of the type of data available. For example, at first the analyst may select watersheds for subunits in Step 2.7 but later find that most data were based on county units. The analyst must then decide whether to prorate the county data to watershed units (see Appendix F) or to use counties as landscape subunits. This will depend on overall project goals and on whether the assumptions necessary for prorating hold true.

Step 3.7 – Conduct Pre-Analysis Review

Before conducting the assessment, the analyst should ask management and technical experts to review the overall management objectives, the synoptic indices that were defined, and the selected landscape indicators. The experts should, in particular, consider the appropriateness of the indicators with respect to objectives and constraints, and also review indicator assumptions for any evidence of violations. If violations are found, data may need to be adjusted or discarded, and alternate indicators considered.

Step 4: Conduct Assessment

Once landscape indicators have been defined and assumptions have been explicitly identified, maps and data can be obtained from the appropriate sources. The technical analyst can begin the process of producing the synoptic maps.

Step 4.1 – Plan Quality Assurance/Quality Control

Data for a synoptic assessment typically come from multiple sources (e.g., state and federal agencies, universities, and non-profit organizations) and come in a variety of formats, including mapped data, tabular data from reports, and computerized databases. Because reliability of the final product depends on quality control of data processing, a set of protocols should be developed for determining and maintaining data quality. The technical analyst should begin this step even before data are received, using information obtained during the data survey phase (Step 3.1).

Protocols should be developed for designing the database and for screening, archiving, and documenting the data. For example, protocols developed for data screening should identify questionable data based on an understanding of expected values and obvious outliers: A value of 100 centimeters per year for average precipitation would be questionable for a state in the arid southwest, and a peak discharge of only 100 cubic meters per second would obviously be too low for a major river. Percentages should add up to 100, and areas for component land uses should add up to total area. Protocols should also be developed for any variables to be measured, e.g., map measurements, and should include criteria for assessing accuracy, precision, completeness, representativeness, and comparability (EPA 1989).

In addition to the initial information collected during the data survey (Step 3.1), data documentation should include descriptions of the protocols, database design, and archiving formats. This information should be included as part of the assessment documentation (Step 5.2).

Step 4.2 – Perform Map Measurements

Much of the information used in a synoptic assessment is derived from maps. Examples of information and sources include: wetland area and number of wetland types from NWI maps, hydric soil area from county soil surveys, elevations and stream channel lengths from USGS topographic maps, and non-wetland land use from USGS Land Use/Land Cover (LULC) maps.

Two types of measurements are often made from maps: area and length. If the map is in digital format, a GIS can be used to generate these measurements. If a GIS is not available, the features can be planimetered or estimated using a dot grid. These three techniques are discussed in Appendix G.

If data reported for one type of spatial unit are to be prorated to another type of unit, joint areas must be calculated to serve as weighting factors. For example, if population data reported by county need to be adjusted to watershed subunits, the percent of the county lying in a particular watershed must be determined from an overlay of the two different areas (see Appendix F).

Error or bias can be introduced in map measurement through inadequate technician training, differences in accuracy between analysts, and defects or improper calibration of equipment. If maps are digitized for analysis in a GIS, compare hard copies of the digitized maps to the originals for accuracy. Also perform a quality control check for all map measurements by having a different analyst repeat 5% to 10% of the measurements to establish an error level. A discrepancy of more than 5% between analysts might be considered unacceptable. If the target is not met, a more comprehensive check is necessary.

The technical analyst must keep in mind the difference between *accuracy of map measurement* and *overall map accuracy*. A map can be measured very accurately, but still have unacceptable overall accuracy if the map itself contains errors. For example, a map produced through photo-interpretation of aerial photography might contain significant classification errors if the photo-interpreter is inexperienced. A good discussion of data quality and errors in mapping is found in Burrough (1986).

Step 4.3 – Analyze Data

A number of calculations could be required to produce an index value for each landscape subunit from the various data sources. Common analyses might include:

- *Calculating Channel Slope* – USGS discharge regressions often include channel slope as a variable. This slope is defined as the difference between the elevation of points located at 85% and 10% of the mainstream channel length. This difference is divided by the channel distance between the two points, i.e., 75% of the channel length (Appendix H).
- *Prorating Areas* – As discussed in Step 4.3, data must be prorated if an indicator is to be calculated for one type of unit based on data reported for a different type of subunit. Many types of data are typically reported by county, e.g., population statistics, agricultural data, soil characteristics data, and endangered species statistics; if the synoptic subunits are not counties, these data must be prorated using the weightings generated in Step 4.2.
- *305b Water Quality Summaries* – Under Section 305b of the Clean Water Act, states are required to report the extent to which their waters are meeting water quality standards. These 305b reports list, by stream segment or type of water body, whether a sampled segment fully supports, partially supports, or does not support (non-supporting) the "designated use" of that segment (for example, a stream can be designated as swimmable or fishable). If the segment is not fully supporting, the report lists the category of pollutant impacting the waters, e.g., point or nonpoint. The percentage of assessed streams that fully support state designated uses could be employed as an indicator of overall water quality. To produce such an indicator, the stream segments within each subunit must be identified and the relevant data summarized for that subunit. Note that the quality of state 305b reports varies by state. The analyst should also be aware of how the data were collected.

Final index estimates are produced by completing any other necessary calculations and converting to standard units, e.g., from English to metric. However, caution must be exercised when using regression equations. For example, the USGS regression equations for Mississippi (Landers and Wilson 1991) estimate peak discharge in ft^3/sec, using area (mi^2), channel length (mi), and slope (ft/mi); using metric units for area, channel length, and slope would be incorrect, since the regression equation was based on those English units. If metric units were desired, discharge should first be calculated in ft^3/sec using the English units, and then converted to m^3/sec. This indicator of hydrologic input could then be combined with an indicator of capacity to produce an estimate of hydrologic function. Additional examples of index estimation are provided in the case studies (Chapter 4).

After index values are calculated for each subunit, the subunits can be ranked by numerical values. For example, in an assessment of 50 subunits, the subunit with the highest value could be given a rank of 1 for that index, and the subunit with the lowest value given a rank of 50. Statistical packages such as SAS® (SAS Institute, Inc. 1988) can perform these calculations automatically. Rankings for each index should be included as part of the database.

The last step in analyzing the data is to perform a complete data quality check on the final database. For any calculations performed by computer, the analyst should recalculate a sample by hand to assure that the algorithms were programmed properly and that the output is accurate.

Step 4.4 – Produce Maps

The final synoptic maps can be produced by a computer mapping package, such as a GIS, or manually if resources are extremely limited or if no automated system is available. A GIS is recommended because it offers easy storage and manipulation of data and allows interim products to be used in later analyses. A GIS also gives the technical analyst greater flexibility to experiment with different display formats.

If a GIS is used, two different databases are typically required: one of the digital boundaries of the study area and its subunits and one of the index values that will be assigned to the subunits. Boundaries for all U.S. states, counties, and USGS accounting units have been digitized and are available at low cost in various formats (see LULC entry, Appendix E). If digital boundary data are not available, hand digitization may be necessary. This could be cost prohibitive if the study area includes a large number of highly detailed polygons, but the benefits of producing computer-generated maps often outweigh the digitizing costs. In some instances, sufficient accuracy may be achieved at even lower cost by using electronic scanners that digitize maps automatically.

The index values and rankings for each subunit must also be entered into the GIS. The method of accomplishing this and the amount of effort required will depend on the particular database-GIS combination. Many GIS packages provide routines for loading information from commonly used commercial databases.

Once the data are in the GIS, map production can begin. We recommend that the technical analyst produce component maps for each index if the index represents a combination of data sources. For example, if the

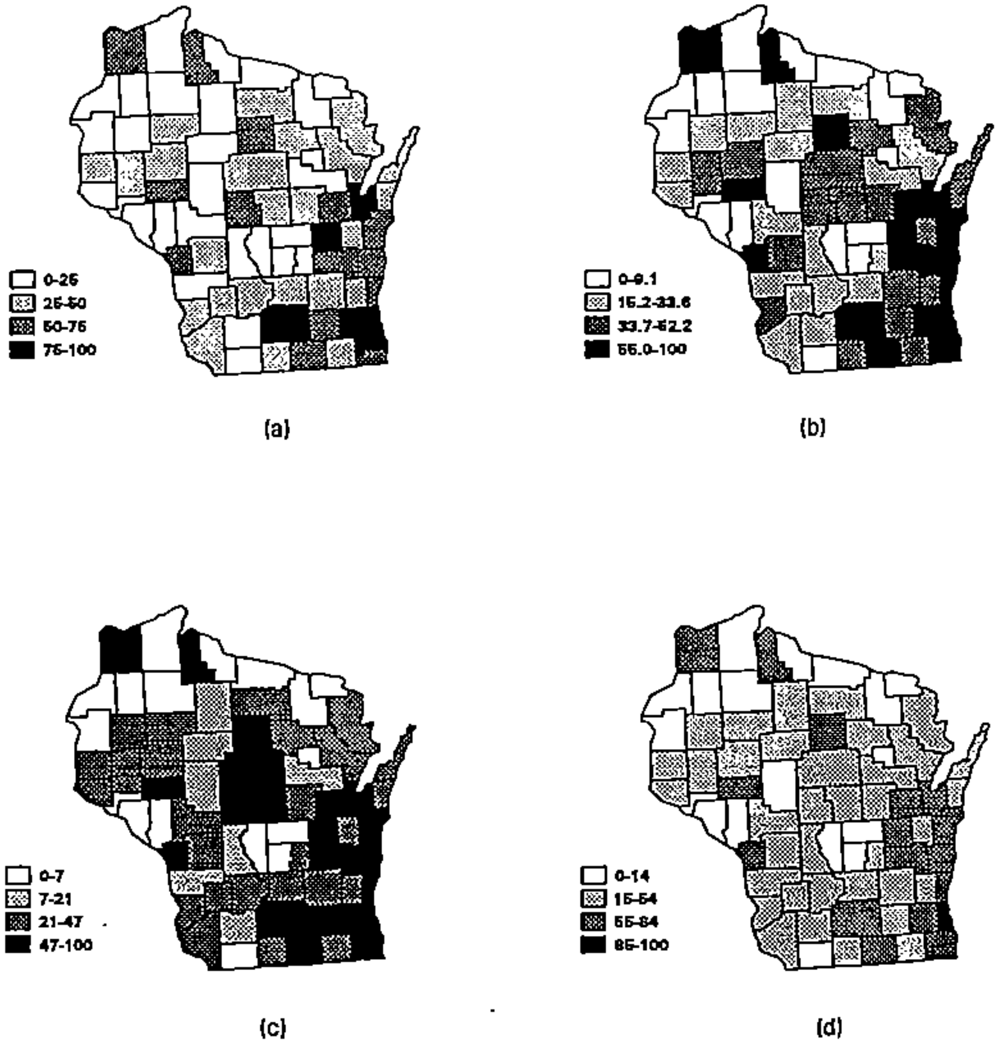


Figure 3.1. Illustration of maps using different class intervals to represent the same data: (a) equal intervals based on the data range; (b) intervals based on quartiles; (c) intervals increasing at constant rate; and (d) intervals based on the frequency distribution (adapted from Robinson et al. 1984).

USGS regressions are being used in Mississippi for peak discharge, then component maps of area, channel length, and slope should also be produced. This would allow the technical analyst and resource specialist to examine the data and determine whether the resulting spatial relationships are reasonable.

One of the most important decisions in the map production phase is how to display the data. At a minimum, the map should include the index value for each subunit. However, to promote interpretation, the data are typically aggregated into classes, or intervals. Ideally, class boundaries should reflect actual thresholds of function or value, e.g., patch sizes below which wildlife use drops precipitously or stream size above which local urban flooding is known to occur. Because such technically specific information is often unavailable, common alternatives are to divide the range of numeric values into equal intervals, or assign an equal number of subunits to each interval based on rankings (e.g., quartiles). The visual appearance of a given set of results can vary greatly, depending on how intervals are selected (Figure 3.1). The choice of class intervals is one of the more important decisions in the entire process because the synoptic maps will be the assessment's most visible outcome. People can easily reach erroneous conclusions if the map they are examining contains improperly displayed data. Perhaps the best way to design the intervals for map display is to first create a histogram or frequency curve showing the distribution of the numerical data (Figure 3.2). This will allow the analyst to detect any natural clumpings and also reveal

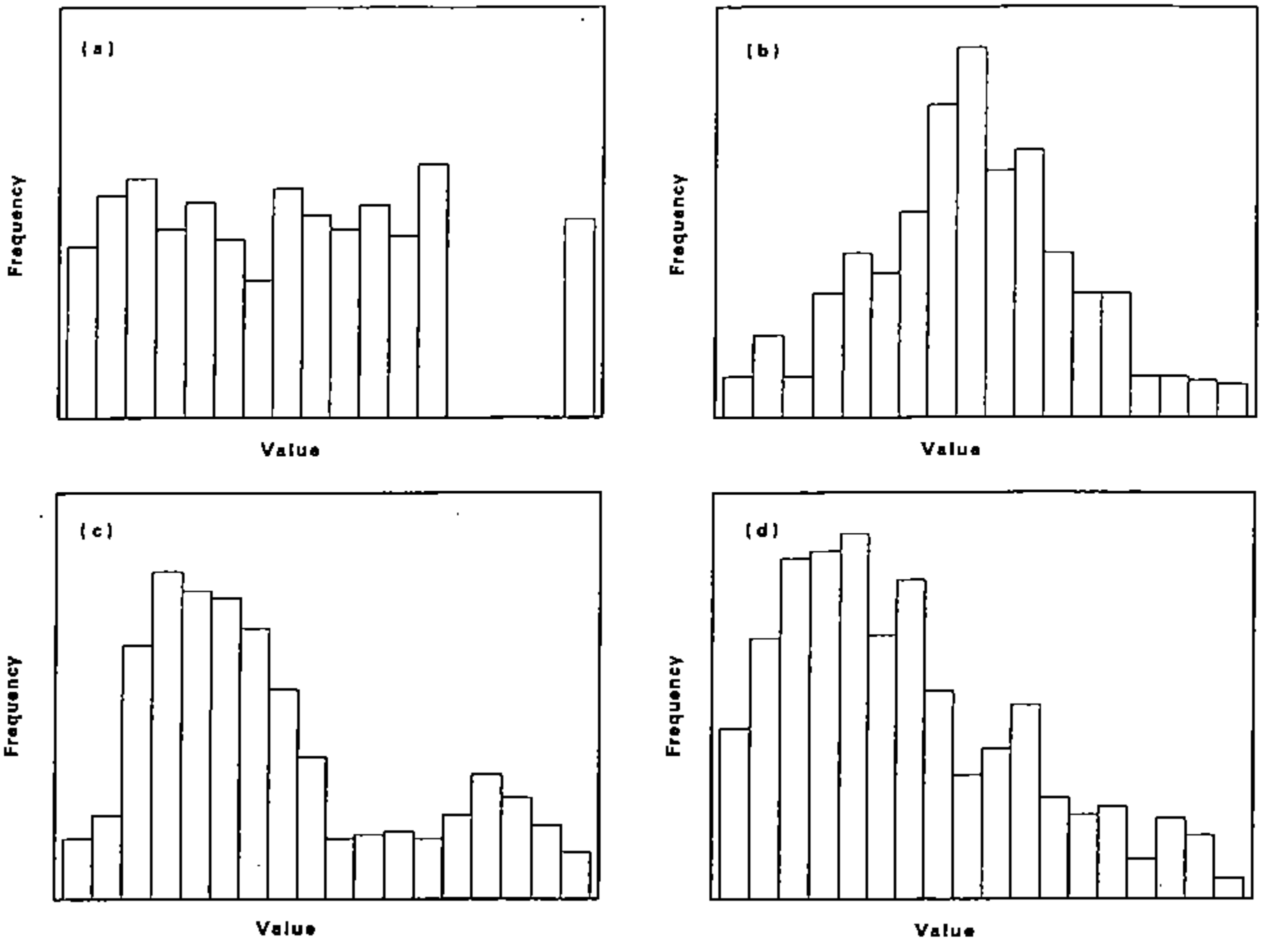


Figure 3.2. Different possible data distributions: (a) uniform with outlier, (b) normal, (c) bimodal, and (d) negative binomial.

common patterns such as normal or logarithmic distributions. Many standard texts on cartography, such as Robinson et al. (1984), include discussions on display of mapped data.

Once the appropriate intervals have been selected, the technical analyst considers options for displaying the range of values, e.g., color, shading, or hatching. Color, although more expensive, gives the greatest contrast and flexibility and should be considered if slide presentations will be made. Document production is less expensive if gray shadings are used; however, the analyst should select shades that provide enough contrast to be distinguished after photocopying.

Step 4.5 – Assess Accuracy

Throughout the course of the assessment, the technical analyst and resource specialist should look for evidence that any of the assumptions stated in Step 3.5 have been violated and consider the effects this would have on the assessment's accuracy. If the assumptions were violated for some units, it might be possible to adjust the index values. For example:

- Selection of an indicator for peak discharge could have been based on the assumption that subunits were not significantly regulated by dams. If a subunit is found to have a large dam or other major regulation, peak discharge would be significantly lower than the discharge that would occur naturally. The index value for that subunit could then be reassigned to the lowest category.
- To calculate wetland loss, the indicator for current wetland area could have been derived from USGS LULC maps if digital NWI wetland maps were not available. In cross-checking the classification, the analyst might have found that some areas classified as seasonally flooded riverine wetlands by NWI are classified on the LULC maps as deciduous forest, i.e., non-wetland. This underestimate of wetland area would cause an overestimate of historic wetland loss. These data may be adequate for relative comparisons of wetland loss if the proportion of deciduous forest

is similar in all subunits. Even if some subunits are much more dominated by deciduous forest than others, the analyst might be able to derive a correction factor to adjust the subunits, based on the percent of riparian land cover.

If the indices cannot be adjusted in such a fashion, the analyst may need to discard the data for the landscape subunits in which violations occurred. In some cases, the analyst might determine that the indicator is unsuitable for the required level of accuracy.

Throughout the entire assessment process, the technical analyst must consider the quality and accuracy of data sources to determine the overall quality of the final products. Unfortunately, no formal process for weighing the various factors exists. Ultimately, the technical analyst and resource specialist must use their own judgment and familiarity with the data to determine whether the synoptic results meet the stated needs (Step 1.3).

Step 4.6 – Conduct Post-Analysis Review

The assessment team should again seek technical experts' review comments following completion of the data analysis and synthesis. This information will assist the team in deriving conclusions and suggesting ways the results can be used. Because there is no method for quantitatively assessing the accuracy of results, this step and the pre-analysis review (Step 3.7) are essential to assure that results are adequate for the intended use.

Step 5: Prepare Synoptic Reports

The last step in the assessment is to report how the information was derived and how it can be used. Two different documents are appropriate: a report for the manager and resource specialist (a user's guide) and a detailed reporting of procedures to serve as a record of the complete assessment process (assessment documentation). Draft versions of these documents could also be included as part of the post-analysis review (Step 4.6).

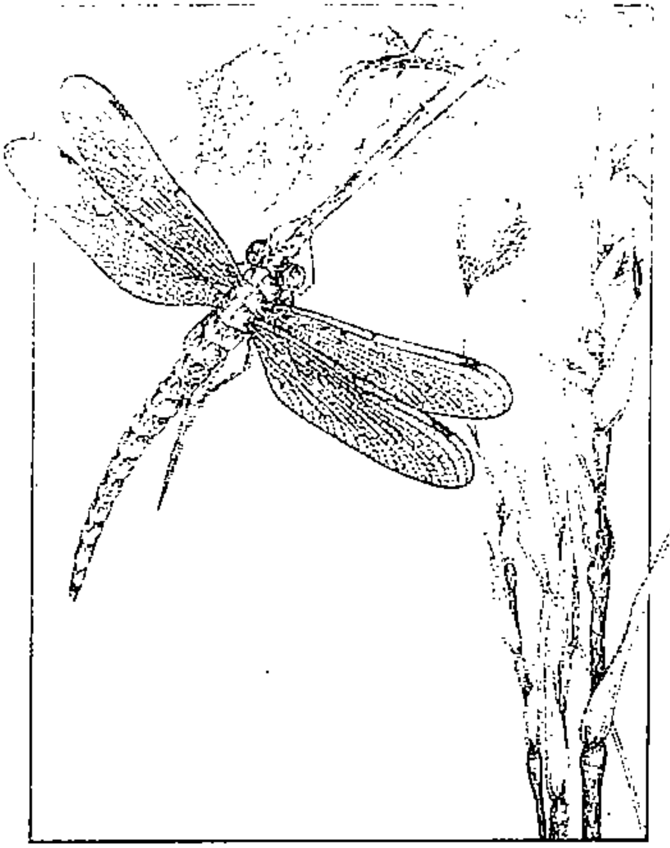
Step 5.1 – Prepare User's Guide

This report should focus on the results of the assessment and how the results can be used to meet the original objectives. It might include protocols and illustrations of how the synoptic maps can be used in 404 permit reviews and should include any important caveats and assumptions as well as the overall level of accuracy. In particular, the user's guide should make clear that final numeric values are relative rankings, and should be treated as such. For example, if a subunit is ranked lowest of six for habitat functions, this does not necessarily mean the subunit lacks habitat or that its habitat is insignificant. It means it has lower habitat function, relative to the other subunits. Similarly, a relatively high subunit ranking for wetland replacement potential does not necessarily mean all wetland losses in that subunit can be easily replaced.

The intended audience for this report includes resource specialists who are involved in decision-making or planning, as well as resource agencies, scientists, and the public.

Step 5.2 – Prepare Assessment Documentation

Each synoptic assessment should include, for internal use or distribution to interested parties, complete documentation of how the assessment was conducted, including the objectives, constraints, rationale for index definition and indicator selection, assumptions related to the indicators, and detailed descriptions of the procedures used in measuring and analyzing the data. Any problems encountered should also be described. The report should carefully document the sources and quality of the various data sets and describe where and how the data are archived. It also should include an overall assessment of data quality and recommendations on how the assessment could be improved in the future. This document is a detailed record of the assessment process, and could be valuable if procedures are forgotten, challenged (e.g., through litigation), or if the assessment is updated.



Chapter 4

Case Studies

This chapter presents four case studies as hypothetical examples of how a synoptic assessment could be used. It illustrates both project-specific applications and regional comparisons.

The management question for project-specific applications focuses on a specific, preselected subunit, e.g., a watershed or ecoregion. The objective could be to determine whether the subunit meets selected criteria, to develop broad goals for the subunit, or to see whether any "red flags" exist for that subunit relevant to a particular management objective. An example would be using a synoptic assessment to determine whether a proposed discharge of fill material is located within an area already at risk when compared to other areas.

For regional comparisons, the management objective is to determine which subunits within a region best meet a specific criteria; for example, subunits could be screened for their restoration potential. In this case the management objective is given, but the geographic locations meeting the criteria are unknown.

Each of the following case studies is designed to (1) provide the reader with an illustration of how results from a synoptic assessment could be used to support a specific management objective, (2) give examples of the kind of information that could be used as landscape indicators, and (3) identify and discuss technical issues. The first case study is purposely kept simple; complexity is added in later examples.

We preface the case studies with one major caveat: these four examples are based on pilot studies conducted as part of the development of the synoptic approach (e.g., Abbruzzese et al. 1990a, 1990b). We made no attempt to focus on real management problems because the method was developmental. Also, one of our specific objectives was to demonstrate that a synoptic assessment could be conducted using information available for most of the country. Where possible, we used the simplest combination rules—no normalization or weighting—because we were developing the method, not applying it. *The maps and data presented do not necessarily include the most appropriate indices or indicators for the management issue being illustrated.* This is why we refer to these as *hypothetical* examples.

In particular, we did not follow all five steps for conducting a synoptic assessment (Table 3.1); our experience with these pilots led to the final development and articulation of these five steps. The four examples presented in this chapter are not true case studies and do not document an actual application of the approach. The reader should keep the hypothetical nature of these examples in mind.

Pearl River Basin

The subject of the first case study is the Pearl River Basin, a 22,600 km^2 region in southern Mississippi and Louisiana (Figure 4.1). The focus is a project-specific management goal: the use of a synoptic assessment in 404 permit review. Functional loss and landscape input are introduced in this example. We illustrate differences between landscape and subunit boundaries by discussing the dependence of hydrologic function on cumulative area.

Management Goal

The goal of this hypothetical application is to provide 404 permit reviewers with information about cumulative impacts within the Pearl River Basin for inclusion in the review process. Two management scenarios will be considered: wetland loss from conversion and the effects of that loss on hydrologic function.

Wetland Types [1]

Bottomland hardwood forests are the dominant type of inland wetland within the basin. Freshwater, brackish, and saline marshes are found within the coastal area.

Landscape Boundary and Subunits

The Pearl River Basin forms a natural watershed boundary. Climate patterns produced by the Gulf of Mexico are significant forcing functions for the southern coastal area. The basin's five USGS cataloging units (Figure 4.1) were used as subunits; they range in size from 3,160 to 6,450 km^2 (Seaber et al. 1984).

Natural Setting

The prevailing climate of the study area is humid subtropical with rain occurring throughout the year (Trewartha 1957). The 130-150 cm of annual precipitation is the only source of runoff in the basin; discharge from the Pearl enters the Gulf of Mexico. Naturally occurring environmental disturbances include hurricanes, tornados, and flooding.

The Pearl River is bordered by the Pascagoula, Tombigbee, and Biloxi river basins to the east, by the Gulf of Mexico to the south, and by the Mississippi River Basin to the west and north. The Pearl River Basin has low relief, with peak elevations of about 120 m occurring in headwater areas. Valleys are steep and narrow at the head, but they grade to level and wide in lower reaches (USDA 1983); streams meander considerably in the lower valley. Loess or silt soils, formed under forest vegetation, dominate the drainage except in the coastal area (USDA 1983). Many of the soils are subject to erosion when disturbed. Southern mixed forest originally dominated the drainage, with cordgrass prairie vegetation in the coastal area and oak-savanna in the northwest edge (Kuchler 1985). Current vegetation patterns reflect land use: oak-hickory-pine forests occur with a mixture of pasture and hay cropping in the upland areas, and oak-gum-cypress forests mixed with agricultural land dominate the valley (USGS 1967).

Wetland Functions

Hydrologic, water quality, and habitat functions are all important in the basin. Among the hydrologic functions, the potential role of wetlands in attenuating peak flow is the focus of the synoptic indices. This role is particularly noteworthy because floodplains are populated and several major cities lie within the basin.

The basin's wetland forests, marshes, and lakes provide habitat for many species of plants and animals. Mink, muskrat, and beaver inhabit riparian and wetland areas. Wild turkey, whitetail deer, and raccoon use both wetland and upland areas. Migrating ducks and geese feed and rest in the region. Common fish species include largemouth bass, crappie, bluegill, and various species of catfish (Lowe and Cooley 1981).

Significant Impacts

Conversion of wetlands for agriculture has been a major economic activity in the basin. Pasture and hay area is about twice that of croplands; soybeans are the dominant crop. Agricultural activities contribute to nonpoint source pollution in the form of suspended sediments, nitrogen, and phosphorous (Gosselink et al. 1990a). Softwood forestry has also been important to the economy. Bottomland hardwood forests have been converted to loblolly pine in conjunction with "bedding," i.e., mounding soil in areas subject to flooding to provide a drier environment for pine.

Sand and gravel mining occurs within current and former river channels of the lower basin; this contributes to channel instability and water turbidity. Although the basin has not been extensively modified hydrologically compared to neighboring river basins in the Gulf Coastal Plain, at least 290 km of streams have been channelized, and the river is impounded above Jackson, below Bogalusa, and west of Picayune (USFWS 1981).

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[1] Information on wetland types, natural setting, wetland functions, and significant impacts was not usually used because the original objective of the assessments was methods development. We include this information as part of the four case studies to illustrate the kind of information that could be incorporated into an actual assessment.

Figure 4.1. The Pearl River Basin in south-central Mississippi and southeastern Louisiana and the five subunits. Subunits are USGS cataloging units.

Synoptic Indices

For the first scenario, we define the percentage of historical wetland area that has been converted as our specific index of functional loss:

$$\%LOSS = [(AREA_H - AREA_C) / AREA_H] \times 100$$

Equation 4.1

where %LOSS is the percentage of lost wetland area, $AREA_H$ is the historical wetland area, and $AREA_C$ is the current wetland area.

In the second management scenario, we are specifically concerned with the cumulative effect this loss may have had on the hydrologic function of wetlands. We assume that loss of hydrologic function will be greatest in areas with high hydrologic input and high rates of wetland loss. We use peak discharge for a 50-year flood event as an estimate of hydrologic input because flood control along the main channel is an important hydrologic function of Pearl River wetlands. Our loss of hydrologic function index is therefore defined as follows:

$$LOSS_H = Q_{50} \times \%LOSS$$

Equation 4.2

where $LOSS_H$ is the index for loss of hydrologic function, Q_{50} is the peak discharge for a 50-year flood, and %LOSS is defined in Equation 4.1. This is a simple index and does not account for wetland influence attributable to position within a subunit or to hydrologic regime. Such factors can influence greatly the cumulative wetland capacity to moderate peak flows. Also, note that we do not normalize or weight either variable; we assume instead a first-order proportionality.

In a real application for cumulative impacts, the resource specialist conducting the assessment could decide to focus specifically on impacts to bottomland hardwood forests and could include degradation. Indices would also be needed for loss of bottomland hardwood function due to impacts of farming, timber harvest, and sand and gravel mining. The analyst could include indices for water quality and habitat function as well as future risk. The latter is included in regulatory definitions of cumulative impacts; see Chapter 1. Illustrations of these indices appear in later case studies.

Landscape Indicators

Table 4.1 summarizes the landscape indicators used for the components of the synoptic indices defined in Equations 4.1 and 4.2. The use of the indicators for LOSS is based on several assumptions: (1) USGS land-use classification of wetlands and SCS classification of hydric soils agree with generally accepted criteria, (2) 1:250,000 scale maps represent current wetland area adequately, (3) Hydric soils can be used to estimate historical wetland extent, and (4) Hydrologic loss is proportional to the loss of wetland area regardless of where in the subunit the loss occurred.

These assumptions are violated in certain instances. Some of the areas adjoining lakes and estuaries are defined as wetlands by USGS, but are classified as open water by SCS. In addition, coastal wetlands lost to open water through subsidence are not accounted for using this method. These sources of error result in an inaccurate depiction of net wetland gain. On the other hand, some areas commonly considered wetlands are not classified as such by USGS maps; in particular, seasonally flooded riverine wetlands are sometimes classified as deciduous forests. In addition, 1:250,000 USGS maps omit small wetland patches. These sources of error would result in an underestimate of current wetland area, causing an overestimate of historic loss. However, this indicator of loss should be adequate for relative comparisons as long as classification errors are consistent between subunits.

Table 4.1. Landscape indicators for the Pearl River Basin case study.

Index Component	Indicator
$AREA_H$ (historic wetland area)	Area of hydric soils, estimated with dot grid from county and parish soil surveys; hydric soils identified from SCS (1987)
$AREA_C$ (current wetland area)	Area of wetland land cover, estimated with dot grid from 1:250,000 USGS LULC maps
Q_{50} (peak discharge for 50-yr flood)	Estimated from USGS regression equations (Landers and Wilson 1991), based on watershed drainage area (A), mainstem channel length (L), and channel slope (S)
A (watershed drainage area)	Defined for USGS cataloging units in Seaber et al. (1984)
L (mainstem channel length)	Measured with planimeter from 1:250,000 USGS topography maps
S (channel slope)	Calculated as the slope between points that are 10% and 85% of the mainstem channel length (Landers and Wilson 1991); mainstem channel length as above, and elevation estimated from USGS 1:250,000 topography maps

Other indicators of loss could be used. These might include percent change in bottomland forest types if data from forest surveys (e.g., McWilliams and Rosson 1990) are considered adequate for the assessment subunits.

For $LOSS_H$, the use of Q_{50} (the 50-year flood event) as an indicator requires using USGS regression equations (Landers and Wilson 1991). This adds the assumption that watershed hydrology has not been significantly altered. The Pearl River Basin does contain a major structural modification, the Ross Barnett Dam near Jackson. However, this dam functions primarily as a reservoir and would have minimal impact on larger floods (personal communication, P. Turnipseed, USGS, Jackson, Miss.). We therefore chose a 50-year flood event in order to minimize this effect. Use of the USGS regression method also assumes that the area is unaffected by tides, which would decrease the rate of discharge but increase flood stage. Use of the regression method further assumes that channelization has no significant effect on discharge or that the effect is similar between subunits. An alternative would have been to use a hydrologic model such as TR-55 (SCS 1986) to calculate peak discharge, which would take into account damming and channelization.

Measurements of watershed drainage area, mainstem channel length, and channel slope are required to calculate discharge for the Pearl River subunits. However, it is important to differentiate between drainage area and subunit (cataloging unit) area because discharge is a cumulative phenomenon. Subunit 1 is a closed hydrologic unit and receives no water input except rain. The discharge from Subunit 1 is therefore dependent on the area of Subunit 1 only. However, Subunit 2 is not a closed watershed; besides local precipitation, it receives downstream import from Subunit 1. The combined area of Subunits 1 and 2 is used to calculate discharge for Subunit 2. Similarly, the discharge for Subunit 4 is dependent on the area of the entire Pearl River Basin (Appendix H).

Mainstem channel length is also cumulative; it is defined as the length of the main channel from the point of discharge to the drainage divide. The channel length used to calculate discharge for Subunit 4 is the combined lengths of Subunits 1, 2, 3, and 4; the length of Subunit 5 would *not* be included in this particular calculation because it is not part of the main channel (see Appendix H). In situations where a political boundary defines the study area, the analysis must similarly consider landscape factors outside of the study area for such a cumulative phenomenon; this is further discussed in the Louisiana case study and Appendix H.

Map Interpretation

The relative ranking of cataloging units in the Pearl River Basin for cumulative wetland loss is shown in Figure 4.2. Subunit 3 has the highest relative wetland loss, followed by Subunits 2, 5, 1, and 4. If a permit were being reviewed for a project in Subunit 4, this particular analysis would indicate that cumulative impacts are of lesser concern. The permit decision would be based solely on site-specific evaluation. If the proposed discharge were located within Subunit 3, however, the high level of wetland loss would raise an additional issue to be considered along with other information. The assumption is that the cumulative loss of wetland area within a subunit reduces valued wetland functions such as flood control.

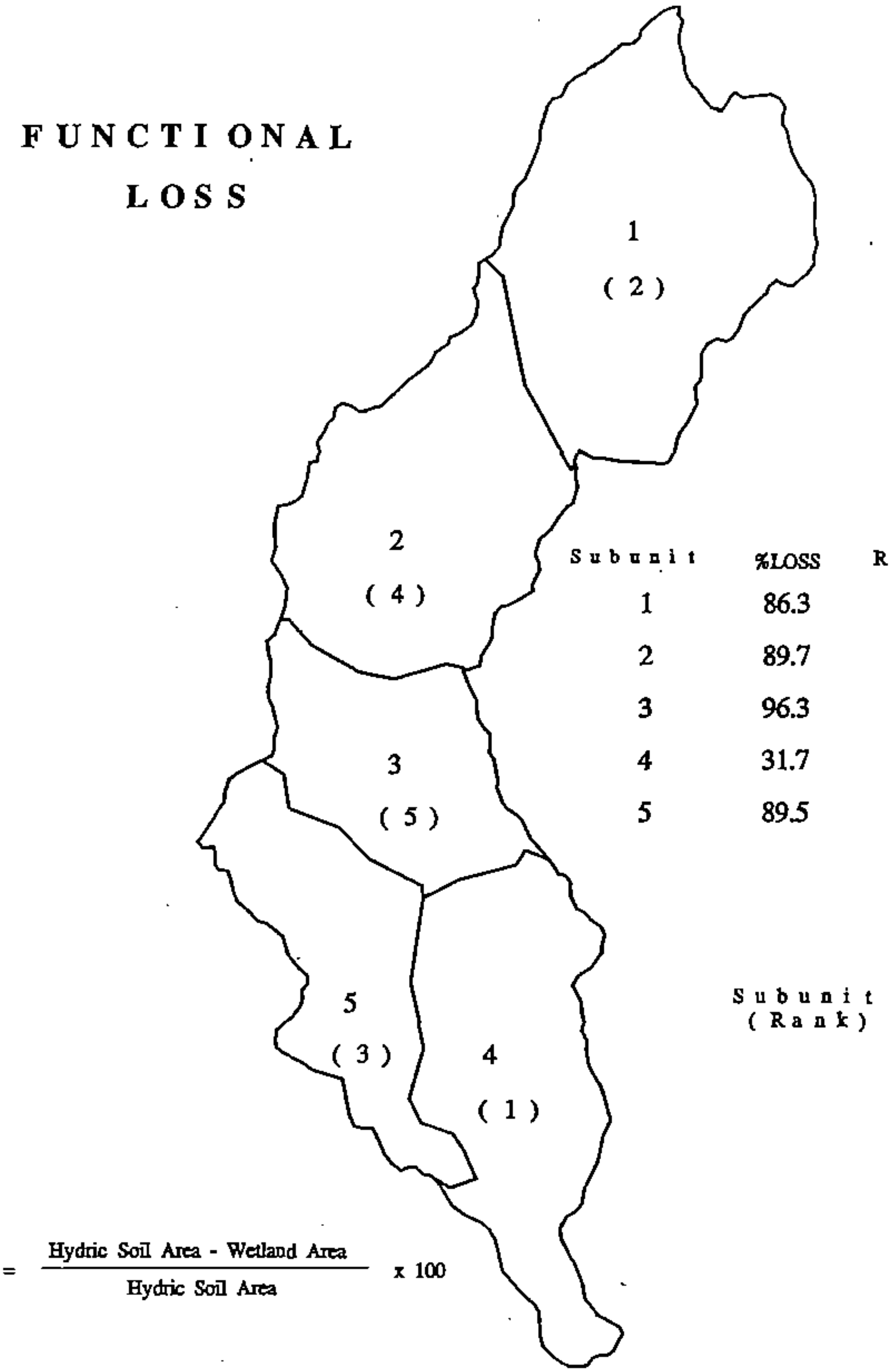
If a site assessment indicated that local impacts would be significant, this plus the cumulative impacts could provide sufficient reason for modifying or denying the permit. Regardless of the local impact, additional compensatory mitigation might be required for the project because this subunit had already experienced a high rate of wetland loss.

Given that the basin is a flood-prone area, the resource manager might be most concerned with loss of hydrologic function. The subunit experiencing the greatest wetland loss need not have experienced the greatest loss of hydrologic function, since that subunit could have a smaller flood potential. The second scenario incorporates hydrologic input as a weighting factor to focus on this particular function. Consider a permit request for gravel mining along the main channel in Subunit 2 (Figure 4.3). The reviewer might determine that additional wetland alteration would exacerbate flooding, since this subunit has a high relative ranking for loss of hydrologic function. This information could strengthen the basis for negotiating on-site mitigation aimed specifically at reducing the risk of increased flooding as a condition of the permit. At a minimum, the reviewer could use this information to require the applicant to demonstrate that increased flooding is *not* a relevant consideration in the particular permit decision.

In this example, both Q_{50} and %LOSS had values that varied by a factor of three (2,151 to 6,417m^3/s for Q_{50} and 32 to 96% for %LOSS). Both would contribute similarly to the range of $LOSS_H$. For a landscape where the mainstem varied from small streams to major rivers, Q_{50} could vary by orders of magnitude and dominate the trends in $LOSS_H$. In such a case, weighting factors could be used to give the wetland-dependent variable %LOSS greater weight, or both variables could be normalized.

State of Louisiana

The Louisiana case study provides a second example of a project-specific application; in this instance, we use synoptic results to help define restoration goals and to determine whether any "red flags" exist for a restoration project. To do this, we introduce restoration potential and wetland function as synoptic indices. We also

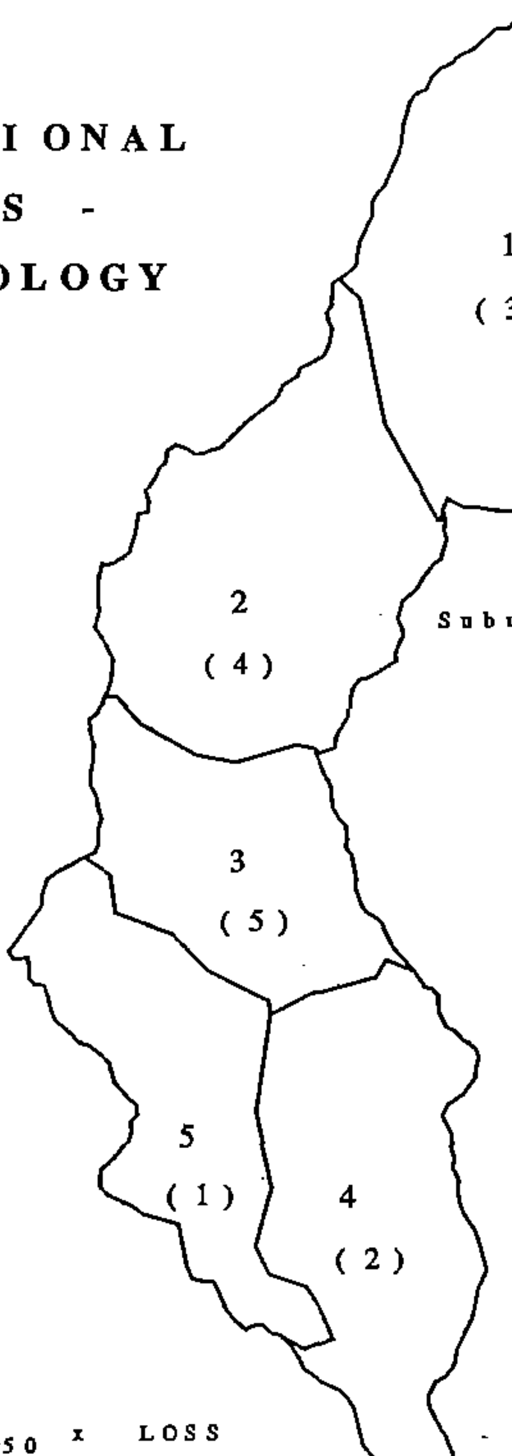


Subunit	%LOSS	Rank
1	86.3	2
2	89.7	4
3	96.3	5
4	31.7	1
5	89.5	3

$$\%\text{LOSS} = \frac{\text{Hydric Soil Area} - \text{Wetland Area}}{\text{Hydric Soil Area}} \times 100$$

Figure 4.2. Functional loss for the Pearl River Basin. Within each subunit, the upper value is the subunit number and the lower, parenthetical value is the rank. The variables included in the equation for %LOSS represent the landscape indicators, not the components of the synoptic index (Equation 4.1).

FUNCTIONAL
LOSS -
HYDROLOGY



Subunit	$LOSS_H$	Rank
1	327,284	3
2	425,872	4
3	484,067	5
4	203,380	2
5	192,592	1

Subunit
(Rank)

$LOSS_H = Q_{50} \times LOSS$

Figure 4.3 Loss of hydrologic function for the Pearl River Basin. Within each subunit, the upper value is the subunit number and the lower, parenthetical value is the rank. The variables included in the equation for $LOSS_H$ represent the landscape indicators, not the components of the synoptic index (Equation 4.2).

discuss difficulties associated with determining hydrologic input when a study area is defined by political, rather than hydrologic, boundaries.

Management Goal

The management goal is to produce synoptic maps that can be used to identify limitations and set specific goals for restoration projects being proposed for compensatory mitigation. The sustainability of a restored wetland is dependent on landscape condition as well as on site characteristics and wetland type (Leibowitz et al. 1992). A synoptic assessment can provide landscape information that allows subunits to be evaluated rapidly for potential environmental problems, and it can help identify landscape functions that would benefit from restoration.

Wetland Types

Louisiana encompasses many wetlands; more than 12,000 km^2 of inland wetlands (freshwater marshes and bottomland hardwood swamps) and 12,000 km^2 of coastal wetlands (swamps and freshwater, brackish, and saline marshes) exist within the state (LDEQ 1988). Approximately 25% of the coastal wetlands in the contiguous United States are found in Louisiana (Alexander et al. 1986).

Landscape Boundary and Subunits

The state is bordered by Arkansas to the north, the Sabine River and Texas to the west, the Mississippi River and the state of Mississippi to the northeast, the Pearl River to the southeast, and the Gulf of Mexico to the south. Because the Mississippi River drains a majority of the United States, the state's hydrologic boundary includes much of the nation.

Water Management Units defined by the Louisiana Department of Environmental Quality are used for landscape subunits. These are modifications of the USGS cataloging units for the state; 124 subunits are included (Figure 4.4).

Natural Setting

Principal factors that influence the state's climate are subtropical latitude, proximity to the Gulf of Mexico, and northerly continental fronts (Gosselink 1984). As much as 160 cm of precipitation falls annually (Conner and Day 1987). Hurricanes and tropical storms occur between July and December and are natural environmental disturbances that cause coastal erosion (Boyd and Penland 1981; Chabreck and Palmisano 1973). With a maximum elevation of 160 meters in the northwest hills, the state has little topographic relief; the landscape gently slopes from the north to the southern coast.

The most important factor that has shaped Louisiana's landscape is the combined Mississippi River system, which drains two-thirds of the continental United States. As a result of coastal deposition the river's sediment supply has formed a broad plain of overlapping deltas (Coleman 1988). Sediment deposition through overbank flooding and erosional cutting by the river has similarly built the Mississippi alluvial valley. Sedimentation by the river and its shifting between deposition sites over thousands of years are critical processes for the construction and maintenance of the state's coastal and alluvial (bottomland hardwoods) wetlands.

Wetland Functions

The hydrologic, water quality, and habitat functions of Louisiana wetlands are important for the entire state. These wetlands constitute one of the nation's most productive environments and they provide habitat for hundreds of bird and mammal species. Two migratory bird routes cross the state and provide wintering grounds for a quarter of the nation's puddle ducks and more than half of the geese found in the Mississippi Flyway. Coastal marshes support a variety of furbearers, including nutria, coyote, muskrat, racoon, mink, red and gray fox, otter, bobcat, opossum, skunk, and beaver; this resource is valued at $25 million annually. Commercial and sport fisheries important to the state's economy are also wetland dependent: commercial landings of fish and shellfish ranked first in the nation in 1984.

Significant Impacts

Human alteration of the Mississippi River system has been extensive and includes three major impacts: (1) a 51% reduction in the river's suspended sediment levels between 1953 and 1962, primarily through construction of upstream locks and dams (Kesel 1989); (2) construction of a control structure that limits flow down the Atchafalaya River to 30% of total discharge, which prevents the system from switching to this distributary; and (3) the construction of a flood-control levee along the lower Mississippi, which prevents overbank flooding. Direct impacts to Louisiana wetlands include conversion of coastal marsh to open water through construction of oil and gas canals and pipelines and conversion of bottomland hardwoods by logging and agricultural drainage.

Synoptic Indices

Two management scenarios are presented here. The first examines wetland restoration from the perspective of landscape replacement potential, i.e., the ability of the landscape to contribute to wetland maintenance. The resulting indices can be used to evaluate the feasibility or sustainability of planned restoration projects. For this particular application, we chose three separate factors relevant to the state's inland wetlands: soils, hydrologic integrity, and water quality.

The first index for replacement potential considers the proportion of non-wetland hydric soils, e.g., soils in former wetlands converted to agricultural land. Replacement potential should be greater for hydric soils because they retain certain wetland characteristics and are located where natural factors favor wetland formation. Thus non-wetland hydric soils are good candidates for restoration. The specific index is given as

$$\mathrm{REPLACE}_S = (\mathrm{AREA}_H - \mathrm{AREA}_W) / \mathrm{AREA}_H \qquad \text{Equation 4.3}$$

where $\mathrm{REPLACE}_S$ is the replacement potential with respect to soil conditions, AREA_H is the area of hydric soils, and AREA_W is the area of current wetlands. Note that this is similar to the index used for loss of wetland area (%LOSS) in the Pearl River case study (Equation 4.1): the more wetlands that have been converted, the greater the number of potential restoration sites.

Since hydrology is critical to wetlands, we assume that long-term replacement of wetland functions will be more difficult in an area where natural hydrology has been altered; thus we include an index based on the degree of hydrologic integrity:

$$\mathrm{REPLACE}_H = \mathrm{WATER}_N / (\mathrm{WATER}_N + \mathrm{WATER}_M) \qquad \text{Equation 4.4}$$

where $\mathrm{REPLACE}_H$ is the replacement potential with respect to hydrologic integrity, WATER_N is the amount of naturally occurring waters, and WATER_M is the amount of hydrologically modified waters.

Finally, restoration can be more difficult in an area that is stressed by pollutant exposure; thus we include an index that represents overall water quality:

$$\mathrm{REPLACE}_{WQ} = \mathrm{WATER}_U / (\mathrm{WATER}_U + \mathrm{WATER}_P) \qquad \text{Equation 4.5}$$

where $\mathrm{REPLACE}_{WQ}$ is the replacement potential with respect to water quality, WATER_U is the amount of unpolluted waters, and WATER_P is the amount of polluted waters.

These indices do not account for several factors important to estimating replacement potential, such as presence of hazardous substances, local climate, and land usage. If data on these or other important factors are available, specific indices could be developed for them.

To help determine restoration goals, the second scenario provides indices of wetland function for hydrology, water quality, and habitat. The index for hydrologic function ($\mathrm{FUNCTION}_{HYD}$) combines wetland capacity ($\mathrm{CAPACITY}_{HYD}$) with hydrologic input:

$$\mathrm{FUNCTION}_{HYD} = \mathrm{CAPACITY}_{HYD} \times 7Q_{10} \qquad \text{Equation 4.6}$$

The variable for hydrologic input, $7Q_{10}$, is defined as the lowest 7-day mean discharge for a 10-year recurrence interval; in other words, this represents a 10-year drought. The contribution of wetlands to maintaining base flow is assumed to be more critical in areas where $7Q_{10}$ values are low.

The next index is a measure of relative wetland function with respect to water quality. The index combines wetland capacity (the ability of wetlands to promote landscape function through processing of pollutants) with pollutant input (the opportunity for wetlands to contribute to landscape function):

$$\mathrm{FUNCTION}_{WQ} = \mathrm{CAPACITY}_{WQ} \times \mathrm{INPUT}_{WQ} \qquad \text{Equation 4.7}$$

where $\mathrm{FUNCTION}_{WQ}$ is an index of pollution reduction actually occurring, $\mathrm{CAPACITY}_{WQ}$ is the capacity of the wetland to remove or otherwise transform pollutants, and INPUT_{WQ} is the pollutant loading rate.

The index for habitat function, $\mathrm{FUNCTION}_{HAB}$, is a measure of function relative to wetland-dependent species. This function is not dependent on landscape inputs and is defined as the density of wetlands within a subunit:

$$\mathrm{FUNCTION}_{HAB} = \mathrm{AREA}_W / A \qquad \text{Equation 4.8}$$

where $\mathrm{FUNCTION}_{HAB}$ is the habitat function, AREA_W is current wetland area, and A is subunit area.

Landscape Indicators

Table 4.2 contains a summary of the indicators for the Louisiana case study. Below we discuss some of the assumptions and issues related to these data.

In the first scenario, the indicators for the three replacement potential indices are based on the following assumptions: (1) Soils mapped as hydric are wetland substrate and exist in landscapes with adequate and appropriately timed sources of water that can sustain wetland processes; (2) The major hydrologic impacts that affect the sustainability of wetlands are damming and channelization; both have similar overall effects on replacement potential, and both are adequately estimated by dot counts; and (3) Water quality data from state 305b reports represent an accurate and unbiased sample of natural water quality as it pertains to wetland stress. Because the indicators for replacement potential

Table 4.2. Landscape indicators for the Louisiana case study.

Index Component	Indicator
$AREA_H$ (hydric soil area)	Area of hydric soils, estimated with dot grid from parish soil surveys; hydric soils identified from SCS (1987)
$AREA_W$ (current wetland area)	Area of wetland land cover, estimated by GIS from digital 1:250,000 USGS LULC maps
$WATER_N$ (naturally occurring waters)	Number of dots on hydrologically unmodified waters from 1:250,000 USGS topographic maps
$WATER_M$ (hydrologically modified)	Number of dots on dammed or channelized waters from 1:250,000 USGS topographic maps
$WATER_U$ (unpolluted waters)	Length of streams listed as "fully supporting" designated uses in 305b report (LDEQ 1988)
$WATER_P$ (polluted waters)	Length of streams listed as "partially supporting" or "non-supporting" designated uses in 305b reports (LDEQ 1988)
$CAPACITY_{HYD}$ (hydrologic capacity)	Area of wetland cover, estimated by GIS from digital 1:250,000 USGS LULC maps
$7Q_{10}$ (7-day low discharge for 10-yr drought)	Estimated using several different methods, based on Lee (1985a); see text
$CAPACITY_{WQ}$ (water quality capacity)	Area of wetland cover, estimated by GIS from digital 1:250,000 USGS LULC maps
$INPUT_{WQ}$ (loading rate of pollutants)	Defined as the percent of polluted waters: $WATER_P/(WATER_P + WATER_U)$; indicators as above
A (watershed area)	Watershed area, estimated by GIS from digital 1:250,000 USGS LULC maps

with respect to soil include those used earlier for %LOSS (compare Equation 4.1 with Equation 4.3 and Table 4.1 with Table 4.2), the earlier assumptions also hold for $REPLACE_S$.

For wetland functions, the 7-day low flow was estimated using several methods based on Lee (1985a); these are discussed in more detail below. Assumptions for functional indicators are as follows: (1) Wetlands contribute to baseflow and this contribution is more significant in areas with smaller 10-year low flows, i.e., those more susceptible to drought; (2) The proportion of streams classified as not fully supporting designated uses such as "public water supply" or "fish and wildlife propagation" is indicative of pollutant loadings; and (3) Wetland function for hydrology, water quality, and habitat is dependent on wetland area as mapped by USGS land-use maps. Since the indicator for landscape input of pollutants is the complement of the indicator used for water quality replacement potential (See Table 4.2 and Equation 4.4), those assumptions also hold.

In this case study we introduce a technical problem related to study area boundaries. Because regulatory jurisdiction is rarely defined by environmental criteria, the boundary for a study will typically not be a natural watershed as it was for the Pearl River Basin. In cases where portions of a subunit are outside of the study area, the analyst must consider hydrologic input from upstream tributaries. Louisiana is such a case because most of the flow for the Mississippi and Red rivers is derived from import into the state. The USGS regression equations provide a relatively simple, standardized technique for estimating discharge; however, these equations are not appropriate for rivers with large watersheds, which are typically excluded from statistical analyses. Even for smaller watersheds, it can be difficult to obtain appropriate and comparable data for areas that lie outside of a state boundary.

Given these limitations, we used several different methods for estimating $7Q_{10}$ based on a USGS report (Lee 1985a). For subunits having a gage station on the mainstem channel near the bottom of the subunit, we used actual $7Q_{10}$ values if they were defined; 37 of the 124 subunits met the criterion. Values for two additional subunits were derived from graphs of $7Q_{10}$ versus the drainage area of those two subunits (Lee 1985a).

For subunits without suitable gage stations, regression equations based on watershed area, precipitation, and channel slope were used if total watershed area was not more than 1,360 km^2 and if the watershed was not within a region of the state for which $7Q_{10}$ was undefinable (Lee 1985a). The latter included the entire coast, which is subject to tidal influence, and portions of the Atchafalaya Basin, where channels have been modified by man and are interconnected. Ten additional subunits met these criteria, and low flow values were calculated using the regressions. Watershed area for these subunits was obtained by GIS from 1:250,000 USGS LULC maps; note that for subunits where a portion of the watershed is outside the study area (e.g., a portion of the watershed for Subunit 705 is in Mississippi), the area of this outside portion must also be estimated. Precipitation was calculated by digitizing precipitation contours and prorating them to watershed units (Appendix F); channel slope was calculated in the same manner as in the Pearl River example.

Two additional subunits were located in a region of the state dominated by low flow values of zero; thus a zero value was assigned to these units. Low flow for the remaining 72 subunits — more than half of the state's subunits — is undefined, either because the subunit was located in an undefined portion of the state or because the subunit area was greater than 1,360 km^2. This clearly illustrates the difficulty in attempting to define discharge for study subunits.

Map Interpretation

Assume that a wetland restoration project has been proposed for compensatory mitigation and that the site is to be located on a parcel of land in Subunit 805 (Figure 4.5). To identify potential problems, the permit reviewer would first examine the synoptic maps to evaluate the subunit's relative replacement potential.

The maps for hydrologic integrity (Figure 4.6) and water quality (Figure 4.7) suggest that hydrology is relatively unimpaired and that water quality problems are not likely to cause stress. However, the relatively low proportion of non-wetland hydric soils (Figure 4.5) raises a red flag; overall, this subunit might not be suitable for wetland restoration projects. The permit reviewer should scrutinize the proposed site more carefully to determine the likelihood of successful restoration. This information could also be the basis for negotiating a project design that specifically addresses any soil problems, e.g., the applicant might be required to supply an appropriate substrate for the site.

If the decision is made to restore a wetland at the site, the three wetland function maps (Figures 4.8-4.10) can be used to help define restoration goals. For example, a function rated as low might be naturally unsuited to that area or unnecessary because of low landscape input, while a function with a high rating is already at an acceptable level; functions with intermediate ratings might benefit most from restoration. The map for hydrology (Figure 4.8) indicates intermediate levels of that function for Subunit 805, which suggests that wetlands might help alleviate low flows. In comparison, the map for water quality (Figure 4.9) shows low function; water quality improvement would be unnecessary in this area because pollutant loadings are low. Habitat function also ranks somewhat low (Figure 4.10) possibly indicating naturally low habitat function. Thus the reviewer might initially focus on hydrologic function (base flow) as a goal for the site. The information from the synoptic maps can therefore be used as a screening tool; however, these initial findings should be confirmed with a site-specific evaluation, especially to assure that the restored wetland was designed in such a manner as to reduce low flow. The degree to which wetlands contribute to base flow is still unresolved (see Chapter 7). We do not mean to imply that wetlands do contribute to base flow in this region. This example merely illustrates how this information would be used if that were the case.

Unlike the Pearl River case study, the subunits in this case study were ranked and mapped based on quartiles. The Pearl River Basin has only five subunits, and an ordinal ranking of the units is easily understood. In a study area with as many units as Louisiana, grouping by quartiles conveniently depicts the relative rankings.

State of Washington

In the next two case studies, we illustrate how synoptic assessments can be used for regional comparisons. We use results for the state of Washington to illustrate how this kind of information could support the development of a State Wetland Conservation Plan. We also introduce value and future risk as synoptic indices and demonstrate the use of weighting factors for combining components of an index.

Management Goal

The purpose of the assessment is to provide information on future risk of valued habitat loss to identify habitat areas for protection as part of the development of a State Wetland Conservation Plan. In particular, habitat that supports rare, threatened, or endangered species is the value of interest in this case.

Wetland Types

Washington contains a diversity of wetland types. These can be grouped according to the four regions in which they are found: the coastal plain, the Puget lowlands, the mountains, and the Columbia Basin (Winter 1990).

Within the coastal region, estuaries and salt marshes predominate. Freshwater emergent marshes, bogs, and freshwater swamps occur in the Puget lowlands. The primary wetland types in the northern mountains are kettlehole depressions and wet meadows; in other mountain regions, freshwater emergent and riparian wetlands are more abundant. Vernal pools, playas, and wet areas are found along intermittent streams in the arid east (Canning and Stevens 1989).

LOUISIANA SUBUNIT INDEX

WATER MANAGEMENT UNITS

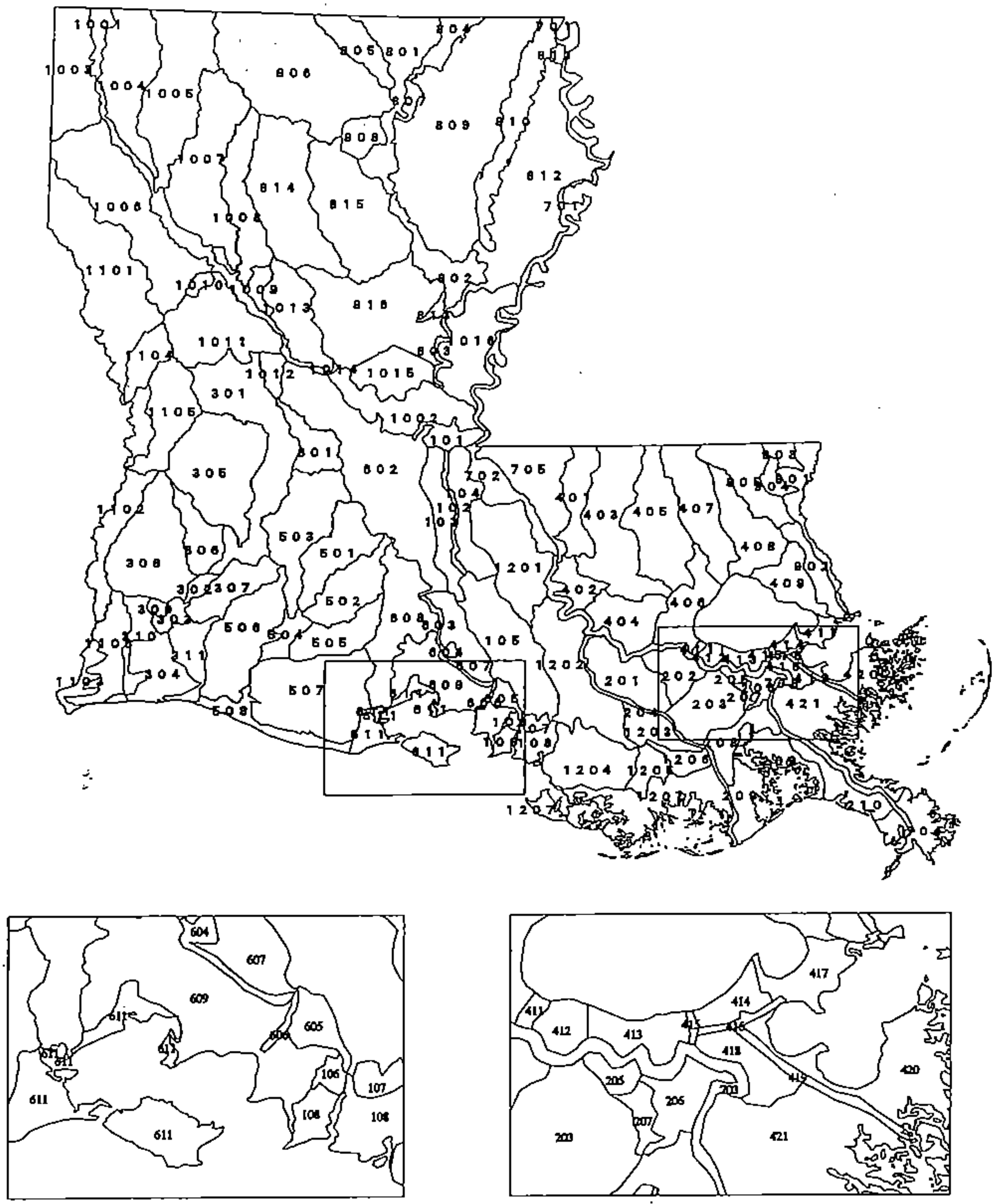
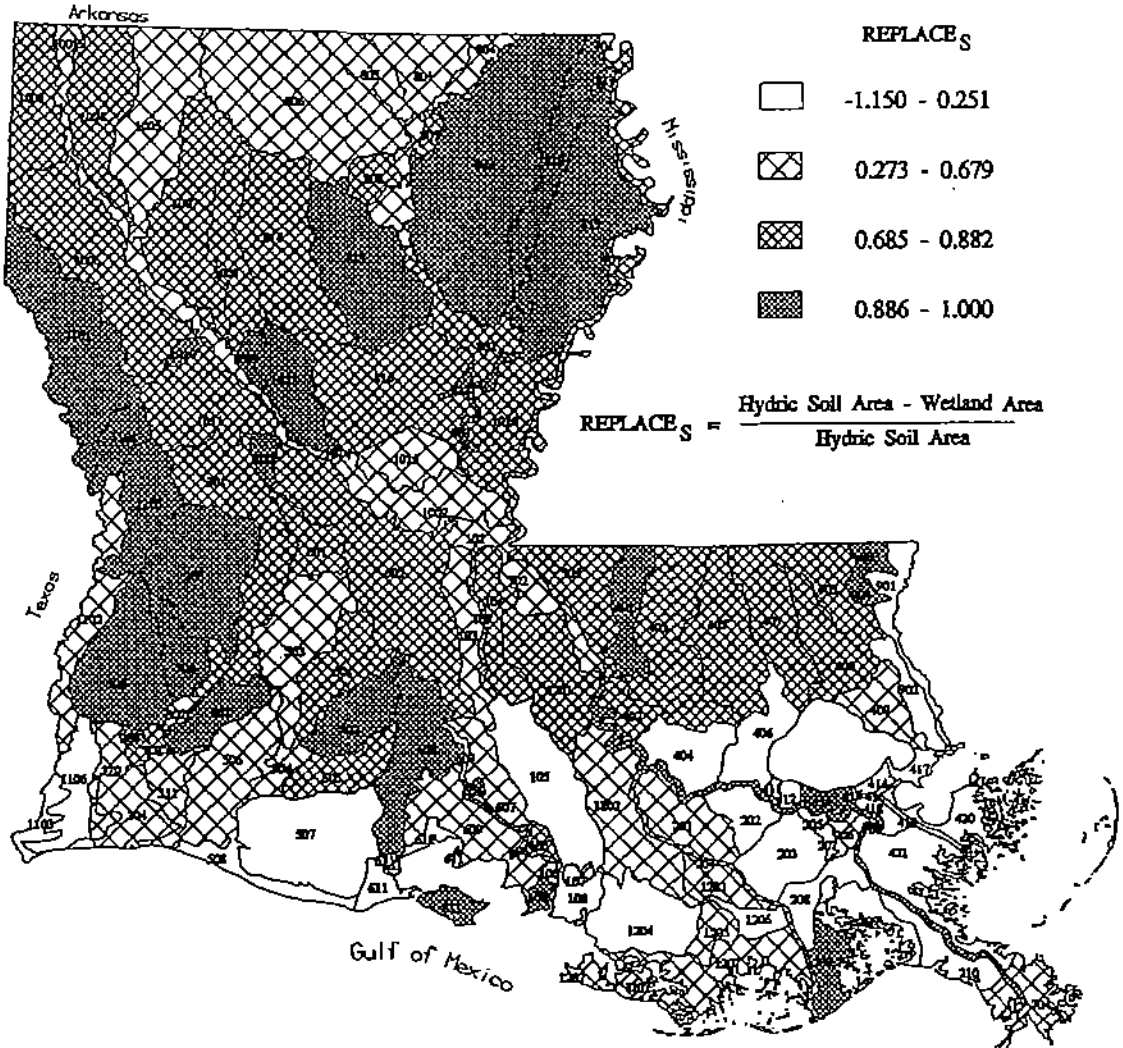


Figure 4.4. The State of Louisiana and the 124 subunits. Subunits are Water Management Units as defined by the Louisiana Department of Environmental Quality.

REPLACEMENT POTENTIAL - SOILS



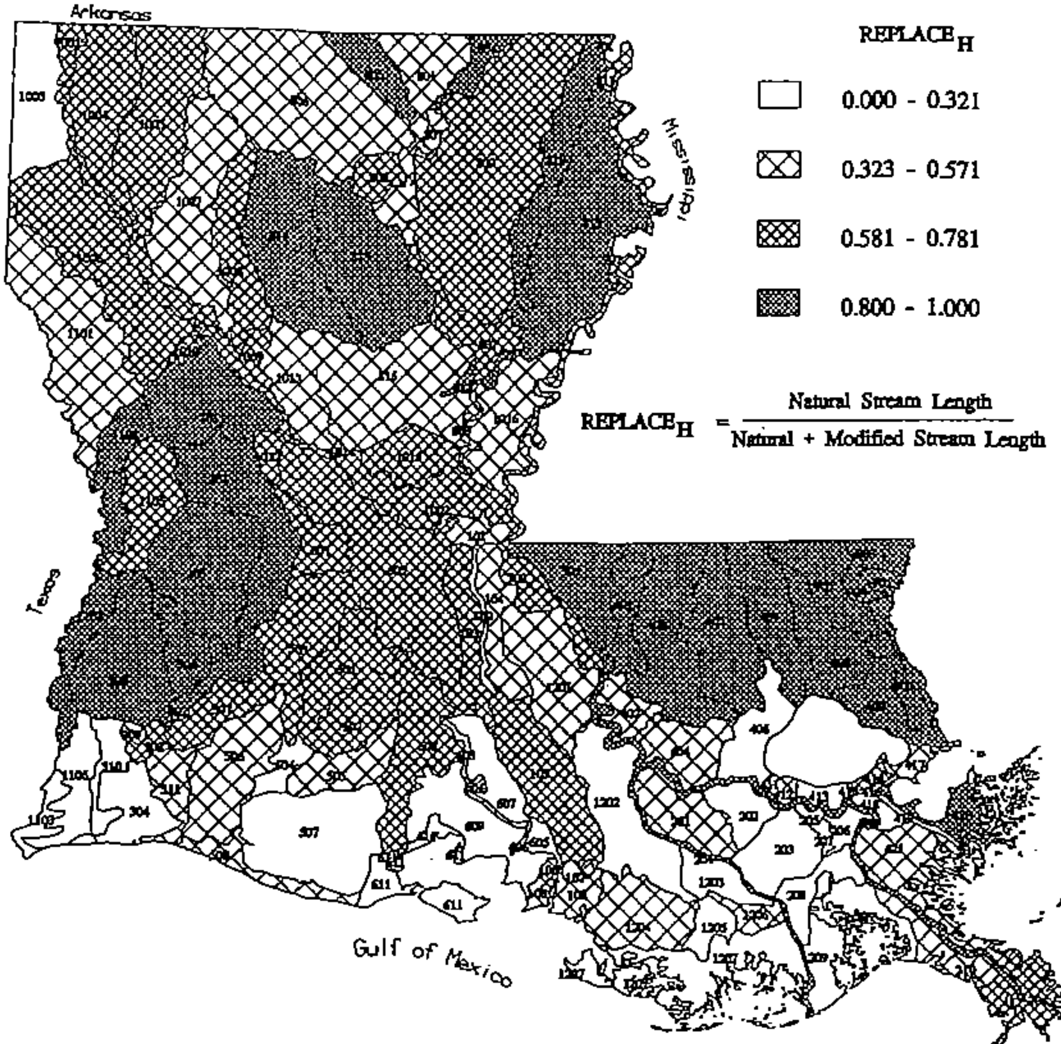
$$\text{REPLACE}_S = \frac{\text{Hydric Soil Area} - \text{Wetland Area}}{\text{Hydric Soil Area}}$$

Subunit - REPLACE_S

101 - 0.437
102 - 0.865
103 - 0.586
104 - 0.771
105 - 1.000
106 - 0.214
107 - 0.571
108 - 0.099
201 - 0.280
202 - 0.098
203 - 0.251
204 - 0.787
205 - 1.270
206 - 0.328
207 - 1.680
208 - 1.160
209 - 0.086
210 - 0.184
301 - 0.685
302 - 0.573
303 - 0.770
304 - 0.369
305 - 0.898
306 - 0.980
307 - 0.896
308 - 0.966
309 - 0.968
310 - 0.679
311 - 0.406
401 - 0.977
402 - 0.846
403 - 0.847
404 - 0.018
405 - 0.791
406 - 0.090
407 - 0.768
408 - 0.882
409 - 0.615
411 - 1.030
412 - 1.020
413 - 0.948
414 - 1.120
415 - 0.000
416 - 1.100
417 - 1.290
418 - 2.150
419 - 1.730
420 - 1.250
421 - 1.580
501 - 0.841
502 - 0.936
503 - 0.634
504 - 0.640
505 - 0.870
506 - 0.539
507 - 0.069
508 - 1.520
601 - 0.859
602 - 0.886
603 - 0.000
604 - 0.982
605 - 0.779
606 - 0.602
607 - 0.570
608 - 0.934
609 - 0.273
611 - 1.010
701 - 0.795
702 - 0.447
703 - 0.897
704 - 0.362
705 - 0.861
801 - 0.481
802 - 0.878
803 - 0.910
804 - 0.487
805 - 0.604
806 - 0.508
807 - 0.780
808 - 0.863
809 - 0.944
810 - 0.997
811 - 0.948
812 - 0.904
813 - 0.980
814 - 0.790
815 - 0.931
816 - 0.767
901 - 1.140
902 - 1.250
903 - 0.997
904 - 0.977
905 - 0.854
1001 - 0.674
1002 - 0.644
1003 - 0.856
1004 - 0.743
1005 - 0.542
1006 - 0.870
1007 - 0.746
1008 - 0.843
1009 - 0.900
1010 - 0.992
1011 - 0.773
1012 - 0.926
1013 - 0.922
1014 - 0.968
1015 - 0.314
1016 - 0.767
1101 - 0.898
1102 - 0.581
1103 - 1.080
1104 - 0.992
1105 - 0.933
1106 - 0.043
1201 - 0.836
1202 - 0.566
1203 - 0.506
1204 - 0.073
1205 - 0.327
1206 - 0.207
1207 - 0.337

Figure 4.5. Replacement potential with respect to soils for Louisiana. Darker hatching corresponds to higher replacement potential. The variables included in the equation for REPLACE_S represent the landscape indicators, not components of the synoptic index (Equation 4.3).

REPLACEMENT POTENTIAL - HYDROLOGY

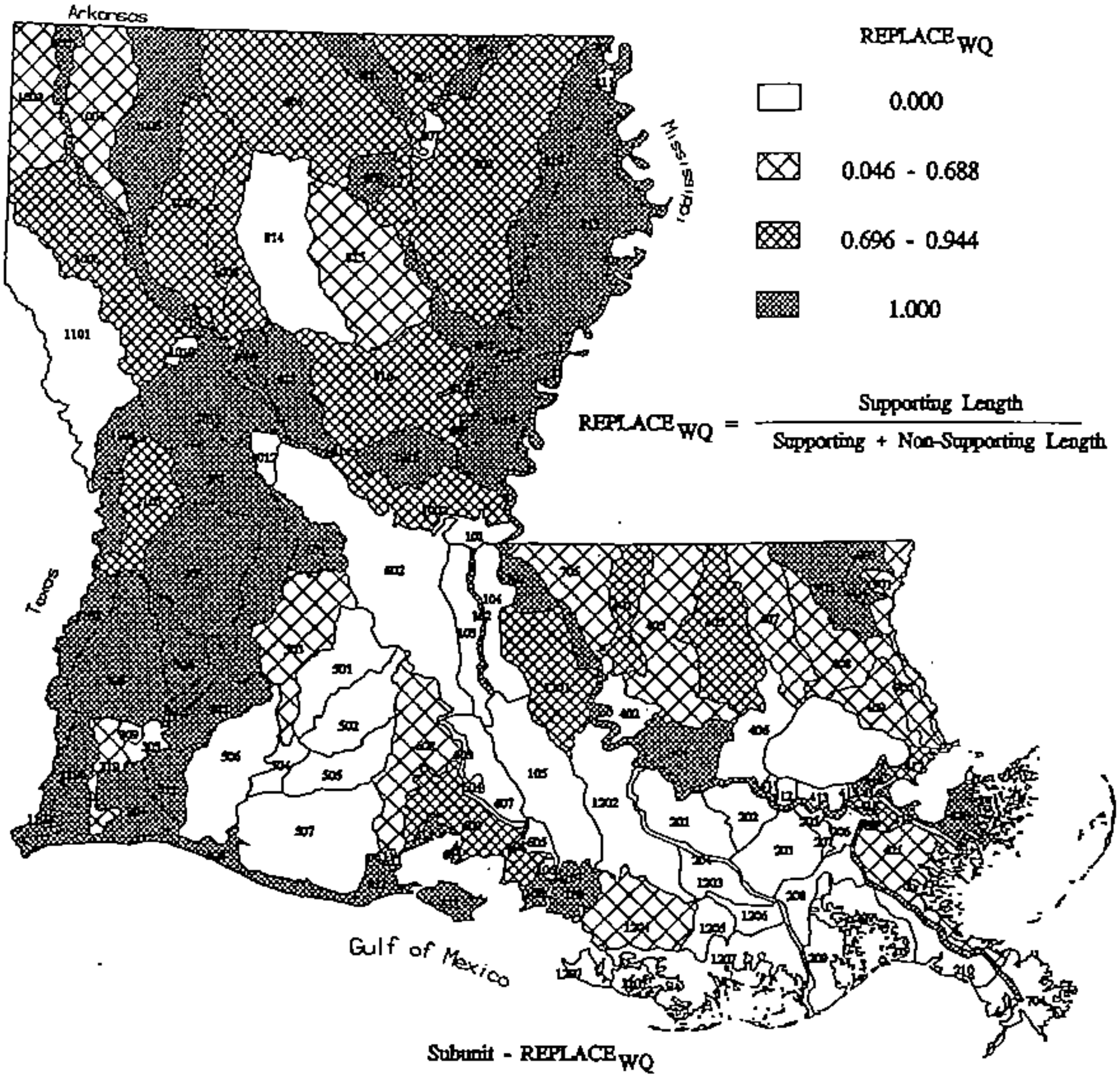


Subunit - $REPLACE_H$

101 - 0.357
102 - 0.286
103 - 0.708
104 - 0.571
105 - 0.582
106 - 0.500
107 - 0.500
108 - 0.462
201 - 0.364
202 - 0.172
203 - 0.122
204 - 1.000
205 - 0.000
206 - 0.083
207 - 0.000
208 - 0.143
209 - 0.321
210 - 0.414
301 - 1.000
302 - 0.800
303 - 0.750
304 - 0.071
305 - 0.953
306 - 1.000
307 - 0.600
308 - 0.938
309 - 0.333
310 - 0.286
311 - 0.467
401 - 1.000
402 - 0.571
403 - 1.000
404 - 0.391
405 - 0.964
406 - 0.111
407 - 1.000
408 - 0.467
409 - 0.917
411 - 0.500
412 - 0.375
413 - 0.125
414 - 0.625
415 - 0.667
416 - 0.333
417 - 0.500
418 - 0.286
419 - 0.000
420 - 0.850
421 - 0.333
501 - 0.583
502 - 0.615
503 - 0.708
504 - 0.286
505 - 0.545
506 - 0.333
507 - 0.072
508 - 0.412
601 - 0.667
602 - 0.594
603 - 0.000
604 - 0.500
605 - 0.000
606 - 0.000
607 - 0.222
608 - 0.647
609 - 0.233
611 - 0.025
701 - 0.634
702 - 0.781
703 - 0.891
704 - 0.722
705 - 1.000
801 - 0.323
802 - 0.600
803 - 0.625
804 - 1.000
805 - 1.000
806 - 0.537
807 - 0.500
808 - 0.667
809 - 0.763
810 - 0.909
811 - 0.333
812 - 0.818
813 - 1.000
814 - 0.917
815 - 1.000
816 - 0.558
901 - 0.944
902 - 0.917
903 - 1.000
904 - 1.000
905 - 1.000
1001 - 0.581
1002 - 0.650
1003 - 0.286
1004 - 0.677
1005 - 0.586
1006 - 0.745
1007 - 0.548
1008 - 0.765
1009 - 0.667
1010 - 0.667
1011 - 0.880
1012 - 0.750
1013 - 0.529
1014 - 0.000
1015 - 0.714
1016 - 0.545
1101 - 0.490
1102 - 0.971
1103 - 0.094
1104 - 0.875
1105 - 0.714
1106 - 0.250
1201 - 0.488
1202 - 0.197
1203 - 0.111
1204 - 0.333
1205 - 0.286
1206 - 0.429
1207 - 0.303

Figure 4.6. Replacement potential with respect to hydrologic integrity for Louisiana. Darker hatching corresponds to higher replacement potential. The variables included in the equation for $REPLACE_H$ represent the landscape indicators, not components of the synoptic index (Equation 4.4).

REPLACEMENT POTENTIAL - WATER QUALITY



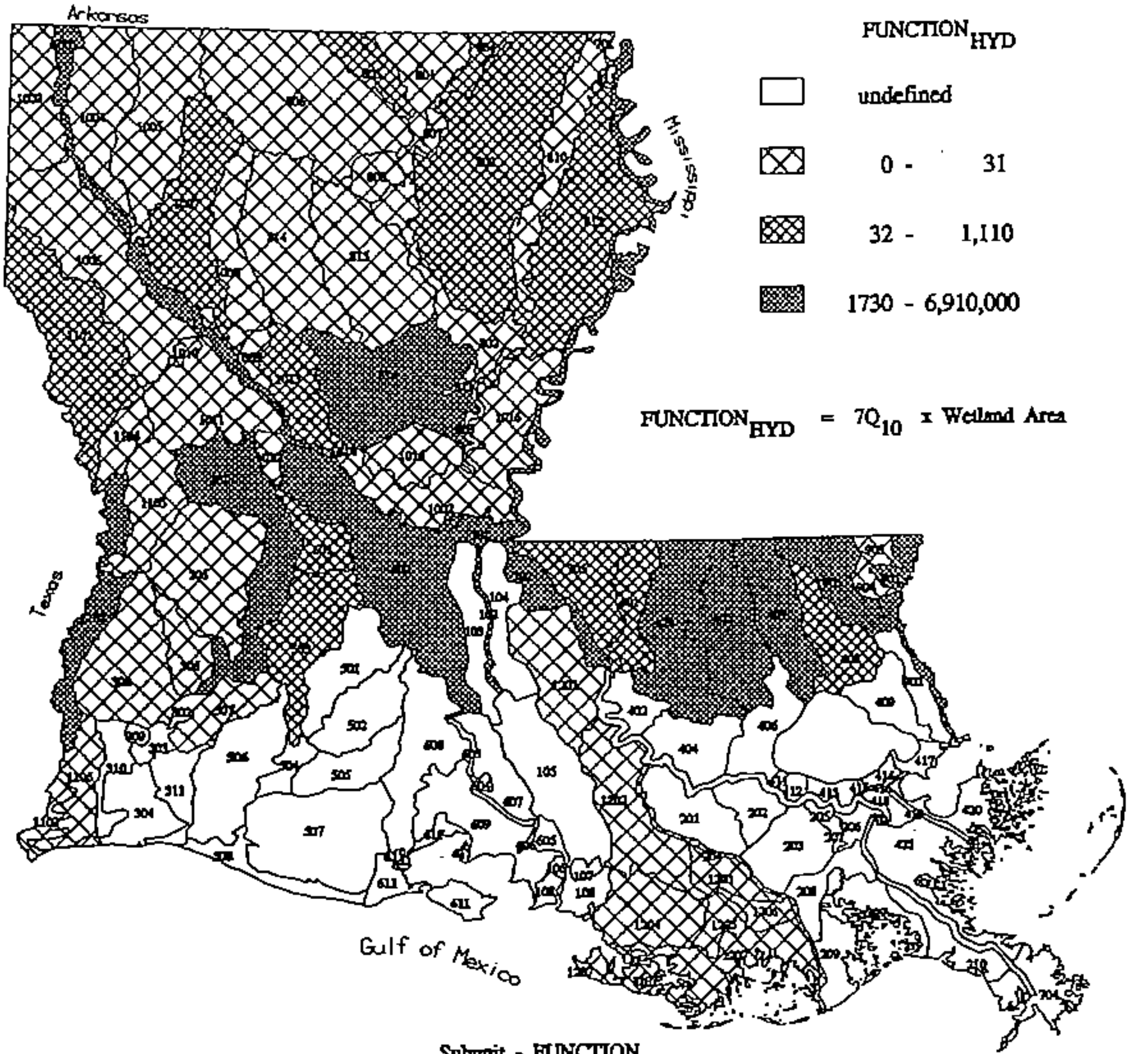
$$REPLACE_{WQ} = \frac{\text{Supporting Length}}{\text{Supporting + Non-Supporting Length}}$$

Subunit - REPLACE$_{WQ}$

101 - 0.000
102 - 1.000
103 - 0.000
104 - 0.000
105 - 0.000
106 - 0.000
107 - 1.000
108 - 1.000
201 - 0.000
202 - 0.000
203 - 0.000
204 - 0.000
205 - 0.000
206 - 0.000
207 - 0.000
208 - 0.000
209 - 0.000
210 - 0.000
301 - 1.000
302 - 1.000
303 - 0.000
304 - 1.000
305 - 1.000
306 - 1.000
307 - 1.000
308 - 1.000
309 - 0.000
310 - 0.444
311 - 1.000
401 - 0.813
402 - 0.000
403 - 0.556
404 - 1.000
405 - 0.925
406 - 0.000
407 - 0.491
408 - 0.309
409 - 0.046
411 - 0.000
412 - 0.000
413 - 0.000
414 - 1.000
415 - 0.000
416 - 0.000
417 - 0.786
418 - 0.696
419 - 0.000
420 - 1.000
421 - 0.500
501 - 0.000
502 - 0.000
503 - 0.058
504 - 0.000
505 - 0.000
506 - 0.000
507 - 0.000
508 - 1.000
601 - 1.000
602 - 0.000
603 - 0.000
604 - 0.000
605 - 0.000
606 - 1.000
607 - 0.000
608 - 0.156
609 - 0.791
611 - 1.000
701 - 1.000
702 - 1.000
703 - 1.000
704 - 0.000
705 - 0.437
801 - 0.944
802 - 1.000
803 - 1.000
804 - 1.000
805 - 1.000
806 - 0.897
807 - 0.000
808 - 1.000
809 - 0.867
810 - 1.000
811 - 0.000
812 - 1.000
813 - 1.000
814 - 0.000
815 - 0.423
816 - 0.944
901 - 0.460
902 - 0.688
903 - 1.000
904 - 1.000
905 - 1.000
1001 - 1.000
1002 - 0.824
1003 - 0.582
1004 - 0.637
1005 - 1.000
1006 - 0.821
1007 - 0.720
1008 - 0.941
1009 - 1.000
1010 - 0.000
1011 - 1.000
1012 - 0.000
1013 - 1.000
1014 - 0.000
1015 - 1.000
1016 - 1.000
1101 - 0.000
1102 - 1.000
1103 - 1.000
1104 - 1.000
1105 - 0.815
1106 - 1.000
1201 - 0.916
1202 - 0.000
1203 - 0.000
1204 - 0.106
1205 - 0.000
1206 - 0.000
1207 - 0.000

Figure 4.7. Replacement potential with respect to water quality for Louisiana. Darker hatching corresponds to higher replacement potential. The variables included in the equation for REPLACE$_{WQ}$ represent the landscape indicators, not components of the synoptic index (Equation 4.5).

HYDROLOGIC FUNCTION



$$\text{FUNCTION}_{HYD} = 7Q_{10} \times \text{Wetland Area}$$

Subunit - FUNCTION$_{HYD}$

101 - 710,000
102 - 106,000
103 - undefined
104 - undefined
105 - undefined
106 - undefined
107 - undefined
108 - undefined
201 - undefined
202 - undefined
203 - undefined
204 - 533
205 - undefined
206 - undefined
207 - undefined
208 - undefined
209 - undefined
210 - undefined
301 - 17,500
302 - undefined
303 - undefined

304 - undefined
305 - undefined
306 - 6
307 - 15
308 - 3
309 - undefined
310 - undefined
311 - undefined
401 - 33
402 - undefined
403 - 12,400
404 - undefined
405 - 2,720
406 - undefined
407 - 7,740
408 - 527
409 - undefined
411 - undefined
412 - undefined
413 - undefined

414 - undefined
415 - undefined
416 - undefined
417 - undefined
418 - undefined
419 - undefined
420 - undefined
421 - undefined
501 - undefined
502 - undefined
503 - 61
504 - undefined
505 - undefined
506 - undefined
507 - undefined
508 - undefined
601 - 574
602 - 8,220
603 - undefined
604 - undefined

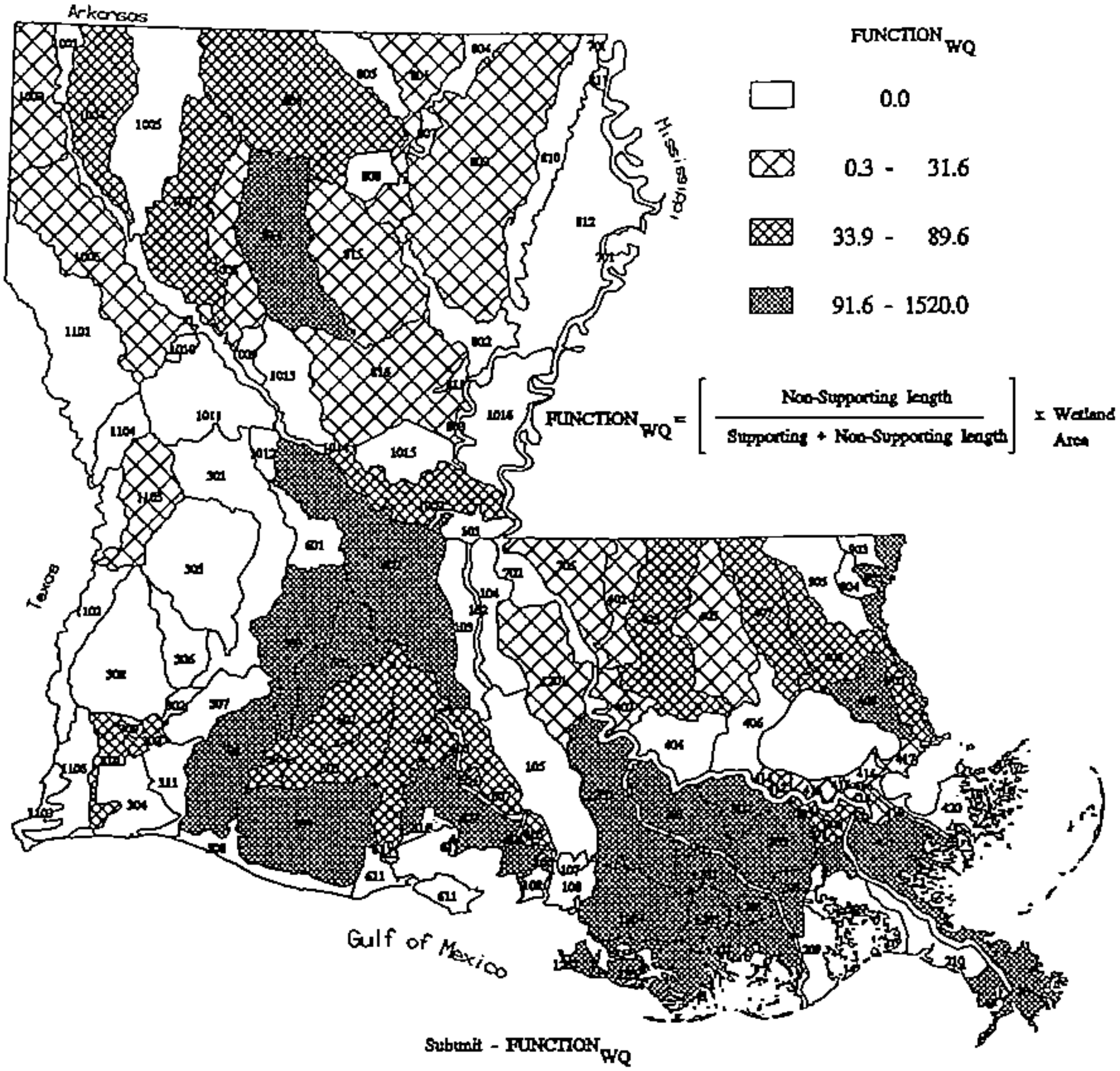
605 - undefined
606 - undefined
607 - undefined
608 - undefined
609 - undefined
611 - undefined
701 - 4,920,000
702 - 6,910,000
703 - undefined
704 - undefined
705 - 544
801 - undefined
802 - undefined
803 - undefined
804 - 39
805 - 41
806 - undefined
807 - undefined
808 - 32
809 - 388

810 - undefined
811 - 5
812 - 172
813 - undefined
814 - 5
815 - 24
816 - 1,730
901 - 115,000
902 - undefined
903 - 3
904 - 7
905 - 6,810
1001 - 51,700
1002 - undefined
1003 - 21
1004 - undefined
1005 - undefined
1006 - undefined
1007 - 298
1008 - 31

1009 - 5
1010 - undefined
1011 - undefined
1012 - 8
1013 - 439
1014 - undefined
1015 - undefined
1016 - undefined
1101 - 1,110
1102 - 35,600
1103 - undefined
1104 - 1
1105 - undefined
1106 - undefined
1201 - undefined
1202 - undefined
1203 - undefined
1204 - undefined
1205 - undefined
1206 - undefined
1207 - undefined

Figure 4.8. Hydrologic function for Louisiana. Darker hatching corresponds to higher hydrologic function. The variables included in the equation for FUNCTION$_{HYD}$ represent the landscape indicators, not components of the synoptic index (Equation 4.6).

WATER QUALITY FUNCTION



$$FUNCTION_{WQ} = \left[\frac{\text{Non-Supporting length}}{\text{Supporting + Non-Supporting length}} \right] \times \text{Wetland Area}$$

Submit - $FUNCTION_{WQ}$

101 - 0.0
102 - 0.0
103 - 0.0
104 - 0.0
105 - 0.0
106 - 40.4
107 - 0.0
108 - 0.0
201 - 592.0
202 - 151.0
203 - 633.0
204 - 24.1
205 - 59.7
206 - 88.9
207 - 82.6
208 - 410.0
209 - 0.0
210 - 0.0
301 - 0.0
302 - 0.0
303 - 34.4

304 - 0.0
305 - 0.0
306 - 0.0
307 - 0.0
308 - 0.0
309 - 2.2
310 - 89.6
311 - 0.0
401 - 0.6
402 - 31.6
403 - 64.1
404 - 0.0
405 - 9.6
406 - 0.0
407 - 49.0
408 - 33.9
409 - 102.0
411 - 0.0
412 - 83.2
413 - 6.0

414 - 0.0
415 - 0.0
416 - 7.0
417 - 26.4
418 - 29.3
419 - 14.6
420 - 0.0
421 - 442.0
501 - 154.0
502 - 42.3
503 - 406.0
504 - 48.8
505 - 42.4
506 - 519.0
507 - 1170.0
508 - 0.0
601 - 0.0
602 - 296.0
603 - 0.0
604 - 0.3

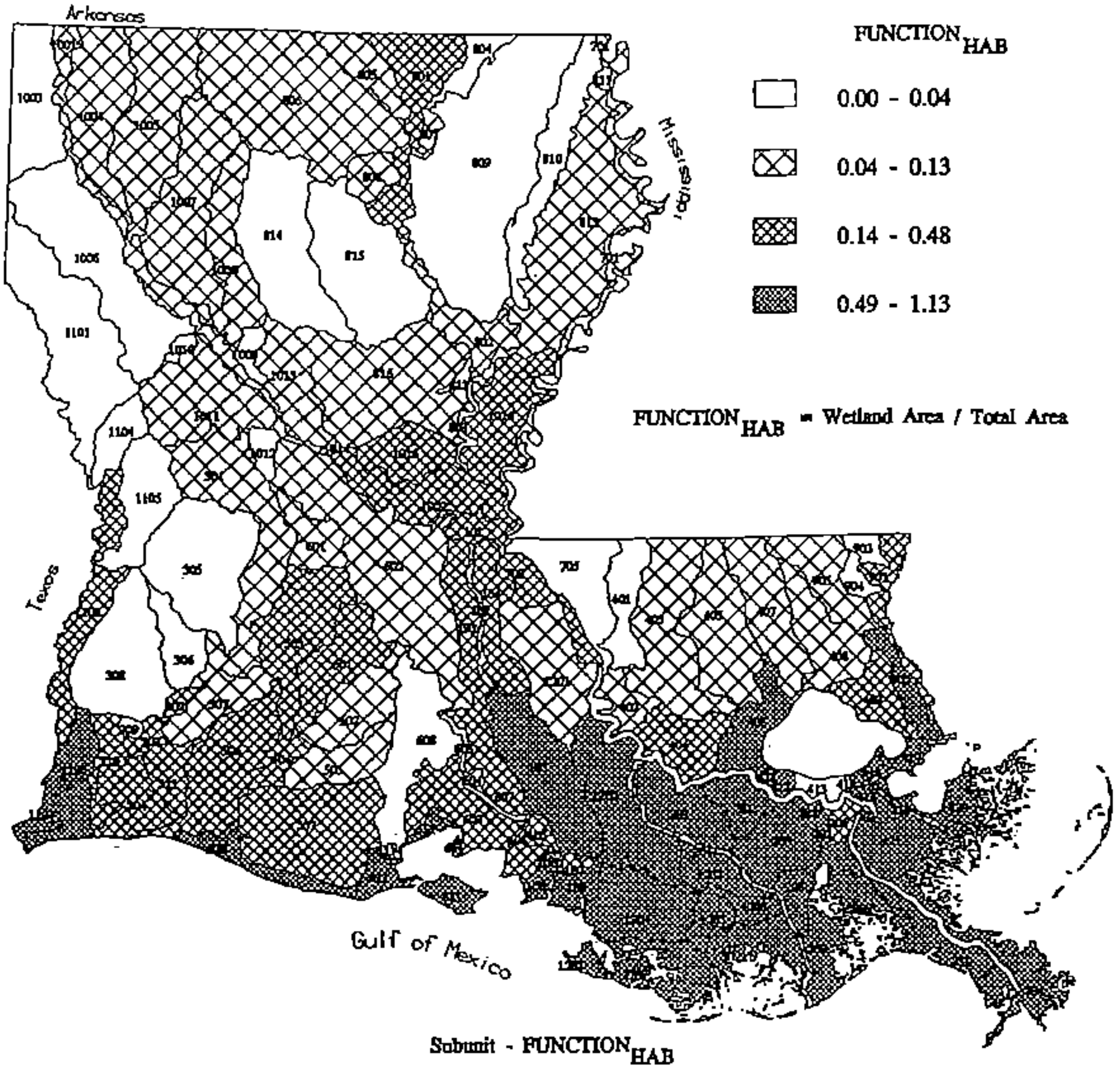
605 - 35.1
606 - 0.0
607 - 88.4
608 - 50.6
609 - 119.0
611 - 0.0
701 - 0.0
702 - 0.0
703 - 0.0
704 - 395.0
705 - 22.9
801 - 10.8
802 - 0.0
803 - 0.0
804 - 0.0
805 - 0.0
806 - 34.5
807 - 0.0
808 - 0.0
809 - 9.6

810 - 0.0
811 - 0.0
812 - 0.0
813 - 0.0
814 - 91.6
815 - 24.3
816 - 14.8
901 - 113.0
902 - 76.6
903 - 0.0
904 - 0.0
905 - 0.0
1001 - 0.0
1002 - 46.1
1003 - 19.7
1004 - 44.5
1005 - 0.0
1006 - 18.2
1007 - 44.1
1008 - 3.2

1009 - 0.0
1010 - 0.0
1011 - 0.0
1012 - 0.0
1013 - 0.0
1014 - 0.0
1015 - 0.0
1016 - 0.0
1101 - 0.0
1102 - 0.0
1103 - 0.0
1104 - 0.0
1105 - 2.5
1106 - 0.0
1201 - 17.2
1202 - 1010.0
1203 - 250.0
1204 - 1080.0
1205 - 241.0
1206 - 226.0
1207 - 1520.0

Figure 4.9. Water quality function for Louisiana. Darker hatching corresponds to higher water quality function. The variables included in the equation for $FUNCTION_{WQ}$ represent the landscape indicators, not components of the synoptic index (Equation 4.7).

HABITAT FUNCTION



Submunit - $FUNCTION_{HAB}$

101 - 0.28
102 - 0.10
103 - 0.41
104 - 0.32
105 - 0.77
106 - 0.69
107 - 0.46
108 - 0.94
201 - 0.61
202 - 0.66
203 - 0.65
204 - 0.08
205 - 0.81
206 - 0.44
207 - 1.05
208 - 0.74
209 - 0.92
210 - 0.59
301 - 0.12
302 - 0.35
303 - 0.17

304 - 0.48
305 - 0.04
306 - 0.01
307 - 0.07
308 - 0.02
309 - 0.03
310 - 0.36
311 - 0.31
401 - 0.00
402 - 0.08
403 - 0.07
404 - 0.36
405 - 0.08
406 - 0.54
407 - 0.07
408 - 0.04
409 - 0.16
411 - 0.70
412 - 0.71
413 - 0.03

414 - 0.66
415 - 0.00
416 - 0.20
417 - 0.65
418 - 0.54
419 - 0.17
420 - 0.88
421 - 0.75
501 - 0.14
502 - 0.04
503 - 0.27
504 - 0.15
505 - 0.05
506 - 0.31
507 - 0.48
508 - 0.94
601 - 0.06
602 - 0.08
603 - 0.00
604 - 0.00

605 - 0.21
606 - 0.17
607 - 0.13
608 - 0.04
609 - 0.42
611 - 0.93
701 - 0.12
702 - 0.37
703 - 0.02
704 - 0.53
705 - 0.03
801 - 0.13
802 - 0.06
803 - 0.03
804 - 0.01
805 - 0.07
806 - 0.09
807 - 0.06
808 - 0.05
809 - 0.01

810 - 0.00
811 - 0.01
812 - 0.04
813 - 0.01
814 - 0.04
815 - 0.02
816 - 0.09
901 - 0.36
902 - 0.54
903 - 0.00
904 - 0.01
905 - 0.05
1001 - 0.09
1002 - 0.21
1003 - 0.03
1004 - 0.07
1005 - 0.08
1006 - 0.04
1007 - 0.07
1008 - 0.05

1009 - 0.03
1010 - 0.00
1011 - 0.06
1012 - 0.02
1013 - 0.07
1014 - 0.01
1015 - 0.29
1016 - 0.21
1101 - 0.02
1102 - 0.24
1103 - 1.13
1104 - 0.00
1105 - 0.01
1106 - 0.78
1201 - 0.13
1202 - 0.59
1203 - 0.49
1204 - 0.94
1205 - 0.66
1206 - 0.79
1207 - 0.91

Figure 4.10. Habitat function for Louisiana. Darker hatching corresponds to higher habitat function. The variables included in the equation for $FUNCTION_{HAB}$ represent the landscape indicators, not components of the synoptic index (Equation 4.8).

Landscape Boundary and Subunits

Washington is bordered on the north by the Olympic Mountains and Canada; on the northwest by Puget Sound; on the west by the Pacific Ocean; on the east by the Blue Mountains, the northern Rockies, and Idaho; and on the south by the Columbia River and Oregon. Subunits were defined using the state's 62 Water Resource Inventory Areas, which are based on natural drainages (Figure 4.11).

Natural Setting

Climate and geomorphology are the most important determinants of wetland location and type in the state. Washington is divided by the Cascade Range into two distinct climatic regions: The west has a mild, wet, maritime climate, and the east has an arid continental climate. Precipitation ranges from 18 cm east of the Cascades to as much as 640 cm for the Olympic Mountains (Cummans et al. 1975).

Coastal and northwestern wetlands are influenced by high precipitation and cooler temperatures. Freeze and thaw cycles contribute to wetland formation in most of the alpine and subalpine regions.

In the Puget lowland, wetlands have developed on underlying gravel, silts, and clays deposited by Pleistocene glaciers (Franklin and Dyrness 1984). The large rivers of the lowlands periodically flood, creating wide floodplains with numerous riparian wetlands (Cummans et al. 1975).

Northern mountain wetlands were formed by receding glaciers that created kettlehole depressions, moraines, and outwash plains (Winter 1990).

Although low precipitation limits wetland density in eastern Washington, damaging floods caused by brief, intense thunderstorms occur during spring snowmelt. Winds deposit loess soils from Canada in the Columbia Basin and create blowout depressions where playas and vernal pools form (Boling 1988).

Wetland Functions

An estimated 359 of 414 wildlife species found in western Washington use wetland habitats during some season or part of their life cycle (Oakley et al. 1985). Washington wetlands play a major role in providing nesting and wintering grounds for the ducks, geese, and swans that use the Pacific Waterfowl Flyway. The ponds and potholes of central and eastern Washington produce one-half million ducks and geese annually and are essential for other wildlife in times of drought. Coastal wetlands provide critical habitat for millions of shorebirds, many species of game, and commercial species of fish and shellfish, which have an estimated value of $1.1 billion annually.

Significant Impacts

Loss of wetlands is the most important problem facing waterfowl and fur-bearing wildlife and is a limiting factor in maintaining wild anadromous fish populations (Canning and Stevens 1989). The variety of impacts that affects these wetlands corresponds to the diversity of regional land use. Coastal impacts include dredging for port development, filling for road construction and urban and industrial development, and drainage for agriculture.

Montane wetlands are less subject to conversion, but are impacted by vegetation removal, soil compaction, and sediment runoff from forestry, grazing, mining, and recreation.

Forestry and agriculture practices, filling for urban development, and pollution from increased urban stormwater runoff impact the Puget lowland wetlands.

Table 4.3. Landscape indicators for the Washington case study.

Index Component	Indicator
$AREA_C$ (current wetland area)	Area of wetland land cover, estimated with dot grid from 1:250,000 USGS LULC maps
ΔAGR (agricultural growth)	The percent annual change in agricultural area between 1972 and 1984, based on agricultural census data (U.S. Bureau of Census 1974, 1982a); prorated from county to subunit areas, and set to zero if subunit showed negative growth
A (subunit area)	Calculated by GIS from digitized subunits
ΔURB (urban growth)	The percent annual change in human population between 1970 and 1980, based on the U.S. Census (U.S. Bureau of Census 1972, 1982b); prorated from county to subunit areas, and set to zero if subunit showed negative growth
RF_{AGR} (agricultural risk factor)	A factor of 87/95 is used, based on historical loss of national wetlands by agricultural conversion (Tiner 1984)
RF_{URB} (urban risk factor)	A factor of 8/95 is used, based on historical loss of national wetlands by urban expansion (Tiner 1984)
RTE (number of rare, threatened, and endangered wetland-dependent species)	County RTE data from Washington Department of Wildlife (1990) and Washington Department of Natural Resources (1990), prorated to subunit areas (Appendix F)

Within the Columbia Basin, primary impacts are vegetation removal, trampling, nutrient loading from grazing, and excavation for energy development and mining (Canning and Stevens 1989).

Synoptic Indices

The first index for this case study is habitat value. Because the management objective specifically focuses on rare, threatened, or endangered species, the index is weighted for subunits where these species occur:

$$\mathrm{VALUE}_{HAB} = (\mathrm{AREA}_C/A) \times \mathrm{RTE} \qquad \text{Equation 4.9}$$

where VALUE_{HAB} is the index for habitat value, AREA_C is current wetland area, A is the subunit area, and RTE is the number of rare, threatened, or endangered species within that subunit. The proportion of the state's rare, threatened, or endangered species occurring within the subunit could also be used as an index. RTE could have been divided by wetland density (AREA_C/A) rather than multiplied; this is discussed further below.

The second index is future risk, which is based on a weighted estimate of agricultural and urban growth:

$$\mathrm{RISK} = (\Delta\mathrm{AGR} \times \mathrm{RF}_{AGR}) + (\Delta\mathrm{URB} \times \mathrm{RF}_{URB}) \qquad \text{Equation 4.10}$$

where RISK is the synoptic risk index, ΔAGR and ΔURB are expected rates of agricultural and urban growth, respectively, and RF_{AGR} and RF_{URB} are risk factors for weighting the relative importance of these two impacts.

Finally, the third synoptic index is future loss of valued habitat with respect to rare, threatened, or endangered species (LOSS_F). This index combines habitat value with future risk:

$$\mathrm{LOSS}_F = \mathrm{VALUE}_{HAB} \times \mathrm{RISK} \qquad \text{Equation 4.11}$$

Landscape Indicators

Synoptic indicators for the Washington case study appear in Table 4.3. The use of rare, threatened, and endangered species assumes that the distribution of such species is uniform and that census taking is unbiased. These assumptions may not be entirely true because (1) census taking can be biased by more intense sampling of urban areas or accessible areas, e.g., near roads, and (2) prorating county rare, threatened, or endangered species data to subunit areas may be unrealistic, especially in counties with few species. For the latter, a better approach in a real application would be to map actual sighting data onto subunits, but these data are not always available.

More importantly, the index for habitat value assumes that it is dependent on the product of wetland density with the number of rare, threatened, or endangered species. This assumes that these species benefit from greater wetland densities; however, the most important wetlands for these species may be scarce wetlands (those that occur at low densities), in which case the density would be used as a divisor.

As an indicator of expected agricultural growth, we use the change in agricultural area from the most recent agricultural census data. Once this value was prorated, we then set any negative subunit values to zero because a loss of agricultural area would not necessarily equate to a gain of wetland area. For urban growth, we use human population as the indicator and calculate the value in a similar fashion.

The risk factors for weighting agricultural and urban growth are based on figures of 87% and 8% for nationwide historical loss of wetlands by agricultural conversion and urban expansion, respectively (Tiner 1984). Since we ignore the remaining 5%, the actual risk factors we use are 87/95 and 8/95 because this makes the sum of the factors one (Appendix H).

Use of the risk factor assumes that (1) agricultural and urban growth in the recent past are good indicators of their future growth, (2) future population growth rates are a good indicator of wetland loss from urban expansion, and (3) historical causes of national wetland loss will also be the important causes of future wetland loss in Washington. In addition, prorating county census data to subunits assumes that agriculture and population are uniformly distributed throughout the area. In some instances this is violated, especially where the populations of counties are clustered around large cities like Seattle. In a real application, data must be adjusted to account for this.

Map Interpretation

The objective for this assessment is to provide information on future risk that can be used to identify habitat protection areas as part of a State Wetland Conservation Plan. The component maps of habitat value and future risk are shown in Figures 4.12 and 4.13 (class intervals for all Washington maps were selected by visual inspection and do not represent quartiles). Figure 4.13 provides planners with a quick overview of areas at risk from combined primary causes of wetland loss. If necessary for planning purposes, risk from agricultural conversion and urban expansion could be separated into two maps; this would indicate that risk from agricultural conversion is ubiquitous throughout the state, but population appears to be more of a threat in the Puget lowlands and along the coast. Combining habitat value and future risk, Figure 4.14 maps in darker hatching areas where future loss of habitat value is predicted to

WASHINGTON SUBUNIT INDEX

(Water Resource Inventory Areas)

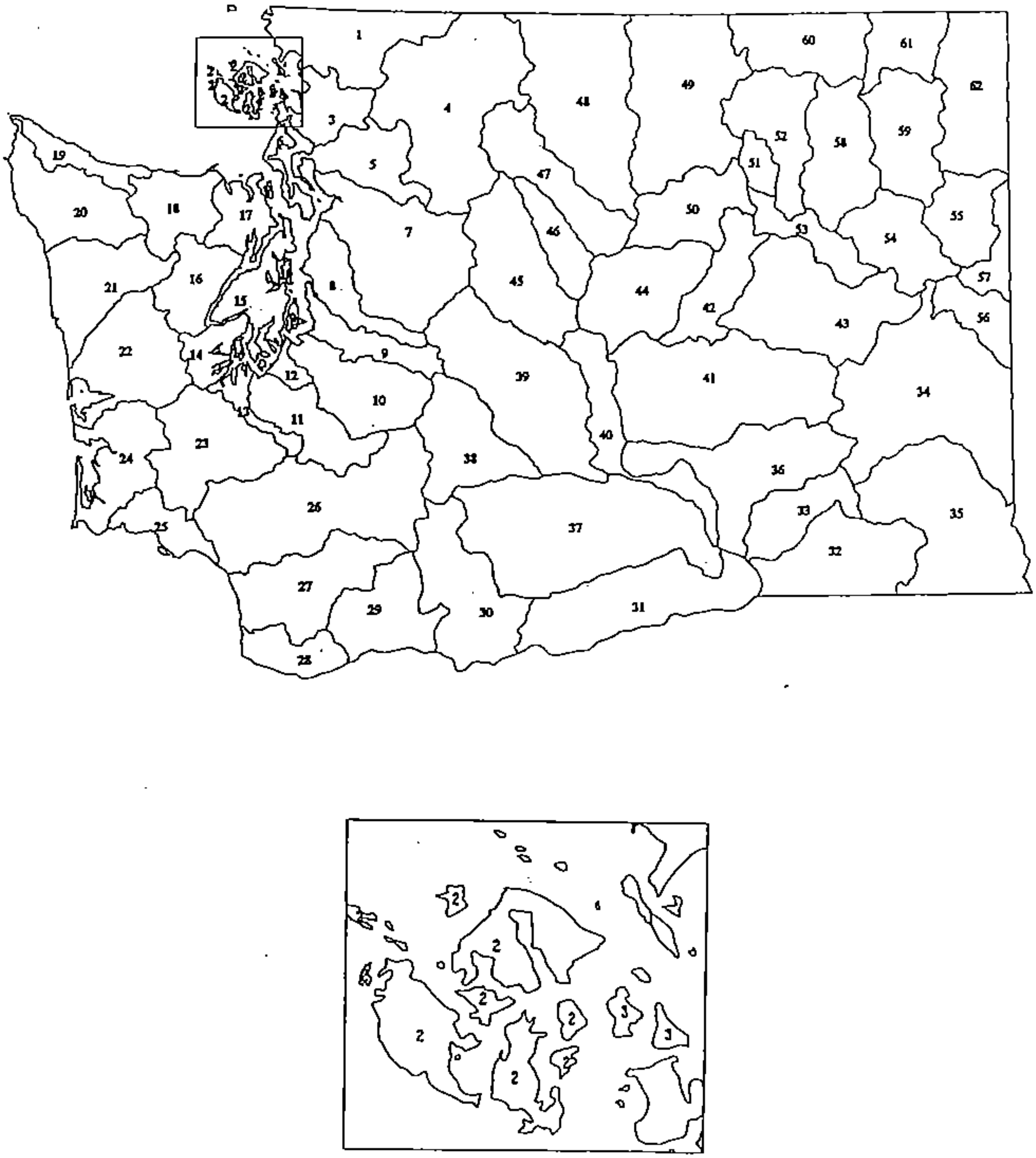
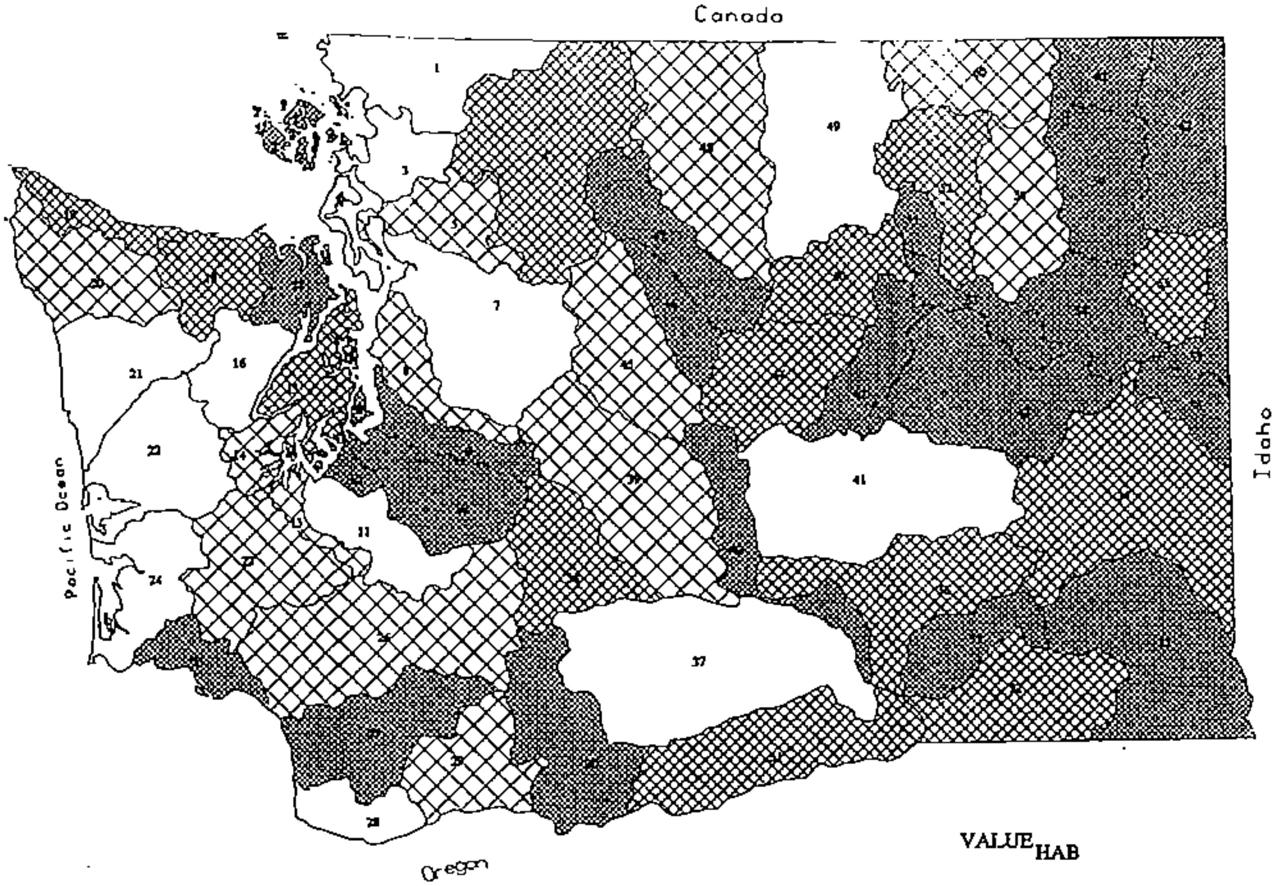


Figure 4.11. The State of Washington and the 62 subunits. Subunits are Water Resource Inventory Areas.

HABITAT VALUE



$\mathrm{VALUE}_{\mathrm{HAB}}$

☐ 0.000

▨ 0.005 - 0.017

▩ 0.022 - 0.057

▦ 0.060 - 0.302

$$\mathrm{VALUE}_{\mathrm{HAB}} = \frac{\text{Wetland Area} \times \text{Number RTE Species}}{\text{Total Area}}$$

Subunit - $\mathrm{VALUE}_{\mathrm{HAB}}$

1 - 0.081
2 - 0.000
3 - 0.302
4 - 0.006
5 - 0.057
6 - 0.088
7 - 0.060
8 - 0.043
9 - 0.000
10 - 0.000
11 - 0.071

12 - 0.000
13 - 0.046
14 - 0.050
15 - 0.013
16 - 0.061
17 - 0.000
18 - 0.009
19 - 0.013
20 - 0.032
21 - 0.137

22 - 0.145
23 - 0.029
24 - 0.157
25 - 0.000
26 - 0.024
27 - 0.000
28 - 0.226
29 - 0.022
30 - 0.000
31 - 0.011

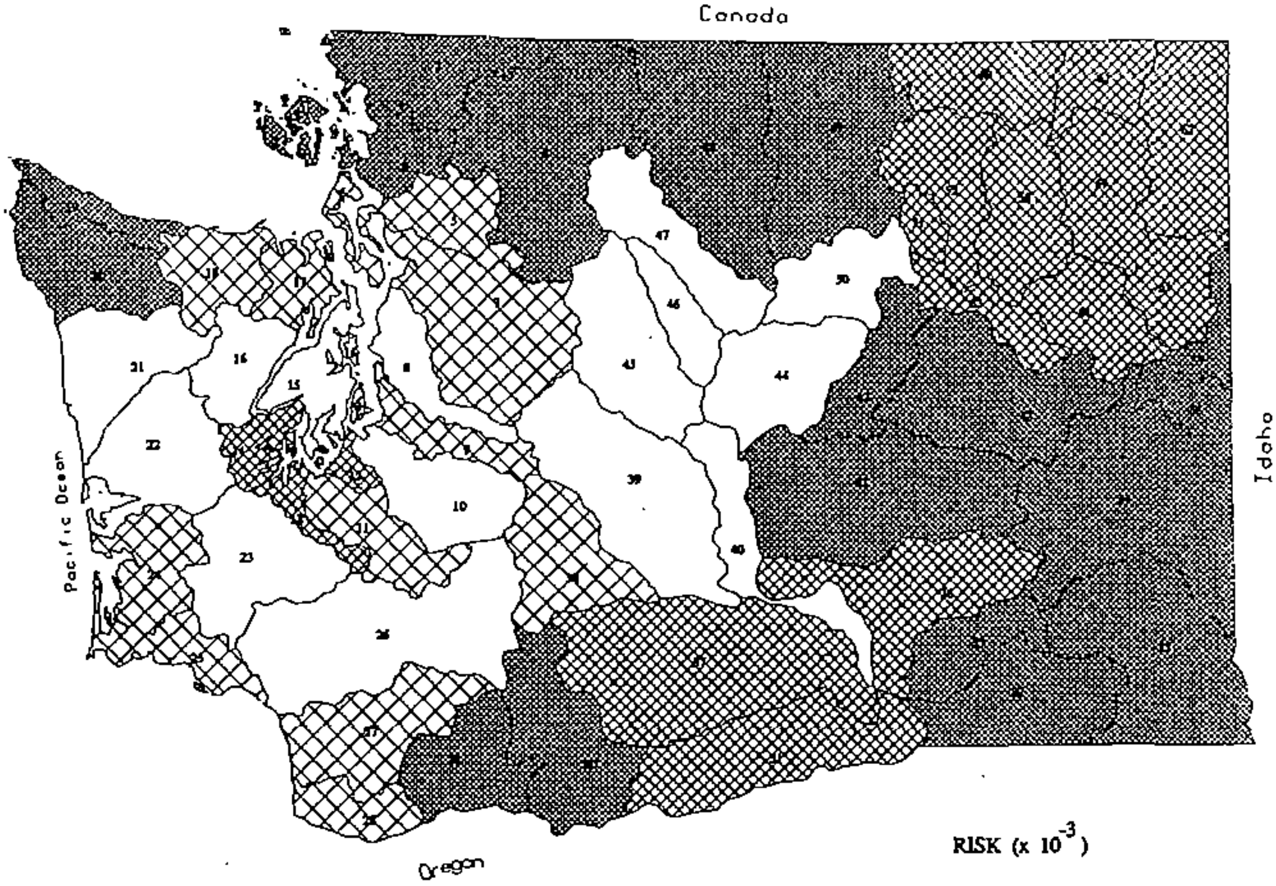
32 - 0.010
33 - 0.000
34 - 0.010
35 - 0.000
36 - 0.011
37 - 0.130
38 - 0.013
39 - 0.052
40 - 0.000
41 - 0.120

42 - 0.000
43 - 0.000
44 - 0.009
45 - 0.035
46 - 0.000
47 - 0.000
48 - 0.025
49 - 0.108
50 - 0.016
51 - 0.000

52 - 0.008
53 - 0.000
54 - 0.000
55 - 0.015
56 - 0.000
57 - 0.000
58 - 0.029
59 - 0.000
60 - 0.030
61 - 0.000
62 - 0.000

Figure 4.12. Habitat value for Washington. Darker hatching corresponds to higher habitat value. The variables included in the equation for $\mathrm{VALUE}_{\mathrm{HAB}}$ represent the landscape indicator, not components of the synoptic index (Equation 4.9).

FUTURE RISK



RISK (x 10^{-3})

▩	1.37 - 9.15
▦	9.16 - 15.03
⊠	15.04 - 33.69
☐	33.70 - 81.82

RISK = % Weighted Annual Pop. Change +
% Weighted Annual Agr. Change

Subunit - RISK (x 10^{-3})

1 - 4.43
2 - 8.69
3 - 25.17
4 - 75.97
5 - 32.70
6 - 29.90
7 - 27.43
8 - 43.39
9 - 17.84
10 - 33.81
11 - 24.26

12 - 14.17
13 - 10.09
14 - 11.95
15 - 67.34
16 - 33.70
17 - 27.86
18 - 27.86
19 - 4.08
20 - 27.86
21 - 33.70

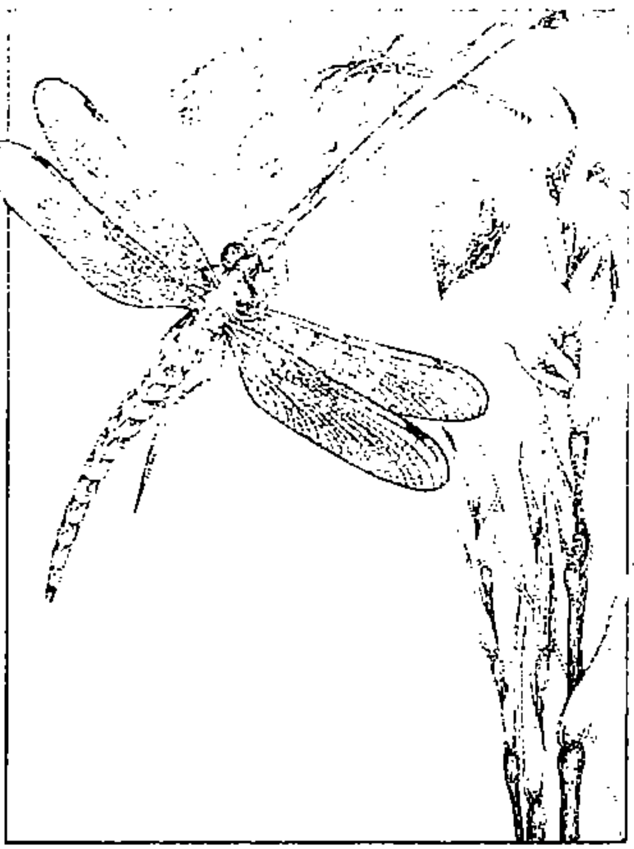
22 - 48.99
23 - 36.84
24 - 15.89
25 - 27.47
26 - 34.14
27 - 27.67
28 - 17.93
29 - 7.14
30 - 9.09
31 - 10.42

32 - 5.54
33 - 8.55
34 - 6.31
35 - 1.37
36 - 11.98
37 - 9.37
38 - 16.71
39 - 51.72
40 - 34.97
41 - 4.87

42 - 4.12
43 - 3.83
44 - 43.02
45 - 77.29
46 - 49.84
47 - 81.82
48 - 52.22
49 - 5.42
50 - 59.94
51 - 13.66

52 - 9.18
53 - 13.31
54 - 12.11
55 - 10.76
56 - 2.08
57 - 5.16
58 - 10.93
59 - 14.13
60 - 12.11
61 - 14.13
62 - 9.16

Figure 4.13. Future risk for Washington. Darker hatching corresponds to lower future risk. The variables included in the equation for RISK represent the landscape indicator, not components of the synoptic index (Equation 4.10)



Chapter 6

Ecological Response to Stress

The synoptic approach allows information on landscape condition to be included in decisions based on available information and limited resources. To achieve this, the synoptic indices were based on a simple landscape model (Chapter 2). In this chapter, we discuss additional information related to cumulative impacts but which is too detailed to be included in a synoptic assessment. This information could still be useful in formulating the synoptic indices. This chapter also introduces some of the relevant ecological literature for those interested in additional information.

We begin with several definitions. In Chapter 1, we introduced the terms "impact" and "effect" because they are found in regulations and literature on environmental assessment. Within ecological literature, however, a second terminology is more commonly used with reference to ecological stress; unfortunately, this second vocabulary is also inconsistently applied. For example, "stress" has been used to signify both cause and effect (Odum 1985). Because there appears to be no standard usage, we will adopt the following definitions (Figure 6.1):

- *Disturbance* — The action that causes a stress. This can also be referred to as a *stressor*.
- *Stress* — The immediate physical, chemical, and biological changes that result from the disturbance.
- *Response* — The long-term physical, chemical, and biological changes that indirectly result from a disturbance.

This terminology is not limited to actions caused by humans; stress caused by natural agents is also included here, e.g., damage from hurricanes or fires. We can redefine *impacts* as the subset of disturbances caused by people; *effects* are a combination of stress (direct effects) and response (indirect effects), and are similarly limited to changes resulting from human actions.

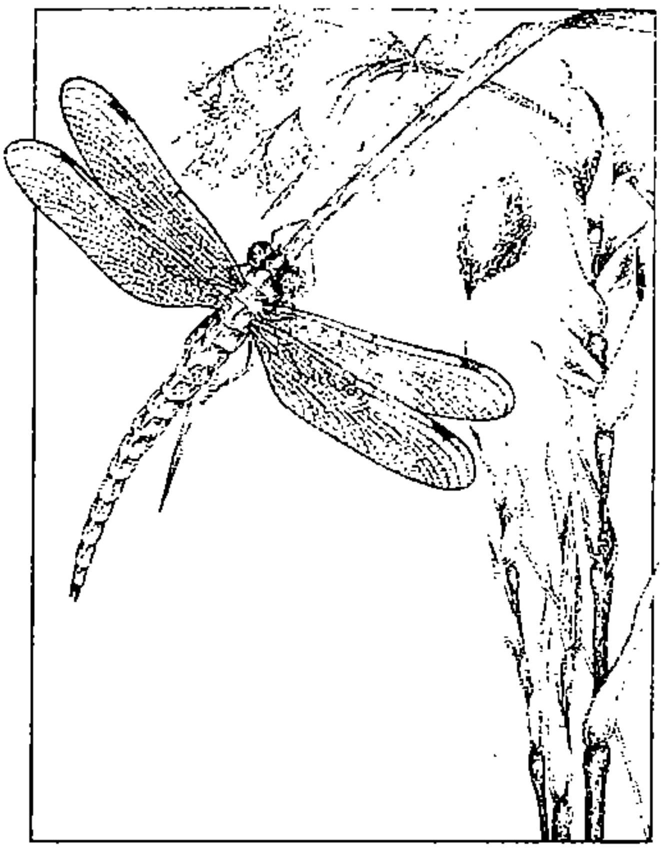
Ecosystem Stability

One of the remarkable properties of natural ecosystems is their ability to persist over time in spite of disturbance and a changing environment. Disturbance occurs in many forms and at various spatial and temporal scales (Figure 6.2). Disturbances can affect individuals, groups of individuals, populations, ecosystems, and entire landscapes. A collection of papers discussing the effect of natural disturbance on various ecological communities is found in Pickett and White (1985a). Natural disturbances such as fire, flooding, and volcanism can be major factors in landscape development (Forman and Godron 1986; Pickett and White 1985b).

A significant body of ecological literature has been devoted to the subject of ecosystem stability in an attempt to provide a theoretical explanation for this

- Remnant patches — the opposite of spot disturbances — which occur when a large disturbance takes place, reducing the background matrix to a patch.

Many organisms have ***home ranges,*** defined as the area around their homes typically used for feeding (Forman and Godron 1986; Harris 1984). Fragmentation reduces patch area and therefore reduces the amount of habitat within the home range. This can lead to local extinction, especially in the later phases. Fragmentation also increases the circumference-to-area ratio of patches, which causes a change in species composition from interior species to edge species (Merriam and Wegner 1992). Although this increases species diversity, the result is a general shift from native (interior) to opportunistic (edge) species (Gosselink and Lee 1989). Fragmentation can also cause a loss of interconnecting corridors and lower the size of a metapopulation. This effect together with increased distance between patches reduces the likelihood that locally extinct populations can be reestablished.



Chapter 7

A Review of Wetland Functions and the Effect of Wetland Impacts

In this chapter we review current research on three major wetland functions, emphasizing the landscape scale. We discuss the effects of wetland degradation, which results in partial loss of function, as well as the effects of wetland conversion, which results in total loss of function. The closing section addresses the effects of cumulative wetland loss on overall landscape function. This information can provide a starting point for defining specific indices of function and functional loss. This chapter can also serve as a resource for those wanting a review of wetland functions or additional information on how these functions are affected by impacts.

Wetland Functions

Over the past several decades, new information has highlighted the functions wetlands perform through various physical, chemical, and biological processes (Table 7.1). These functions can be divided into three major categories: hydrologic functions, water quality functions, and habitat functions.

Hydrologic Functions

Wetlands can function as hydrologic sinks by removing water from local surface flow systems; this occurs when floodwaters are temporarily stored within a wetland, when runoff infiltrates the wetland surface, or when runoff is converted to water vapor through transpiration. Wetlands can also act as hydrologic sources, conserving water and sustaining local moisture. Wetlands function as sources by serving as conduits for groundwater discharge or by increasing or conserving hydrologic inputs through interception, snow detention, condensation, or reduced evaporation. The factors that determine whether source or sink functions dominate in a given setting include regional climate, season, landscape geomorphology, and wetland type and position. Adamus et al. (1991), Carter (1986), Duever (1988), Kadlec (1987), LaBaugh (1986), Winter (1988, 1990), and Winter and Woo (1990) review literature on hydrologic functions of wetlands.

Almost any wetland has the potential to stagger the arrival of runoff to downstream areas, and in so doing reduce flood peaks. Many studies have found inverse correlations between streamflow and the percentage of watershed area occupied by wetlands, or variables that could be related to wetlands (Table 7.2). Most often, these studies support the hypothesis that wetlands are important for attenuating peak flows (e.g., Table 7.3). Watersheds with a large proportion of wetlands have qualitatively different streamflow response to precipitation, both in urban settings (Brown 1988) and in vast peatland watersheds (Schwartz and Milne-Home 1982).

Table 7.4. Examples of area-sensitive wetland bird species[1].

Species	Minimum Patch Size (ha)	Reference
Pied-billed grebe	5	Brown and Dinsmore 1986
Great blue heron	A, B	Gibbs and Melvin 1990
Black-crowned night heron	[>20], C	Brown and Dinsmore 1986
American bittern	C	Brown and Dinsmore 1986
Least bittern	D [<1], C [12]	Gibbs and Melvin 1990 Brown and Dinsmore 1986 Tyser 1983
Canada goose	11, [5]	Brown and Dinsmore 1986
Blue-winged teal	1-5	Brown and Dinsmore 1986
Green-winged teal	C	Brown and Dinsmore 1986
Mallard	1-5	Brown and Dinsmore 1986
Gadwall	C	Brown and Dinsmore 1986
Northern pintail	C	Brown and Dinsmore 1986
Northern shoveler	[5], C	Brown and Dinsmore 1986
Redhead	5, C	Brown and Dinsmore 1986
Ruddy duck	11	Brown and Dinsmore 1986
American coot	A [<1], C	Gibbs and Melvin 1990 Brown and Dinsmore 1986
Virginia rail	A, B	Gibbs and Melvin 1990
Sora	A	Gibbs and Melvin 1990
Forster's tern	C	Brown and Dinsmore 1986
Swallow-tailed kite	[15]	O'Meara 1984
Red-shouldered hawk	225, E	Robbins et al. 1989
Black tern	20, [5] [25], B [12]	Brown and Dinsmore 1986 Gibbs and Melvin 1990 Tyser 1983
Pileated woodpecker	165, E	Robbins et al. 1989
Acadian flycatcher	15, [0.2], E C, E C [24], E	Robbins et al. 1989 Harris and Wallace 1984 Triquet et al. 1990 Blake and Karr 1987
Veery	20, [9], E [28], E	Robbins et al. 1989 Blake and Karr 1987
Marsh wren	A, B [<1], A [12]	Gibbs and Melvin 1990 Brown and Dinsmore 1986 Tyser 1983
Northern parula	520, [10], E [54], E [24], E	Robbins et al. 1989 Hayden et al. 1985 Blake and Karr 1987
Prothonotary warbler	A	Robbins et al. 1989
Northern waterthrush	200, [24], E	Robbins et al. 1989
Louisiana waterthrush	300, [25], E [42], E C, E C	Robbins et al. 1989 Hayden et al. 1985 Harris and Wallace 1984 Triquet et al. 1990
Kentucky warbler	17, [9], E [8], E [2.3], E	Robbins et al. 1989 Hayden et al. 1985 Blake and Karr 1987
Swainson's warbler	A	Harris and Wallace 1984
Swamp sparrow	1-5	Brown and Dinsmore 1986

[1] Does not include non-wetland species that are also area-sensitive and partially supported by wetlands.

Numbers represent patch size at which probability of occurrence is 50% of the maximum as determined from a series of habitat patch inventories; this level has been suggested as appropriate for conservation planning by Robbins et al. (1989). Bracketed figures are sizes of smallest patches found to be occupied; it cannot be assumed that birds bred successfully in these areas (Gibbs and Faaborg 1990).

A: The listed species' breeding occurrence appears to be influenced by wetland patch size.
B: The listed species' breeding occurrence appears to be influenced by local wetland density.
C: Results not statistically significant given sample size; however, distribution pattern suggests area dependence.
D: The listed species' breeding occurrence appears to be influenced by proximity to other wetlands.
E: Area includes adjoining undeveloped forest.

Wetland Conversion

A wetland can be so severely stressed that it is completely transformed into a different type of ecosystem or land use; we refer to this process as conversion. Historically, most wetland conversion has been intentional, e.g., to increase agricultural area. However, conversion can also be caused inadvertently. For example, severe long-term sedimentation in a shallow wetland can raise the wetland substrate above the water table, accelerate invasion by upland species, and eventually cause succession to upland.

A number of studies have assessed cumulative loss of wetland area at various scales. Between the 1780s and 1980s, losses in the 50 states ranged from 0.1% for Alaska to 91% for California (Figure 7.1). Historical loss of wetland area for the entire United States was estimated as 30% over the last two centuries; if Alaska is excluded, this amount increases to 53% (Dahl 1990). During the 1970s and 1980s, a net 1.1 million of the 41.8 million hectares of wetlands in the United States (2.5%) were lost through conversion (Dahl et al. 1991). Freshwater wetlands accounted for most of this recent loss, particularly Southeastern forested floodplain wetlands.

Table 7.5. Stresses and associated impacts that can degrade wetlands.

Stress	Impacts	
Acidification	Fossil fuel combustion	Mineral extraction
Biomass Removal	Agricultural/silviculture Aquatic weed control Channelization	Defoliation from airborne contaminants Grazing, herbivory, disease, and fire Urban development
Compaction or Erosion	Agriculture/silviculture Mining and construction	Disturbance of stream flow regimes Deposition of dredged or other fill material
Contamination/Toxicity [1]	Agricultural/silvicltural pesticides Aquatic weed control Fossil fuel combustion Hazardous waste sites Industrial air pollution	Landfills Mineral extraction Urban stormwater Wastewater treatment systems Mosquito control pesticides
Dehydration	Anthropogenic water withdrawals Global climate change Subsurface tile drainage	Invasion by highly transpirative plant species Ditching/channelization of nearby streams Surface ditching, drainage, and outlet widening
Eutrophication/Enrichment	Artificial drainage Fertilizer application Fossil fuel combustion Landfills Livestock	Mineral extraction Peat extraction Urban stormwater Wastewater treatment systems
Habitat Fragmentation and Exotic Species Invasion	Channelization/ditching Land clearing Road construction Grazing	Silvicultural activities Urban development Impoundments Artificial drainage
Inundation	Excavation (deepening) Impoundment	Flow blockage by road construction Land use that increases runoff to wetlands
Light Reduction	Agricultural runoff Urban stormwater Sediment resuspension by animals and wind Ineffective wastewater treatment plants	Placement of bridges and other structures Disturbance of stream flow regimes Erosion from mining and construction sites Blooms of algae responding to excess nutrients
Salinization	Domestic/industrial wastes Irrigated soil	Road salt used for winter ice control Saltwater intrusion from tidal or groundwater
Sedimentation	Agriculture Deposition of dredged or other fill material Disturbance of stream flow regimes	Erosion from mining and construction sites Ineffective wastewater treatment plants Urban stormwater
Thermal Warming	Global climate warming Impoundments	Power plants and industrial facilities Vegetation removal

[1] From heavy metals.

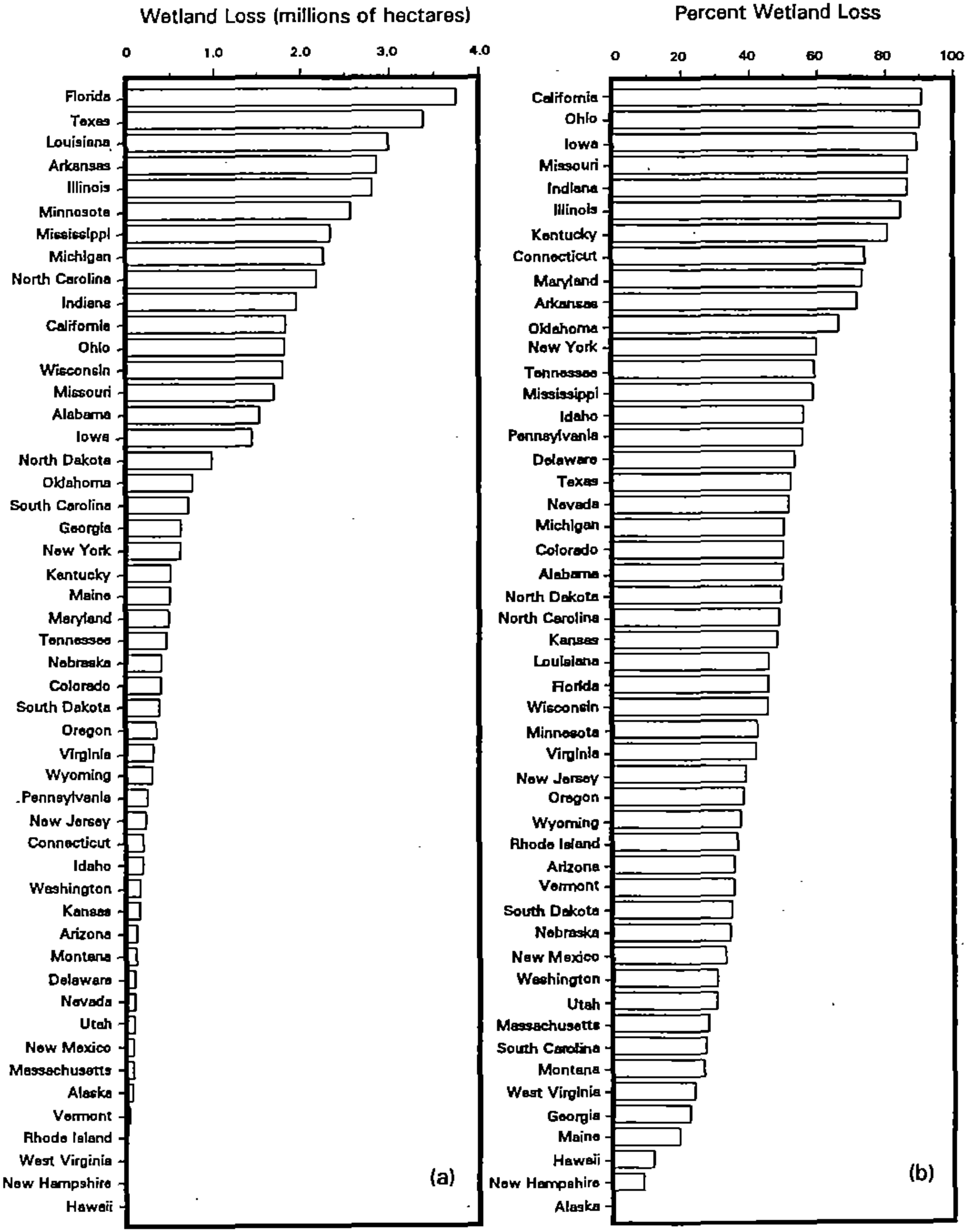


Figure 7.1. Historical loss of wetland area (a) and percent loss (b) in the United States, by state (data from Dahl 1990).

Table 7.6. Wetlands whose functions may be more sensitive or less resistant to particular types of stress.

Sensitive Function	Type of Stress	Wetland Type
Hydrology	Sedimentation	Physically isolated wetlands
	Vegetation removal	Forested wetlands
	Dehydration	Permanently flooded wetlands Wetland depressions overlying thin impermeable strata
	Inundation	Wetlands not permanently flooded
	Fragmentation	Wetlands in flat landscapes
Water Quality	Enrichment and contamination	Wetlands that have been previously exposed to large chemical loadings
	Organic loading	Physically isolated wetlands with high annual production
	Acidification	Wetlands with cation exchange capacity only at the substrate surface
	Turbidity/shade and vegetation removal	Wetlands where submerged plant uptake rather than microbial metabolism or adsorption is the major process controlling nutrient or contaminant cycling
	Dehydration	Permanently flooded wetlands
	Inundation	Wetlands not permanently flooded
Habitat	All degradation types	Wetlands connected to others only by narrow corridor Wetlands near a size threshold for a species Wetlands with a poor seed bank

While agricultural conversion has been the primary cause of wetland loss since the 1950s, it has become less dominant. Agricultural conversion, urbanization, and other forms of development (conversion of wetlands to non-agricultural, rural land uses) accounted for 87%, 8%, and 5% of loss from the 1950s to the 1970s, respectively (Tiner 1984), compared with losses of 54%, 5%, and 41% for these same categories during the 1970s and 1980s (Dahl et al. 1991).

Effects of Cumulative Wetland Loss on Landscape Functions

Because few studies have examined degradation of wetland function on a large scale, our understanding of how conversion and degradation affect wetland functions at the landscape level is even more limited. The following three sections discuss the possible effects of cumulative wetland loss on hydrologic, water quality, and habitat functions. The findings are based upon studies that generally fall into three categories (Leibowitz et al. 1992): empirical landscape analyses, case studies, and landscape modeling. Adamus (1989) discusses strengths and limitations of various approaches.

Loss of Hydrologic Functions

In only a limited number of studies have researchers attempted to measure and compare hydrologic functions before and after loss or alteration of wetlands. Among them are studies of Mississippi River flooding by Belt (1975), southwestern riparian areas by Burkham (1976), diked Florida wetlands by Hammett et al. (1978), and prairie pothole wetlands by Brun et al. (1981). Although none of these investigations contradicts the notion that loss of wetland area causes increased flow peaks, the limited number of study sites makes it difficult to distinguish effects of wetland loss from effects of other land use changes within the watershed and from short-term climate trends.

Nevertheless, results from spatially-based empirical analyses can be used to explore the effects of wetland loss. In Minnesota, Johnston et al. (1990a) suggested and demonstrated the use of simple equations based on spatial data (such as those found in the references in Table 7.2) to estimate how past wetland loss may have affected peak flow for any particular watershed and to infer changes in discharge that might occur from future wetland losses. The results were then used to rank watersheds according to relative risk. Andersson and Sivertun (1991) used a simulation model to estimate regional impacts to groundwater recharge and discharge resulting from decades of wetland drainage.

Computer simulations have also been used to examine wetland and floodplain behavior and, in most cases, have supported the role of cumulative wetland area or other forms of natural storage in attenuating streamflow peaks. In what was perhaps the first such study, Dewey and Kropper Engineers (1964) simulated floodplain storage in the Connecticut River. Their findings indicated that flood stage could increase by 0.3, 1.2, and 2.1 meters as the result of 10%, 20%, and 30% reductions in storage, respectively. Subsequently, the Corps of Engineers conducted simulations of the Charles River in Massachusetts, concluding that downstream flooding can be reduced more cost-effectively by preventing floodplain encroachments than by constructing control structures (Childs 1970). Other watershed simulations (e.g., Dreher et al. 1989; Flores et al. 1982; Haan and Johnson 1968; Moore and Larson 1979; Ogawa and Male 1983, 1986, 1990) have conditionally supported and quantified the cumulative effects of wetlands as runoff dissipators. However, reductions in floodplain storage and channel roughness appeared to have little effect on peak flows in watershed simulations conducted by Johnson and Senter (1977). Hydrologic modeling of wetlands and floodplains is addressed in reviews by Corps of Engineers (1988), DeVries (1980), Dreher et al. (1989), and Duever (1988).

The effect cumulative wetland loss can have on landscape hydrology depends on (a) the remaining percentage of wetlands in the watershed, (b) the positions of other wetlands and storage areas, and (c) whether the altered wetlands are located at a hydrologic control point (a place where channel storage or conveyance influences a much wider area because flows are funneled by landforms). With regard to the role of wetland area, limited evidence from Wisconsin and Minnesota watersheds suggests that loss of wetlands in watersheds having a small proportion of wetland area will have greater effect than the same loss in watersheds with a larger proportion of wetland area. This is particularly true if the new losses occur disproportionately in areas near mainstem channels. Where conversion losses occur mainly in headwater areas, watersheds with a large proportion of wetland area (perhaps >10%) can partly compensate for the associated loss of storage (Ogawa and Male 1983). The influence of wetland position on prediction of instantaneous streamflow probably increases with increasing proportion of wetland area (e.g., NEEC 1984). The position of wetland area within a watershed influences the nature of the cumulative effect. Watersheds where wetland conversions are focused within mainstem floodplains (Ogawa and Male 1983), or where headwater wetlands are channelized but wetlands downstream or at a control point are not, may experience the greatest increase in flood peaks. This is because the position of such conversions, or even activities such as new wetland creation, can synchronize the arrival of runoff and lead to higher flood peaks (McCuen 1979). Finally, no evidence suggests that maintaining wetland type or size diversity provides greater support for streamflow-related values.

Loss of Water Quality Functions

Only a few published studies (e.g., Beasley and Granillo 1988; Mader et al. 1989) compare watershed water quality before and after alterations in wetland vegetation or changes in a watershed's proportion of wetland area. An analysis of Louisiana's Tensas Basin by Childers and Gosselink (1990) found that turbidity, total phosphorus, and total suspended solids were significantly related to water level at three sites. Observing that these trends were characteristic of cleared watersheds, the authors suggested that stream enrichment in the Tensas could

Table 7.7. Generally expected effects of various stresses on hydrologic functions of wetlands [1].

Sedimentation/Soil Compaction	Reduction in storage, infiltration, and groundwater recharge causing an increase in surface runoff
Vegetation Removal	Reduction in interception, condensation, evapotranspiration, and surface roughness (runoff resistance), and an increase in runoff velocity and groundwater discharge
Dehydration	Reduction in groundwater exchange (sometimes) and an increase in evapotranspiration (during early vegetational succession); these effects are especially likely where dehydration results from channelization or artificial drainage (Winter 1988)
Inundation	Usually increases infiltration and recharge within the wetland, but may convert nearby wetlands from recharge to discharge areas or vice-versa (Born et al. 1979)
Fragmentation	Can reduce groundwater recharge and discharge in remaining wetlands (Winter 1988)

[1] This is intended as a general guide, and effects may differ depending on wetland type and the timing, duration, extent, and intensity of the stress.

Table 7.8. Generally expected effects of various stresses on water quality functions of wetlands [1].

Enrichment	Increase in denitrification rate, sediment stabilization, and biological uptake and processing; may depress the latter if extreme or chronic
Organic Loading	Reduces biological uptake/processing, especially at high loadings or if associated with acidification; increases sedimentation and denitrification rates under moderate loadings; enhances mobilization of some substances through oxidation effects
Contamination [2]	Variable effects, depending on the specific contaminant and other factors; can depress denitrification, biological uptake/processing, and photosynthesis
Acidification	Usually depresses denitrification, biological uptake and processing, and perhaps photosynthesis; effects on chemical adsorption depend on the chemical, but acidification usually results in increased mobility of heavy metals
Salinization	May depress denitrification, biological uptake, and photosynthesis and enhance adsorption of some chemicals; response depends partly on the degree to which the system is adapted to salinity
Sedimentation/Soil Compaction	Depresses biological uptake, processing, and photosynthesis, and may reduce hydrologic residence time; other effects are variable
Turbidity/Shade	Reduces photo-oxidation of some contaminants, and usually depresses denitrification, photosynthesis, and perhaps biological uptake
Vegetation Removal	Reduces sedimentation, sediment stabilization, photosynthesis, biological uptake/processing, and perhaps denitrification. Sediment removal capacity of early successional forested wetlands may increase (Aust et al. 1991; Cooper et al. 1986)
Thermal Warming	Increases rates of most chemical and biological functions up to a point
Dehydration	Concentration of inorganic chemicals increases as dehydration proceeds; complete drawdown temporarily remobilizes many substances, especially organics and phosphorus, but may renew wetland adsorption capacity for some substances; effects on other water quality functions are variable (e.g., Bourbonierre 1987; Moore 1987).
Inundation	May increase sedimentation and decrease biological uptake and processing, and photosynthesis; effects on other functions are variable
Fragmentation	Increasing the distance between wetlands could reduce the effectiveness of coupled functions important to water quality

[1] This is intended as a general guide, and effects may differ depending on wetland type and the timing, duration, extent, and intensity of the stress.

[2] From heavy metals and pesticides.

have been caused by logging bottomland hardwoods. The number of streams was not large enough to test whether other factors might have caused these water quality trends. However, considering this evidence along with other findings (Gosselink et al. 1990b), the investigators concluded that the water quality function of the Tensas declined as a result of forested wetland loss. In Illinois, Osborne and Wiley (1988) demonstrated the use of regression equations to estimate the risk that a watershed would exceed water quality limits if forested land were converted to urban or agricultural uses.

Computer simulations have also been used to estimate the cumulative effects of wetland loss on downstream sedimentation and water quality. Examples of such analyses are simulations by Auble et al. (1988), Bedient et al. (1976, 1985), and Maristany and Bartel (1989). Attempts to model water quality functions of wetlands are restricted partly by the limited ability of existing hydrologic models to account for biological functions within wetlands and partly by uncertainty regarding appropriate routing algorithms in complex situations such as floodplain and peatland watersheds (Costanza and Sklar 1985; Mitsch 1983).

Loss of Habitat Functions

Numerous anecdotal accounts of species loss are associated with cumulative wetland loss (e.g., Bellrose et al. 1979; Harris 1988; Hunter et al. 1987; Kushlan 1979; Williams et al. 1989), but apparently only one study (Burdick et al. 1989) has attempted to statistically link reductions in regional biodiversity over time with loss of wetlands. These authors compared trends in the relative abundance of birds with reductions in bottomland hardwood areas and examined the relative abundance of birds in areas with varying amounts of forest. They found evidence that the declining number of forest species and the densities of interior species were related to cumulative loss of forest area. The investigators also suggested that reduction in forested

Table 7.9. Generally expected effects of various stresses on habitat functions of wetlands (from Adamus and Brandt 1990)[1].

Enrichment and Organic Loading	Initial enrichment increases production and within-wetland biotic diversity, but prolonged or extreme enrichment results in increased dominance of a few invasive species, decreased species richness, diminished wetland structural diversity, decreased production and, in some regions, succession to upland vegetation
Contamination [2]	All habitat functions are generally impaired
Acidification	Results in diminished native biodiversity and production
Salinization	In freshwater wetlands, usually results in diminished species richness (especially of woody species), but surviving species may be relatively unique and thus contribute disproportionately to overall regional diversity
Sedimentation/Soil Compaction	Diminishes species richness as a result of reduced light, smothering, etc.; however, moderate amounts of sediment can increase production of some woody plants in floodplains and can increase habitat in deeper depressions by providing additional shallow substrate for colonization
Turbidity/Shade	Variable effects; can diminish habitat suitability by reduced plant biomass, but can benefit some species by providing shelter from predation and extreme heat
Vegetation Removal	Diminishes habitat space; scattered thinning of dense stands can increase species richness and spatial heterogeneity; selectively benefits some species but detrimental to many others
Thermal Warming	Reduces species richness, but surviving species may be relatively unique and thus contribute disproportionately to regional diversity if warming is local
Dehydration	Temporary dehydration, if infrequent and brief, can reinvigorate nutrient cycling in wetlands and thus increase primary production; effects of partial drawdowns are variable; drawdowns can result in invasion by undesirable weed species, such as common reed or purple loosestrife; permanent dehydration results in conversion to upland habitat
Inundation	Can increase habitat space for aquatic communities (particularly if the result is an interspersion of wetland vegetation and open water), facilitate dispersal of isolated aquatic populations, increase bank erosion, and dilute contaminants; contaminants, suspended sediment, plant material, and nutrients can also be reintroduced from newly flooded areas
Fragmentation	Increasing the distances between wetlands usually reduces regional biodiversity, although invasion by aggressive non-native species can be similarly reduced

[1] This table is intended as a general guide, and effects may differ depending on wetland type and the timing, duration, extent, and intensity of the stress.
[2] From heavy metals and pesticides.

wetlands might have caused the elimination of the red wolf and Florida panther in parts of Louisiana and led to reduction in the number of the black bears, now listed as a threatened species there. Comparing relatively undisturbed and disturbed watersheds in Pennsylvania, Brooks et al. (1990) and Croonquist and Brooks (1991) reported differences in avian, amphibian, and mammalian community structure. They attributed these differences to multiple impacts associated with development in the watershed, e.g., channelization, a reduction in natural land cover types surrounding wetlands, and increased human visitation. Continental waterfowl declines have also been blamed on a combination of wetland habitat loss, contamination, over-harvest, and disease. However, analyses of this sort encounter problems with a scarcity of consistently collected long-term data and the presence of major confounding variables (e.g., annual variation in climate, interspecific competition, and other land uses).

Because many vertebrate species require multiple wetlands or wetland types to meet their feeding and reproductive needs (Cowardin 1969; Dzubin 1969; Flake 1979; Kantrud and Stewart 1984; Patterson 1976), diminished diversity of wetland types or increased wetland isolation (i.e., increased patch distance; see Chapter 6) can be detrimental. Similar isolation effects have been described for communities of wetland microbes (McCormick et al. 1987) and invertebrates (e.g., Jeffries 1989).

Habitat loss through wetland fragmentation is an area of recent interest. Fragmentation increases vulnerability of wetland species to predation, and causes some species to expend so much energy traveling (and being exposed to hazards) that the costs of using the nearest wetland offset the gains. Data from semipermanent Iowa wetlands (Brown and Dinsmore 1986) suggest that, at least in that region, a wetland density of 1 to 5 hectares per square kilometer may be required to support a diverse aquatic avifauna. Richness of aquatic bird communities in individual Maine wetlands was also correlated with local wetland density, but not with distance to the nearest wetland (Gibbs and Melvin 1990). From various studies (e.g., Cowardin et al. 1988; Frederick 1983), it is apparent that wetland-dependent bird species characteristically requiring multiple wetlands during a breeding season generally need the wetlands to be located within 0.5 to 25 kilometers of each other; the exact travel distance depends on the species and other factors. Amphibians and wetland reptiles need wetlands in even closer proximity (Brown et al. 1990). If the increased patch distance is greater than the usual distance an individual is able to safely travel, population losses can potentially occur. Factors that could mitigate habitat fragmentation include:

- Suitability of intervening land cover for habitat;
- Suitable type, dimensions, and hydrologic permanence of habitat corridors that form connections among wetlands or between wetlands and other ecosystems crucial to some species;
- Ecological integrity and type of dominant wetland;
- Diversity of local wetland types (e.g., as defined by hydrology, vegetation, water quality and size).

Suppose many wetland-dependent species in a region must, for energetic reasons, forage within 1 km of where they breed (i.e., wetland patch distances <1 km required). If a mitigation banking arrangement or evaluation technique allows for loss of many small (but proximate) wetlands and protection of fewer large but more isolated ones, then patch distances will probably increase and cumulative effects on populations could be adverse. The same could occur if a new regulation excluding small wetlands indirectly resulted in increased patch distances among the remaining wetlands. Loss of wetland area could also have a disproportionate effect on wildlife if losses are focused on temporary concentration areas (e.g., migratory staging areas, corridors, or nodes within a wildlife dispersal network).

Wetland plant communities may be better able to resist the effects of fragmentation than wetland animal populations. Field data from more than 400 lakes surveyed by Rorslett (1991) indicate that the richness of herbaceous plants was not strongly related to the pool of aquatic plant species potentially available for colonization in a region. However, simulations by Hanson et al. (1990) predicted that fragmentation would lead to reduced richness of woody plants in remaining riparian areas.

It is important to reiterate that travel distance and patch size are only two factors that affect habitat use. The ecological integrity or suitability of within-patch habitat quality is often at least as important (Kushlan 1979). For example, the placement of dikes or pathways built on fill within wetlands can decrease water bird nesting success because of increased predator access (Peterson and Cooper 1991). The point is not that a particular wetland characteristic such as size is "better," but that wetlands be assessed as whole complexes and that their distribution patterns, condition, and actual wildlife use be taken into consideration by resource managers in wetland regulatory programs.

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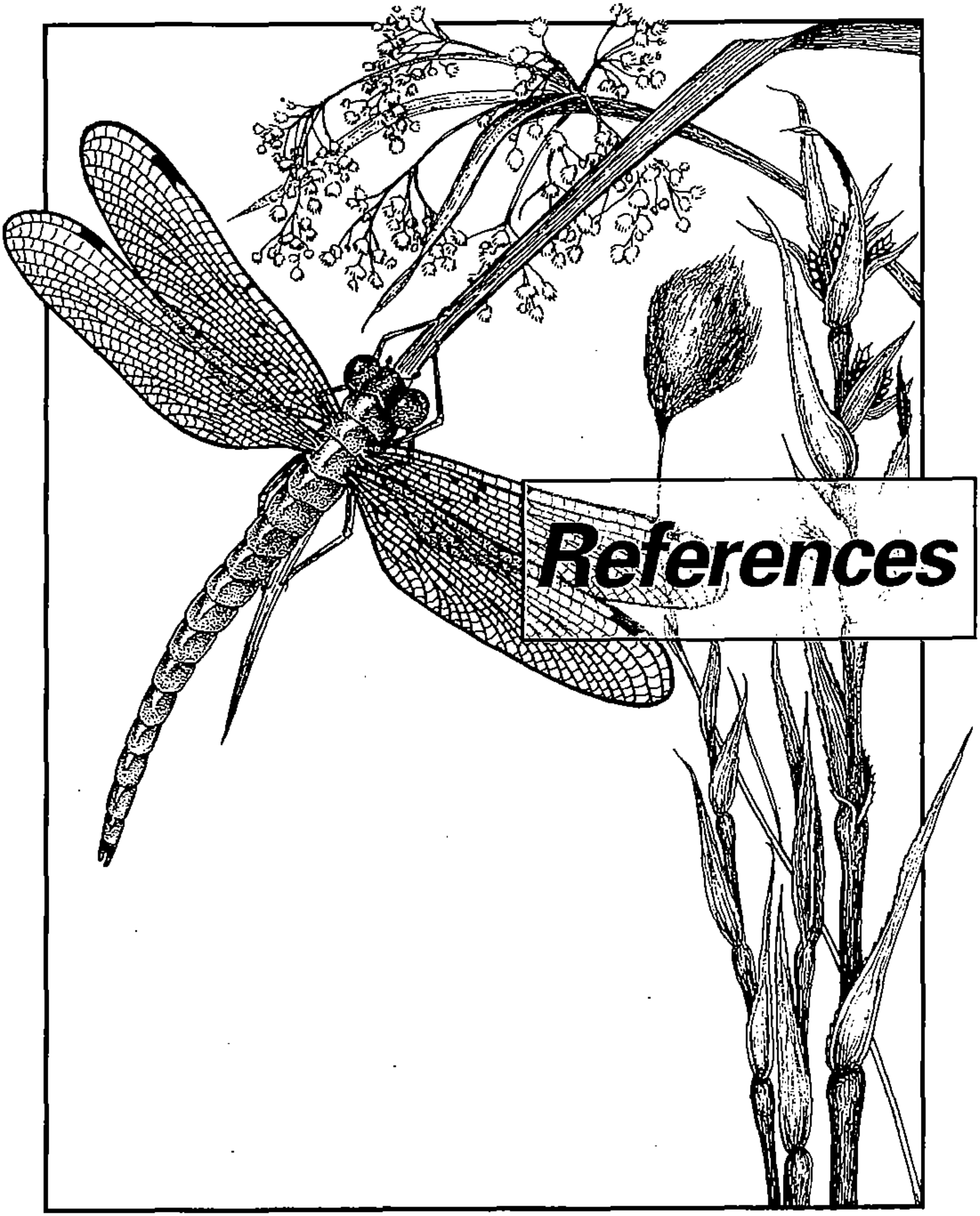

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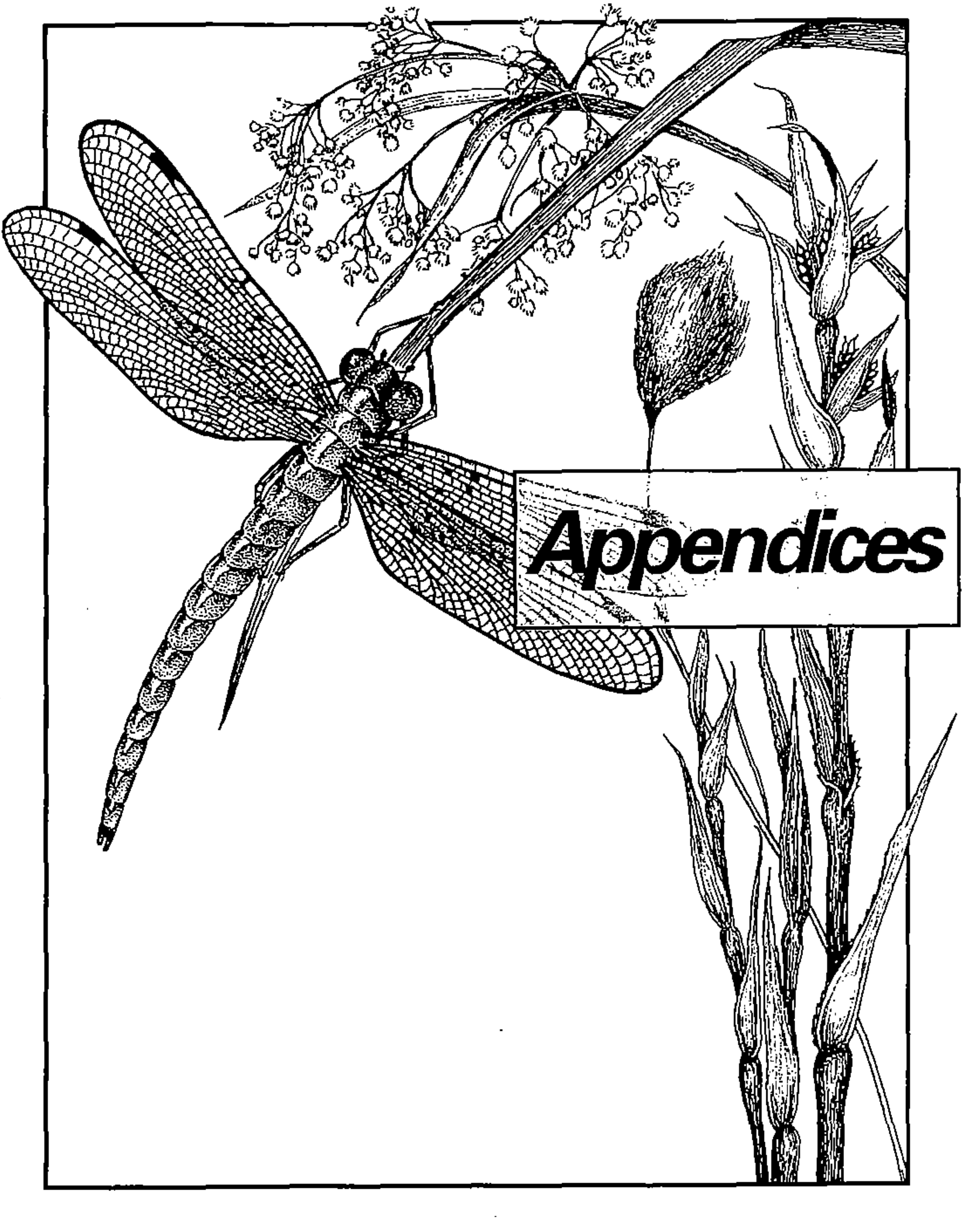

Appendices

APPENDIX A

Review of Methods for Assessing Cumulative Impacts

Although none deals specifically with wetlands, a number of methods have been devised for assessing the effects of cumulative impacts (see reviews by Horak et al. 1983; Lane and Wallace 1988). Each method was examined prior to and during development of the synoptic approach. In addition to not addressing wetlands specifically, their drawbacks include:

- Focus on individual ecosystems rather than landscape subunits such as watersheds;
- Focus on interactions of impacts rather than on the influence of wetlands or other ecosystems on landscape function;
- Incompatibility with use of widely available data; and
- Lack of speed and flexibility.

Existing methods can be grouped as follows:

Conceptual Frameworks

These methods provide general narrative procedural guidance for incorporating cumulative impacts in decision-making. Products are not pre-specified, so they can differ greatly, ranging from narrative descriptions of cumulative impacts, to quantitative assessments. They include reports by Bedford and Preston (1988b) for EPA; Dames and Moore Inc. (1981) for the Army Corps of Engineers; Horak et al. (1983) for the U.S. Fish and Wildlife Service; Lane and Wallace (1988) for the Canadian government; and Stull et al. (1987) for the U.S. Department of Energy.

Descriptive Cause-Effect Methods

These methods are intended to describe mechanistically (and in some cases, dynamically) the direct and indirect effects of one or more disturbances. They assume that cumulative effects to a resource can be estimated by identifying individual effects and mathematically representing the manner in which they interact and accumulate. In most cases, products are ratings for particular project alternatives or activities that describe their relative potential for generating cumulative effects; they are organized as flow diagrams, matrices, or networks. Bain et al. (1986) developed a matrix method that was then used by Stull et al. (1987), O'Neil and Witmer (1991), and Witmer and O'Neil (1991) for assessing multiple hydropower projects. Other examples include Armour and Williamson (1988), Emery (1986), and Patterson and Whillans (1984).

Map Overlay Methods

Perhaps closest to the synoptic approach, these methods are intended to identify areas most sensitive or vulnerable to impacts and areas where consequences of impacts are expected to be greatest, or both. Maps are used as planning tools with the assumption that future impacts will be of greatest concern where (for example) sensitivity, value, and past losses have been most severe. Map overlay methods employ thematic maps or databases according to some aggregation scheme to rate landscapes generally (e.g., Bastedo et al. 1984; Canters et al. 1991; McHarg 1969; Radbruch-Hall et al. 1987) or to rate water resources specifically (e.g., Aller et al. 1987). Map overlay methods also (a) assess past impacts by overlaying maps of land cover trends and erosion sensitivity (Dickert and Tuttle 1985), (b) assess relative geographic risks by overlaying maps of impacts (e.g., Parrish and Langston 1991), or (c) prioritize individual habitat patches at a landscape level using maps and biogeographic theory (e.g., Gosselink and Lee 1989; Gosselink et al. 1990b; Scott et al. 1987). Bailey (1988) discusses methodological issues.

Methods Based on Statistical Data Analysis or Simulation

These methods attempt to quantitatively assess or predict cumulative impacts based on analysis of historical patterns of impacts by examining permit use (e.g., Contant and Ortolano 1985), airphotos, or field data (e.g., Gosselink and Lee 1989; Gosselink et al. 1990a, b). Products include tabulations, graphs, and interpretations of trends. In some cases, statistical models are developed to specify landscape assimilative capacity, or thresholds of degradation and loss, that if surpassed result in unacceptable effects (e.g., Osborne and Wiley 1988). As summarized by Adamus (1989), these models include statistical methods applied in Louisiana (Burdick et al. 1989; Childers and Gosselink 1990; Gosselink and Lee 1989; Gosselink et al. 1990b) and Minnesota (Johnston et al. 1988), as well as models used by an Army Corps District (Contant and Ortolano 1985) and forest managers (Chatoian 1988; Cobourn 1989; Megahan 1992). They also include landscape simulations of hydrology (e.g., Bedient et al. 1985; Dreher et al. 1989; Flores et al. 1982), water quality (e.g., Ziemer et al. 1991), and wildlife habitat (e.g., Cowardin et al. 1988; Winn and Barber 1985).

APPENDIX B

Table B.1. Typical relationships expected between resource extraction impacts and wetland degradation based on best professional judgment. Letter indicates degree of expected association and not the intensity or duration of impact (H = high, M = medium, L = low).

Impact	Acidification	Altered Animal Behavior	Compaction	Contamination/Toxicity	Denudation
Blasting/Drilling [3]		M		M	L
Burning/Air pollution [2]	H			H	L
Channelization [3]		M			H
Drainage [2,3]	L	H	L	M	
Dredging/Excavation [3]	M			M	M
Fertilizers [2]	L			L	M
Harvesting		H[1-3]			M[1-3]
Pesticides [2]				H	M
Solid Waste Disposal [3]	H			H	
Species Introduction [1,2]		H			
Structures/Pavement [3]		L	H		H
Trampling [1-3]		H	L		M
Vehicles/Boats/Planes [1-3]		M	M	L	L
Water Consumption [3]				M	

[1] Fishing/Hunting/Trapping
[2] Forestry
[3] Mining – Mineral and Peat

Impact	Dehydration	Eutrophication/Enrichment	Erosion	Inundation	Light Reduction
Blasting/Drilling [3]	L				
Burning/Air pollution [2]		H			
Channelization [3]	M	M	M		L
Drainage [2,3]	H	M	M		M
Dredging/Excavation [3]		M	H	M	M
Fertilizers [2]		H			L
Harvesting				M[2]	
Pesticides [2]					
Solid Waste Disposal [3]		M	L		L
Species Introduction [1,2]	L				L
Structures/Pavement [3]			L		L
Trampling [1-3]		M	L		L
Vehicles/Boats/Planes [1-3]			M		L
Water Consumption [3]	H	M			

[1] Fishing/Hunting/Trapping
[2] Forestry
[3] Mining – Mineral and Peat

Impact	Salinization	Sedimentation	Surface Runoff Timing	Thermal Warming
Blasting/Drilling [3]	L	L		
Burning/Air pollution [2]	L			H
Channelization [3]			H	L
Drainage [2,3]	L	M	H	
Dredging/Excavation [3]	L	H	M	
Fertilizers [2]	M			
Harvesting [1-3]		M[2]	M[2]	H[2]
Pesticides [2]				
Solid Waste Disposal [3]	L	M		L
Species Introduction [1,2]				
Structures/Pavement [3]			M	
Trampling [1-3]				
Vehicles/Boats/Planes [1-3]				
Water Consumption [3]	M		H	L

[1] Fishing/Hunting/Trapping
[2] Forestry
[3] Mining – Mineral and Peat

Table B.2. Typical relationships expected between urbanization impacts and wetland degradation based on best professional judgment. Letter indicates the degree of expected association and not the intensity or duration of impact (H = high, M = medium, L = low).

Impact	Acidification	Altered Animal Behavior	Compaction	Contamination/Toxicity	Denudation
Blasting/Drilling		M		L	L
Burning/Air pollution	H			H	L
Channelization		M			H
Drainage	L	H	L	M	
Dredging/Excavation	M			M	M
Fertilizers	L			H	M
Fill	L			M	H
Harvesting		H			M
Impoundment		H		M	
Industry/Manufacturing	L	L		H	
Pesticides				H	M
Sewage Treatment					
Solid Waste Disposal	H			H	
Species Introduction		H			
Stormwater Runoff	L			M	
Structures/Pavement		L	H		H
Trampling		H	L		M
Vehicles/Boats/Planes		M	M	L	L
Water Consumption				M	

Impact	Dehydration	Eutrophication/Enrichment	Erosion	Inundation	Light Reduction
Blasting/Drilling	L				
Burning/Air pollution		H			
Channelization	M	M	M		L
Drainage	H	M	M		M
Dredging/Excavation		M	H	M	M
Fertilizers		H			L
Fill	H	M	L		H
Harvesting				M	
Impoundment		M	L	H	M
Industry/Manufacturing		L			
Pesticides					
Sewage Treatment		H		M	
Solid Waste Disposal		M	L		L
Species Introduction	L				
Stormwater Runoff		M	L	H	L
Structures/Pavement			L		H
Trampling		M	L		L
Vehicles/Boats/Planes			M		L
Water Consumption	H	M			

Impact	Salinization	Sedimentation	Surface Runoff Timing	Thermal Warming
Blasting/Drilling	L	L		
Burning/Air pollution	L			H
Channelization			H	L
Drainage	L	M	H	
Dredging/Excavation	L	H	M	
Fertilizers	M			
Fill	L	H	M	
Harvesting		M	M	H
Impoundment	M	M	H	L
Industry/Manufacturing	L			H
Pesticides				
Sewage Treatment	L		M	
Solid Waste Disposal	L	M		L
Species Introduction				
Stormwater Runoff	L		M	L
Structures/Pavement			M	
Trampling				
Vehicles/Boats/Planes				
Water Consumption	M		H	L

Table B.3. Typical relationships expected between water management impacts and wetland degradation based on best professional judgment. Letter indicates degree of expected association and not the intensity or duration of impact (H = high, M = medium, L = low).

Impact	Acidification	Altered Animal Behavior	Compaction	Contamination/Toxicity	Denudation
Blasting/Drilling [1]		M		L	L
Channelization [1,2]		M			H
Drainage [1]	L	H	L	M	
Dredging/Excavation [1,2]	M			M	M
Fertilizers [1]	L			H	M
Fill [1]	L			M	H
Harvesting [1]		H			M
Impoundment [1,2]		H		M	
Irrigation/Flooding [1,2]	L	M		M	
Pesticides [1]				H	M
Saltwater Intrusion [2]	L	M			L
Water Consumption [2]				M	

[1] Flood Management
[2] Water Supply

Impact	Dehydration	Eutrophication/Enrichment	Erosion	Inundation	Light Reduction
Blasting/Drilling [1]	L				
Channelization [1,2]	M	M	M		L
Drainage [1]	H	M	M		M
Dredging/Excavation [1,2]		M	H	M	M
Fertilizers [1]		H			L
Fill [1]	H	M	L		H
Harvesting [1]					
Impoundment [1,2]		M	L	H	M
Irrigation/Flooding [1,2]		M	M	H	M
Pesticides [1]					
Saltwater Intrusion [2]					
Water Consumption [2]	H	M			

[1] Flood Management
[2] Water Supply

Impact	Salinization	Sedimentation	Surface Runoff Timing	Thermal Warming
Blasting/Drilling [1]	L	L		
Channelization [1,2]			H	L
Drainage [1]	L	M	H	
Dredging/Excavation [1,2]	L	H	M	
Fertilizers [1]	M			
Fill [1]	L	H	M	
Harvesting		M[2]	M[2]	H[2]
Impoundment [1,2]	M	M	H	L
Irrigation/Flooding [1,2]	H	M	M	
Pesticides [1]				
Saltwater Intrusion [2]	M			
Water Consumption [2]	M		H	L

[1] Flood Management
[2] Water Supply

APPENDIX C

Table C.1. Effect of wetland degradation on water quality functions and degree of expected association based on best professional judgment (H = high, M = medium, L = low).

Input	Sediment Detention	Sediment Stabilization	Phosphorus Detention	Nitrate Removal	Detoxification	Water Quality
Acidification			H	M	H	M
Animal Behavior	L	M	L	L	L	M
Compaction	H	H	M	M	M	H
Contamination/Toxicity		L	L	M	H	H
Denudation	M	H	H	H	M	M
Dehydration	H	L	H	H	H	M
Eutrophication/Enrichment	L	L	H	H	M	H
Erosion	H	H	M	M	M	H
Habitat Fragmentation	L	L	L	L	L	M
Inundation	H	L	H	H	H	M
Light Reduction			L	L	L	L
Salinization	L		L	L	M	H
Sedimentation	H	H	H	M	M	H
Surface Runoff	H	L	H	H	H	M
Thermal Warming	L		L	M	M	M

Table C.2. Effect of wetland degradation on habitat functions and degree of expected association based on best professional judgement (H = high, M = medium, L = low).

Input	Biological Production	Biodiversity[1]
Acidification	L	M
Animal Behavior	M	H
Compaction	M	M
Contamination/Toxicity	M	H
Denudation	H	H
Dehydration	H	H
Eutrophication/Enrichment	H	H
Erosion	M	M
Habitat Fragmentation	L	H
Inundation	H	H
Light Reduction	H	H
Salinization	L	M
Sedimentation	M	H
Surface Runoff	M	H
Thermal Warming	H	H

[1] Number of normally uncommon native species per unit area.

APPENDIX D

Table D.1. Potential sources of mapped and tabular data for landscape indicators of synoptic indices [1].

Mapped Data	Resolution [2]	Wetland Extent	Hydrology			Water Quality			Habitat		Loss [3]		Rep. Pot. [4]
			Input	Capacity	Value	Input	Capacity	Value	Function	Value	Conv.	Degr.	
CCAP	P	X											
CESCR	P								X	X			
DEM	SC		X										X
DLG	SC	X		X									
FEMA Maps	P		X									X	
GAP	P								X	X			X
LULC	P	X				X							
NATSGO	SS	X	X			X							
NHBCDS	P								X	X			
NWI Maps	P	X		X			X		X				
PNV	SS								X		X		X
STATSGO	SC	X	X	X		X	X		X		X		
Stream N/P	SC					X		X			X		

Tabular Data	Resolution [2]	Wetland Extent	Hydrology			Water Quality			Habitat		Loss [3]		Rep. Pot. [4]
			Input	Capacity	Value	Input	Capacity	Value	Function	Value	Conv.	Degr.	
AgrCensus	C					X						X	
BBS	SC								X	X	X	X	
CBC	SC								X	X	X	X	
CCAP	SC	X											
CRPL	C					X			X		X	X	X
DrainStat	C										X	X	
DWSF	SC							X					
EMAP [5]	R	X					X		X		X	X	
FEMA Data Files	C	X			X								
FIA	SS	X								X	X		
ISS	P								X	X			
Marine Fish	R									X	X	X	
NADP	SS					X						X	
NASS	C					X						X	
NAWQA	R		X			X						X	
NHVCA	S								X	X			
NPUD	C					X						X	
NRCBR	P											X	
NRI	SS	X									X		
NWI Trends	R										X		
NWUDS	SC							X				X	
Precip	SS		X									X	
Priority	P									X			
RCF	SC	X	X	X									
STORET	P					X						X	
TIGER	SC				X			X				X	
TRI	P					X						X	
WATSTORE	SC		X									X	
WBGS	SS								X	X		X	
WPF	C								X	X			
WWS	SC								X	X		X	
305b	SC					X		X				X	

[1] Data from these sources are believed to be of potential use for applications of the synoptic approach. Most sources are national in coverage and publicly available at minimal or no cost. However, listing of a source does not necessarily indicate it is available for all areas of the U.S., nor does it imply quality or convenience of use. Mapped data mostly include sources available in digital format. An "X" in the matrix means the data could be appropriate for some of the information needed for that synoptic component; no single source provides all necessary information. Further information on contacts for these data sources and the full database name is given in Appendix E. For a more complete description of some of these sources, see Adamus (1992).

[2] Resolution is the finest resolution at which data are compiled (not necessarily comprehensively): R (multi-state region) < S (state) < SS (substate, e.g., major river basin) < C (county) < SC (subcounty, e.g., watershed or town) < P (point, e.g., specific wetland).

[3] Loss through conversion (Conv.) or degradation (Degr.).

[4] Replacement potential.

[5] Program currently under development; data for portions of the country should become available by 1995.

APPENDIX E[1]

Contact Information and Examples of Variables from National Maps and Databases

AgrCensus - Census of Agriculture

Customer Service
Census of Agriculture
Agricultural Division
Bureau of the Census
U.S. Department of Commerce
Washington, DC 20233
(301) 763-4100

Example of derivable variables: "percent change in number of cattle (or fertilized cropland, harvested wild hay, irrigated land, etc.) in Fort County, 1982-1987."

BBS - Breeding Bird Survey

Coordinator
Breeding Bird Survey
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, MD 20708
(301) 498-0330

Example of derivable variable: "percent of surveys in southern Missouri in which wetland-dependent songbirds declined, 1976-1985."

CBC - Christmas Bird Count

Christmas Bird Count Database Coordinator
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, MD 20708
(301) 498-0490

Example of derivable variable: "numbers of egrets in Mississippi delta counts reporting > 6 wading bird species."

CCAP - Coastwatch Change Analysis Program

Program Manager
Coastwatch Change Analysis Program
Beaufort Fisheries Laboratory
National Marine Fisheries Services
101 Pivers Island Road
Beaufort, NC 28516
(919) 728-3595

CESCR - Commercially/Ecologically Significant Coastal Resources

For coastal areas, contact regional office of the U.S. Fish and Wildlife Service and request atlases of coastal waterbird colonies, Coastal Ecological Inventory maps, and Ecological Characterization Project maps.

CRPL - Conservation Reserve Program Lands

CRP Data Coordinator
Agricultural Stabilization and Conservation Service
P.O. Box 2415
Washington, DC 20013
(202) 720-6303

Example of derivable variable: "percent of county with highly erodible land idled from cultivation."

DEM - Digital Elevation Model

DEM Data Coordinator
National Cartographic Information Center
U.S. Geological Survey, Bldg. 3101
NSTL Station, MS 39529
(601) 688-3541

Example of derivable variable: "percent of Muddy Creek watershed with < 2% slope."

DLG – Digital Line Graphs

Reach File Coordinator
Monitoring Branch (WH553)
Assessment and Watershed Protection Division
U.S. EPA
401 M Street SW
Washington, DC 20460
(202) 260-7028

Example of derivable variable: "area of instream impoundments located < 20 km upriver of Smithville."

DrainStat - Drainage Statistics

Example of variable: "area of drainage in Sioux County in 1960." See reports cited in: Pavelis, G.A. (ed.). 1987. Farm drainage in the United States: History, status, and prospects. Misc. Pub. No. 1455, USDA Economic Research Service, Washington, DC.

DWSF - Drinking Water Supply File

Drinking Water Supply File Coordinator
Monitoring Branch (WH553)
Assessment and Watershed Protection Division
U.S. EPA
401 M Street SW
Washington, DC 20460
(202) 260-7028

Example of derivable variable: "number of drinking water intakes located < 15 km downstream from Marshville."

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[1] Potential uses of these data as landscape indicators can be found in Appendix D. "Derivable variable" is a variable that could be derived from the map or database using a GIS or statistical package, respectively.

EMAP - Environmental Monitoring and Assessment Program

EMAP-Wetlands Technical Director
U.S. EPA Environmental Research Laboratory
200 SW 35th Street
Corvallis, OR 97333
(503) 754-4457

Example of derivable variable: "percent change in percent cover of regularly flooded tidal emergent wetlands, southeastern region." Data are not currently available, but will become available beginning in the mid to late 1990s.

FEMA (maps and data files) - Federal Emergency Management Agency

Flood Map Distribution Center
Federal Emergency Management Agency
6930 San Tomas Road
Baltimore, MD 21227-6227
(800) 333-1363

Example of derivable variable: "number of residences in the Fargo, ND, 100-yr floodplain."

FIA - Forest Inventory Analysis

FIA Coordinator
USDA Forest Service
Washington, DC
(202) 205-1343

Example of derivable variable: "percent change, 1967-1982, in > 25-cm diameter oak-gum-cypress stands in southeastern Georgia." For specific data, contact USDA Forest Service experimental stations (Fort Collins, CO; Ogden, UT; St. Paul, MN; Broomall, PA; Portland, OR; Berkeley, CA; Asheville, NC; New Orleans, LA).

GAP - Gap Analysis Projects

GAP Analysis Projects
Idaho Cooperative Fish & Wildlife Res. Unit
University of Idaho
Moscow, ID 83843
(208) 885-6960

Example of derivable variable: "percent of Utah areas in public ownership that are inhabited by uncommon wetland mammals."

ISS - International Shorebird Survey

Data Coordinator
International Shorebird Survey
Manomet Bird Observatory
P.O. Box 936
Manomet, MA 02345
(508) 224-6521

Example of derivable variable: "numbers of shorebirds at monitored sites in Region 4 having the largest concentrations of migratory shorebirds."

LULC - USGS Land Use/Land Cover

Earth Science Information Center
U.S. Geological Survey
507 National Center
Reston, VA 22092
(800) USA-MAPS

Example of derivable variable: "percent of forested wetlands and open water in Green County."

Marine Fish - Marine Fisheries

Statistical Coordinator
Commercial and Recreational Fisheries Statistics Offices
National Marine Fisheries Service
Washington, DC
(301) 713-2328

Example of derivable variable: "percent change in catch of wetland-dependent fish species in southeast reporting region, 1980-85."

NADP - National Atmospheric Deposition Program/National Trends Network

Data Manager
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523
(303) 491-1464

Example of derivable variable: "percent change in nitrogen deposition of Coastal Piedmont sites."

NASS - National Agriculture Statistics Service

Database Coordinator
Statistical Methods Branch
Estimates Division
National Agricultural Statistics Service
Washington, DC 20250
(202) 720-7590

Example of derivable variable: "percent change in soybean area in Thomas County, 1989-1990."

NATSGO - SCS NATSGO Maps

National Cartographic and GIS Center
USDA Soil Conservation Service
P.O. Box 6567
Fort Worth, TX 76115
(817) 334-5559

Example of derivable variable: "percent of region having hydric soils with > 5% organic matter and slope < 1%."

NAWQA

NAWQA Coordinator
Water Resources Division
U.S. Geological Survey
Reston, VA 22092
(703) 648-5114

Example of derivable variable: "percent change in nitrogen loading to the Sacramento River estuary." Data are currently available only for selected areas.

NHBCDS - National Heritage/Nature Conservancy Biological and Conservation Data System

Database Coordinator
Biological and Conservation Data System
The Nature Conservancy
201 Devonshire Street - 5th Floor
Boston, MA 02110
(617) 542-1908

NHVCA - National Heritage/Nature Conservancy Vertebrate Characterization Abstracts

Database Coordinator
Vertebrate Characterization Abstracts
The Nature Conservancy
201 Devonshire Street - 5th Floor
Boston, MA 02110
(617) 542-1908

Example of derivable variable: "number of wetland types in Michigan used by raptors vs. by songbirds."

NPUD - National Pesticide Use Database

Coordinator
National Pesticides Use Database
Resources for the Future
1616 P Street NW
Washington, DC 20036
(202) 328-5025

Example of derivable variable: "area of corn treated with atrazine in Jones County in 1988."

NRCBR - Nest Record and Colonial Bird Registry

Coordinator
Nest Record Program
Cornell Laboratory of Ornithology
Sapsucker Woods Road
Ithaca, NY 14850
(607) 254-2473

Example of derivable variable: "percent success of central Iowa nests of wetland-dependent species, 1980-1990."

NRI - National Resource Inventory

Resources Inventory Division
USDA Soil Conservation Service
P.O. Box 2890
Washington, DC 20013
(202) 720-5420

Example of derivable variable: "percent wetland loss, 1982-87, in areas having > 10% highly erodible land." Federal lands not included. For data specifically on substate trends in wetlands, contact:

Dr. Curtis Flather
USDA Forest Service
Fort Collins, CO
(303) 498-1660

NWI - National Wetlands Inventory

U.S. Fish and Wildlife Service
c/o Earth Science Information Center
U.S. Geological Survey
507 National Center
Reston, VA 22092
(800) USA-MAPS

Example of derivable variable: "percent of Iowa wetlands > 5 ha that are seasonally flooded emergent wetlands." Not available for all of the U.S.

NWI Trends - National Wetland Inventory

National Wetlands Inventory
U.S. Fish and Wildlife Service
9720 Executive Center
Monroe Bldg. - Suite 101
St. Petersburg, FL 33702
(813) 893-3624

Example of derivable variable: "regional wetland loss between 1950 and 1970."

NWUDS - National Water Use Data System

Coordinator
National Water Use Data System
Water Resources Division
U.S. Geological Survey
Reston, VA 22092
(703) 648-6815

Example of derivable variable: "percent of groundwater withdrawals in Kansas used for irrigation." Formerly called the State Water Use Data System.

PNV - Potential Natural Vegetation

GIS Coordinator
U.S. EPA Environmental Research Laboratory
Corvallis, OR 97333
(503) 754-4352

Example of derivable variable: "regions of California potentially supporting tule wetland vegetation."

Precip - Precipitation Network

Precipitation Network Data Coordinator
National Weather Service
U.S. National Climatic Data Center
Federal Building
Asheville, NC 28801-2696
(704) 259-0682

Priority - Listings of Priority Wetlands

Contact (a) the regional office of the U.S. Fish and Wildlife Service, and (b) the State Conservation and Outdoor Recreation Plan (SCORP) Coordinator and request the "Regional Wetlands Concept Plan" for a particular state or region. Listings also available from other state and federal resource agencies and from private conservation groups.

RCF - Reach Characteristics File

Reach Characteristics File Coordinator
Monitoring Branch (WH553)
Assessment and Watershed Protection Division
U.S. EPA
401 M Street SW
Washington, DC 20460
(202) 260-7028

Example of derivable variable: "percent of mainstem Fish River channelized, between Adams and Jefferson."

STATSGO - SCS STATSGO Maps

National Cartographic and GIS Center
USDA Soil Conservation Service
P.O. Box 6567
Fort Worth, TX 76115
(817) 334-5559

Example of derivable variable: "percent of watershed or region having hydric soils with > 5% organic matter and slope < 1%."

STORET - EPA STORET Database

STORET Coordinator
Monitoring Branch (WH553)
Assessment and Watershed Protection Division
U.S. EPA
401 M Street SW
Washington, DC 20460
(202) 260-7028

Example of derivable variable: "percent of sampling stations in Rock Creek watershed that violated nitrate criteria > 75% of the time, 1968-1988."

Stream N/P - Stream Nitrate/Phosphate

Regional Effects Program
U.S. EPA Environmental Research Laboratory
Corvallis, OR 97333

Send to above address for maps: Omernik, J.M. 1977. Nutrient concentrations in streams from nonpoint sources.

TIGER - U.S. Census

TIGER Database Coordinator
Data User Services Division
Customer Services
Bureau of the Census
Washington, DC 20233
(301) 763-4100

Example of derivable variable: "percent change in rural population of Jackson County, 1980-1990."

TRI - Toxic Release Inventory

Coordinator
Toxic Release Inventory
Information Management Division
Office of Pollution Prevention and Toxics (NEG008)
U.S. EPA
401 M Street SW
Washington, DC 20460
(202) 260-3938

Example of derivable variable: "kgs of cadmium released annually upstream from Eagle Wildlife Refuge."

WATSTORE - USGS WATSTORE Discharge Files

Coordinator
WATSTORE Database
Water Resources Division
U.S. Geological Survey
Reston, VA 22092
(703) 648-5659

Example of derivable variable: "number of days annually at which discharge in the Black River was < 1 cms at the gaging station below Marshton."

WBGS - Waterfowl Breeding Ground Surveys

Database Coordinator
Waterfowl Breeding Ground Surveys
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, MD 20708
(301) 498-0404/0401

Example of derivable variable: "assessed wetlands having > 4 nesting duck species."

WPF - Waterfowl Parts Files

Coordinator
Waterfowl Parts Database
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, MD 20708
(301) 498-0404/0401

Example of derivable variable: "numbers of geese in 5 Arkansas counties with the largest annual harvest of waterfowl."

WWS –Winter Waterfowl Survey

Database Coordinator
Winter Waterfowl Surveys
U.S. Fish and Wildlife Service
Patuxent Wildlife Research Center
Laurel, MD 20708
(301) 498-0404/0401

Example of derivable variable: "number of waterfowl wintering in three areas of Oregon reporting the highest annual use by waterfowl."

305b –State 305b Reports

Waterbody Database Coordinator
Monitoring Branch (WH553)
Assessment and Watershed Protection Division
U.S. EPA
410 M Street SW
Washington, D.C. 20460
(202) 260-7028

Example of derivable varible: "percent of assessed stream segments in Mitchell County with riparian destruction listed as a probable source of water quality degradation." Available for all states, but coverage within states is limited.

APPENDIX F

Areal Prorating

In conducting a synoptic assessment, data that are required might be reported by spatial units that differ from those needed for the assessment. For example, population data may be reported by county, but could be needed by watershed. In such instances, the reported data are prorated to the needed subunits. The method for prorating depends on the type of data. Two examples are discussed below. A more in-depth treatment of this problem is given in Flowerdew and Green (1989).

Aggregate Data

With aggregate data, the value associated with the reported unit represents the total number of objects found in that unit. Total number of people, number of rare, threatened or endangered species, total income, and farm area are examples of aggregate data. The following equation is used to prorate aggregate data for the reported units to the subunits needed for the assessment

$$TOTAL_s = \Sigma\, TOTAL_r \times (AREA_{(r,s)} / AREA_r) \qquad \text{Equation F.1}$$

where $TOTAL_s$ is the value for the needed subunit *s*, $TOTAL_r$ is the value for reported unit *r*, $AREA_{(r,s)}$ is the joint area of *r* and *s* (i.e., the intersection of *r* and *s*), and $AREA_r$ is the total area of reported unit *r*.

Figure F.1 shows Subunit 4, which is a watershed from the Illinois case study, overlaid with county boundaries. The areas of each county and the joint county-watershed areas are also shown (areas were determined by GIS, as described in Appendix G). Table F.1 shows how population from the three counties was prorated to Subunit 4.

The validity of this approach depends on the assumption that the aggregate data are distributed uniformly throughout the reported unit. A possibility for error exists in this method when the objects represented by the aggregate data are clustered, as in population centers, or are isolated, such as a particular endangered species. If this assumption is violated, it may still be possible to adjust the data to account for bias (see for example the discussion of "Landscape Indicators" within the Washington case study). Generally this error decreases as the size of the final subunit increases, because random variations and local heterogeneities are averaged out.

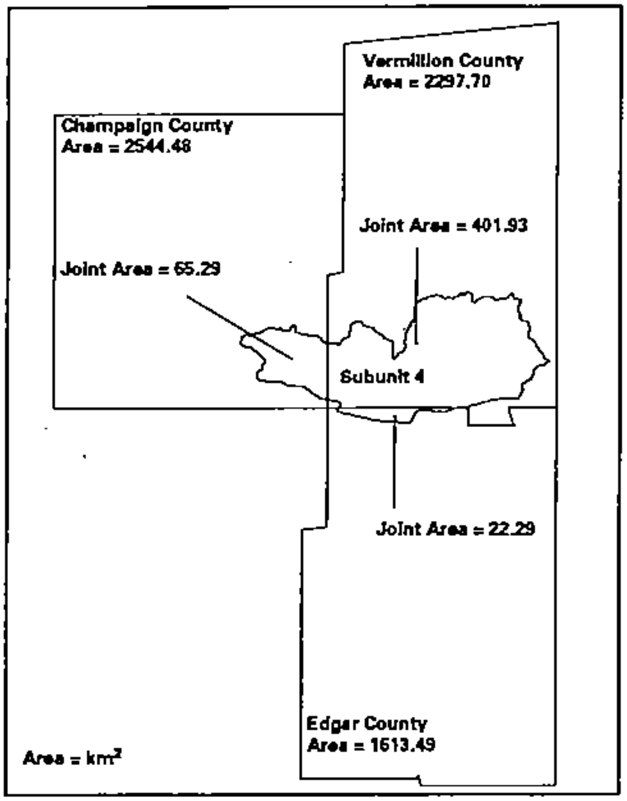

Figure F.1. Subunit 4 from Illinois case study overlaid with county boundaries.

Table F.1. Prorating county data to Subunit 4 for the Illinois case study.

County	Population by county [1] $TOTAL_r$	Joint area [2] $AREA_{(r,s)}$	County area [2] $AREA_r$	Partial sum [3]
Champaign	168392	65.29	2544.48	4321
Edgar	21725	22.29	1613.49	300
Vermillion	95222	401.93	2297.70	16657
Subunit 4 Total				21278

[1] 1980 population from U.S. Bureau of the Census (1982b).
[2] Area in km² derived by GIS; see Appendix G.
[3] The population within the joint county-subunit area, equal to $TOTAL_r \times (AREA_{(r,s)} / AREA_r)$.

Intensity Data

With intensity data, the reported value is not a total, but instead is an average intensity or rate of some process; the intensity represents the average value at every point within the bounded area. For example, mean annual precipitation is the average amount of precipitation received in a year at each point within the reported unit, in inches or centimeters. Other examples would include mean elevation, mean insolation (solar energy), average depth to groundwater, etc. Such data are prorated according to the following equation:

$$\text{INTENSITY}_s = \sum \text{INTENSITY}_r \times (\text{AREA}_{(r,s)} / \text{AREA}_s)$$

Equation F.2

where INTENSITY_s is the value for the needed subunit *s*, INTENSITY_r is the value for the recorded unit *r*, AREA_s is the total area of the needed subunit, and $\text{AREA}_{(r,s)}$ is the joint area of *r* and *s*. Note that in this case area of the needed subunit is used as the denominator, rather than the area of the recorded unit.

Figure F.2 shows Subunit 815, which is a state Water Management Unit from the Louisiana case study, overlaid with precipitation zones. The precipitation zones were derived by taking the average value between adjacent contours of mean annual precipitation, in inches (precipitation was required in inches for calculation of $7Q_{10}$ values using USGS regression equations; see Appendix H). Table F.2 shows how precipitation data from the four zones were prorated to Subunit 815.

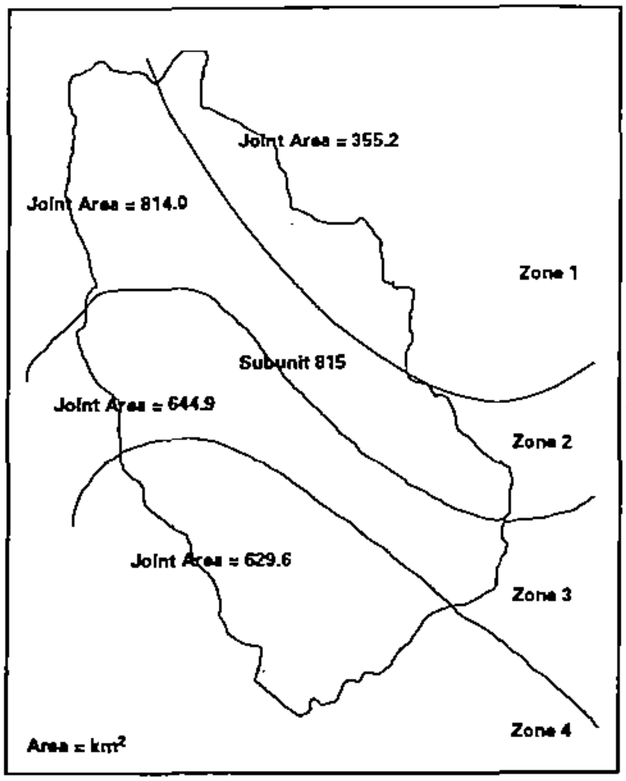

Figure F.2. Subunit 815 from Louisiana case study overlaid with precipitation zone boundaries.

Table F.2. Prorating precipitation data to Subunit 815 for the Louisiana case study.

Zone	Precipitation by zone [1] INTENSITY_r	Joint area [2] $\text{AREA}_{(r,s)}$	Subunit area [2] AREA_s	Partial sum [3]
1	51	355.2	2441.5	7.4
2	53	814.0	2441.5	17.7
3	55	644.9	2441.5	14.5
4	57	6296	2441.5	14.7
Subunit 815 Total				54.3

[1] Mean annual precipitation in inches, derived by averaging the value of adjacent precipitation contours; precipitation contours digitized from Lee (1985b).

[2] Area in km² derived by GIS; see Appendix G.

[3] The average annual precipitation within the joint zone-subunit area, equal to: $\text{INTENSITY}_r \times (\text{AREA}_{(r,s)} / \text{AREA}_s)$.

APPENDIX G

Areal Estimation Techniques

In this appendix we briefly discuss three methods for estimating mapped areas. We also discuss quality assurance and quality control measures to be employed when using the methods.

Dot Grid Method

Figure G.1 shows a map of Subunit 4 from the Illinois case study (Chapter 4) overlaid with a dot grid. The proportion of the subunit area in a particular land use was calculated by counting the dots falling into each land-use category and dividing by the total number of dots within the subunit.

land use = dot count/total dots

Equation G.1

To arrive at the area of each land use, this proportion is multiplied by subunit area:

area = land use x subunit area

Equation G.2

The results of estimating area using the dot grid method for Subunit 4 appear in Table G.1.

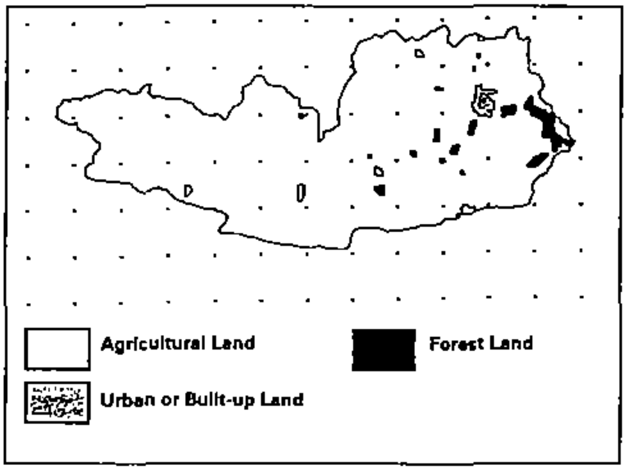

Figure G.1. Subunit 4 from the Illinois case study overlaid with dot grid. Polygons represent different land-use classes.

Table G.1. Area estimates using dot grid method. "Land Use" represents the Level I land use class from Anderson et al. (1976).

Land Use Class	Dot Count	Land Use	Area (km²)
Agricultural Land	28	0.903	442.1
Urban or Built-up Land	1	0.032	15.8
Forest Land	2	0.065	31.6
Totals	31	1.000	489.5

Figure G.2 shows a higher grid density (four times as many dots) imposed on the same map. Area estimation results using this dot grid are given in Table G.2. Although results are more accurate when using a denser grid, the effort in counting the dots also increases (Muehrcke 1978).

Geographic Information System (GIS)

A GIS is a valuable tool in the construction, manipulation, and display of spatial data. The area estimates here were generated using the ARC/INFO® GIS software. Table G.3 shows a partial list of polygon areas by land-use type. The software automatically calculates the AREA in ft^2; SQKM is a user-defined conversion of those values into km^2. Table G.4 contains land-use totals arrived at using the ARC/INFO® GIS package for comparison with Tables G.1 and G.2.

Note that 0.2 km^2 of barren land is included in the GIS estimate; neither of the dot grid estimates contained this category because the grid density was too low for sampling small, rare polygons. If estimating the number or area of such polygons is essential, a higher grid density would need to be used.

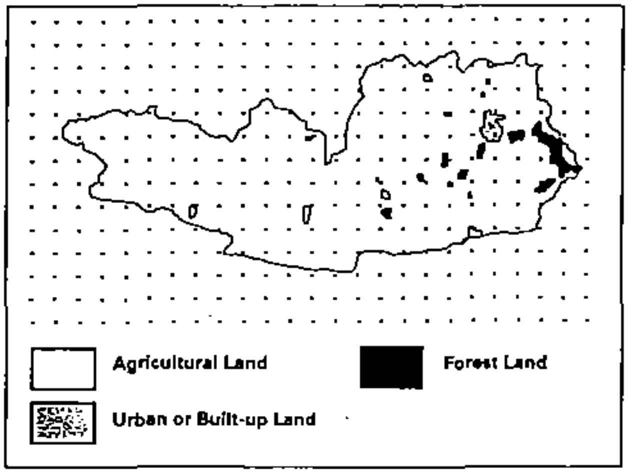

Figure G.2. Subunit 4 from the Illinois case study overlaid with denser dot grid. Polygons represent different land use classes.

Table G.2. Area estimates using denser dot grid. "Land Use" represents the Level I land use class from Anderson et al. (1976).

Land Use Class	Dot Count	Land use	Area (km²)
Agricultural Land	120	0.945	462.5
Urban or Built-up Land	2	0.016	7.7
Forest Land	5	0.039	19.3
Totals	127	1.000	489.5

Planimeter

Under certain conditions, a planimeter can be used to calculate area. A polygon is planimetered by tracing its perimeter with a pen-like tool. If a polygon contains a smaller polygon, the smaller area must be subtracted from the larger "donut" polygon. The overall size of the various polygons within a subunit determines whether this method is practical. Where polygons are mostly large, measurements are fairly quick and accurate. As the average polygon size decreases, however, the effort increases and accuracy decreases. Figure G.3 shows an electronic planimeter; manual versions are also available.

Quality Assurance and Quality Control

It is important to check the data to ensure that the areal measurements meet the requirements of an assessment. Therefore, various checks must be performed depending on which estimation technique is being used.

When using a dot grid, several steps can be taken to reduce error. First, position the dot grid and tally the dots at least twice — three times if the dot counts differ substantially between the first two counts. Second, use a grease pencil or water-based marker and a tally meter to eliminate confusion when counting large numbers of dots. Third, check to ensure that the proportions of all land-use types add to one. Finally, have another individual repeat the process on 10% of the areas measured.

When using a GIS package, various data sets are entered, manipulated, and displayed. Each step can lead to errors. Maintain copies of the raw data sets to verify how these data are displayed in the end product. If digitizing is required, certain operating procedures should be followed. When beginning the digitizing session, establish the acceptable amount of error allowed for the project, then make sure it is not exceeded by comparing hard copies of the digitized maps against the originals for accuracy. This is done by overlaying the original and the digitized maps on a light table. If boundaries do not match, the polygon data in the GIS should be edited.

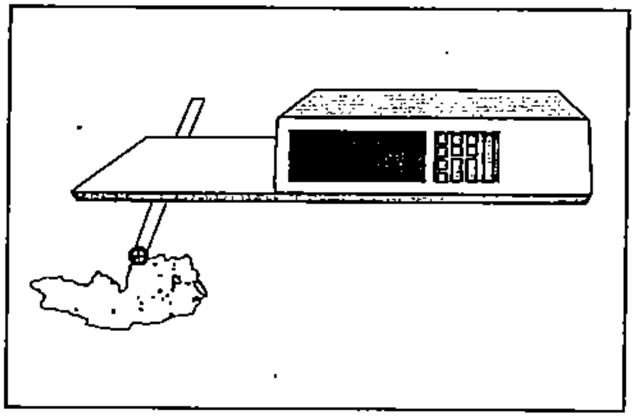

Figure G.3. Electronic planimeter.

Table G.3. Partial listing of land-use areas for polygons within Subunit 4 of the Illinois case study (see Figure G.1). AREA is in ft² and is automatically generated by ARC/INFO®; SQKM is a user-defined variable that converts area to km². LEVEL2 is the code for the Anderson et al. (1976) Level II land use class.

LEVEL2	AREA	SQKM
12	1035258.0	0.10
11	2153979.0	0.20
41	60510968.0	5.62
17	1429273.0	0.13
21	5074137000.0	471.40
13	873996.8	0.08
41	11819784.0	1.10
11	29863508.0	2.77
.	.	.
.	.	.
.	.	.

Table G.4. Area estimates using GIS package. "Land Use" represents the Level I land-use class from Anderson et al. (1976).

Land Use Class	Area (km²)
Agricultural Land	471.4
Urban or Built-up Land	7.0
Forest Land	10.9
Barren Land	0.2
Totals	489.5

If a planimeter is used, make sure it has been recently calibrated. Use the scale bar on a quality map to determine whether the area registering on the machine corresponds to a geographic area as represented on the map. Be sure to enter the proper scaling factor on the planimeter. As with the dot count, the average of two or more readings should be used. Again, another person should check 10% of the areas measured. Further information on errors in mapping and geographic analysis appears in Burrough (1986).

APPENDIX H

Sample Calculations

Stream Discharge

Hydrology can be influenced by factors outside of subunit boundaries if the subunit is not a closed drainage unit. Upstream characteristics such as slope, precipitation, and land use are examples of potential influences on hydrology within a particular subunit. Figure H.1 shows the Pearl River Basin overlaid with subunit boundaries; the basin contains two main channels. Subunits 1 and 5 are closed drainage areas, meaning that precipitation provides the only input of water. However, Subunits 2, 3, and 4 are not closed because they receive hydrologic input from upstream subunits in addition to rainwater (Figure H.1). Streamflow in these subunits is cumulative, i.e., it is dependent on upstream subunits. We illustrate how this can affect calculations by calculating the peak discharge for a 50-year flood (Q_{50}) for Subunit 4. Q_{50} can be estimated using the following regression equation developed by the USGS (Landers and Wilson 1991):

$$Q_{50} = 648 \times \text{AREA}^{0.85} \times \text{SLOPE}^{0.11} \times \text{LENGTH}^{0.31}$$

Equation H.1

where Q_{50} is the peak discharge for a 50-year flood in ft^3/s, AREA is the watershed area (mi^2), SLOPE is the mainstem channel slope (ft/mi), and LENGTH is the mainstem channel length (mi). Note that English units must be used with the independent variables, as the regression was developed to calculate Q_{50} in ft^3/s.

Because AREA represents total watershed area, not subunit area, AREA for Subunit 4 includes the entire basin and is equal to the sum of the five subunit areas:

$$\begin{aligned} \text{AREA} &= 2478.88\ \text{mi}^2 + 1972.49\ \text{mi}^2 + 1194.29\text{mi} + 1785.10\ \text{mi}^2 + 1294.81\ \text{mi}^2 \\ &= 8725.57\ \text{mi}^2 \end{aligned}$$

Equation H.2

The mainstem channel length is the length of the longest channel and is therefore equal to the combined channel lengths within Subunits 1 through 4:

$$\begin{aligned} \text{LENGTH} &= 81.8\ \text{mi} + 98.5\ \text{mi} + 74.2\ \text{mi} + 145.8\ \text{mi} \\ &= 400.3\ \text{mi} \end{aligned}$$

Equation H.3

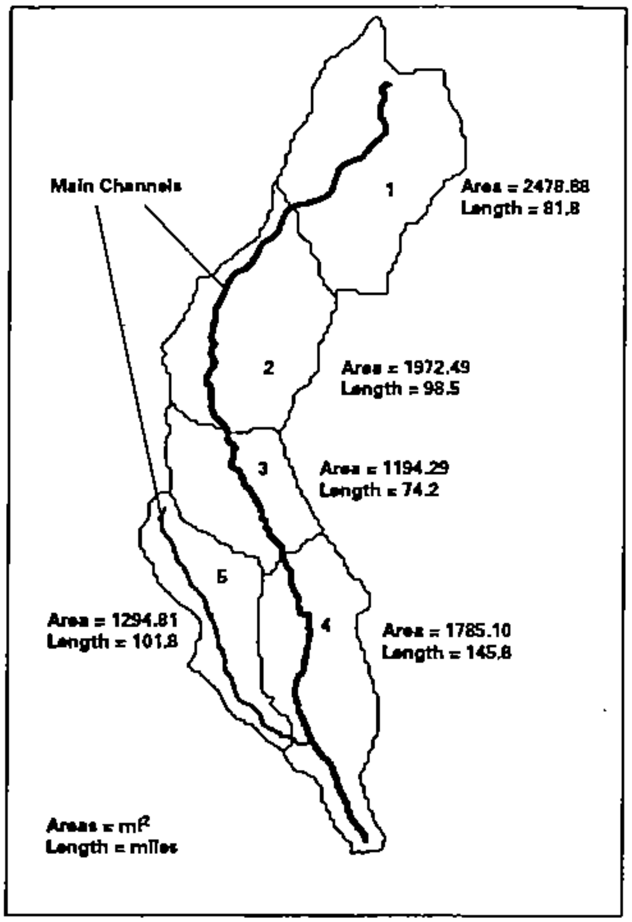

Figure H.1. The Pearl River Basin with subunit boundaries. Areas and lengths are for each individual subunit and are not cumulative.

Note that the channel length of Subunit 5 is not included because it is not a part of the main stem. The mainstem channel slope is similarly dependent on Subunits 1 through 4. For Equation H.1, slope must be calculated from points 10% and 85% up the mainstem channel (Landers and Wilson 1991), which in this example is at points 40.0 miles (0.10 x 400.3 mi) and 340.2 miles (0.85 x 400.3 mi) up the channel length. The elevations at these points are 35 and 340 feet, respectively, based on a 1:250,000 USGS topographic map. The length between these points is 75% of the channel length (85% - 10%), and SLOPE for Subunit 4 is equal to:

$$\begin{aligned} \text{SLOPE} &= \frac{(\text{ELEVATION}_{85\%} - \text{ELEVATION}_{10\%})}{(\text{LENGTH} \times 0.75)} \\ &= (340\ \text{ft} - 35\ \text{ft})/300.2\ \text{mi} = 1.02\ \text{ft/mi} \end{aligned}$$

Equation H.4

Substituting the values of AREA, LENGTH, and SLOPE into Equation H.1 gives the following peak discharge for Subunit 4 (values rounded):

$$Q_{50} = 648 \times 8725.57^{0.85} \times 1.02^{0.11} \times 400.3^{-0.31}$$
$$= 226{,}602 \text{ ft}^3\text{/sec}$$

Equation H.5

This value can be converted to m^3/s using a conversion factor of 0.02832 m^3/ft^3, giving a value of 6417 m^3/s. A similar approach was used to calculate $7Q_{10}$ values (7-day mean discharge for a 10-year recurrence interval for the State of Louisiana (Lee 1985a).

Future Risk

The calculation of future risk for the State of Washington (Equation 4.10 and Table 4.3) is based on recent urban and agricultural growth. Because population and agricultural census data are reported by county, weighting factors must be calculated first (Appendix F) so county data can be prorated to the subunits needed for the assessment. Weighting factors (WEIGHT) are calculated by dividing the joint county-subunit area (J_AREA) by total county area (AREA):

$$\text{WEIGHT} = \text{J\_AREA/AREA}$$

Equation H.6

Table H.1 contains weighting factors calculated for the five counties that overlap Washington Subunit 26. Using these data, joint population or agriculture area (e.g., the estimated population for the portion of the county within the subunit) is calculated using the following general equation:

$$\text{J\_VALUE} = \text{VALUE} \times \text{WEIGHT}$$

Equation H.7

where J_VALUE is the joint value, VALUE is the county value, and WEIGHT is the weighting factor from Equation H.6. Joint values are calculated for 1970 population, 1980 population, 1974 agricultural land, and 1982 agricultural land in Table H.2.

The weighted percent annual change in population and agriculture is then calculated for each joint area using the following two equations:

$$\text{WTPOPCHG} = \frac{\left[\dfrac{\text{J\_POP80} - \text{J\_POP70}}{(\text{J\_POP70})}\right]}{10} \times \frac{8}{95}$$

Equation H.8

$$\text{WTARGCHG} = \frac{\left[\dfrac{\text{J\_AGR82} - \text{J\_AGR74}}{(\text{J\_AGR74})}\right]}{8} \times \frac{87}{95}$$

Equation H.9

where WTPOPCHG and WTAGRCHG are the weighted percent annual change in population and agriculture, respectively, and the other variables are as previously defined. The terms are divided by the number of years between the census dates (10 and 8 for population and agriculture, respectively) to put the change on an annual basis. Because 8 and 87% of national wetland loss has been due to urban expansion and agricultural conversion (Tiner 1984), these values are used as weights in Equations H.8 and H.9 to account for the relative importance of the two impacts (8/95 and 87/95 are actually

Table H.1. Calculation of weighting factors for counties overlapping Washington Subunit 26.

County	J_AREA [1]	AREA [2]	WEIGHT [3]
Cowlitz	1757.11	2964.12	0.5928
Lewis	3816.26	6407.65	0.5956
Pierce	135.98	4299.84	0.0316
Skamania	700.03	4369.82	0.1602
Yakima	18.81	11104.69	0.0017

[1] Joint county-subunit area in km^2

[2] County area in km^2

[3] Weighting factor from Equation H.6.

Table H.2. Conversion of county census data into joint county-subunit values for counties overlapping Washington Subunit 26.

County	WEIGHT [1]	POP70 [2]	J_POP70 [3]	POP80 [2]	J_POP80 [3]	AGR74 [2]	J_AGR74 [3]	AGR82 [2]	JAGR82 [3]
Cowlitz	0.5928	68616	40675	79548	47155	153.93	91.25	165.22	97.94
Lewis	0.5956	45467	27079	56025	33367	554.97	330.53	548.71	326.80
Pierce	0.0316	411027	12998	485643	15358	251.33	7.95	279.09	8.83
Skamania	0.1602	5845	936	7919	1269	33.72	5.40	36.19	5.80
Yakima	0.0017	144971	246	172508	292	7155.05	12.12	6942.55	11.76

[1] Weighting factor from Equation H.6.

[2] POP70, POP80, AGR74, and AGR82 are county values for 1970 population, 1980 population, 1974 agricultural land, and 1982 agricultural land, respectively; areas in km^2.

[3] J_POP70, J_POP80, J_AGR74, and J_AGR82 are joint county-subunit values for 1970 population, 1980 population, 1974 agricultural land, and 1982 agricultural land, respectively; areas in km^2.

used so that the factors sum to one; the remaining 5% of national loss is ignored). Table H.3 contains data for WTPOPCHG and WTAGRCHG by joint area and gives totals for Subunit 26 (if either of the two subunit sums were less than zero, the value would have been set to zero since a loss of population or agricultural area would not necessarily translate into a gain in wetlands). Adding the subunit totals for WTPOPCHG and WTAGRCHG gives the actual risk factor for Subunit 26:

$$\text{RISK} = (9.41 + 24.73) \times 10^{-3} = 34.14 \times 10^{-3}$$

Equation H.10

Table H.3. Weighted percent annual population change and agricultural change for joint county-subunit areas of counties overlapping Washington Subunit 26 (values rounded).

County	J_POP70 [1]	J_POP80 [1]	WTPOPCHG [2] ($\times 10^{-3}$)	J_AGR74 [3]	J_AGR82 [3]	WTAGRCHG [4] ($\times 10^{-3}$)
Cowlitz	40675	47155	1.34	91.25	97.94	8.40
Lewis	27079	33367	1.96	330.53	326.80	-1.29
Pierce	12998	15358	1.53	7.95	8.83	12.64
Skamania	936	1269	2.99	5.40	5.80	8.38
Yakima	246	292	1.60	12.12	11.76	-3.40
Total			9.41			24.73

[1] J_POP70 and J_POP80 are joint county-subunit populations for 1970 and 1980, respectively.

[2] Weighted percent annual change in population (Equation H.8)

[3] J_AGR74 and J_AGR82 are joint county-subunit agricultural land areas (in km^2) for 1974 and 1982, respectively.

[4] Weighted percent annual change in agriculture (Equation H.9)

APPENDIX I

Information Form

To the Reader,

We hope you have found *A Synoptic Approach to Cumulative Impact Assessment* valuable. In the event that we update this report, we'd appreciate having your opinion about how it might be improved.

We'd like to get an idea of who our audience is, so please fill in the information below and mail it back to us. Feel free to make any other comments as well.

Many thanks for helping.

Wetlands Research Program
U.S. Environmental Protection Agency
200 SW 35TH Street
Corvallis, OR 97333

Name: ____________________

Affiliation: ____________________

Address: ____________________

____

____

____

Phone: ____________________

Fax: ____________________

Educational Background: ____________________

____

Job Position: ____________________

Is your primary responsibility policy, regulatory, technical, or other? ____________________

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____

____

Would you like to receive revisions of this document if it is updated, or related reports as they become available?

☐ YES ☐ NO

Would you like to receive the WRP update?

☐ YES ☐ NO

What do you like best about *A Synoptic Approach to Cumulative Impact Assessment*?

____

____

____

____

What do you like least about *A Synoptic Approach to Cumulative Impact Assessment?*

____

____

____

____

What isn't in *A Synoptic Approach to Cumulative Impact Assessment* that should be?

____

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Primary reason you are interested in this approach:

____

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____

____

Do you plan on conducting a cumulative impact assessment?

☐ YES ☐ NO

If so, do you plan on using the synoptic approach?

☐ YES ☐ NO

If you answered no, could you please tell us why you felt the synoptic approach was inappropriate?

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