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Expanding Wetland Assessment Procedures: Linking Indices of Wetland Function with Services and Values

Dennis M. King, Lisa A. Wainger, Candy C. Bartoldus, and
James S. Wakeley

September 2000

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Expanding Wetland Assessment Procedures: Linking Indices of Wetland Function with Services and Values

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Assessing Wetland Services and Values

Expanding Wetland Assessment Procedures: Linking Indices of Wetland Function with Services and Values (ERDC/EL TR-00-17)

ISSUE: The evaluation of Section 404 permit applications under the Regulatory Program of the U.S. Army Corps of Engineers often requires consideration of wetland functions and the value of those functions to people. The Hydrogeomorphic (HGM) Approach provides a method for assessing the functional capacity of a target wetland, but no simple, objective method exists for incorporating information on economic values into permit decisions.

RESEARCH: Wetland functions (e.g., surface water storage, nutrient and contaminant removal, wildlife habitat support) provide useful services to society (e.g., flood damage avoidance, water quality improvement, aesthetic and recreational services). These services, in turn, have value that can be expressed in either monetary or relative terms. This research is an attempt to develop indices of wetland services and values that can be used to supplement an assessment of wetland functions.

SUMMARY: This report describes a general approach, using readily available public and private

databases, to expand indices of wetland function to reflect human services and values. It is intended as a first step in the development of a practical tool for assessing wetland trades based on accepted economic principles.

AVAILABILITY OF REPORT: The report is available at the following Web site: <http://www.wes.army.mil/el/wetlands/wlpubs.html>. The report is also available on Interlibrary Loan Service from the U.S. Army Engineer Research and Development Center (ERDC) Research Library, telephone (601) 634-2355, or the following Web site: <http://libweb.wes.army.mil/index.htm>. Individuals should arrange for Interlibrary Loan Service either through the library of their business concerns or through the interlibrary loan services of their local libraries. To purchase a copy call the National Technical Information Service (NTIS) at 1-800-553-6847 or (703) 605-6000, or visit the following Web site: <http://www.ntis.gov/>. For help in identifying a title for sale call 1-800-553-6847. NTIS report numbers may also be requested from the ERDC librarians.

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Characterization and Restoration of Wetlands Research Program (CRWRP). The work was performed under Work Unit 32635, “Applications of the Hydrogeomorphic (HGM) Approach,” for which Dr. James S. Wakeley, CEERD-ER-W, was Technical Manager. Mr. Dave Mathis, CERD-C, was the CRWRP Coordinator at the Directorate of Research and Development, HQUSACE; Ms. Colleen Charles, CECW-OR, served as the CRWRP Technical Monitor’s Representative; and Dr. Russell F. Theriot, Environmental Laboratory (EL), Vicksburg, MS, U.S. Army Engineer Research and Development Center (ERDC), was the CRWRP Program Manager. This work was performed under the general supervision of Dr. Morris Mauney, Chief, Wetlands Branch, Ecological Research Division, EL; Dr. Conrad Kirby, Chief, Ecological Research Division; and Dr. John Keeley, Acting Director, EL.

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Summary

This report describes a method to expand indices of wetland function to reflect the services and values of wetlands. Services are defined as the beneficial outcomes of wetland functions, and the value of services depends on the ability of wetlands to satisfy the needs and preferences of people. This report outlines the Wetland Value Index (WVI) System and describes the information required to apply it. A second report will illustrate the WVI System by developing prototype indices of wetland services and values and using them to compare gains and losses resulting from actual wetland mitigation trades. Both reports describe the preliminary results of work in progress. More research and field testing will be needed to make the WVI System a credible and practical tool for assessing wetland trade-offs.

This report illustrates the proposed method by expanding indices of wetland function generated using the Hydrogeomorphic (HGM) Approach. The HGM Approach involves classifying wetlands into functionally similar types within a region (i.e., regional subclasses) and assessing the level of function of a target wetland in relation to other wetlands in the same subclass. HGM assessment models use readily measured characteristics of the wetland and its surrounding landscape to estimate functional capacity indices (FCIs) for each potential function (e.g., floodwater retention, nutrient transformation, fishery support habitat). By design, the HGM Approach takes no account of whether wetland functions are scarce or replaceable or have other characteristics that may make them more or less important or valuable to people.

Because HGM assessment models are developed and calibrated for a particular wetland subclass, FCIs estimated for wetlands in different subclasses cannot be compared directly with one another. Nor does the HGM Approach provide a mechanism for ranking or prioritizing the functions provided by wetlands within a subclass. Both of these characteristics limit the usefulness of the HGM Approach for decision makers who must prioritize wetlands or evaluate wetland trades. On the other hand, certain components of the HGM Approach can be used as a basis for developing practical economic indices of wetland values. These indices, in turn, can be used to compare wetlands as economic assets and can provide credible economic criteria for prioritizing wetlands, evaluating wetland mitigation trades, and establishing debit/credit criteria for wetland mitigation banking.

Indices of wetland functions such as FCIs are used as a starting place for deriving value indices. The expected levels of service that result from a particular level of function are affected by the landscape and demographic context of the wetland (e.g., upslope land use, downstream water use, proximity

to people). Other landscape factors affect the value of these services (e.g., scarcity, access) and determine the risk of service flow disruptions (e.g., the exposure of a wetland to floods, droughts, invasive species). The WVI System described in this report addresses these landscape factors, which can differ significantly between sites with the same level of wetland functional capacity and are not usually reflected in FCIs.

The proposed WVI System is based on three generally accepted economic concepts: the production function, which relates outputs (wetland services) to inputs (wetland site and landscape characteristics); comparative advantage, which relates the “productivity” of different wetlands with respect to each service to the availability of productive inputs at and near wetland sites; and scarcity, the difference between the supply and demand of wetland services, which is affected by where and when they are available, who has access to them, and whether substitutes are available.

To reflect individual and community preferences, the services that result from various wetland functions are weighted on the basis of surveyed preferences. This allows the development of a single overall index of relative wetland value without the need for absolute dollar-based measures of wetland value. The WVI System can incorporate dollar-based measures of service values when they are available and credible, but they are not required to compare wetland values.

1 Introduction

Background

The demand for tools to assess and compare the magnitude of the functions, services, and values provided by wetlands has increased recently as a result of growing investments in wetland restoration and the increased use of wetland mitigation and mitigation trading systems. Requirements for wetland comparisons based on functions and values are formalized in laws and regulations (e.g., see Clean Water Act 33 - U.S.C. 1344, especially Section 404). However, these terms are not always defined or used in the same way by wetland scientists and regulators, and it is not always clear how they should be measured or how they relate to one another. This report uses Smith et al. (1995), who define a wetland *function* as a “normal or characteristic biophysical activity that takes place in a wetland ecosystem.” This report defines a wetland *service* as a beneficial outcome of such a function, and the *value* of a wetland service as a measure of the relative importance that individuals or groups place on a wetland service.

Many wetland assessment procedures have been developed to meet the specific needs of state and Federal regulatory programs (Bartoldus 1999). The primary purpose of most of these procedures has been to measure and assess functions. A cursory review of these procedures may leave the impression that they also address the “social significance” of wetland functions or provide indices related to services or values. However, a more careful examination reveals that the components of wetland assessment procedures that address these outcomes are either undeveloped or involve answering one or two general questions. None of the procedures address wetland values using analytical approaches that are consistent with accepted economic concepts or practices, and only a few of the approaches that focus beyond wetland functions have ever been field tested. Most have never been applied even in the regulatory setting for which they were developed.¹

Reasons for the inadequate treatment of services and values in wetland assessment procedures include the following:

- a. Development of many of the procedures to serve permit review processes that require technical analyses of functions but assume that issues related

¹ For an overview of how economic issues have been addressed in ecosystem assessment procedures, see King (1997).

to services and values can be addressed during the public interest review process.

- b.* The historical lack of readily accessible geographic and demographic data to address the effects of landscape and socioeconomic context on wetland services and values.
- c.* Development of most assessment methods by wetland scientists with limited background or interest in protocols for assessing services and values.
- d.* The desire by many wetland scientists to refine an approach for assessing wetland functions before considering other wetland characteristics (e.g., wetland values and services).
- e.* The preference of wetland regulators for blending socioeconomic and political criteria in ways that give them more negotiating flexibility.

In any case, the methods used to document differences in wetland values have progressed only to the level of best professional judgment and a few simplistic “models,” and even these methods have not been applied very often.

However, as investments in wetland restoration and interest in wetland mitigation increase, wetland regulators are being asked more often to prioritize wetlands or their functions, to rank wetlands in terms of their “importance” or “value,” and to assure the public that wetland trading systems protect what is important about wetlands. They are also being asked to justify their decisions using socioeconomic analysis as well as functional assessments. The Hydrogeomorphic (HGM) Approach provides some of the information wetland regulators and managers need for these purposes and is an improvement over earlier assessment methods in terms of its ability to characterize wetland functional capacity. An overview of the HGM Approach and the need for supplemental indices of services and values is presented later in this chapter. However, like its predecessors, it is not an approach that can be used to assess or justify decisions that require comparing wetlands as scarce assets or involve choosing between wetlands on the basis of the services and values they provide.

However, components of the HGM Approach do provide a useful foundation for developing economic indices of wetland values. The need to expand the HGM Approach in this direction is based on three presumptions. First, planners and regulators will make wetland decisions based on socioeconomic considerations as well as biophysical conditions whether they have credible information about socioeconomic trade-offs or not. Second, value-based wetland indices provide them with a more credible basis than pure functional indices for defending wetland decisions. Third, monetary measures of wetland benefits are not available, may not become available, and are not necessary to assess many important wetland trade-offs or to defend most wetland management and regulatory decisions.

Overview of Previous Methods for Assessing Wetland Functions and Values

Until the 1960's the typical way to assign an economic value to a wetland area was to use its market value as a development site. This was followed by occasional attempts to measure the value of recreational services wetlands supported, especially those associated with hunting and fishing. Wetland assessment procedures were developed starting in the 1970's in an effort to demonstrate that wetlands provide benefits beyond narrowly defined commercial and recreational outcomes (see reviews in Lonard et al. 1981 and U.S. Environmental Protection Agency 1984). The Habitat Evaluation Procedure or HEP (developed by the U.S. Fish and Wildlife Service in 1980) is the most noteworthy of these procedures because it was one of the first and most comprehensive. It is still a widely used method for establishing nonmonetary currencies of habitat value (U.S. Fish and Wildlife Service 1980). The habitat suitability index (HSI) and habitat units (HUs) developed using HEP provide a means to document professional judgments about the adequacy or equivalency of habitats for various fish and wildlife species. They can be used to evaluate some types of habitat trades and mitigation proposals.

However, HEP focuses primarily on site characteristics that satisfy the needs and preferences of particular fish and wildlife species (e.g., breeding and feeding conditions), not on site and landscape characteristics that determine how improving habitats for those fish and wildlife is likely to satisfy the needs and preferences of people. A significant amount of conceptual work went into the development of a component of HEP called the Human Use and Economic Evaluation or HUEE (U. S. Fish and Wildlife Service 1985), which did deal with habitat values. However, indices related to wetland values were never fully developed or field tested and, unlike the rest of the HEP method, the HUEE module has not been widely used.¹

Numerous assessment procedures specific to wetlands have been developed since HEP.² Some of them attempt to address wetland values by measuring functions and then identifying significant risks or exceptional values associated with each function using "red flags" or "noteworthiness" rankings (e.g., Habitat Assessment Technique (Cable, Brack, and Holmes 1989), Evaluation for Planned Wetlands (EPW) (Bartoldus, Garbisch, and Kraus 1994), New England Freshwater Wetlands Invertebrate Biomonitoring Protocol (NEFWIBP) (Hicks 1997)). These simple add-on approaches are based on the presence or absence of notable features, such as endangered species or designated historic or archeological areas. They do not attempt to make links between functions, services, and values. A few procedures include simplified models or questions that are used to assign scores to wetlands based on social categories such as recreation, aesthetics, agricultural potential, and educational values (e.g., New Hampshire Method

¹ The concepts described in the HUEE module of HEP were very useful in developing the indicator system proposed here. However, the indicators proposed there were not always consistent with modern concepts of valuation, and after nearly 20 years of research on related topics are now out of date.

² These methods are reviewed in World Wildlife Fund (1992) and Bartoldus (1999).

(Ammann and Stone 1991), the Connecticut Method (Ammann, Frazen, and Johnson 1986), Hollands-Magee Method (Hollands and Magee 1985), Minnesota Routine Assessment Method for Evaluating Wetland Functions (MNRAM) (Minnesota Board of Water and Soil Resources 1998), Oregon Freshwater Wetland Assessment Methodology (OFWAM) (Roth et al. 1996)). Some of them also weave concepts of function and value into a measure called “functional value” (e.g., Ammann, Frazen, and Johnson 1986; Ammann and Stone 1991). However, the criteria used in those methods to assign relative values to different wetlands or to distinguish between levels of function and associated values are not clearly defined.

The Wetland Evaluation Technique (WET) (Adamus et al. 1987) is exceptional in that it provides a basis for estimating separate ratings of social significance for most functions. However, in the WET approach, site evaluators are asked to “value” a function as low, medium, or high based on the *likelihood* of its being “socially significant,” not on the *level* of social significance. Because these ratings relied on only a few easily recognized factors, the social significance component of the WET approach was used fairly often and yielded predictable and consistent results when applied by different wetland assessors. However, the advantage of having an approach that was easy to use and consistent came at a cost. WET indices did not address many important differences between wetlands that influence the links between wetland functions, services, and values and yielded empirical rankings that were difficult to interpret or defend. Because of these technical limitations, the valuation component of the WET method is rarely used today.

Overall, wetland assessment procedures that have attempted to link individual functions with services and values did so in a very limited way, were not fully developed or field tested, and have not been widely used. They were also developed before it was possible for them to take advantage of advances in valuation theory and modern data storage and retrieval systems. The current trend in wetland assessment has been to improve procedures for evaluating functions (e.g., HGM Approach (Smith et al. 1995), Index of Biological Integrity (IBI) (Karr 1981, 1998), WEThings (Whitlock, Jarmon, and Larson 1994; Whitlock et al. 1994) and to leave the assessment of all related socioeconomic trade-offs to be worked out through the political process. This limits the usefulness of wetland assessment procedures and makes it difficult for wetland managers and regulators to defend using the results. It also leaves them with very little technical justification for protecting “valuable” wetlands or preventing mitigation trades that result in the replacement of “valuable” wetlands with less “valuable” wetlands.

Overview of the HGM Approach and the Need for Supplemental Indices of Wetland Services and Values

The HGM Approach is a set of procedures for assessing the functions of wetlands (Brinson 1995; Smith et al. 1995). It was developed mainly to meet the needs of Federal agencies--the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and Natural Resources Conservation Service--that

have wetland regulatory responsibilities under the Clean Water Act and Food Security Act. The goal of the HGM Approach is to integrate the best available scientific information, along with the experience of regional wetland experts, into an objective and repeatable method for assessing the functions of wetlands. By design, the HGM Approach makes no judgments about the value of wetlands or wetland functions to people.

The HGM Approach differs from previous assessment methods in at least two important ways. First, it starts with a system of wetland classification that is designed to group wetlands across the Nation into functionally similar types, thereby allowing only relevant functions to be considered in an assessment and reducing the variability that must be addressed in the development of assessment models. The HGM Classification (Brinson 1993 and subsequent modifications) groups the Nation's wetlands into seven major "classes" based on geomorphic settings, sources of water, and hydrodynamics: depression, coastal fringe, lacustrine (lake) fringe, slope, mineral flat, organic flat, and riverine. Guidebooks for assessing wetland functions under the HGM Approach are developed for a particular wetland class in a specified geographic area (e.g., a watershed, a state, an ecoregion) where the underlying climatic and physiographic conditions affecting wetland functions are relatively uniform. This regional subset of wetlands within a particular wetland class is called a *regional subclass*. For example, two recently completed regional guidebooks focus on low-gradient riverine wetlands in western Kentucky (Ainslie et al. 1999) and wet pine flats of the Atlantic and Gulf coastal plains (Rheinhardt, Rheinhardt, and Brinson, in preparation).

Second, under the HGM Approach, the functions of a target wetland are assessed in relation to reference wetlands of the same regional subclass (Smith et al. 1995; Brinson and Rheinhardt 1996). During the development of assessment models for a regional wetland subclass, the assessment team identifies a number of actual wetland sites that are relatively unaffected by human alteration and continue to function at high levels across the suite of functions identified for that subclass. These fully functional examples of the regional subclass are called *reference standard wetlands*. Assessment models for each function are then calibrated such that levels of function equivalent to those exhibited by reference standard wetlands are assigned a Functional Capacity Index (FCI) of 1.0 and lesser levels of function are given FCI scores between 0 and 1.0.

HGM regional guidebooks provide assessment models for a number of functions (generally five to eight, depending upon the subclass) that can be loosely categorized as hydrologic, biogeochemical, or biological. Hydrologic functions might include Temporary Storage of Surface Water or Shoreline Stabilization. Biogeochemical functions might include Retention of Particulates or Retention and Transformation of Nutrients and Contaminants. Biological functions might include Maintenance of Native Plant Diversity or Provision of Wildlife Habitat. Each function is assessed independently based on field measurements of model variables made within the wetland and the surrounding landscape. Model variables are combined in an aggregation equation to calculate the FCI for that function (Smith and Wakeley 1999).

Although designed to facilitate the evaluation of wetland impacts due to proposed projects and the development of appropriate mitigation, the HGM Approach has some significant limitations in the Clean Water Act Section 404 permitting context. First, because HGM models are developed and calibrated for a particular regional wetland subclass, it is not appropriate to compare assessment results between different subclasses. One reason is that the list of functions or their definitions may be different between subclasses. Another reason is that reference standards used in the scaling of assessment results are different between subclasses.

Second, the HGM Approach does not put weights or values on different functions (Brinson 1995; Smith et al. 1995) and, therefore, provides no additional help to regulators who must consider trade-offs among functions. For example, a wetland proposed for development might score high for Function A and low for Function B. However, a mitigation plan might involve the restoration of a wetland that would score low for Function A and high for Function B. One option is to require full compensation for each function. This would mean that the overall compensation ratio (i.e., number of acres of mitigation wetland required per acre of impacted wetland) would equal the largest ratio calculated for any individual function and would require no value judgments. Another option would be to allow trade-offs such that the gain in one function (e.g., Surface Water Storage) might compensate for the loss in another (e.g., Provision of Wildlife Habitat). Except in rare cases where it is reasonable to assume that all functions are equally valuable, this option requires an assessment of the relative value of different functions.

The expanding use of off-site mitigation and mitigation banks has the potential to make trade-off decisions even more complicated. The challenge of dealing with trade-offs that involve different wetland types, different wetland functions, and different levels of function is compounded when impact sites and mitigation sites are geographically separated, perhaps even in different watersheds. Different landscape contexts may make one wetland more valuable than another regardless of their levels of function.

One way to improve the objectivity and consistency of wetland trades when different functional levels or wetland types are involved is to supplement HGM assessment results with indices of wetland services, benefits, and risks. Indices of the economic value of wetland services could be used as the common denominator to facilitate trade-off decisions where estimates of function alone are not sufficient.

Functional Indices as a Foundation for Economic Indices of Wetland Values

The HGM Approach evaluates wetlands within a regional wetland subclass based on their capacity to provide functions. This is a logical starting point in the wetland valuation process. The goal of the Wetland Value Index (WVI) System described in this report is to expand on wetland functional capacity assessments to arrive at relative (nondollar) indices of wetland values that can be estimated by

field office staff with generally available data. The WVI System is intended to provide an economic basis for comparing and prioritizing wetlands, for evaluating wetland mitigation trades, and for establishing debit/credit criteria for wetland mitigation banking. Because the WVI System does not result in absolute (monetary) measures of value, it is less useful for conducting conventional cost-benefit analyses or for justifying that the economic benefits of wetland protection or restoration exceed the economic costs. On the other hand, the indices developed here may make monetary estimates of “average” wetland values more useful by providing a basis for scaling them up or down to account for differences between wetlands that limit or enhance their capacity to provide value. They also allow the focus of wetland valuation to address a broad range of variables that constitute “leading indicators” of wetland value.

The indices reflect differences in the mix and level of services provided by different types of wetlands and by similar wetlands in different landscape settings. They also reflect differences in the risk of service flow disruptions from wetlands at different sites. Most watersheds include a variety of wetlands and landscape features, so together these differences can demonstrate significant variation in the relative value of different types of wetlands and of similar types of wetlands in different locations. The abundance or scarcity of wetland services provided at different locations (e.g., aesthetics, educational or recreational opportunities) may also be different. Taking regional supply and demand conditions into account allows an objective assessment of relative wetland values without resorting to controversial “nonmarket valuation” studies. Where the results of monetary wetland valuation studies are available and do more than provide average or typical values for all wetlands, they can and should be used in a value index system. However, they are not absolutely necessary for making value-based comparisons between wetlands and are often ill-suited for this purpose.¹

Functions versus Services

The overall economic value of a wetland is derived from the values associated with the wetland services it is expected to provide over time. Wetland services can include any outcome that contributes to a generally accepted measure of human welfare, including recreational and educational opportunities, aesthetics, spiritual enrichment, and market-based goods and services. At broad geographic scales, the services of wetlands include beneficial outcomes associated with biodiversity support, carbon sequestration, and water filtration. Measures of wetland characteristics, including many of those addressed by the HGM Approach, provide an initial basis for comparing wetlands in terms of their potential to contribute to outcomes that improve human welfare. The services associated with some wetland functions, biodiversity support or carbon sequestration, for example, do not depend on the location of the wetland. Other

¹ Most attempts to assign monetary values to wetlands assign typical or average values to specific services provided by typical or average wetlands. Even when this is done successfully, the results are not very useful when comparing the relative value of different wetlands or similar wetlands in different landscape contexts.

services, those related to aesthetics and educational/recreational opportunities, for example, are highly site-dependent.

Figure 1 provides categories of active (use) values and passive (nonuse) values that have been associated with wetlands.¹ These values result directly and indirectly from the kinds of wetland functions addressed in the HGM Approach. However, FCIs developed through the HGM Approach measure “how far the expected level of function of a particular wetland departs from the level of function of a similar wetland in an unaltered or minimally altered condition” (Brinson 1995). This provides a relative measure of wetland function with respect to the level expected from an optimal or fully functional wetland. However, the measure does not reflect the scarcity or replaceability of the function where it is provided, differences in the services or values it provides, or the risk that it might be lost. By themselves, FCIs provide a very limited basis for distinguishing between wetlands on the basis of any of the outcomes listed in Figure 1. They also provide a limited basis for assessing wetland trade-offs or determining when and where they are important.

For purposes of assessing wetland *value*, it is useful to consider wetlands as “factories” of beneficial services. The capacity of a wetland to provide these services is partially derived from its level of function and partially derived from location-specific characteristics. All wetlands may provide some valued services, but different wetland types and wetlands in different landscape contexts can provide very different mixes of services. These services, when they are provided in different locations, may not be equally scarce, substitutable, or replaceable and may be more or less accessible to people who value them.

There are three reasons for maintaining a clear distinction between wetland *functions* and wetland *services* when assessing wetland *values*. First, people can attach values to services, but usually cannot attach values to the underlying functions or processes on which they depend.² This is true of most economic and environmental assets, not just wetlands. People may be able to assign values to fish or fishing or even to songbirds, but not to the critical natural processes on which they depend. Second, the site and landscape factors that affect the level of services a wetland will provide are different from those that determine levels of wetland function. For reasons that will be discussed, minimum levels of wetland function reflected in certain FCI scores are a necessary but not sufficient condition for a wetland to provide the services listed in Table 1. Third, reaching

¹ Various types and measures of ecosystem values are described in Freeman (1993) and Kopp and Smith (1993). For recent summaries of how dollar-based valuation methods have been applied to wetlands see Barbier, Acreman, and Knowler (1997) and Scodari (1993).

² The “cognitive difficulty” of attaching values to the underlying processes that result in beneficial services usually prevents survey respondents from providing meaningful expressions of the value they place on those processes. This limits the use of contingent valuation for evaluating all complicated assets, not just wetlands. The problem has been discussed in several recent contributions to nonmarket ecosystem valuation literature (e.g., Mitchell and Carson 1989; Arrow et al. 1993; Carson, Flores, and Meade 1996). It is one reason why the value of wetland functions needs to be imputed from the values people assign to the services they generate, as discussed in Chapter 3.

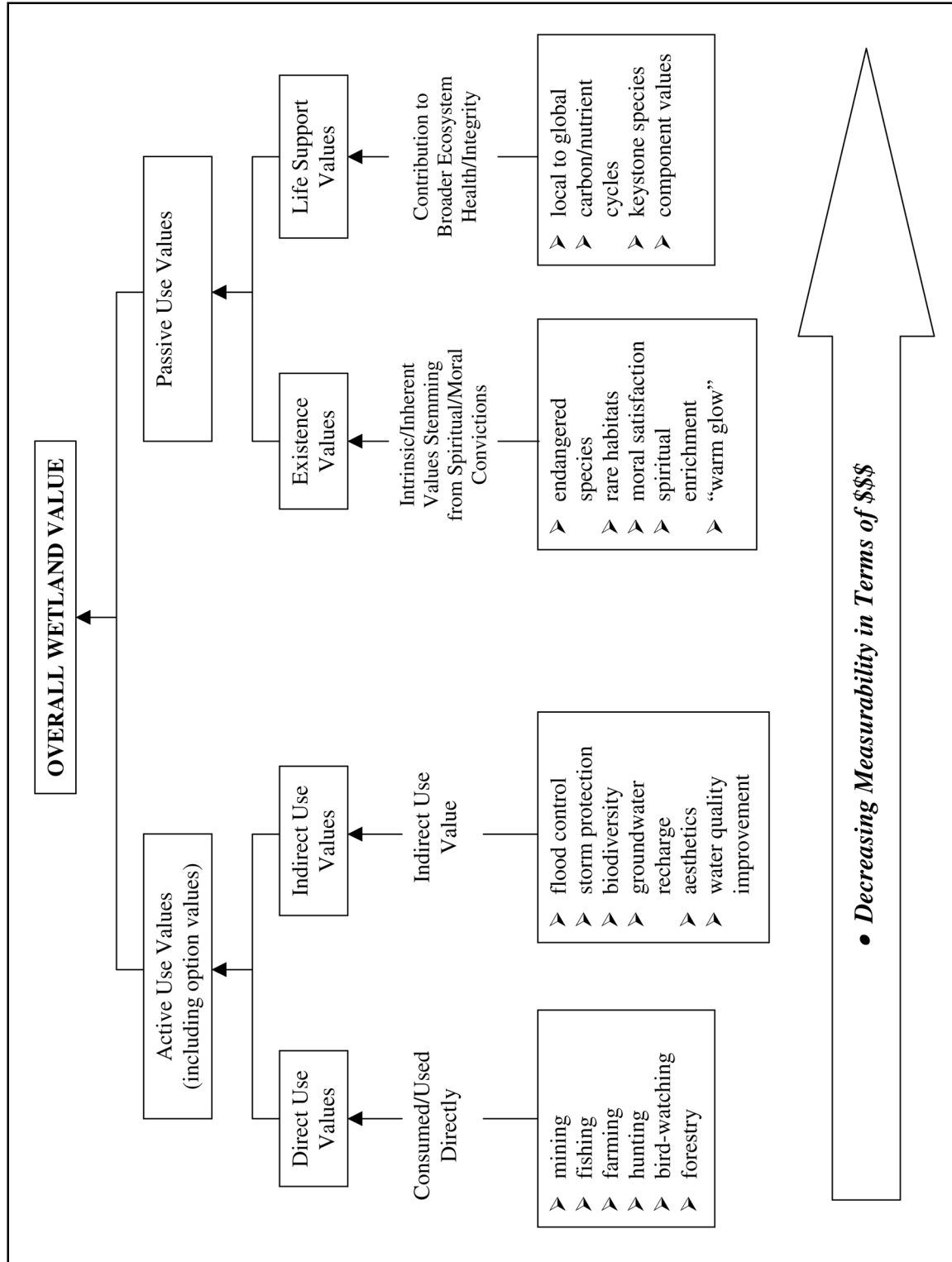


Figure 1. Types of wetland values

Table 1 Examples of Wetland Services: Pathways from Wetland Functions to Wetland Benefits	
Active	Passive
1. Commercial Uses 1.1 Agriculture 1.2 Trapping 1.3 Mining (including genetic) 1.4 Forestry 1.5 Fisheries 2. Recreational Uses 2.1 Fishing 2.2 Swimming 2.3 Hiking 2.4 Nature Viewing 2.5 Hunting 2.6 Birding 2.7 Boating 3. Municipal Uses 3.1 Groundwater Recharge/Discharge 3.2 Drinking Water Purification 3.3 Pollution Prevention 4. Other Active Uses 4.1 Aesthetics - visibility, odor, noise 4.2 Education/Learning Opportunities 4.3 Research/Scientific Opportunities 4.4 Cultural/Spiritual Enrichment	5. Property Damage Avoided 5.1 Flooding 5.2 Storm/Waves/Surge 5.3 Siltation/Sedimentation 5.4 Overnutrification 5.5 Noxious Weed Infestations 6. Human Health Risks/Costs Avoided 6.1 Nutrient Cycling 6.2 Carbon Cycling 6.3 Chemical Cycling 6.4 Oxygen Cycling 7. Ecosystem Health Risks Avoided 7.1 Biodiversity Support 7.2 Endangered Species Protection 7.3 Protection of Ecological Infrastructure 8. Climate Regulation 8.1 Global Climate Effects/Attenuation 8.2 Microclimate Effects/Attenuation 9. General Nonuse (Can be attached to places, species, features, etc.) 9.1 Existence Values 9.2 Option Values 9.3 Bequest Values

the right answers requires asking the right questions. The right questions for assigning a relative value to a wetland involve the importance and scarcity of the services it provides. Depending on the landscape context of a wetland, these may or may not be related to the levels of function or service it provides. Definitions of various terms that are used in this report as “building blocks” of wetland values are provided in Figure 2.

Functions, services, values, risk, and several other terms are used in different ways in the wetland assessment literature and in the economics literature. The following definitions are offered here to minimize confusion over what will be used in the following sections as building blocks of wetland value indices:

- **Features:** on-site characteristics of a wetland that establish its capacity to perform or support various environmental functions (e.g., soil, ground cover, hydrology).
- **Functions:** the biophysical processes that take place within a wetland (e.g., fish and wildlife habitat support, carbon cycling, nutrient trapping). The level of wetland function depends on site and landscape characteristics and can be assessed independently of any human context.
- **Landscape context:** proximity of the wetland to other natural and human-made features in the surrounding landscape. Landscape context influences the opportunity of the wetland to function at capacity, the services that will flow from those functions, the value of those services, and the risk that the services will not persist.
- **Relative preferences:** the rank of wetland services in order of importance. Relative preferences for various wetland services are much easier to determine than differences in dollar measures of service values. Although less common than dollar measures of value, individual and community indices of ranked preferences can be used to aggregate service values and compare wetlands using a single measure.
- **Risk:** the volatility of potential outcomes. In the case of wetland values, the important risk factors are those that affect the possibility of service flow disruptions and the reversibility of service flow disruptions. These are associated with controllable and uncontrollable on-site risk factors (e.g., invasive plants, overuse, restoration failure) and landscape risk factors (e.g., changes in adjacent land uses, water diversions).
- **Services:** the beneficial outcomes that result from wetland functions (e.g., better fishing and hunting, cleaner water, better views, and reduced human health risks and ecological risks). These require some interaction with, or at least some appreciation by, humans. However, they can be measured in physical terms (e.g., increased catch rates, greater carrying capacity, more user days, reduced risk, property damage avoided). The capacity of a wetland to provide services can be estimated without any ethical or subjective judgments about how much the services are worth. The types of potential services depend to some degree on the level of functions but predominantly on other factors (e.g., access, proximity to people).
- **Values:** Defined in strict economic terms, the full range of wetland values includes each person's "willingness-to-pay" in dollars for each wetland service summed across all people and all services. In most cases, tracing and estimating the absolute (dollar) value of a wetland is impossible. However, overall willingness to pay for a wetland service depends on the number of people with access, their income and tastes, the cost of access, the availability of substitutes, and other factors related to local, regional, and national supply and demand.

Figure 2. Building blocks of wetland values

Purpose and Scope of Report

This report describes a method for expanding indices of wetland function derived from biophysical assessment procedures into indices of wetland values. It focuses on expanding the FCIs developed using the HGM Approach¹ and refers to the method as the WVI System. The HGM Approach is used to illustrate the index system because it is widely viewed as being an improvement over previous wetland assessment procedures, and its implementation has been identified as a priority by a number of cooperating Federal agencies (Federal Register 1997).

¹ For a description of the HGM Approach, see Smith et al. (1995), Brinson (1995, 1996), Smith and Wakeley (in preparation), and Wakeley and Smith (in preparation). For illustrations of how to conduct the HGM Approach, see Brinson and Rheinhardt (1996), Rheinhardt, Brinson, and Farley (1997), and Ainslie and Sparks (1999).

2 Economic Background

Measuring Economic Value

The first step in reaching general agreement about economic indices of wetland value is establishing what economic value means. “Value” is defined in Webster’s dictionary as “that quality of a thing according to which it is thought of as being more or less desirable, useful, estimable, or important to people.” The term is often used in the wetland assessment literature to reflect the importance of wetlands to plant and animal populations or in providing certain biophysical functions. However, in conventional economics it is generally accepted that any measure of value should be based on what people want, and that people in general, not just scientists, bureaucrats, or ministers, should be the judge of what they want.¹ Based on this notion of value, the amount of one thing that a person is willing to give up to get more of something else is considered a fair measure of the relative value of the two things to that person. To be generally accepted as an economic index of the value of a wetland, what is being measured must reflect how much people would be willing to pay (give up) for the services of the wetland.²

There are three reasons why dollars are an enormously useful and universally accepted basis for expressing and comparing economic values. First, the number of dollars that people are “willing to pay” for something reflects how much of all other for-sale goods and services they are willing to give up to get it. People understand this and so they understand what the dollar value of something represents. Second, dollars can be used to compare the value of the many diverse products and services that are traded in markets. This allows people to use dollars as a general measure of the opportunity costs of their production, investment, and purchasing decisions. Third, because markets assign credible dollar values to so many things, this value allows the use of benefit-cost analysis

¹ Public preferences may be reflected in market decisions or they may be revealed or expressed in other ways as discussed in Chapter 1, “Overview of Previous Methods for Assessing Wetland Functions and Values.” Aggregate measures of value should be based on the preferences of society as a whole, not specific stakeholders, which is one reason why the design of preference surveys is important. See Bateman and Willis (1999).

² Strictly speaking, how much money people are “willing to accept” to forego a wetland service is also a valid measure of its economic value. The difference between surveyed estimates of “willingness to pay” and “willingness to accept payment” for the same environmental services has been the focus of considerable attention in the nonmarket valuation literature. See Carson, Flores, and Meade (1996).

to evaluate complex production and investment decisions. These are sound reasons to attempt to assign dollar values to wetland services if it is at all possible.

Valuing Wetland Services

In principle, a product or service does not need to be traded in markets to have a measurable dollar value. Nonmarket valuation methods exist that, in principle, can be used to estimate the dollar value that people would be willing to pay for nonmarketed products and services if they were bought and sold. However, economists have been attempting to use these methods to estimate the dollar value of nonmarketed wetland services for about 20 years with limited success.¹ These attempts fall into three general categories:

- a. *Revealed willingness to pay (e.g., market prices).* When people purchase something (e.g., a home near a wetland) or spend time and money to get somewhere (e.g., a fishing spot or a bird-watching site dependent on a nearby wetland), they reveal that they are willing to pay at least what they actually spend for those services; they may be willing to pay more.
- b. *Expressed willingness to pay (e.g., survey results).* People may never “reveal” what they are willing to pay for wetland services that are not traded in markets (e.g., a scenic view or a day of bird watching). In this case, simply asking them what they would be willing to pay can sometimes yield useful results. However, surveys of willingness to pay are expensive, controversial, and usually yield results that are reliable only when questions are asked about specific wetland services provided in specific contexts.
- c. *Derived willingness to pay (e.g., circumstantial evidence).* This method involves tracing and measuring the functions provided by a wetland (e.g., retaining floodwater, reducing wave energy, maintaining water quality) and estimating what people would be willing to pay to avoid the adverse effects of losing those functions. The dollar value of flood and siltation damage avoided because of a wetland is an example of derived willingness to pay for wetland services.²

To appreciate what would be involved in developing a comprehensive estimate of the monetary value of a wetland, consider the wide range of values listed in Table 1. Attempting to measure the value of some of these services would require tracing biophysical linkages across vast distances in space and time. The dollar value of next year’s catch of bottom fish off the coast of Maryland, for example, may depend in critical ways on conditions in spawning and feeding areas in and around coastal New England wetlands several years ago.

¹ These methods are reviewed in World Wildlife Fund (1992) and Bartoldus (1999).

² “Choice modeling” is another method that can sometimes be used to derive monetary values for nonmarketed environmental services. It involves analyzing how people decide when faced with hypothetical choices between different combinations of products and services (Freeman 1993).

Gulf of Mexico shrimp landings in one year may depend on the level of nutrients or floodwaters trapped by wetlands along the Upper Mississippi River a few years earlier, and so on.

During the past 10 years, at least five major reviews of wetland valuation methods and numerical estimates of wetland values have been published. The authors of this report know of three in the United States (Anderson 1991; Scodari 1993; and Heimlich et al. 1998), one in Sweden (Beijer Institute 1994), and one in England (Barbier, Acreman, and Knowler 1997). All five of these studies, along with many unpublished reviews, reached the same general conclusions:

- a. Wetland functions provide a wide range of services with economic benefits that accrue primarily off-site. Most of these are not reflected in markets, or at least not in markets linked directly with wetlands, and cannot be captured as profits or rents by the owners of wetlands.
- b. Although some accepted methods exist for tracing and estimating the economic value of some off-site wetland services, they have not been widely applied and have not been applied in a consistent manner.
- c. The few useful estimates of economic value that exist are related to specific wetland services. There are no reliable *comprehensive* estimates of the economic value of any wetland.
- d. Many wetlands function primarily as components of broader ecosystems (e.g., watersheds) and generate off-site economic values that may be impossible to isolate from those of the broader ecosystems.
- e. The economic value of a particular wetland and its contributions to broader ecosystem functions and values depend in critical ways on its location within the broader ecosystem, and also on the number, size, condition, and location of other similar wetlands in that ecosystem.
- f. The cost of replacing a wetland can be estimated reliably and puts an upper bound on what people *should be* willing to pay to protect a wetland. However, it does not establish that people *would be* willing to pay that amount to replace a wetland if it were lost. Therefore, replacement cost is not an acceptable measure of economic value.

Overall, three convincing arguments can be made as to why it may not make sense to try to assign absolute dollar values to wetlands using any of the generally acceptable methods: (a) most important wetland services are not traded in markets so people cannot *reveal* the dollar value they place on them; (b) people do not know about or appreciate the many functions and services that wetlands provide and therefore cannot be expected to *express* what they are willing to pay for wetlands; and (c) wetlands generate so many diverse functions, services, and products that the cost of tracing and measuring all of them to *impute* their dollar value is prohibitive.

The Production Function Approach

The limitations of dollar-based wetland valuation are finally causing attention to shift to nondollar methods for estimating wetland values. However, there is a critical gap between the information available from wetland scientists about wetland function and the information required by economists to perform nonmonetary wetland valuation. Wetland scientists study biophysical processes that affect wetland functioning but do not generally link specific functions to services that matter to people. On the other hand, economists who have been working in the area of ecosystem valuation have focused primarily on estimating the dollar value of specific wetland services without considering the biophysical processes on which they depend. The WVI System proposed here attempts to bridge this gap by addressing the necessary conditions for a wetland with a given functional capacity in a given location to provide services, and the necessary conditions for those services to be valuable.

The conceptual basis of the WVI System described in this report is a widely used analytical tool called a production function.¹ This is a relationship that shows how the quantity and composition of the outputs of a productive process are related to the quantity and composition of inputs that are used in the process. Production functions are at the core of most economic studies related to industrial, agricultural, and manufacturing operations. They are also the basis of most industrial engineering studies, and are the source of many index systems that are used to determine the risks and potential payoffs from corporate investment portfolios. The availability of inputs and the likely effects of controllable and uncontrollable risks on the availability of inputs are critical determinants of the output that should be expected from a productive process. For obvious reasons these factors are widely used as leading indicators of the value of the output expected from a process and the value of the assets that are committed to the productive process.

Agricultural production functions are widely used to describe the combinations of land, water, labor, equipment, energy, seed, soil amendments, and so on that could be used to produce a given level of crop yield. These functions show how substituting one on-farm input for another (e.g., land for fertilizer, tractors for man-hours) will affect production levels. They also show how changes or differences in natural factors affect yields and why farm sites in one area are likely to yield greater output from a certain mix of inputs than farm sites in another area. Differences in the economic value of farmland can be a result of on-site differences (e.g., soil quality, hydrology) or a result of landscape context (e.g., proximity to pollution, invasive species, roads, markets, migrant workers). The economic value of a wetland depends in similar ways on site and landscape conditions that affect expected streams of wetland services. The unit value of wetland services, like the unit value of farm crops, may be relatively

¹ The concept of the production function as a general relationship between the inputs and outputs of a productive process is described in all standard microeconomics texts (e.g., Samuelson and Nordhaus 1995, elementary; Mankiw 1997, elementary; and Varian 1992, intermediate). Clark (1976) describes the use of mathematical production functions in natural resource industries where the results of natural processes provide a basis for developing indices of critical inputs.

uniform across sites and may provide a poor basis for comparing wetland value. The more critical focus for comparing site values might be differences in productive capacity.

Production functions are usually based on some underlying engineering relationships, but many times they include uncontrollable relationships related to natural systems. In fisheries and agriculture, for example, many of the input categories that are used in production functions are natural and uncontrollable and are frequently represented by indices (e.g., soil productivity, degree-days, fish abundance, rainfall). A production function that treats wetland services as an output and on-site and off-site indices as inputs is not much different from these forms of production functions. It is a logical economic basis for comparing the economic value of wetlands as assets. Taking this approach, the wetland functions that are the focus of the HGM Approach are an intermediate process whose “value” is based on whether they result in services that benefit people and when and where those services are provided.

Relative Value and Service Preference Weights

A system of indices based on a production function approach generates measures of relative value for particular services provided at particular locations. To compare the *overall* value of wetlands at different locations reflecting all services, it is necessary to assign relative weights to services based on individual and community preferences. All other things being equal, a wetland that provides more of all services than another can be said to be more “valuable” regardless of the weights assigned to individual services. However, if one wetland provides more of some services and less of other services, the relative value of the two wetlands could depend on the relative preferences that people attach to various services.

Several promising new applications of nonmarket valuation research can contribute to the development of service preference weights. These differ from nonmarket valuation methods in that the service preference weights are not designed to assign dollar values to specific resources or services. Instead, they use stated preferences to rank and assign relative values to various services. Applications of these techniques appear in the economic literature under several different names including choice modeling, ranked preference analysis, contingent choice analysis, and conjoint analysis.

Using most of these techniques the development of service preference weights can be based on direct survey data, secondary source information about supply and demand conditions in the wetland service area, or some combination of both. Options for using secondary-source information about preferences include reviews of previously developed planning and guidance documents, the results of community and regional “visioning” sessions, stakeholder meetings, or opinion polls; analyses of demographic statistics and supply and demand conditions; participation and visitation data; records of charitable giving; and, most importantly, results of special-purpose stated preference surveys.

In stated preference surveys, respondents may be questioned using three general approaches:

- a. *Simple (dichotomous) preference surveys.* Do you prefer A to B or B to A?
- b. *Ranked preference surveys.* Rank in terms of importance: A, B, C, and D.
- c. *Contingent valuation.* How much would you be willing to pay for A and for B?

For several reasons, the second type, ranked preference surveys, will probably be the most useful for assigning relative weights to services. Such surveys can be simple and inexpensive. They can be designed in such a way to extract rankings from simple survey questions and thereby ease the intellectual burden on survey respondents. Surveys of individual and community preference rankings may not need to be conducted frequently, perhaps only every few years or only when observable changes in supply and demand conditions provide reason to suspect that relative service values have changed. Such surveys can yield defensible indices associated with individual and community preferences for wetland services (Mitchell and Carson 1989). Depending on circumstances, it may be appropriate to sample populations at different geographic scales (local, regional, state, national) and to address any potential differences in the ranking of services at different geographic scales.¹

Another option, which has not been widely used but may yield convincing results, is citizen environmental valuation juries (Brown, Peterson, and Tonn 1995). This involves selecting groups of citizens to represent the public interest, not the interests of specific-interest groups or stakeholders, in assigning relative weights to environmental services. Scientists and representatives of special interests might present evidence to these juries, which would then be asked to prioritize services based on the evidence presented. The results, although subject to many forms of criticism, may be more convincing than statistical interpretations of contingent valuation surveys or opinion polls.

Interest in techniques such as ranked preference studies and citizen juries is growing because they are a relatively inexpensive alternative to monetary valuation methods and provide results that are often easier to interpret and defend. There is a growing consensus that the cognitive difficulty of attaching dollar values to nonmarketed environmental attributes or services makes willingness-to-pay surveys unusable in the case of wetlands (King 1998). On the other hand, people seem to find it relatively easy to determine and express their preferences for one set of environmental attributes or services over another, and

¹ Private survey companies are now offering to conduct low-cost surveys of Internet Web users. One company claims to be able to target and stratify samples from over 38 million Web users and address them using any number of open-ended, multiple-choice, or dichotomous-choice questions. For information visit www.insightsexpress.com.

find it not too much more difficult to express by how much they prefer one set over another.¹

¹ Several reviewers pointed out that unlike monetary valuation methods, where significant conceptual and practical problems have been uncovered and are being addressed, the problems associated with choice modeling and citizen juries are largely unknown and have not been addressed.

3 Development of Wetland Value Indices

Most wetland indicators, including many FCIs developed using the HGM Approach, reflect differences in how well wetlands serve the needs of various plants and wildlife. Similarly, indices can show how a wetland, and the plants and wildlife it supports, can provide for the needs of people. There are many reasons why wetland scientists have been reluctant to step into the social sciences and develop indices that consider people. However, doing so does not require any more ethical, moral, or value-based judgements than developing indices that reflect the ability of a wetland to meet the needs of other species. Taking things one step further by assigning estimates of value to various needs of people does require determining how much people want or need particular services. However, this too can be done objectively.

Indices representing risk can also be developed objectively and can be based on measures of expected changes in any condition that might affect wetland functions, services, or value. These should include physical, biological, and chemical threats to components of FCIs. A planned highway development or water diversion and an unmanaged invasive species problem are examples of potential risks to wetland functions that have direct effects on wetland services and values.

The questions that need to be addressed to arrive at a meaningful set of wetland value indices are listed in Figure 3. The HGM Approach addresses most of the questions listed under “Function.” Supplemental indices are needed to address questions listed under “Services,” “Values,” and “Risk.”

Valuation Overview

In the WVI System, FCIs form the core of wetland production functions. They reflect how on-site inputs and landscape or off-site inputs combine to generate expected Level of Function. Figure 4 illustrates the logic of how additional indices are combined with FCIs to generate four additional measures: Level of Service, Nominal Service Value, Expected (risk-modified) Service Value, and Adjusted (preference-weighted) Service Value. These are combined to form an overall wetland value index as follows:

- a.* **Level of Function** is measured by the HGM-derived **FCIs**.

Functions

- What environmental functions does this wetland have the capacity to provide?
- Does the landscape context of the wetland allow it to provide these functions?
- If so, are there factors that will cause it to function at less than full capacity?
- Are there factors that may cause the wetland to function beyond its sustainable capacity?

Services

- What services, products, and amenities will these wetland functions generate?
- Over what geographic area do people benefit from these services, products, and amenities?

Values

- How scarce are these services, products, and amenities in this area?
- How many people benefit from them; what is their income, ethnicity, etc.?
- How much does it cost in money or time for people to enjoy these services?
- Are there near-perfect *natural* substitutes that exist or could be developed?
- Are there near-perfect *human-made* substitutes that exist or could be developed?
- How could the affected population adapt to having fewer of these services?
- How much would the affected population benefit from having more of these services?

Risk

- How might future development make the services provided here more/less important?
- How vulnerable are services generated by this site to temporary/permanent disruptions?
- How restorable are these services in this region compared to other regions?
- How might future development make the services provided here more/less vulnerable?
- Will demographic/land use change increase/decrease preferences for these services?
- Will demographic/land use changes increase/decrease availability of these services?

Figure 3. Essential questions about wetland benefits

- b.* **Level of Service** depends on the level of function and the **Service Capacity Subindices**, which reflect off-site characteristics that either limit or enhance the ability of a wetland to provide the service.
- c.* **Nominal Service Value** is developed from **Value of Service Subindices** that are related to regional supply and demand conditions and preference rankings that reveal the value of incremental increases or decreases in service flows.
- d.* **Expected Service Value** is the **Nominal Service Value** modified using the **Service Risk Subindices**, which reflect conditions and trends that influence the risk of service flow disruptions.
- e.* **Adjusted Service Value** for a service is the **Expected Service Value** weighted by a **Service Preference Weight**.

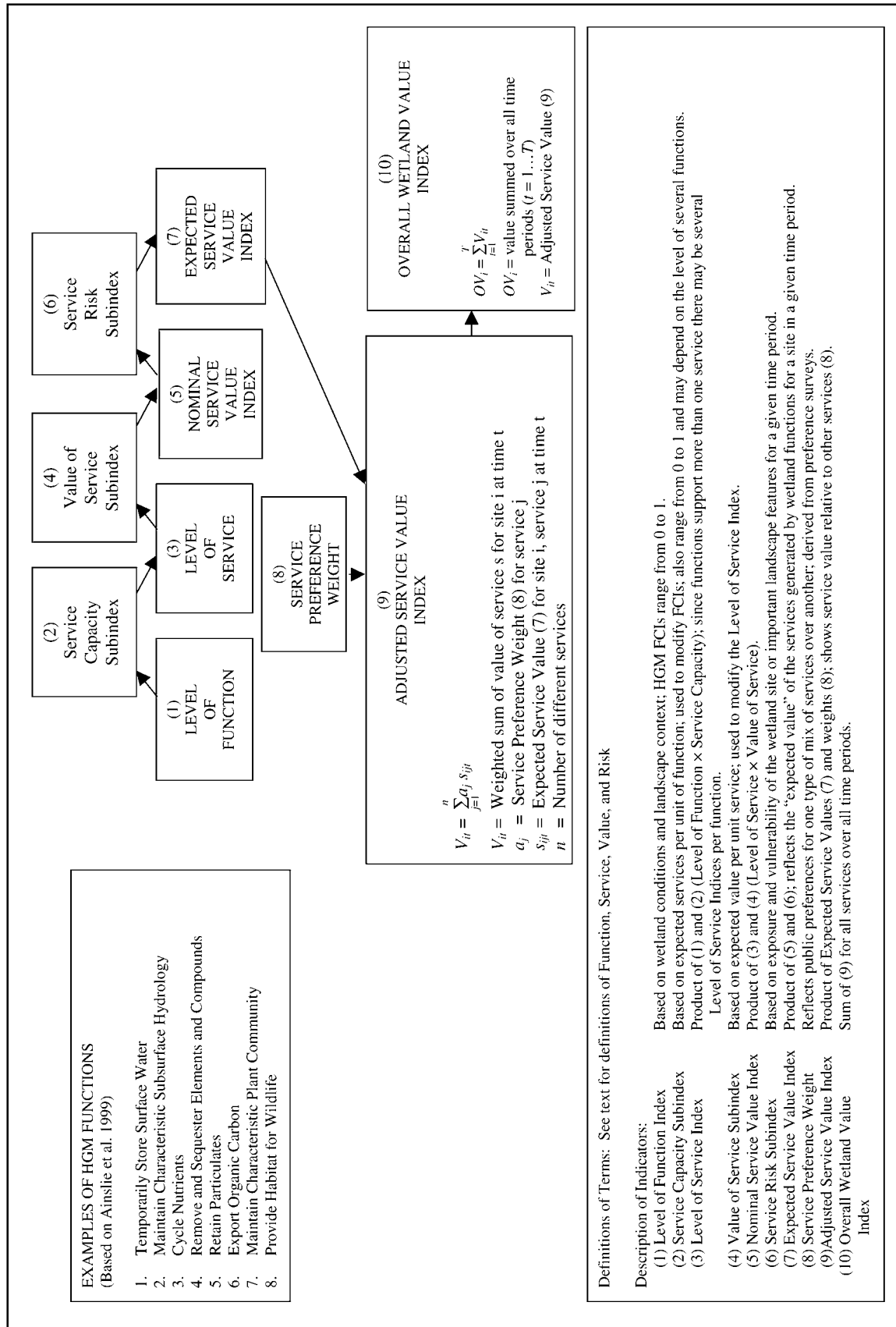


Figure 4. Flow of indicator development to arrive at a relative index of wetland value

- f. **Overall Wetland Value Index** for a wetland, representing the asset-value of the wetland, is the sum of the **Adjusted Service Value** indices for all services.

This report employs a two-tier system that considers both the relative value of the service provided by wetlands (indices contributing to Expected Service Value Index at different locations), and the relative preferences that people have for different wetland services (Service Preference Weights and Adjusted Service Value Index). Service Value Indices that reflect the relative value of a unit of service provided at a site are developed using site-based information and secondary information about local and regional supply and demand conditions, numbers of users, participation rates, access costs, established watershed goals, and planning, zoning and permitting decisions. Public preference surveys are then used to develop Service Preference Weights that rank individual services and permit the aggregation of service values into a single index of wetland value.¹

Developing each of the first-tier indices used to extend the FCIs follows the same logic as developing FCIs themselves, but does not require the same commitment to field work and may not require field work at all.² Table 2 demonstrates the process of developing Service Capacity Subindices; Table 3 demonstrates the process of developing Value of Service Subindices; and Table 4 demonstrates the process of developing Service Risk Subindices.

Illustration of Analysis

To illustrate a typical analysis, three wetland functions (i.e., provision of wildlife habitat, retention of sediments and contaminants, and temporary storage of surface water) were selected; and examples of four potential services that could be the focus of value-based indices were used: recreational fishing opportunities; birding, hunting, and wildlife viewing opportunities; water quality maintenance; and flood damage avoidance (Table 2). The indices are used to consider aspects of landscape context (e.g., land arrangement, upslope sources, accessibility) that enhance or limit the ability of the site to provide these services.

Many services can be evaluated by examining the proximity of the site to other natural and man-made landscape features. For active use services, variables describing the ability of humans to get to a wetland or adjacent sites supported by the wetland are particularly useful in determining which services are being provided. As shown in Table 2, a service capacity index for

¹ The approach outlined here discusses assigning preference weights to wetland services, not to the underlying wetland functions on which they depend. For reasons discussed in Chapter 1, “Functions versus Services,” this is the proper focus for surveying preferences. Alternative methods for assigning preferences are not discussed here, but are described in Bateman and Willis (1999).

² Most of the supplemental indices are based on landscape, land use, and demographic information that can be obtained without visiting individual wetland sites. See “Overall Wetland Value Index.”

**Table 2
Service Capacity Subindex Development**

Service (On- or Off-site)	Wetland Contribution	Necessary Conditions	Measures of Necessary Conditions	Potential Components of Service Capacity Index
Recreational fishing opportunities	Provide feeding, breeding, and nursery habitat	Game fish present in adjacent or connected water body and fish/larvae have access; people have access	Presence of game fish or larvae; infrastructure to support fishing in connected waterway	Obstructions to fish movement; fishable classification downstream; % of time wetland hydrologically connected to adjacent waterway; fish population surveys; recreational infrastructure (fishing pier, fishing bank area, parking lot size, boat ramp, restroom capacity)
Birding, hunting, and gathering opportunities	Provide habitat for fungi, plants, birds, and animals that use wetlands	Support of appropriate (especially diverse or rare) habitat; access by enthusiasts	Presence of rare or desirable species; access by birders/hunters/ gatherers	Biodiversity indices; presence/absence data; property ownership; trail miles; hunting restrictions
Water quality maintenance	Trap sediments, cycle nutrients, filter contaminants	Surface water usage; water quality (fishable, swimmable, drinkable)	Sources of erosion and contaminants upslope/upstream; runoff/shallow throughflow received, low gradients; access; significant contribution to water quality given current conditions	Sources: presence of industrial or agricultural activity; area in unsewered residential; volume of waste water discharged upstream. Usage/Access: beaches, parking, restrooms, municipal water intakes
Flood damage avoidance	Hydrologic regulation	Vulnerable property downstream; ability of wetland to hold water	Structures and crops in 100-year floodplain downstream; depression area volume; upslope area drained by wetland	# of structures in 100-year floodplain downstream; ownership type, land use; depression area volume; upslope area drained by wetland

Table 3
Value of Service Subindex Development

Service (On- or Off-site)	Geographic Extent of Service	Population Benefiting	Supply Conditions	Demand Conditions	Potential Components Value of Service Index
Recreational fishing opportunities	Local	8-km (5-mile) radius	Alternative sites within 8 km (5 miles); quantity, quality, and capacity of alternative sites within 97 km (60 miles)	Level and frequency of participation; expressed/revealed preferences; leisure time	# fishing permits in ZIP code; user days; contributions and memberships; # fishing-related businesses; #alternative sites; preference survey results; average income/property value
	Regional	97-km (60-mile) radius	Alternative sites within 97 km (60 miles)	Level and frequency of participation; expressed/revealed preferences; leisure time	# fishing permits in state; # fishing-related businesses; contributions and memberships; average income
Birding, hunting, and gathering opportunities	Local	8-km (5-mile) radius	Alternative sites within 8 km (5 miles); alternative sites within 97 km (60 miles)	Level and frequency of participation; expressed/revealed preferences; leisure time	# hunting permits; # related businesses; # alternative sites; value of gathered goods; access fees; contributions and memberships; average income
	Regional	97-km (60-mile) radius	Alternative sites within 97 km (60 miles)	Level and frequency of participation; expressed/revealed preferences; leisure time	# hunting permits; # related businesses; # alternative sites; value of gathered goods; access fees; contributions and memberships; average income
Water quality maintenance	Regional	Regional	Existing water quality; safe alternatives	Expressed/revealed/imputed preferences	Stream order; stream designation (swimmable/fishable); water volume; salinity; flow rates, residence time; types of use
Flood damage avoided	Local	Owners of downstream property within floodplain	Alternative natural or human-made storm water control	Potential property and income losses; proportion of industrial, residential, and business property; insurance costs	Volume of runoff controlled by storm water devices and natural depressions/vegetation; value of property at risk; proportion of industrial/residential/business property

**Table 4
Service Risk Subindex Development**

Service	Major Threats to Function ¹		Major Threats to Services		Potential Components of Service Risk Subindex
	On-site	Off-site	On-site	Off-site	
Recreational fishing opportunities	Biological, physical, and chemical threats to wetland	Biological, physical, and chemical threats to landscape features	n/a	Change in access/property ownership/regulation and zoning; change in land use	Projected population growth rates (by locale/ZIP code/watershed); expected development patterns in area (e.g. % impervious surface at buildout); disturbance level in adjacent area (mowing, boat traffic, agriculture, unsewered residential, channelization, invasive species); planned changes to nutrient loads, hydrologic regimes (e.g., waste water discharges, reservoirs, water diversions, groundwater drawdowns); invasive species spread rates.
Birding, hunting, and gathering opportunities	Biological, physical, and chemical threats to wetland	Delivery of excess sediments, nutrients, or contaminants (beyond wetland filtering capacity)	Change in access/property ownership; conversion to developed use (agricultural/ residential); excavation; draining	Change in access/property ownership/regulation and zoning; change in land use	
Water quality maintenance	Change in water table depth; alien invasive plant/animal species; erosion; sea level rise; change in soil or plant characteristics	Activities that generate delivery of excess sediments, nutrients, or contaminants (beyond wetland filtering capacity)	Conversion to developed use: excavation; draining; logging; fire	Projected land or water use that precludes service; water diversion; logging; fire; dredging	Existing land use risk factors: agriculture, feed lots, septic fields; projected land use risk factors: water withdrawals; new feed lots, septic fields, logging, etc.; fire frequency; changes to hydrologic regime: flood-control structures, water diversions, groundwater drawdowns.
Flood damage avoided	Change in water table depth; alien invasive plant/animal species; decrease in floodplain storage or roughness	Excess sediment delivery; increased runoff upslope; change in flood frequency; change in floodplain slope; change in channel	Conversion to developed use: excavation; draining	Change in land use	Homes in flood-plain modified/moved/ destroyed; changes to hydrologic regime: flood-control structures, water diversions, groundwater drawdowns.

¹ Since services depend on function, the service risk subindex includes risk factors related to threats to functions as well as threats to service flows.

recreational fishing might depend on the connection between the wetland and open-water habitat, the presence of fish in open water, and availability and suitability of facilities or infrastructure that would allow people to reach adjacent fishing grounds. In many cases, the presence of obvious features such as boat ramps, restrooms, and parking areas will affect the level of service provided and are reflected in Service Capacity Subindices. The number of anglers within a particular distance of the fishing site, the number of alternative fishing sites, and other similar measures provide reasonable indices of demand and an additional basis for comparing service values.

Geographic Information Systems (GIS) combine and analyze spatial data to provide a host of useful tools for characterizing service capacity. For example, using elevation data, the “viewshed” or viewable area from a site can be characterized. Locations of toxic discharges are often available and, when combined with elevation or streamflow data, can show the receiving area of such discharge and the habitats or species at risk. Data that are readily available in many locales can be analyzed in a GIS to determine the following:

- a.* Whether a wetland is upstream of a water body used by swimmers or fishers, which will partially determine the ability of the wetland to contribute to a swimming or fishing service.
- b.* The likely constituents of runoff, which can be predicted from the types of land covers and land uses of runoff-generating areas.
- c.* The proximity of toxic discharges, which will be a factor in whether a wetland provides the service of water decontamination.
- d.* Accessibility of the site, which will determine levels of service associated with aesthetics, recreational opportunities, and educational opportunities.

Services that accrue at the state, regional, national, or international levels may be assessed by determining what role a wetland plays in planning goals at each scale. Zoning maps, land use maps, or water flow networks can be used to assess whether a wetland is contributing to an environmental service as part of a coastal protection zone, a drinking water protection area, or a wildlife corridor. A variety of land arrangement variables may be used to supplement functional measures and relate them to broader scale services. For example, fragmentation measures have been related to the attractiveness of forest patches to migrant bird species (Flather and Sauer 1996). In this case, measures of land arrangement can suggest the degree to which local habitat influences the abundance of migrant species whose primary habitat is elsewhere. Simultaneously, this may be a measure of the desirability of a forest for local birding recreational uses. Where appropriate, indices that measure the carrying capacity of a bird habitat in terms of birds and bird watchers may be useful to identify areas where there may be important trade-offs between services (e.g., bird viewing) and risks (e.g., bird breeding).

Service Capacity Subindex: Connections between Landscape Setting and Services

The level of output (services) expected to flow from a wetland depends on inputs that are related to both site and landscape features. Certain landscape conditions are considered to be necessary for a wetland to generate beneficial services. Typical factors affecting Level of Service include access, adjacent land use, and downstream resources that affect the opportunity of a wetland to provide services. The Level of Service associated with the flood storage capacity of a wetland, for example, depends on the presence of residential and commercial property in the area of potential flood damage. The Level of Service associated with recreational fishing depends on the proximity of the wetland to water bodies that support recreationally important species and to fish spawning and feeding habitats and the relative scarcity of those habitats. Each type of service needs to be examined in terms of specific landscape factors, and these factors accounted for in the Service Capacity Subindex (Figure 4).

Many of the physical and biological distinctions that determine the ability of a wetland to provide services are reflected by landscape variables related to upstream and downstream land uses and land configurations. For example, using elevation maps and GIS analysis tools that characterize surface water flow networks, wetland differences can easily be quantified by calculating the upland area that would contribute to surface runoff or shallow underground flow (throughflow) passing into any particular wetland. These variables, when combined, provide reliable indicators of the level of water filtration at a wetland site. Variables that reflect the proximity of the wetland site to downstream resources threatened by sediments, nutrients, and contaminants provide indices of the potential payoff from filtration functions provided at the site.

Landscape conditions that affect wetland service flows can be described using a variety of descriptive spatial statistics that are available at various geographic scales (Turner 1989). By examining the relationship between patches of land use types, for example, one can establish the connectedness, adjacency, and extent of land use types. Land types can be divided into those that support a service and those that do not (e.g., habitat versus nonhabitat), to determine important aspects of land use relationships. Statistics that describe the degree of landscape fragmentation, small patches as opposed to large contiguous tracts, have been linked to changes in ecological functions and occasionally services (Bedford and Preston 1988; Quinn and Harrison 1988; Hunsaker and Levine 1995). Landscape fragmentation has been most closely linked to habitat functions and therefore can be linked to passive-use services, such as maintaining rare species, and bequest and option values. Statistics related to landscape fragmentation may be especially useful for examining coarse-scale functions such as those related to migratory bird habitat (Flather and Sauer 1996)

Landscape pattern statistics can be derived from spatial data within a GIS, other data sources such as paper maps, and generally accessible regional (e.g., county or ZIP code level) data sets. The scale, spatial resolution, and quality of the data will limit the value of these derived statistics, but data quality is continually improving. As states and other government entities expand their use

of GIS for analysis, they are refining data and developing finer scale data to facilitate land use planning, ecological assessments, and resource evaluations.

The Value of Service Subindex

The Value of Service Subindex should be based on conventional economic concepts and should reflect aggregate willingness to pay for an incremental unit of wetland service based on the economic definition provided earlier. General measures of the supply and demand of wetland services exist that can be used to develop indices of relative service values. Other things being equal, for example, services that are provided where they are relatively scarce and for which there are few substitutes are more valuable than services provided where they are abundant and for which there are many substitutes. All other things being equal, services provided where they benefit more people are worth more than services that benefit few people. All other things being equal, reducing risk to species or habitat where it is the least reversible is more important than reducing risk where it is the most reversible. Those types of factors are reflected in Value of Service Subindices.

In general, the factors that affect aggregate willingness to pay for a particular wetland service provided at a particular location include (a) the number of people with access to the service, (b) their incomes and wealth, (c) the cost in time or money of getting or keeping access to the service, (d) the availability of perfect or near-perfect substitutes for the service, and (e) people's expressed or revealed preferences for this service compared with other competing services.

Site-based indices of factors that contribute to site value can be developed using generally available landscape, demographic, and socioeconomic data and provide a credible basis for comparing the value of services provided by different types of wetlands. If the geographic range of wetland services is important, relevant indices can be developed from many different data sources. Data on recreational use by locale and by socioeconomic variables are available (e.g., U.S. Fish and Wildlife Service 1998) to use in judging the demand for a recreational service in a region. The availability, capacity, and comparability of recreational sites can be identified and considered as factors that limit or enhance the value of any individual site. ZIP code-scale demographic, socioeconomic, and land use statistics are generally available and are analyzed routinely by regional economists and business analysts to compare regional markets and demand for service at various sites. The purpose of those analyses, like the purpose of the analysis described herein, is to compare regional and local supply and demand conditions and population preferences that affect the value (marketability) of services.

The value of service can sometimes be illustrated through landscape pattern variables. Local or regional scarcity of a habitat may be related to the presence of land use types or the amount of edge between land use types. Total wetland area or total core area of wetland in a region, for example, is an obvious and potentially useful measure for examining habitat scarcity for an endangered species. However, from the point of view of a particular species, it is not merely

quantity of habitat that matters, but how it is arranged on the landscape. Wetlands that provide a favorable pattern of attributes for many species, all other things equal, are more valuable than wetlands that do not. Wetlands that do this without requiring restrictions on other wetland uses, all other things equal, are more valuable than those that cannot.

For passive use services related to natural habitats, it will be useful to further describe a service using the maximum or average nearest-neighbor distance between wetlands to reflect the scarcity of the habitat at a scale relevant to a set of organisms. For habitat mosaics to be useable, organisms must be willing and able to cross between habitat patches. Some land patches may be particularly valuable in connecting habitat. This concept can be illustrated by considering the stepping stones one might use to cross a river. If a person's stride is a maximum of 1.5 m (5 ft) and the maximum nearest-neighbor distance between stones in a river crossing is 1.2 m (4 ft) or less, that person can cross the river. If removing a stone increases the maximum distance between neighboring stones to 2.1 m (7 ft), the person can no longer cross the river. That one stone was a necessary condition for that person to be able to cross the river.

In terms of habitat configuration, this nearest-neighbor distance measure can be used to identify a site (land use patch) that has particular value as a critical "stepping stone" (Keitt, Urban, and Milne 1997) that connects or creates useable habitat. The same is true for determining the capacity of a wetland site to generate services and their value. For example, the limiting landscape factor affecting the capacity of a wetland site to provide scientific, educational, recreational, or aesthetic opportunities might be the ownership of the surrounding land use or the number of nearby parking facilities. The nearest-neighbor distance that determines the aggregate value of these wetland services may involve the nearest park or point of public access.

Table 3 lists other factors that may be examined as potentially useful indices of the value of wetland services. Once the Value of Service subindices are developed for each service, a Nominal Service Value during any particular time period may be calculated by multiplying the Level of Service by the appropriate Value of Service Subindex (Figure 4).¹ Therefore, the Nominal Service Value takes into account functional level, service capacity, and value as represented by scarcity of a service, number of people benefiting from a service, and preferences for a service.

Service Risk Subindex

The economic value of a wetland depends on the *expected* flow of services it provides over time, where *expected* means risk-adjusted. Risks of service

¹ This employs the conventional economic method of assigning overall value by multiplying the number of units (quantity produced) by per-unit value (price). In this application, the Level of Service is a unit measure and the Value of Service Subindex is a per-unit value measure, so multiplying the two to arrive at an index of overall value is appropriate. If the actual indices that are developed do not reflect these characteristics, another mathematical expression may be more appropriate.

disruptions differ from site to site and are associated with the exposure and vulnerability of the wetland site itself and the vulnerability and exposure of important landscape features that affect the “economic productivity” of the site. Threats that cause risk can arise from natural processes (flood, drought, wind, fire, disease, invasive species), from human actions (illegal draining or hunting, vandalism), or from human activities outside the wetland (construction, road travel, water diversion). Risk is accounted for by introducing the Service Risk Subindex, which is used in the WVI framework to adjust the Nominal Service Value and arrive at the Expected Service Value (Figure 4).

This adjustment, like the others, is intended to simulate how markets would adjust the relative value of assets to account for differences in risk. All other things equal, the market value of homes, factories, and farms located on an earthquake fault or in a floodplain or where there is a high level of political instability or crime is lower than in other areas. The reason is that the services they provide are more likely to be disrupted. Similarly, the expected services from a wetland in a rapidly deteriorating landscape, all other things equal, are less valuable than those expected from a wetland in a stable setting. Threats to wetland services can vary widely, and determining which wetlands are threatened most and least by adverse landscape changes is important in assessing and comparing wetland values. In extreme situations, this may be the only important criterion for assigning relative values to wetlands.

Many sources can provide reliable information about what threats exist and which wetlands are at risk. Zoning plans, sewer extensions, and road construction, in combination with population projections, can suggest a great deal about the potential effects of population growth on wetland services and values. Intensive agriculture or feedlot operations and unsewered medium- and low-density residential land use have also been shown to be strong predictors of pollutants in groundwater and surface water (Harper, Goetz, and Willis 1992; Hall et al. 1994). Plans for these types of land uses adjacent to or upstream of a wetland suggest increased risk. Factors that would tend to mitigate or exacerbate risk from development include limits on allowable population densities, limits on land parcel size, and stormwater zoning regulations. These factors can be incorporated directly into Service Risk Subindices and can be measured directly from GIS or other sources.

FCIs may already incorporate certain subindices that could be used to project future risk of service flow disruptions. These may include recent sediment delivery, proportion of invasive species, upland land use, and plant species composition. However, human activities and planned activities need to be directly included because of the potential for sudden and extreme disturbance of function. Increases in population, land or water use per person, or industrial activity can be the most significant factors in assessing potential risk within a watershed (U.S. Geological Survey Biological Resources Division 1999). Increases in population and land use per person result in new housing development and transportation activity that can bring dramatic changes to the regional hydrologic regime and nutrient cycles, as well as direct wetland destruction and degradation. These human-induced risk factors can be mitigated through land use planning and environmental controls (e.g., stormwater management), and the value of certain wetland services can be increased by new

development. Therefore, planned development, as well as regulation and land use management, will need to be assessed to characterize the major sources of risk for most wetlands.

The explicit distribution of new development within a region can be examined with a tool known as scenario analysis, which considers multiple sources of risk. The analysis combines forecasts of population growth, landscape and land use data, and zoning and regulatory restrictions to evaluate effects of development on economic and environmental conditions. In Maryland, a statistical model has been used specifically to identify which parcels are most likely to be developed under various regulatory and zoning conditions (Bockstael 1996; Geoghegan, Wainger, and Bockstael 1997). These analyses are sometimes taken to the extreme “build out” condition, when all buildable parcels have been developed, to understand the maximum possible effects of a zoning plan.

Scenario analysis can involve complex models or simple correlations. A variety of variables contribute to the level and location of development, but zoning and other governmental policies in particular have been shown to be strong predictors of future development (Bockstael and Irwin, in preparation). Many jurisdictions generate predictions of population growth by locale or ZIP code to facilitate this kind of analysis. Such projection tools can be used to show how changes in regulatory conditions will affect the size and location of wetlands at risk. The results of scenario analyses can also be used to show how the unavoidable degradation of certain wetlands will increase the expected value of the services provided by other wetlands that can be protected. Table 4 provides some risk factors that might be included in indices of wetland site risks for some wetland services.

Process-based or statistical models that explicitly link risk factors with demonstrated risk may be the preferred method of risk analysis. However, where data or budgets are insufficient for these tasks, risks can be assessed using qualitative methods such as cumulative scoring or ranking systems. In such a system, sources of previously identified disturbances or risks (e.g., upland unsewered residential zoning, planned highway, etc.) are summed to produce a total score for a site. Sites are then generally lumped into risk quartiles (very high, high, medium, low) based on the score distribution over a range of sites.

Natural processes (or those controlled indirectly by human activities), such as apparent sea level rise, will be important in many regions. Known risk factors can be assessed through trend or scenario analysis (e.g., spread of invasive plants), but the potential for new natural risk factors may be difficult to characterize. In areas where human risk factors markedly outweigh natural risk factors, it may be sufficient to characterize anthropogenic risk factors only. The converse will also be true.

The Service Risk Subindex aggregates the risk factors for a service, and is expressed in the WVI System as the likelihood that a wetland will *continue* to provide a particular service during a particular time period. Therefore, the

Expected Service Value during that time period would be the product of the Nominal Service Value and the Service Risk Subindex (Figure 4).¹

It is useful to note that the site characteristics that have adverse effects on the Service Risk Subindex may tend to be the same ones that cause some Level of Service and Value of Service indices to be high. The value of bird watching, for example, goes up with proximity to residential development, but so does the risk that the service will be lost as a result of overuse. These kinds of trade-offs are better understood by developing separate site-based indices to reflect wetland service, value, and risk. It may even be possible to develop decision rules or response protocols that are based on relative changes in indices that reflect how close a wetland may be to reaching service capacity overload.

Combining Indices

The WVI System described in this report could be used with Level of Function scores derived from a number of different wetland assessment methods. This report focuses on function scores (i.e., FCIs) obtained by applying the HGM Approach because the development and implementation of the HGM Approach have been identified as priorities by the Corps of Engineers and a number of Federal agencies. A fundamental characteristic of the HGM Approach is that FCIs should be on a ratio scale (Zar 1984; Smith and Theberge 1987) and should be linearly related to the actual magnitude of function across a series of wetlands of the same type (Smith and Wakeley, in preparation; Wakeley and Smith, in preparation). Therefore, a wetland that no longer performs a function should get an FCI of zero, and a change in FCI from 0.1 to 0.2 should represent the same magnitude of change in actual level of function as a change in FCI from 0.8 to 0.9. Similarly, in the WVI System it is highly desirable that Value of Service indices be linearly related to what one might expect to be the actual willingness to pay for the service if it could be measured. Thus, a wetland that has an Expected Service Value of 0.6 for a particular service should be twice as valuable as one that scores 0.3 for that service.

The approach presented for combining subindices involves multiplying them by one another (Figure 4). The Nominal Service Value, for example, is the product of the Value of Service Subindex and the Level of Service (i.e., value per unit multiplied by the number of units). The Expected Service Value, in turn, is the product of the Nominal (riskless) Service Value and the Service Risk Subindex, which reflects the likelihood of service continuance. This approach leads to certain favorable and unfavorable characteristics in the final index score. For example, if the HGM Approach is followed and a 0-1 range of subindex values is used, final scores will also be in the 0-1 range and should be readily

¹ This is known as a “knife-edge” probability function because it assumes that there is an $X\%$ likelihood that the expected level of service will be provided, and a corresponding $(100 - X)\%$ likelihood that the expected level of service will not be provided. More complicated formulations of the probability function that allow for outcomes other than success or failure would be more accurate. However, they would also require estimating more than one parameter. In some cases the single parameter X might be used to reflect more complicated assessments of comparative risk.

interpretable (i.e., 0 = no value, 1 = maximum value). Using this approach, the dependence of one outcome upon another is also taken into account, so that high service subindex scores for a site can lead to a high overall score only if the function necessary to provide the service is not limiting at the site.

However, there are some drawbacks to such an approach. One of them is that relatively small differences in subindex scores can lead to large differences in overall value scores. A site that scores 0.5 for Level of Function and 0.5 for all three supplemental subindices, for example, would receive an Expected Service Value score of only 0.06 (i.e., $0.5 \times 0.5 \times 0.5 \times 0.5$). Another site scoring 50 percent higher (i.e., 0.75) for all these same indices would receive an Expected Service Value score of 0.32 (i.e., $0.75 \times 0.75 \times 0.75 \times 0.75$), which is five times higher. Whether this reflects the actual magnitude of the difference in willingness to pay for the services provided by the two sites is a question that will require further attention.

Another potential problem with using multiplication to combine indices ranging from 0 to 1 is that the Expected Service Value can never exceed the Level of Function. A wetland that provides one of the last remaining refuges for a species that has lost most of its habitat or one that provides the only potential wetland encounter for school children over a broad area may have an extremely high value even though its levels of function and service are quite low. Another potential problem is that linear scoring criteria do not directly allow for the consideration of the discrete nature of some services and nonlinear relationships between function and value. For example, river water may be swimmable or not swimmable based on a specific fecal coliform level. If poor-quality water cannot become swimmable as a result of a change in nutrient filtering capacity of an adjacent wetland, then that wetland cannot contribute to the services related to local swimming. This can be represented, of course, by associating a service with a discrete range of functional scores; but the procedures for defining threshold points and making other decisions will also require further attention.

In summary, the authors of this report are not confident that the decision to combine indices using multiplication would be the right one for all types of wetland services. Other qualitative or quantitative procedures involving scaling and adding index values may be more appropriate to combine some kinds of service, value, and risk subindices (e.g., Smith and Theberge 1987). The goal should be to arrive at an overall index of service value that is linearly correlated with what aggregate willingness to pay for that service would be expected to be. Scoring rules and methods of aggregating service value indices toward this end will be considered further in a follow-up report describing the application of the WVI System to actual wetland trades.

Adjusted Value of Service: Service Preferences and Weights

The Expected Service Value Index that would be developed by assessing Service Capacity, Value of Service, and Service Risk Subindices would reflect the relative value of a particular service provided at a particular wetland site at a

period in time. It does not provide a basis for assessing the relative value of that wetland service with respect to other wetland services provided at that site or other sites. The final step in assessing wetland value is to factor in people's preferences for different wetland services using Service Preference Weights (Figure 4). The Adjusted Service Value of a wetland is calculated by weighting the Expected Service Value Index for each service, based on relative preferences for each of the services the wetland provides, and summing the weighted values. Service Preference Weights are used to show the relative preferences that people have for individual services in a particular geographic region and do not need to be site-specific. They may be used for years or until changes in supply and demand conditions suggest that public preferences for various wetland services may have changed. One survey-based approach to assigning preference-based weights to wetland services involves asking respondents to make paired comparisons as outlined in Figure 5.

A variety of methods exist for estimating and ranking preferences (Nijkamp, Rietveld, and Voogd 1990). Table 5 illustrates the use of pairwise preference comparisons. In the illustration, a five-step process is used to evaluate how respondents rank their absolute preference for one type of service over another. An alternative method could involve asking respondents to express the intensity of their preferences for one service over another by ranking pairs of services on a 1-5 scale (equal importance to absolute importance). Weights from individuals can be aggregated for purposes of statistical analysis, or sets of weights representing different points of view can be compared to examine distributional or equity effects. The differences in Service Preference Weights assigned by sample respondents selected from populations at different geographic scales would be particularly instructive for examining equity issues.

Overall Wetland Value Index

For many planning purposes, the indices described in this chapter may provide a useful basis for assessing wetland trade-offs and establishing wetland priorities. However, for many regulatory purposes, including wetland mitigation and mitigation banking, it is useful to have a single metric of wetland "value" or "equivalency." For such purposes, the final step is to develop an overall wetland value index by summing the Adjusted Service Value Index calculated for each time interval over the time period of interest (Figure 4). This step allows the aggregate effect of the changes in risk and value to be evaluated and may be adjusted to reflect both the magnitude and timing of service flows.

The paired comparisons method is one survey technique used to derive ranked preferences from a group of respondents (Table 5). To simplify the cognitive demands of such a ranking, participants are asked to compare pairs of options and to say which one is absolutely preferred or to rank on a numbered scale the degree of preference. The following are steps to developing preferences:

- **Step 1 List Wetland Services**

This can be a subset of the services listed in Table 1 that are important in a particular watershed or are the focus of important trade-offs.

- **Step 2 Develop Paired Comparison Matrix**

The purpose here is to identify all possible pairs of wetland services in a matrix for a limited set of wetland services as illustrated in Table 5a.

- **Step 3 Select a Representative Sample of Respondents**

The selection and stratification of samples would depend on the nature of the comparisons. It might be useful to sample from the public in general or from selected stakeholder groups. Since the geographic ranges of wetland services differ widely, it might be useful to test for preference differences in sampled populations selected at different geographic scales.

- **Step 4 Develop Paired Preference Rankings**

Have respondents select their preferred wetland service from each pair presented in Table 5a. Service Preferences are then aggregated to develop Service Preference Rankings as illustrated in Table 5c.

If there are ties or close rankings, it may be useful to provide respondents with additional information and conduct a second iteration of paired preference ranking for selected pairs of services.

- **Step 5 Use Statistical Methods to Develop Rank Orderings**

Various statistical methods can be applied to the results of paired preference comparison surveys to arrive at relative service weights or rank orderings of services (David 1988; U.S. Department of Agriculture 1997).

Figure 5. Using paired comparisons to assign preference weights to wetland services

Finding Information and Ease of Application

In recent years, a wide range of land use and demographic information has become available in regional databases, which is often ready to use in GIS applications. A simple survey of available data should quickly indicate the difficulty of extending the HGM Approach to include estimates of wetland services and values in a particular region. In some areas, for example, it might be possible for researchers completing an HGM assessment to merely enter the coordinates or ZIP code of a wetland into a Web-site-accessible database to

Table 5
Illustration of Paired Comparison Approach to Service Preference Ranking

a. Pairs of Selected Wetland Services Presented to Respondents

	Waterfowl Hunting	Waterfowl Viewing	Local Freshwater Fishing	Downstream Water Quality	Reduced Flood Damage	Biodiversity Protection
Waterfowl Hunting						
Waterfowl Viewing						
Local Freshwater Fishing						
Downstream Water Quality						
Reduced Flood Damage						
Biodiversity Protection						

b. Hypothetical List of Paired Service Comparisons and Preferred Choice Based on Local, Regional, National Surveys

Comparison	Preferred Choice		
	Local	Regional	National
Waterfowl Hunting/Waterfowl Viewing	Hunting	Hunting	Viewing
Waterfowl Hunting/Local Freshwater Fishing	Fishing	Fishing	Hunting
Waterfowl Hunting/Downstream Water Quality	Hunting	Water Quality	Water Quality
Waterfowl Hunting/Reduced Flood Damage	Hunting	Reduced Damage	Reduced Damage
Waterfowl Hunting/Biodiversity Protection	Hunting	Hunting	Biodiversity
Waterfowl Viewing/Local Freshwater Fishing	Fishing	Fishing	Viewing
Waterfowl Viewing/Downstream Water Quality	Viewing	Water Quality	Water Quality
Waterfowl Viewing/Reduced Flood Damage	Reduced Damage	Reduced Damage	Reduced Damage
Waterfowl Viewing/Biodiversity Protection	Viewing	Viewing	Biodiversity
Local Freshwater Fishing/Downstream Water Quality	Fishing	Water Quality	Water Quality
Local Freshwater Fishing/Reduced Flood Damage	Fishing	Fishing	Reduced Damage
Local Freshwater Fishing/Biodiversity Protection	Fishing	Fishing	Biodiversity
Downstream Water Quality/Reduced Flood Damage	Reduced Damage	Reduced Damage	Water Quality
Downstream Water Quality/Biodiversity Protection	Water Quality	Water Quality	Water Quality
Reduced Flood Damage/Biodiversity Protection	Reduced Damage	Reduced Damage	Biodiversity

c. Illustrative Service Preference Ranking Based on Paired Comparison Surveys

Wetland Service	Local		Regional		National	
Waterfowl Hunting	IIII	4	III	3	I	1
Waterfowl Viewing	II	2	II	2	II	2
Local Freshwater Fishing	IIIIIIII	9	IIII	6		
Downstream Water Quality	I	1	III	3	IIIIII	7
Reduced Flood Damage	III	3	IIII	5	IIII	4
Biodiversity Protection					IIII	5

receive information for developing general value-based indices to use with FCIs.¹ In other cases, data availability may be poor and simplified indices would be more practical.

In most areas, information about public preferences for specific wetland services is limited and may require some targeted survey work. An alternative to using preference rankings is to develop secondary-source indices of service weights using regional supply and demand conditions and other indices of preferences based on visitation and participation rates, voting results, and so on.

The site and landscape factors that influence Level of Service, Value, and Risk are different for different services. However, it should be possible to develop indices for each of them by tapping into the same general information pool. The following general categories of information might be used to develop value indices:

- a. *Topographic characteristics:* adjacent and nearby hydrological/geological features (e.g., upslope/downslope gradients, proximity to water bodies, floodplains).
- b. *Habitat characteristics:* connectedness to fish, wildlife, fur-bearer habitats (e.g., flyways, wildlife corridors, other wetland areas).
- c. *Development characteristics:* proximity to current or planned residential, commercial, industrial land uses, including proximity to roads, parking lots, rights of way, etc.
- d. *Demographic characteristics:* size, age, ethnicity, and geographic distribution of human populations that benefit from specific wetland services.
- e. *Socioeconomic characteristics:* income, assets, and other characteristics of the population that benefit from specific wetland services.
- f. *Scarcity of services:* the overall abundance of wetland services in the region and the availability of natural or human-made substitutes. All other things equal, fewer perfect and near-perfect substitutes mean higher willingness to pay per unit of service.
- g. *Population served:* the size of the population that has access to the service. All other things being equal, the greater the number of people with access to wetland services, the greater the economic value of the services.

¹ The U.S. Geological Survey and U.S. Environmental Protection Agency maintain Web sites with an enormous amount of geo-referenced data related to wetlands and natural habitats, water bodies, flow rates, and other biophysical landscape features. The U.S. Department of Commerce, Census Bureau, and Bureau of Labor Statistics maintain ZIP code level data related to a variety of land use, demographic, and socioeconomic characteristics.

- h. Cost of service access:* time and money required to take advantage of the wetland service. All other things equal, the lower the cost of access to a wetland service, the greater the value of the services to those who have access.
- i. Revealed preferences:* participation rates, purchasing patterns, subscriptions, donations, and other decisions that reveal preferences for wetland services.
- j. Stated preferences:* relative values assigned to wetland services by individuals, community leaders, elected officials, or citizen “valuation juries.”
- k. Imputed preferences:* individual and community preferences assigned to wetland services and associated with wetland functions and features as a result of choice modeling, conjoint analysis, and other forms of multiattribute analysis.

Figure 6 provides a preliminary regional checklist that might be used to help gather initial information and determine the types of indicators that can be developed for a particular region.

A. <u>MAPS</u>	PAPER COPY		DIGITIZED INFORMATION			
	Coarse	Fine	Coarse	Fine	Isolated	Format
1. Flood Zones	_____	_____	_____	_____	_____	_____
2. Soil Types	_____	_____	_____	_____	_____	_____
3. Hydrologic Features	_____	_____	_____	_____	_____	_____
4. Topography	_____	_____	_____	_____	_____	_____
5. Geology	_____	_____	_____	_____	_____	_____
6. Vegetation	_____	_____	_____	_____	_____	_____
7. Wetlands	_____	_____	_____	_____	_____	_____
8. Land Use	_____	_____	_____	_____	_____	_____
9. Infrastructure	_____	_____	_____	_____	_____	_____
10. Natural Resources	_____	_____	_____	_____	_____	_____
11. Fish/Wildlife Inventories	_____	_____	_____	_____	_____	_____
12. Natural Hazards	_____	_____	_____	_____	_____	_____
13. Pollution Inventory (RCRA/Superfund)	_____	_____	_____	_____	_____	_____
14. Endangered Species	_____	_____	_____	_____	_____	_____
15. Critical Habitat	_____	_____	_____	_____	_____	_____
16. Natural Areas	_____	_____	_____	_____	_____	_____
17. Historical / Archeological Sites	_____	_____	_____	_____	_____	_____
18. Motor Traffic	_____	_____	_____	_____	_____	_____
19. Population	_____	_____	_____	_____	_____	_____
20. Income	_____	_____	_____	_____	_____	_____
B. <u>PLANS & FORECASTS</u>						
21. Coastal Zone	_____	_____	_____	_____	_____	_____
22. Shoreline and Shore Land	_____	_____	_____	_____	_____	_____
23. Wild and Scenic Rivers	_____	_____	_____	_____	_____	_____
24. Floodplains and Greenways	_____	_____	_____	_____	_____	_____
25. Environmental Corridors	_____	_____	_____	_____	_____	_____
26. Water Quality	_____	_____	_____	_____	_____	_____
27. Critical Areas	_____	_____	_____	_____	_____	_____
28. Local Land Use	_____	_____	_____	_____	_____	_____
29. Watershed Restoration	_____	_____	_____	_____	_____	_____
30. Growth Projections	_____	_____	_____	_____	_____	_____
C. <u>PARCEL/PLOT INFORMATION</u>						
31. Parcel Size/Ownership	_____	_____	_____	_____	_____	_____
32. Use of Parcel	_____	_____	_____	_____	_____	_____
33. Property Value	_____	_____	_____	_____	_____	_____
34. Taxes	_____	_____	_____	_____	_____	_____
35. Zoning	_____	_____	_____	_____	_____	_____
36. Easements/Restrictions	_____	_____	_____	_____	_____	_____
37. Utilities Available	_____	_____	_____	_____	_____	_____
D. <u>REGIONAL SURVEY RESULTS</u>						
38. Regional surveys of Outdoor Recreation: participation rates, willingness to pay, etc.	_____	_____	_____	_____	_____	_____
39. Regional surveys of Preferences for Environmental Amenities	_____	_____	_____	_____	_____	_____

Figure 6. Example checklist of regional information to develop wetland benefit indicators

4 Discussion

Geographic Scale of Services

Only a few wetland services accrue at the wetland site; most are provided downstream and elsewhere in the watershed (Table 6). The area over which services are provided and over which values accrue can be quite large. However, the size of the wetland service area will differ significantly from service to service. This means that a multiscale evaluation of services may be necessary to assess both the geographic range of services and the changing preferences that people have for them as distance increases from the wetland site. This can be particularly important if value-based indices are being used to “score” wetland mitigation trades or determine the service area of a mitigation bank.

Table 6 lists some important wetland services, indicates the scale at which they provide active and passive values, and identifies some basic landscape variables that could be used to measure the level of wetland services. The landscape variables listed in Table 6 are ones that can be measured with relative ease in a GIS that includes land use and topographic maps. The on-site services associated with the habitat functions provided by a wetland are generally limited to hunting, viewing, or gathering. However, by using landscape measures to consider the connections between the wetland site and other wetland sites in the region, it is possible to establish whether a particular wetland is part of a habitat corridor or stream buffer that provides other regional services, such as providing views from nature trails, and how much they contribute to broader regional and national values, such as biodiversity and carbon cycling.

A range of wetland types is desirable to provide a range of services. Not every wetland within each wetland type and not all wetland types need to perform the same services to be equally valuable. Some services are mutually exclusive. For example, increasing public access to improved recreational opportunities may limit the potential for the site to provide breeding habitat for endangered species. This suggests that maintaining some diversity of functions and services, even within wetland types, may be desirable. Recommending how various sets of indices should be used to prioritize trade-offs among wetland services is beyond the scope of this paper. However, research suggests that the types of indices proposed here do focus attention on essential wetland trade-offs and do provide a basis for framing questions about the relative value of different wetlands. With additional work on indicator development it is expected that an indexing system similar to the one outlined here could provide a credible and practical basis for answering questions about the relative value of wetlands.

Table 6
Indicators to Link Functions to Services at Various Spatial Scales

Generalized Function	Potential Landscape Components of Service Subindices	Potential Services			
		On-site (Active Use)	Watershed/County (Active Use)	Regional/State (Active Use)	Global (Passive Use)
Habitat/biodiversity: provide for variety of plants & wildlife using wetlands	Core area and nearest neighbor distances between local wetlands (or other fragmentation measure); site access; adjacent/nearby land use; ownership	Hunting; viewing; gathering (berries, nuts, mushrooms)	Property value maintenance; fishing via habitat support (e.g., organic matter inputs, spawning and nursery habitat); tourism related to viewing endangered species	Variability of production (option value); fishing via habitat support (organic matter inputs); reduce risk of function loss (through resilience to perturbation); research opportunities	Existence value/bequest option of flora and fauna; human life support; health risks avoided
Water quality related: sequester and cycle nutrients and particulates; aquatic habitat	Downstream: Connection to water source? Swimmable/fishable? Upstream: Land use in residential, industrial, or commercial land uses? RCRA/Superfund sites?	Aesthetics	Swimming; fishing via habitat support (chemical); human health support; food supply	Protect drinking water resource for current/future needs	Existence value/bequest option of water source; fish habitat
Hydrologic functions: store water; moderate peak and base flow fluctuations	Residential/commercial riparian land uses downstream; land area potentially draining to that site	Erosion control, peat or hay supply, aesthetics	Flood control; channel maintenance; fishing via habitat support (structural, e.g., maintaining base flows)	Food production and fishing through fish habitat support in estuary, near-coastal habitat (e.g., by reducing sediment inputs to receiving waters); protect groundwater supply	Existence value/bequest option of fish habitat

Next Steps

To be useful, the proposed WVI System would need to be cost-effective and yield results that would withstand technical and legal challenges. It is hoped that these requirements will be satisfied by undertaking further research in three areas. First, further index development will identify the necessary core components of various subindices and determine the most commonly available data for their development. It is planned to develop regional databases to enable the indices to be applied consistently using default values but still leave the opportunity to adapt the indices to individual situations. Second, it is hoped that index testing will be able to provide guidelines or decision trees that will allow many wetland sites to be excluded from a full analysis. Certain site characteristics or combinations of characteristics consistently lead to scores high enough or low enough to obviate the need for a full analysis. Third, it is planned to develop a broad consensus among at least applied environmental economists that the proposed indices are based on sound economics, reflect wetland values, and in the absence of dollar-based estimates of wetland value, provide a credible basis for comparing wetlands in terms of their contribution to human welfare.

There are socioeconomic considerations that need to be taken into account when comparing wetland values that were not described here, but could be included in the WVI System later. The two most important considerations involve equity and scale distinctions. For example, moving functions and services from one location to another (e.g., urban to rural settings) affects who gains and who loses from wetland trades, as well as overall gains and losses. Society may not be indifferent to such wetland trades even if the overall gains exceed the losses. Similarly, functions that generate beneficial services at broader geographic scales may impose “disservices” or “disamenities” at smaller scales (e.g., mosquito-breeding wetlands support downstream trout fisheries, but may be a local nuisance). The indices developed here can be used to illustrate who gains and loses as a result of wetland policies and wetland trades and to identify when and where equity and scale issues may be significant.

5 Conclusions

The purpose of this report was to introduce a system for developing indices of relative wetland values on the basis of biophysical indices of wetland functions (i.e., the Wetland Value Index (WVI) System). Developing an overall index of wetland value will require supplementing site-based indices of Level of Function (e.g., FCIs) with a combination of site-based and landscape-based indices reflecting Level of Service, Nominal Service Value, and Expected (risk-adjusted) Service Value. It will also require establishing individual and community preferences for various services. A variety of methods and potential indices for building on the results of the HGM Approach to arrive at service-specific and overall wetland values were described. Several options need to be examined more carefully before specific methodological or practical recommendations can be made. However, work so far resulted in three general conclusions that should form the basis for further research.

First, the FCIs developed using the HGM Approach provide a useful but limited basis for developing relative indices of wetland values. The main limitation is that FCIs are based on an implicit preference for a balanced mix of functions being provided by all wetlands within a regional wetland subclass. FCIs are pegged to conditions in “reference standard wetlands,” those wetlands in a region that exhibit the highest level of function across the entire suite of functions performed by that wetland subclass (Smith et al. 1995). Other wetlands will score lower than the reference standard if they provide less function, and may score lower if they perform a function at a level higher than the reference standard if that level of function is deemed to be unsustainable or is detrimental to other functions. In other words, if a wetland provides more than the reference standard site of a function that is scarce or important or irreplaceable, it actually may have a negative effect on its FCIs. This makes FCIs a difficult basis for building value indices that must reflect the scarcity of wetland functions as well as comparative advantage of wetland sites.

Second, developing indices of wetland services, values, and risks to supplement the results of HGM assessments would make the results of the HGM Approach much more useful for evaluating wetland trade-offs, prioritizing wetland restoration, and managing wetland mitigation trades. Extensions of FCIs into the realm of wetland services and risks can be made objectively without making any ethical or moral judgments about the value of services or the appropriate response to various types of risk. Even extensions into the realm of service values can be made objectively using conventional analyses of supply and demand conditions and various methods of ranking public preferences.

Third, it may be possible to develop credible indices of wetland services, values, and risks without getting involved in costly data collection efforts or relying on complicated process-based risk assessment models or controversial nonmarket valuation studies. It may also be possible to develop these indices in ways that are objective, would withstand technical and legal challenges, and would provide a stronger economic justification for protecting wetlands than are now available. These indices would be similar in most ways to indices that are used to compare the economic values of other types of privately and publicly owned assets. Applications of modern GISs should make it possible to "automate" the development of crude low-cost indices of relative wetland values that could improve wetland management decisions considerably.

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