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Ecological functions and values of nontidal wetlands

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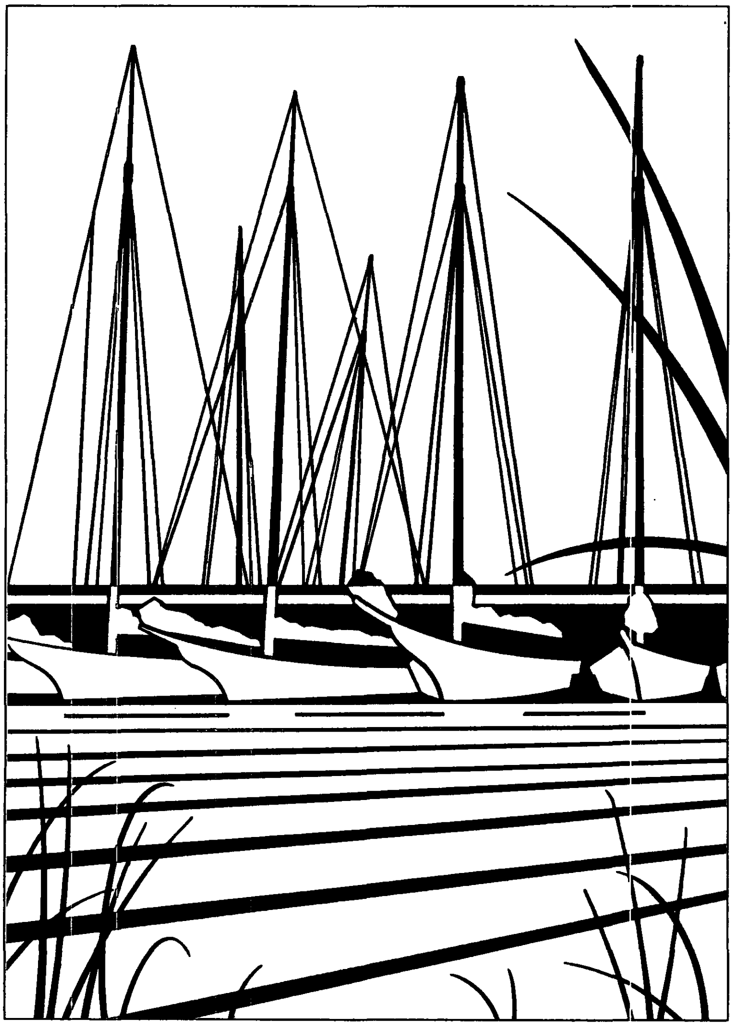
Virginia Institute of Marine Science

Perspectives on Chesapeake Bay, 1992: Advances in Estuarine Sciences



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INTRODUCTION

Perspectives on Chesapeake Bay, 1992 is the third in a series of research volumes that have been published by the Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) since 1988. The purpose of these literature syntheses is to provide managers, scientists, legislators, and other interested people with summaries of research findings, key management issues, and other information on a range of Chesapeake Bay–oriented topics—all presented at a technical level comprehensible to the generalist. Each volume, therefore, is intended to make a useful contribution to a better understanding and the improved management of the Bay's ecosystem—and ultimately to the restoration and sustained well-being of what is the nation's largest estuary.

This volume consists of four papers, each of which focuses on a specific research topic:

- "Ecological Functions and Values of Nontidal Wetlands," by Carl Hershner, reviews our current understanding of the functions of nontidal wetlands, assesses the problems of assigning values to wetland functions, and surveys the use of these functions and values in management programs of the mid-Atlantic states. Although the author discusses nontidal wetlands in general, he makes it clear that the findings and implications of numerous wetlands research studies are directly applicable to all wetlands in the Bay.

The focus on nontidal wetlands is timely and relevant. Even though they account for over two-thirds of the Bay area's wetland acreage, research generally has been limited to specific wetland types and functions; it has not yet led to an equal understanding of all potential wetland functions. Among the functions described in the paper are groundwater recharge and discharge, flood storage and desynchronization, shoreline anchoring and the dissipation of erosive forces, sediment trapping, nutrient retention and removal, food chain support, provision of habitat for fisheries and wildlife, and recreational opportunities.

Currently, wetlands managers are faced with a dilemma of competing interests: the preservation of these irreplaceable resources versus the demand for development of natural areas by our rapidly expanding population. Given the "fundamental incompatibility" of these two interests, the author declares, it is essential to have "a generally accepted method for determining the value of a wetland and for comparing the value of one wetland with that of another." However, as he concludes, such a method is not yet available, although considerable progress could be made in the Chesapeake Bay region "if the efforts of multiple research and funding agencies could be . . . [incorporated into a] well-planned research strategy."

- "Groundwater Discharge in Coastal Systems: Implications for Chesapeake Bay," by William G. Reay and George M. Simmons, Jr., examines the role of groundwater as both a source and transport mechanism of nutrients and other contaminants. As the authors demonstrate, that role is a significant one in many coastal regions, but it needs to be better understood in the Chesapeake Bay watershed, where most research to date has concentrated on the contributions of point-source contaminants and non-point source surface runoff. Furthermore, the studies reviewed by the authors mostly concentrate on dissolved inorganic nitrogen; however, there are other groundwater contaminants, such as synthetic toxic compounds and pesticides, that also should be studied closely.

Drawing from their analysis of the leading studies, the authors conclude their paper with several broad research recommendations that are designed to provide a more complete scientific understanding of the Bay region's groundwater discharge processes and groundwater/wetland interactions, a more comprehensive system of groundwater monitoring, and the development of so called best management practices that take into account groundwater contamination and the transport of such groundwater-borne pollutants to aquatic systems.

- "Low-Level Effects of Toxic Chemicals on Chesapeake Bay Organisms," by David A. Wright, Jacqueline D. Savitz, and S. Ian Hartwell, focuses on the low-level effects that toxic substances have on certain Bay species. These effects are generally less obvious and more pervasive than the lethal responses measured in the laboratory and observed in the Bay waters. The authors describe the principal toxological approaches used by researchers and summarize the findings of numerous field and laboratory studies. They conclude that, although there is strong evidence that toxic substances do have adverse effects on the Bay's biota (tumors in fish have been correlated with exposure to toxicants, for example), more research is needed to ascertain the precise linkages that may or may not exist between low-level exposures and various effects, such as the decline of a fish stock. Furthermore, most of the studies to date have concentrated on the Elizabeth River, which is the most heavily polluted portion of the Bay system, and those studies have been useful in establishing a reliable connection between contaminant and effect. Accordingly, the authors call for a systematic approach to a Baywide determination of toxicity.

- "Fisheries Assessment and Management Synthesis: Lessons for Chesapeake Bay," by William A. Richkus, Steven J. Nelson, and Herbert M. Austin, describes the basic approaches that are used for stock assessment of the fish and shellfish stocks of the Chesapeake Bay system. The authors summarize the principal methods of stock assessment and fisheries management that have been—and are being—applied to Bay fisheries, with particular emphasis on data collection and the use of models. They then present case studies of three critical species: (1) the striped bass, a Bay-spawning pelagic predator that has suffered a serious stock decline during the past two decades but holds promise of being restored through the current use of a vigorous and effective management strategy; (2) the blue crab, a benthic scavenger that has been the basis of the Bay region's most valuable fishery for almost a decade but now faces the possibility of undergoing a serious stock collapse caused by overfishing; and (3) the Eastern oyster, a native shellfish species that was long the basis of the Bay's leading fishery but, since the 1960s, has declined to the point where it is questionable that the fishery can continue.

Both in the body of their paper and in the three case studies, the authors summarize the findings of a variety of studies (including some that look at striped bass stocks elsewhere in the United States, for comparative purposes), and they also summarize the status of stock assessment efforts and the pros and cons of the various models that have been developed and applied to Bay species. Based on their review, the authors conclude that the data required for effective stock assessment are still not available, which seriously hampers the use of models and other useful analysis and management tools. Accordingly, they state, "current fisheries management priorities for the Bay must continue to be focused on recruitment-related issues."

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Ecological Functions and Values of Nontidal Wetlands

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Introduction

Until the latter half of this century, wetlands were generally considered to be wastelands, and efforts to drain or fill them were applauded. Today, the United States has already lost more than half of its original wetlands. An ever-expanding body of research is clarifying our understanding of the functions of wetlands and has brought with it the realization that wetlands are of enormous value to us.

Wetlands directly or indirectly benefit the entire ecosystems in which they are found, including the resident human population. Among other beneficial functions, wetlands can filter out excess nutrients and contaminants from runoff and can facilitate their breakdown before they are transported to open water or aquifers. If they occur in a flood zone, wetlands can absorb some or all of the destructive force of floodwater, protecting land and human populations located downriver.

About 1.2 million acres of wetlands dot the Chesapeake Bay drainage basin, covering about 3% of the watershed's total area. Contrary to popular impression, two-thirds of this acreage consists of nontidal, or inland freshwater, wetlands. Recognizing the significance of nontidal wetlands has led to an appreciation of the need for preservation and conservation of these resources, especially in the Bay region.

Currently, we are confronted with the problem of managing wetlands in the face of demands associated with a dramatically expanding human population. Among these demands is the pressure to convert natural areas, especially wetlands, into developed landscapes for direct and obvious short-term advantages to humans. Such conversions, though, not only reduce or nullify the function and value of the converted wetlands but also place increased pressures on remaining wetland resources. These two competing interests—the demand for space for an expanding human population and the obligation to preserve irreplaceable natural resources—represent an obvious dilemma for wetland managers. Given the fundamental incompatibility of the two interests, it is now more important than ever that we have an established and generally accepted method for determining the value of a wetland and for comparing the value of one wetland with that of another.

Establishing appropriate management practices for nontidal wetland resources has become the focus of extensive public debate in recent years. Several factors have combined to make the issue particularly contentious within the Chesapeake Bay region. For example, many of the remaining nontidal wetlands occur where population growth

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and development are most pronounced, as in southeastern Virginia. In addition, many of the areas now recognized as nontidal wetlands consist of land types that, in the Chesapeake Bay region, historically have been converted to other uses. Consequently, preservation or conservation of the resource requires a departure from previously accepted practices [92].

A thorough understanding of the functions of nontidal wetlands—what they do that is of value to society—is key to resolving the debates about wetland management. Should wetlands be preserved in favor of competing uses for the land area? How can our knowledge of wetland functions be used to better manage these disappearing resources?

This paper provides a brief review of the current state of understanding of nontidal wetlands and their functions and notes current management programs that are making an effort to incorporate such information. It analyzes some aspects of the relationship between management efforts and the current technical understanding of the resource. Finally, it forecasts a general trend in the management of nontidal wetlands based on the integration of developing technical insights into management efforts.

Two terms, *function* and *value*, are used throughout this paper. *Functions* of nontidal wetlands are biological and physical processes that can be measured, usually quantitatively. A *value* of a nontidal wetland refers to a positive characteristic that results from the performance of one or more functions. For example, floodwater storage is a function of some wetlands, and, for obvious reasons, it lends value to those wetlands. Values are either qualitative or quantitative and are identified through an assessment process.

Classification of Nontidal Wetlands

The structure of a nontidal wetland is influenced by many factors, including the vegetative community, soils, hydrology, water chemistry, local topography, and human activities [34, 50, 81]. Efforts to classify nontidal wetlands can be based on any one or several of these characteristics, but most commonly the vegetative community and hydrology serve as discriminating factors. In reference to dominant vegetation, there are four general groups of nontidal wetlands common to the Chesapeake Bay region: (1) forested wetlands, (2) scrub-shrub wetlands, (3) emergent wetlands, and (4) aquatic beds. Of these, forested wetlands are by far the most common [112, 113, 119].

The most broadly employed and referenced classification scheme for nontidal wetlands is one developed by the U. S. Fish and Wildlife Service (USFWS) to conduct an inventory of the nation's wetlands [34]. It classifies wetlands on the basis of three factors: (1) the source and frequency of flooding of the wetland, (2) the predominant type of vegetation occurring in the wetland, and (3) the soil type within the wetland.

According to the USFWS classification, the majority of nontidal wetlands in the Chesapeake Bay region fall within the palustrine system. Palustrine wetlands are tidal or nontidal freshwater systems (other than riverine or lacustrine) typically dominated by trees, shrubs, or other emergent plants. The common water regime for forested wetlands is either seasonal or temporary flooding.

Although the USFWS classification scheme is referenced frequently in wetland management programs, it is not usually the basis for organizing the management effort. Most state programs that distinguish between wetland types for regulatory purposes classify wetlands on the basis of landscape position or performance of a special function or functions. For example, Virginia's Chesapeake Bay Preservation Act identifies nontidal wetlands of interest to the management effort on the basis of their proximity to surface waters or tidal wetlands. Maryland identifies "wetlands of special State concern" based on their service as habitat or as ecologically important buffers for endangered or threatened species. At the federal level, the USFWS is developing a national wetlands priority conservation plan [118] by identifying those wetlands that provide significant functions or value that affect at least two of the following areas: wildlife, fisheries, water supply, flood and erosion protection, outdoor recreation, or special concerns (such as research, education, archaeology, uniqueness of the resource).

Currently, classification of nontidal wetlands appears to take one of two forms in the Chesapeake Bay region. Wetlands tend to be classified based on their structure (for purposes of inventory development) or on their function (for management purposes). If management is based on an interest in function, why are inventories not produced on that basis? Structure is easy to observe, but functions are much more difficult to determine, which reflects our current state of knowledge. Although there are links between these two aspects of a wetland, the relationship is not strong enough to permit the prediction of one from the other with certainty. Nevertheless, structure is used commonly to assess the opportunity a wetland has to perform certain functions, and management decisions are frequently based on opportunity assessments rather than an absolute determination of functions.

Nontidal Wetland Functions

The technical understanding of nontidal wetland functions is expanding rapidly. At present, there are volumes of information on particular wetlands and on specific functions of various wetland types, but research is not progressing uniformly in that we do not equally understand all the potential functions of a wetland. Understanding has progressed, however, to the point that numerous efforts have been supported to develop methods for cumulative assessments of the value of individual wetlands.

Definitions of the potential roles of wetlands are generally agreed upon among researchers. This consensus is evidence of progress toward a truly comprehensive understanding of the role of wetlands within the ecosystem. The list of roles currently used in most discussions of the resource has not changed drastically in more than a decade. On the other hand, the methods for assessing many of these functions and values remain the focus of much debate and development, and no one seems willing to accept any one method as appropriate for all systems. This debate does not reflect a failure of the science. Rather, it is a consequence of the evolving understanding of the complexity of processes both within wetlands and between wetlands and the surrounding landscape.

There have been many attempts to develop a composite list of the functions of wetlands. One of the first such efforts was conducted in the 1970s by the National Wetlands Technical Council [27], which grouped functions into five general categories: (1) food chain values, (2) habitat values, (3) hydrologic and hydraulic values, (4) water quality maintenance values, (5) harvest and heritage values.

In an effort to develop an assessment methodology for wetlands, Adamus [1] expanded the council's list to include 11 specific functions. Although his expanded list is often modified by subdividing certain functions [4, 67, 104], one form or other of the basic list is commonly used as a practical basis for current work. As developed by Adamus, the basic list of wetland functions is:

(1) Groundwater recharge
(2) Groundwater discharge
(3) Flood storage and desynchronization
(4) Shoreline anchoring and dissipation of erosive forces
(5) Sediment trapping
(6) Nutrient retention and removal
(7) Food chain support
(8) Habitat for fisheries
(9) Habitat for wildlife
(10) Active recreation
(11) Passive recreation and/or heritage value

In the following brief discussion, the basic list has been collapsed into 8 categories.

Groundwater Recharge or Discharge

Wetlands may serve to recharge groundwater supplies or as points of groundwater discharge to the surface. The probability of these occurrences is related to the wetland's position with respect to the local groundwater table and the surrounding topography [56, 64, 81]. Wetlands that are net recipients of surface and interflow waters are potential contributors to local groundwater aquifers if they also possess a positive hydraulic head with respect to the aquifers. Even when the physical setting is appropriate, a wetland must overcome significant evapotranspiration losses before it becomes a net contributor to groundwater [30, 39]. In addition, because the soils of wetlands are typically less permeable than soils associated with groundwater recharge areas [70], wetlands are less likely to recharge groundwater than other areas are. Nontidal wetlands have been shown to play significant roles in groundwater recharge in certain settings [64, 76, 79], but typically they accomplish this function only seasonally, if at all.

Wetlands commonly occur in areas where groundwater is being discharged and, in this context, they may serve as indicators of shallow, high-yield aquifers [55]. This correlation has been demonstrated in glaciated landscapes, such as in Wisconsin [87] and Massachusetts [83], but remains uncertain elsewhere. For example, it is believed that bottomland hardwood wetlands generally do not serve as groundwater discharge sites because of their saturated conditions, flat hydraulic gradients, and tendency to accumulate organic matter [3, 25].

The role of wetlands as groundwater recharge or discharge sites is apparently site-specific, with the net direction of water flux determined by the local hydrology. In the Chesapeake Bay region, many nontidal wetlands may play only minor roles in the recharge of groundwater aquifers. Some wetlands may vary seasonally between serving as significant discharge sites when evaporation and transpiration are highest, and as minor recharge sites during wet winters. Without site-specific investigations, hydrologists do not agree on the characteristics that might be used to indicate whether a wetland is primarily a discharge or recharge site [104].

Flood Storage and Desynchronization

The role of wetlands in modifying the impact of runoff from storm events is widely accepted and extensively documented. Wetlands occupy positions in the floodplains of many rivers, providing a uniquely adapted avenue for the downstream transport of floodwaters [25, 63, 72]. Wetlands also are found at or near the headwaters of many small tributaries. In such locations, they can intercept and slow the movement of runoff, thereby reducing the "flashy" behavior of some watersheds where upland runoff conditions develop rapidly following rain events [69, 103]. Individual wetlands can absorb and thereby retard some or all of the force of a flood. Retardation of flood flows by multiple wetlands in a watershed generally results in desychronization of flood flows in the sub-watershed area served by the wetlands.

Six major factors have been identified by Adamus and Stockwell [4] as affecting the ability of wetlands to perform flood control functions:

(1) Magnitude and duration of storm events
(2) Ability of upslope areas to retain and dissipate runoff
(3) Above-ground wetland basin storage capacity
(4) Frictional resistance offered by wetland basin morphology and vegetation
(5) Below-ground water storage capacity of wetland sediments
(6) Position of wetland basin in the watershed

The beneficial function of wetlands in flood storage and desynchronization of flood flows has been demonstrated in studies of two specific basins in Massachusetts [29, 31, 35]. These studies estimated the change in flood stage resulting from removal of wetlands from the watershed, channelization of the river, or replacement of wetlands with man-made flood control structures. The U. S. Army Corps of Engineers developed a framework for analyzing floodwater storage and retardation functions of wetlands [100]. The corps concluded that flood storage potential is high when wetlands constitute more than 20% of the total watershed area, and that the potential for flood retardation is high when the vegetative cover of wooded or shrub swamps is more than 30%.

More recent work in Massachusetts [94, 95, 96] has demonstrated that the effectiveness of a wetland in reducing downstream flooding increases with (1) the size of the wetland, (2) the wetland's proximity to the area of potential damage, and (3) the magnitude of flooding. On the other hand, the wetland's effectiveness decreases (1) as the distance increases between the wetland and the area of potential damage downstream, (2) with increased human encroachment into the wetland, and (3) as the areas of water storage decrease upstream of potential damage locations.

Shoreline Anchoring and Dissipation of Erosive Forces

Wetland vegetation is generally regarded as effective in binding soil particles to roots and rhizomes, but the degree to which nontidal wetland plants perform this important function is not extensively documented. Studies of coastal wetlands indicate that they can establish themselves in low-energy settings and will persist in those settings given sufficient opportunity to establish below-ground structures [54]. It is likely that similar processes enable nontidal wetlands to be effective in buffering sediments against erosive forces that occur in occasional and unusual episodic events [59]. Little has been published on landscape anchoring of nontidal wetlands. Consequently, no criteria or characteristics of nontidal wetlands can be applied generally to an assessment of their value in this role.

Sediment Trapping

Wetlands are widely considered to be effective traps for sediments; thus, they help mitigate the effects of nonpoint-source pollution. The development of wetlands in certain settings, particularly in areas bordering open-water environments, is attributed to their ability to retain deposited sediments and organic matter. The success of a wetland in acquiring and retaining sediments is affected by the amount of sediments transported into the wetland, the capacity of the wetland vegetation to dissipate the energy that keeps the sediments in suspension, and the ability of the vegetation to protect the sediments from resuspension [10, 12, 20, 28, 59].

The relevant literature provides no specific criteria for assessing the values of nontidal wetlands as sediment traps, but there have been a few studies of specific wetlands that give evidence of the sediment-trapping capacity of such systems [59, 66]. Analysis of watersheds in northern Wisconsin has established a relationship between the amount of wetlands in a watershed and the sediment load of the system [86]. Watersheds with 40% coverage by wetland and open-water acreage had sediment loads approximately 90% lower than watersheds with no wetlands. A similar study conducted in Minnesota [88] concluded that maintaining about 10% of a watershed as wetlands achieved a practical maximum level of efficiency in sediment retention. Greater amounts of wetlands produced only marginal increases in retention effectiveness. Studies on the transport and deposition of sediments in a North Carolina agricultural watershed [28] found that 80% of sediment loss from fields was deposited in riparian areas, with the remaining 20% being deposited in the floodplain swamp. The above studies suggest that freshwater wetlands can be particularly effective as filters in the landscape, but currently there are no generalized quantitative methods for assessing this function without site-specific studies.

Nutrient Retention and Removal

The role of nontidal wetlands in the interception and processing of excess nutrients and other pollutants is of intense interest in the Chesapeake Bay region. The capacity for wetland systems to reduce the transport of such substances to adjacent open-water systems is one of the principal reasons for management interest. There have been numerous studies of selected wetland systems that demonstrate the capacity of wetlands to serve as sinks, sources, or transformers of nutrients [14, 15, 16, 20, 23, 24, 32, 33, 45, 46, 48, 61, 62, 63, 65, 66, 68, 77, 78, 79, 85, 90, 93, 97, 102, 111, 114, 120, 122, 123].

Although much research has focused on this function, there are no quantitative generalizations applicable to all wetlands. For management purposes, most evaluations of the function rely on qualitative assumptions that, in essence, address the opportunity a wetland has to perform the function. A wetland can be either a sink or source depending on the nutrient (whether it is organic or inorganic, reduced or oxidized, and what its loading rate is), the time of year, and whether the wetland is aggrading owing to deposition or degrading owing to erosion [101]. In general, a wetland's opportunity to trap or transform a substance is positively related to the duration of contact. Anything that increases the duration of contact, such as greater wetland size or greater dispersion of transport pathways, potentially increases the ability of a wetland to perform the trapping or conversion processes successfully. These relationships are not unbounded, however. Studies have repeatedly indicated that there are limits to the capacity of wetlands to retain nutrients and other pollutants. The processes that reduce the transport of these substances to adjacent waters result in physical, biological, and chemical changes in wetland systems that can reduce their capacity for additional assimilation. The biological and chemical processes involved in nutrient removal also are constrained by their own rate limitations [33].

In many respects, the increasing understanding of how a wetland's biological, geochemical, and physical characteristics define its capacity to influence water quality has complicated efforts to produce generalizations about this wetland function. A wetland's efficiency in nutrient retention apparently varies depending on several characteristics, including the wetland's vegetative makeup, geographic location, size, water chemistry, temperatures, and pH level, and the nature of the substrate in which the nutrient is located [104]. Accurate evaluation of nutrient retention and removal in a particular wetland can require rather specific information about the wetland's structure.

Food Chain Support

Adamus and Stockwell [4] have defined food chain support in wetlands as the direct or indirect use of nutrients, in any form, by animals inhabiting aquatic environments. Wetland vegetation supports food chains by converting solar energy and inorganic nutrients into useful organic compounds. Wetlands are typically more efficient in performing this activity than terrestrial systems are. Formerly, the organic output of their high productivity was assumed to provide valuable support to adjacent aquatic systems. This feature is no longer accepted as a uniform characteristic of wetlands. The relationship between a wetland and the adjacent aquatic system is influenced primarily by hydrologic conditions (e.g., frequency of flooding) [17, 18, 25, 30, 33, 53, 101, 111, 120, 123]. Although wetlands may generally be very productive parts of the landscape, the contribution of nutrients and organic material to adjacent systems is controlled primarily by the movement of water through the wetland. This process has not been studied as extensively in inland freshwater wetlands as it has in coastal wetlands. In 1981, Brinson et al. [18] reviewed the literature and concluded that rivers draining watersheds in which wetlands are a significant component have higher levels of total organic carbon than do watersheds with few wetlands. In 1983, however, Adamus and Stockwell [4] summarized the available information and determined that no link between wetland-derived materials and fisheries production had been decisively documented for any freshwater system. In a more recent review, Sather et al. [104] have concluded that the functional value of wetlands, in terms of food chain support, is not well understood. They attribute this finding to the large number of factors and processes that can influence the function, and to the lack of reliable information on the ways in which these factors and processes are related to the support of food chains.

Habitat for Fauna and Flora

The habitat function of wetlands has probably received more intensive study than any other aspect [4, 26, 38, 40, 49, 93, 104, 109, 123]. A great deal of information has been amassed about the characteristics of wetlands that make them suitable habitat for those species of birds and fish studied. Less information is available for flora; the presence of various plant species in wetlands has been documented, but habitat requirements for wetland plant species, particularly rare and endangered species, have not been documented as well as many of the faunal species requirements have been. As a consequence, though some important research has been done on floral habitat requirements, the information bases that have been generated for faunal habitat requirements are disproportionately stronger.

In general, a wetland's value as habitat seems related to the complexity of both the wetland and the surrounding landscape. For some fauna, wetlands typically serve as only a part of a species's overall habitat requirement. Birds use wetlands for refuge, nesting sites, and feeding areas. Similarly, fish enter wetlands from adjacent aquatic habitats in search of refuge, food, and nursery areas. Few faunal species are restricted to wetlands for their entire life cycle; however, wetlands are often critical to the successful completion of some phase in the life cycles of many species. The quality of the adjacent terrestrial and aquatic systems is related to wetland value as habitat. Interspersion of relatively pristine upland, wetland, and open-water areas within a region seems to enhance the habitat value of the landscape for most species investigated.

Socioeconomic Values, including Recreation and Heritage Value

This suite of wetland roles includes aesthetic, historic, and archaeological values, as well as service for recreation, education, and research. Adamus and Stockwell [4] identified categories of active and passive recreation functions, which have been expanded in many more recent reviews of the subject to include the potential economic benefits derived from the use of wetland resources. Although such functions are included in most efforts to assess individual wetlands, there is no generally applicable value. The importance of the functions varies greatly among wetlands. In addition, no concensus has been reached concerning the choice of methods used to determine their importance.

Socioeconomic and recreational functions of wetlands are usually grouped into consumptive- and nonconsumptive-use values. The nonconsumptive uses are not easily translated into quantifiable values. Numerous methodologies for measuring, for example, the aesthetic, historic, or other social values of wetlands have been developed and argued [11, 41, 43, 52, 75, 84, 99, 105, 106, 107, 108, 115, 117, 121]. Although the science of measuring human perception continues to evolve, precise quantification of these functions or their values remains elusive. Several authors [104, 110] have noted that many of the wetland characteristics typically employed in assessment of nonconsumptive-use values are the same as those that are key to the function of wetlands as animal habitat.

Consumptive uses of wetlands have been extensively documented and evaluated. The ability of wetlands to produce or support harvestable resources has been assessed for timber [13, 58, 60], agricultural crops [36, 37], energy [42, 98, 100], fisheries [74], wildlife [22, 74], and water supply [7, 82]. Despite the extensive documentation of the existence of wetland values in these areas, there is no consensus on an appropriate evaluation method [11, 19, 44, 67, 91, 104, 105, 106, 107, 108]. The capacity of a wetland to support consumptive uses is dependent on specific characteristics of the wetland (both physical and biological), and the value of such uses is related to the opportunities or demand for the uses. One characteristic of consumptive uses that makes them difficult to assess is the inherent alteration of the wetland system. The resultant impact—usually negative—on other wetland functions is unavoidable and often long term.

Methods for Assessing Wetland Functions

Through the years, a number of methodologies have evolved for assessing one or more of the functions of wetlands [1, 2, 3, 4, 5, 8, 9, 21, 43, 49, 57, 67, 69, 70, 71, 73, 75, 89, 96, 99, 115, 117]. The development of these various methodologies has occurred as a result of increased technical understanding of the systems and in response to the needs of management programs. The USFWS's Habitat Evaluation Procedures (HEP) [116] are an example of one method that has been frequently employed or modified for analysis of a single wetland function. However, the U. S. Army Corps of Engineers' Wetlands Evaluation Technique (WET) [1, 2, 4] probably is the most commonly used or adapted method for a comprehensive assessment of wetlands.

One characteristic of both the HEP and the WET, and their many subsequent modifications, is the focus on an individual wetland or set of wetlands. Neither method is designed to support assessment of broad types or classes of wetlands. As such, the most significant use of the methods is in implementing, rather than developing, wetland management policies.

The HEP is useful in assessing an area's value as habitat for selected fish and wildlife species. Use of the HEP involves selection of a species or group of species as the focus of the assessment. If the species's habitat requirements have been described by a Habitat Suitability Index (HSI) model, which assigns a value based on a field checklist, then an index value can be developed for the wetland area of interest. This index value, in conjunction with the wetland's size, can be used to develop a quantitative assessment of the habitat value of the wetland for the species selected. The HEP can be used to evaluate changes in habitat quantity and quality resulting from actual or proposed changes to an area. The method requires specific definition of each species's habitat requirements (HSI models). Its application is therefore limited to those species for which the information is available. The method is sometimes criticized because there is no consensus on the suite of species that is most appropriate for inclusion in an analysis; the species included can influence the assessment derived by using the method.

The WET is used to evaluate individual wetlands for performance in groundwater recharge/discharge, flood flow alteration, sediment stabilization, sediment/toxicant retention, nutrient removal/transformation, production export, aquatic diversity/abundance, wildlife diversity/abundance, and recreation/uniqueness/heritage. This technique seeks to evaluate a wetland on the basis of the social significance of each function, how effectively each is performed, and the likelihood that the wetland will have the opportunity to perform each function. The result is a qualitative rating (high, medium, or low) of the probability that the wetland performs the function. The WET can be used to assess the consequences of change if sufficient information is available. Criticisms of the WET generally focus on the substantial amount of effort and information needed to complete an assessment. In addition, the WET is not equally appropriate for all types of wetlands. As a consequence, there have been numerous efforts to modify the procedure for specific types of wetlands or specific geographic regions [3, 47, 51, 58, 94, 118].

One example of such a modification is the Wetlands Evaluation Technique for Bottomland Hardwoods (WET-BLH) [3], which applies specifically to bottomland hardwoods in the southeastern United States. The assessment method is similar to that used in the WET, but the functions assessed are altered to be more appropriate to bottomland wetlands.

Regional modifications of the WET are being developed in both Maryland and Virginia. In these efforts, the conceptual approach remains unchanged, but the range of parameters evaluated is narrowed to reflect more accurately the conditions typical of the region.

Use of Wetland Functions and Values in State Management Programs

State management programs for nontidal wetlands vary in the manner in which they incorporate information on wetland functions. The values most commonly cited include flood and storm water control, wildlife habitat, fisheries habitat, water quality maintenance, and sediment control. Values that are also commonly cited, though less frequently, include aesthetics, erosion control, water supply, recreation, commercial uses, education, and scientific research. All management programs cite the importance of nontidal wetlands as habitat for threatened and endangered species.

The approaches taken by New York, New Jersey, Delaware, Connecticut, and Pennsylvania typify those in which selected functions are prioritized as a matter of policy, and wetlands are managed according to their involvement in those functions. Maryland uses a version of this approach but actually identifies specific wetland areas in its regulations as priority management concerns. Virginia's approach is another variation, differing in its implicit focus on a relatively restricted group of functions that affect water quality maintenance. North Carolina, while also using wetland functions to direct management efforts, does not explicitly rate functions. There, for example, wetlands can achieve similar cumulative valuations by providing a variety of combinations of services.

In classification systems, prioritizing wetlands for protection is based on wetland type. Evaluation techniques, however, rank wetlands on a site-specific basis; they generate a relative value for each particular wetland. Although the two ranking methods differ in purpose and application, they share some similarities in that both are based on wetland values. For example, in classification systems, all wetlands that provide habitat for threatened and endangered species are given the highest priority. Likewise, evaluation techniques assign the highest numerical rank to specific wetlands that provide habitat for threatened and endangered species.

A state-by-state summary of wetland management programs follows.

New York state regulations (New York Code of Regulations, title 6, chapter 10, part 664, 1980) define four ranked classes of wetlands based on the following characteristics: cover type, ecological associations, special features, hydrological features, pollution control features, distribution, and location. Each class of wetlands is defined by a specific set of characteristics. Class I wetlands must have any one of the following five characteristics: They must (1) have the geophysical structure of a classic kettlehole bog, (2) serve as habitat for endangered or threatened species, (3) serve as habitat for unusual animal species, (4) have the potential to reduce flood damage, or (5) be connected to public water supplies. Class II wetlands are defined by 17 characteristics. They include archaeological significance, association with an unusual geological feature, potential future significance in reduction of flood damage, connection to potentially useful water supplies, and service as tertiary treatment for sewage disposal systems. Class III wetlands are identified by any of 15 characteristics, which include the presence of certain types of vegetation (e.g., deciduous swamps, shrub swamps, or submerged vegetation), amelioration of pollution entering surface waters, and the presence of certain aesthetic functions. Class IV wetlands consist of all wetlands that do not qualify for the other three classes.

New Jersey state regulations (Freshwater Wetlands Protection Act, N.J.S.A. 13:9B-1, 1982) include a relatively simple classification system that distinguishes among "freshwater" wetlands of exceptional, ordinary, and intermediate resource value. Wetlands of exceptional resource value are those that discharge into waters of specific interest or that serve or might serve as habitat for threatened and endangered species. Freshwater wetlands of ordinary resource value are those that do not exhibit characteristics of exceptional wetlands. This category consists of certain isolated wetlands, man-made ditches, swales, or detention facilities. Freshwater wetlands of intermediate resource value are all wetlands not classified as exceptional or ordinary.

Delaware is preparing nontidal wetlands protection legislation that will require the state secretary of natural resources and environmental control to establish five wetland categories. Category I wetlands are those that provide exceptional value or unique biotic assemblages, such as Delmarva bays, dune swale wetlands, Atlantic white cedar swamps, and bald cypress swamps. Category II wetlands are those generally considered "permanently wet" to "seasonally wet" or those that provide significant habitat or biotic values. Category III wetlands include temporarily flooded wetlands and all wetlands not included in another category. Category IV wetlands consist of farmed wetlands. Category V wetlands are all man-made wetlands created from uplands for purposes other than compensation (e.g., drainage ditches, farm ponds, storm water retention basins, and borrow pits).

Connecticut has an evaluation procedure to assess "inland" wetlands of the state [6]. The original procedure, which assessed 13 functional values, is being modified to include 14 such values. The 14 values to be assessed by the procedure are flood control, ecological integrity, wildlife habitat, finfish habitat, nutrient retention and sediment trapping, educational potential, visual or aesthetic quality, agricultural potential, forestry potential, recreation, groundwater, erosion protection, archaeological site potential, and noteworthiness (i.e., serving as habitat for threatened and endangered species or possessing other natural uniqueness). This evaluation procedure uses simple mathematical calculations and qualitative guidelines to determine *wetland value units* for each of the functional values. The number of value units is adjusted for each area so that wetlands can be compared in terms of their functional values.

Pennsylvania manages its wetlands under authority granted to its Department of Environmental Resources by the Dam Safety and Encroachments Act. Regulations set forth under the act (chapter 105) define "important" wetlands and establish management protocols for activities in or around such wetlands. An "important" wetland is one that performs any of six functions deemed important to the public interest: (1) providing important habitat for aquatic or land species; (2) serving as a sanctuary, refuge, or research site; (3) maintaining natural drainage characteristics, sedimentation patterns, natural water filtration, or other environmental characteristics; (4) buffering erosion; (5) providing storage for storm and floodwaters; and (6) serving as prime natural recharge areas. Proposed amendments to the regulations are intended to define and clarify the department's wetlands protection policy. The amendments would continue the approach taken in the existing regulations by identifying wetlands of "exceptional value."

Maryland requires expanded buffers for nontidal wetlands of special state concern and for wetlands with adjacent areas containing steep slopes or highly erodible soils. Nontidal wetlands of special state concern are defined in state regulations as being wetlands that provide habitat or ecologically important buffers for habitat of plant and animal species listed as endangered or threatened or considered as candidates for listing, or wetlands that are unique or contain ecologically unusual natural communities [title 8, subtitle 5, Water Resources Administration]. The wetland values associated with these protective measures are fish and wildlife habitat, erosion and sediment control, and water quality improvement.

Although Virginia currently does not have a specific management program for nontidal wetlands, the resource is explicitly addressed by the state's Chesapeake Bay Protection Act. Implementation of the act, which occurs at the level of local government, calls for establishment of protective buffers around nontidal wetlands that are adjacent to surface waters or tidal wetlands in the coastal plain of the commonwealth. Other nontidal wetlands may be afforded varying levels of protection at the discretion of local governments. The intent of the act is to protect those wetland areas so that they may continue to maintain or improve the water quality of Chesapeake Bay and its tributary rivers and streams.

North Carolina is in the process of finalizing a wetland quality index evaluation procedure that will support a cumulative functional assessment of individual wetlands. The system, to be used for both nontidal and tidal wetlands, rates 12 to 14 wetland values on a numerical scale of zero to five. The numerical ratings for each value are combined to produce the cumulative assessment. Values being considered for incorporation into the evaluation procedure include endangered and threatened species habitat, wildlife habitat, groundwater recharge, sediment removal, and commercial uses. This evaluation procedure is intended to take less time than other methods currently available and to generate a quantitative evaluation to facilitate resource management efforts.

The Relationship Between Wetland Values and Management Policy

The rationale for managing nontidal wetlands is based on a wetland's ability to perform functions that are valued by society. Technical understanding of these functions affects management efforts in several ways. Management policies and/or rationales generally reflect the latest technical understanding within the field, although they may not be in perfect synchronization. Early in the 20th century, wetlands were understood as habitat for noxious pests, and accordingly, management policies focused on eliminating the habitat value or the wetland itself. In the last 25 years, numerous other functions of significant potential value to natural and human systems have been identified. This expanded awareness has resulted in the evolution of *no-net-loss* policies at both state and federal levels, which focus on the maintenance of existing areas and functions of all extant wetlands.

The degree of asynchrony between technical understanding and management policy goals is demonstrated best, perhaps, by the emergence of the no-net-loss policy. The policy was a reaction to the mounting evidence that wetlands could, and often did, perform valuable functions. However, at the time the policy was first articulated, there was no evidence that *all* wetlands performed valuable functions. In this sense, the policy leaped ahead of the technical information. Nevertheless, the goal of maintaining and even increasing the resource is justified by a recognition of the limits of current understanding about the resource. If current knowledge is incomplete, then decisions to alter or eliminate wetlands require an assumption that no additional valuable functions of wetlands will be identified in the future. A no-net-loss policy seeks to minimize this risk.

Despite an inability to generate comprehensive assessments of wetland values, the resource must still be managed. Most states within the Chesapeake Bay region have officially articulated a no-net-loss policy, but, interestingly, the regulatory programs implementing these policies generally adopt a more pragmatic approach. In most programs, the desire or need to regulate activities in a wetland is conditioned by the identifiable functions of the wetland. In essence, the states recognize that not all wetlands are equal, and, therefore, the public's interest in wetlands can vary. The acknowledgment that wetlands vary in value may be viewed as a deviation from the blanket assertion of implicit value reflected in the no-net-loss statements. However, it establishes a link to the current state of understanding and implies a responsiveness to future advances in that understanding.

Management on the Basis of Opportunity to Perform

Our understanding of nontidal wetland functions continues to expand, and the insights gained seem to reflect an increasing appreciation of the variable nature of wetland processes. For example, although one wetland may be structured similarly to another, it may perform a given function at an entirely different level in response to factors external to that wetland. Habitat value, for instance, is influenced by the composition of the surrounding landscape and by the needs of the extant biota of the system. As a function, nutrient retention and removal are valuable only if there are nutrients to retain or remove. Even when certain functions are provided by a wetland, they are usually not constant over time. Absolute determination of the functions and consequent value of a wetland can thus be a laborious task that must be repeated for every wetland. Such a task is clearly beyond the resources of most management programs. As a consequence, most management decisions are based on an assessment of the potential or opportunity that a given wetland may have to perform functions of interest. These assessments are typically based on identification of structural similarities between wetlands that are being managed and wetlands in which functions and values have been documented.

Most people agree that managing nontidal wetland resources on the basis of the wetland's opportunity to perform certain functions is the most reasonable approach. Scientists have documented the values of certain wetlands sufficiently to convince policymakers that the resource can be important; however, practical implementation of management policies necessitates making generalizations based on assumptions.

Future Management Based on Wetland Functions and Values

The understanding of nontidal wetland functions and values will continue to evolve on many fronts. Most certainly, the ability to assess functions associated with habitat requirements, water quality enhancement, and socioeconomic values will become more sophisticated and accurate. Undoubtedly, new techniques for more comprehensive evaluations of individual wetlands will be developed. All going well, they will converge into one generally agreed-upon approach.

In addition to these possible future trends, the one area of developing understanding that seems to promise the greatest revolution in current management approaches is the analysis of the relationships between wetlands and the rest of the ecosystem. This is not a new area of investigation, but it is an extraordinarily complex one. It is also increasingly appreciated as the only effective way to manage natural resources. Essentially, this approach recognizes and incorporates the understanding that wetlands do not perform their functions in a vacuum. A wetland has value because the functions it performs are essential to the system in which it is found. By extension, the wetland loses value as the need for its functions or the opportunity to perform those functions diminishes. These effects can be induced by alteration of the landscape surrounding the wetland. Because the value of the wetland resource is so intimately linked to the condition of the larger system, the public benefit derived from the wetland can be maximized only if the entire system is managed as a whole.

Conclusion

Currently, we do not have a practical method for determining the value of nontidal wetlands. Although the natural pace of science will undoubtedly fill in the deficiencies in our technical understanding of the functions and values of nontidal wetlands, the need for decisions regarding the management of the resource is immediate. On a daily basis, managers are faced with decisions concerning the development of wetlands and the consequences of such development. Similarly, it is critical that the latest technical information on nontidal wetlands be available for legal, economic, and land development decisions. Specifically, we need a sound scientific basis for revising the federal *Manual for Defining Wetlands* and other governmental procedures.

There is an obvious and urgent need for effective and efficient methods for evaluating the functions performed by individual wetlands. Although various techniques have emerged, most require so much specific information that they are impractical for routine application. The time and effort required to identify a function and assess the extent to which a specific wetland performs the function preclude the use of such an assessment for immediate management needs.

Although it might be best to preserve all wetlands until we have full knowledge of their value, the scientific community realizes that this is not a practical alternative. In an attempt to offer advice based on the best available information, researchers often extrapolate to ascertain a wetland's function, and thus its value, based on its structure or type. However, this is an imperfect method. The evolving understanding of wetland functions suggests that value may be more appropriately assessed if information on a wetland's structure or type is amended to include an analysis of the surrounding landscape. The relationships among wetland type, surrounding landscape configuration, and wetland value are difficult to define. The problem may be most tractable if approached on a regional basis; however, even on that scale, success will require a substantial and well-planned research effort.

It is important to recognize that there is not, and there cannot be, a single simple solution to the problem of appropriate recognition and management of nontidal wetland functions and values. The fact that decisions must be made immediately about management of certain wetlands requires scientists, no matter how imperfect the knowledge base, to offer guidance. However, we should consider it our responsibility to improve the existing body of knowledge with every available opportunity, in that today's decisions can have far-reaching consequences. Similarly, it is essential that management programs be designed with enough flexibility to allow them to evolve along with advances in understanding.

In the Chesapeake Bay region, considerable progress could be made in developing an appropriate method for determining wetland value if the efforts of multiple research and funding agencies could be coordinated. A well-planned research strategy is called for, which will require cooperation across scientific disciplines and on a multi-jurisdictional level. Only through such an integrated effort can we hope that it will be found 50 or even 100 years from now that we managed this critical resource wisely.

References

1. Adamus, P.R. 1983. A method for wetland functional assessment. Vol 2. Rep. No. FHWA-IP-82-24. Washington, DC: U.S. Dept. of Transportation, Federal Highway Admin., 134 pp.
2. Adamus, P.R, E.J. Clairain Jr.; R.O. Smith, and R.E. Young. 1987. Wetland evaluation technique (WET). Vol. 2: Methodology. Vicksburg, MS: U. S. Army Corps of Engineers Waterways Experiment Station. Operational Draft Technical Rep. Y-87.
3. Adamus, P.R, R.D. Smith, and T. Muir. 1990. Manual for assessment of bottomland hardwood functions. Washington, DC: U.S. Environmental Protection Agency, Office of Wetlands Protection, 72 pp.
4. Adamus, P.R. and L.T. Stockwell. 1983. Method for wetland functional assessment. Vol. 1: Critical review and evaluation concepts. Rep. No. FHWA-IP-82-23. Washington, DC: U.S. Dept. of Transportation, Federal Highway Admin. 185 pp.
5. Amacher, G.S., R.J. Brazee, J.W. Bulkley, and R.A. Moll. 1988. Interdisciplinary approach to valuation of Michigan coastal wetlands. Washington, DC: U.S.G.S. Water Resources Div. Rep., 112 pp.
6. Amman, A.P., R.W. Franzen, and J.L. Johnson. 1986. Method for the evaluation of inland wetlands in Connecticut. Hartford, CT: Connecticut Dept. of Envir. Protection, Bull. No. 9, 68 pp.
7. Baker, J.A. 1960. Wetland and water supply. Reston, VA: U.S. Geol. Survey, Circular 431, 3 pp.
8. Balco, J.J. 1981. Assessing wetland values: Evaluation dilemmas. In: Richardson, B., ed. Selected proc. of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 421-430.
9. Barnard, W.D., C.K. Ansell, J.G. Harn, and C. Kevin. 1985. Establishing priorities for wetlands management. Water Resources Bull. 21(6): 1049-1054.
10. Bartel, R.L. and A.E. Maristany. 1989. Wetlands and stormwater management: A case study of Lake Munson. Part II: Impacts on sediment and water quality. In: Fisk, D.W., ed. Wetlands: Concerns and successes. Bethesda, MD: American Water Resources Assoc., Technical Publ. No. TPS-89-3, 231-246.
11. Batie, S.S. and L.A. Shabman. 1982. Estimating the economic value of wetlands: Principles, methods, and limitations. Coastal Zone Manage. J. 10: 255-278.
12. Boto, K.G., and W.H. Patrick, Jr. 1979. Role of wetlands in the removal of suspended sediments. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 479-489.
13. Boyce, S.G. and N.G. Cost. 1974. Timber potentials in the wetland hardwoods. In: Blount, M.C., ed. Water resources utilization and conservation in the environment. Reynolds, GA: Taylor Printing Company, 130-151.
14. Boyt, F.L., S.E. Bayley, and J. Zoltek, Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. Journal WPCF 49(5):789-799.
15. Brinson, M.M. 1988. Strategies for assessing the cumulative effects of wetland alteration on water quality. Environ. Management 12(5):655-662.
16. Brinson, M.M., H.D. Bradshaw, and E.S. Kane. 1984. Nutrient assimilative capacity of an alluvial floodplain swamp. Journal of Applied Ecology 21:1041-1057.
17. Brinson, M.M., A.E. Lugo, and S. Brown. 1981. Primary productivity, decomposition and consumer activity in freshwater wetlands. Ann. Rev. Ecol. Syst. 12:123-161.
18. Brinson, M.M., B.L. Swift, R.C. Plantico, and J.S. Barclay. 1981. Riparian ecosystems: Their ecology and status. FWS/OBS-81/17. Washington, D C: U. S. Dept. of Interior, USFWS, 155 pp.
19. Brown, R.G. 1976. A study of the impact of the wetlands easement program on agricultural land values. Land Economics 52:509-517.
20. Brown, R.G. 1984. Effects of an urban wetland on sediment and nutrient loads in runoff. Wetlands 4:147-158.
21. Cable, T.T., V. Brack, Jr., and V.R. Holmes. 1989. Simplified method for wetland habitat assessment. Envir. Management 13(2):207-213.
22. Chabreck, R.H. 1979. Wildlife harvest in wetlands of the United States. In: Greeson, P.E., J.R. Clark and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 618-631.
23. Checheir, G.M., J.W. Gilliam, R.W. Skaggs, R.G. Broadhead, and R. Lea. 1987. Hydrology and pollutant removal effectiveness of wetland buffer areas receiving pumped agricultural drainage water. Washington, DC: U.S.G.S. Water Resources Div. Rep., 187 pp.
24. Chescheir, G. M., R.W. Skaggs, J.W. Gilliam, and R. Broadhead. 1988. Wetland buffer areas for treatment of pumped agricultural drainage water. In: Proc. of the symposium on coastal water resources. Minneapolis, MN: American Water Resources Assoc. Technical Publ. Ser., 255-264.
25. Clairain, E.J., Jr., and B.A. Kleiss. 1989. Functions and values of bottomland hardwood forests along the Cache River, Arkansas: Implications for management. In: Proc. of the symposium: The forested wetlands of the southern United States, July 12–14, 1988 Orlando, FL. Asheville, NC: U.S. Dept. of Agriculture, U.S. Forest Service, Southeastern Forest Experiment Station, Gen. Technical Rep. SE-50, 27-33.

26. Clark, J.E. 1979. Freshwater wetlands: Habitats for aquatic invertebrates, reptiles and fishes. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 330-343.
27. Clark, J.R. and J.E. Clark, eds. 1979. Scientists' report: The national symposium on wetlands. Washington, DC:National Wetlands Technical Council, 127 pp.
28. Cooper, J.R., J.W. Gilliam, and T.C. Jacobs. 1986. Riparian areas as a control of nonpoint pollutants. In: Correll, D.L., ed. Water research perspectives. Washington, DC: Smithsonian Institution Press, 166-192.
29. Correll, D.L., ed. 1986. Water research perspectives. Washington, DC: Smithsonian Institution Press.
30. Corps of Engineers, U.S. Army. 1972. Charles River, Massachusetts, appendices. Waltham, MA: New England Division, Dept. of the Army.
31. Corps of Engineers, U.S. Army. 1972. Charles River, Massachusetts, main report and attachments. Waltham, MA: New England Division, Dept. of the Army, 68 pp.
32. Corps of Engineers, U.S. Army. 1990. Temporarily flooded/saturated palustrine forested wetlands on acredale-like soils, functions and values study: Report of findings. Norfolk, VA: Norfolk District, U. S. Army Corps of Engineers.
33. Correll, D.L., and D.E. Weller. 1989. Factors limiting processes in freshwater wetlands: An agricultural primary stream riparian forest. In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 9-24.
34. Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetland and deepwater habitats of the United States. Washington, DC: U.S. Dept. of Interior, U.S. Fish and Wildlife Service FWS/OBS-79/31, 103 pp.
35. Degnan, J. 1971. Neponset River basin flood plain and wetland enroachment study. Boston, MA: Div. Water Resources, Massachusetts Water Resources Commission, 56 pp.
36. Diderikson, R.I., A.R. Hildebaugh, and K.O. Schmude. 1979. Wet soils for crop production in the United States. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 632-641.
37. Diedrick, R.T. 1981. The agriculture value of wet soils in the upper Midwest. In: Richardson, B., ed. Selected proc. of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 97-106.
38. Dieffenbach, D.R., and R.B. Owen, Jr. 1989. A model of habitat use by breeding American black ducks. J. Wildl. Management 53(2):383-389.
39. Dolan, T.J., A.J. Hermann, S.E. Bayley, and J. Zoltek, Jr. 1984. Evapotranspiration of a Florida, U.S.A., freshwater wetland. J. Hydrol. 74(3-4): 355-371.
40. Ehrenfeld, J.G. 1986. Wetlands of the New Jersey pine barrens: The role of species composition in community function. Am. Midl. Nat. 115(2): 301-313.
41. Ellis, G.M. and A.C. Fisher. 1987. Valuing the environment as input. J. Environ. Management 25(2):149-156.
42. Farnham, R.S. 1979. Wetlands as energy sources. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 661-672.
43. Farnsworth, E.G., T.H. Tidrick, C.F. Jordan, and W.M. Smathers, Jr. 1981. The value of natural ecosystems: An economic and ecological framework. Environ. Conserv. 8:275-284.
44. Foster, J.H. 1979. Measuring the social value of wetland benefits. In: Greeson, P.E., J.R. Clark and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 84-92.
45. Gehrels, J. and G. Mulamoottil. 1989. The transformation and export of phosphorus from wetlands. Hydrol. Process. 3(4):365-370.
46. German, E.R. 1989. Removal of nitrogen and phosphorus in an undeveloped wetland area, central Florida. In: Fisk, D.W., ed. Wetlands: Concerns and successes. Bethesda, MD: American Water Resources Assoc. Technical Publ. No. TPS-89-3, 139-147.
47. Glooschenko, V. 1983. Development of an evaluation system for wetlands in southern Ontario. Wetlands 3:192-200.
48. Godfrey, P.J., E.R. Kaynor, S. Pelczarski, and J. Benforado, eds. 1985. Ecological considerations in wetlands treatment of municipal wastewaters. New York: Van Nostrand Reinhold Company.
49. Golet, F.C. 1976. Wildlife wetland evaluation model. In: Larson, J.S., ed. Models for assessment of freshwater wetlands. Amherst, MA: Univ. Massachusetts, Water Resources Research Center, Publ. No. 32, 13-34.
50. Golet, F.C. and J.S. Larson. 1974. Classification of freshwater wetlands in glaciated Northeast. Washington, DC: U.S. Dept. of Interior, U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. Res. Publ. 116, 56 pp.
51. Gosselink, J.G. and L.C. Lee. 1989. Cumulative impact assessment in bottomland hardwood forests. Wetlands. 9:81-174.
52. Gosselink, J.G., E.P. Odum, and R.M. Pope. 1974. The value of the tidal marsh. Baton Rouge, LA: Louisiana State Univ. LSU-SG-70-03, 36 pp.

53. Gosselink, J.G. and R.E. Turner. 1978. The role of hydrology in freshwater wetland ecosystems. In: Good, R.E., D. Whigham, and R.L. Simpson, eds. Freshwater wetlands: Ecological processes and management potential. New York: Academic Press, 63-78.
54. Hardaway, C.S., G.R. Thomas, and A.W. Zacherle. 1982. Vegetative erosion control project and appendices. Gloucester Point, VA: Virginia Institute of Marine Science Contract Rep., 86 pp.
55. Heeley, R.W. and W.S. Motts. 1976. A model for the evaluation of groundwater resources associated with wetlands. In: Larson, J.S., ed. Models for assessment of freshwater wetlands. Amherst, MA: Univ. Massachusetts, Water Resources Center Publ. No. 32, 52-65.
56. Hollands, G.G. 1986. Assessing the relationship of groundwater and wetlands. In: Kusler, J.A. and P. Riexinger, eds. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Tech. Rep. 1., 55-57.
57. Hollands, G.G. and D.W. McGee. 1986. A method for assessing the functions of wetlands. In: Kusler, J.A. and P. Riexinger, eds. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Technical Rep. 1, 108-118.
58. Ireland, L.C. 1979. Determining the value of forests to communities and the general public: The case of the southern bottomland hardwood. In: 25th ann. forestry symposium. Baton Rouge, LA: Louisiana State Univ., 17-35.
59. Ischinger, L.S. and G.T. Auble. 1986. Assessment of sediment control functions in bottomland hardwoods. In: Kusler, J.A. and P. Riexinger, eds. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Tech. Rep. 1, 46-54.
60. Johnson, R.L. 1979. Timber harvests from wetlands. In: Greeson, P.E., J.R. Clark and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 598-605.
61. Kibby, H.V. 1978. Effects of wetlands on water quality. In: Johnson, R.R.and J.F. McCormick, eds. Proc. of the symposium on strategies for protection and management of floodplain wetlands and other riparian ecosystems. Washington, DC: Dept. of Agriculture, U.S. Forest Service Publ. GTR-WO-12, 289-298.
62. Kleiss, B.A., E.E. Morris, J.F. Nix, and J.W. Barko. 1989. Modification of riverine water quality by an adjacent bottomland hardwood wetland. In: Fisk, D.W., ed. Wetlands: Concerns and successes. Bethesda, MD: American Water Resources Assoc. Technical Publ. No. TPS-89-3, 429-438.
63. Knight, R.L., B.H. Winchester, and J.C. Higman. 1985. Ecology, hydrology, and advanced wastewater treatment potential of an artificial wetland in north-central Florida. Wetlands 5:167-180.
64. Kratz, T.K. and V.L. Medland. 1989. Relationship of landscape position and groundwater input in northern Wisconsin kettle-hole peatlands. In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 1141-1151.
65. Kuenzler, E.J. 1988. Sewage nutrient removal by North Carolina swamp systems. In: Proc. of the symposium on coastal water resources. Minneapolis, MN: American Water Resources Assoc. Technical Publ. Ser., 281-292.
66. Kuenzler, E.J. 1989. Value of forested wetlands as filters for sediments and nutrients. In: Hook, D.D. and R. Lea, eds. Proc. of the symposium: The forested wetlands of the southern United States, July 12–14, 1988 Orlando, FL. Asheville, NC: U.S. Dept. of Agriculture, U.S. Forest Service, Southeastern Forest Experiment Station, Gen. Technical Rep. SE-50, 85-96.
67. Kusler, J.A. and P. Riexinger, eds. 1986. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Technical Rep 1.
68. Laney, R.W. 1988. The elimination of isolated and limited-flow wetlands in North Carolina. In: Proc. of the symposium on coastal water resources. Minneapolis, MN: American Water Resources Assoc. Technical Publ. Ser., 243-254.
69. Larson, J.S., ed. 1976. Models for assessment of freshwater wetlands. Amherst, MA: Univ. of Massachusetts, Water Resources Research Center Publ. No. 32, 91 pp.
70. Larson, J.S. 1990. Wetland value assessment. In: Patten, B.C., ed. Wetlands and shallow continental water bodies. Vol. 1: Natural and human relationships. The Hague, the Netherlands: SPB Academic Publishing, 389-400.
71. Larson, J.S., P.A. Adamus, and E.J. Clairain. 1989. Functional assessment of freshwater wetlands: A manual and training outline. Amherst, MA: Univ. of Massachusetts Environmental Institute, 52 pp.
72. Larson, L.A. 1986. Wetlands and flooding: Assessing hydrologic functions. In: Kusler, J.A. and P. Riexinger, eds. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Technical Rep. 1, 43-54.
73. Lee, L.C. and J.G. Gosselink. 1988. Cumulative impacts on wetlands: Evaluating scientific assessments and regulatory alternatives. J. Environ. Management 12(5):591-602.
74. Leitch, J.A. and D.F. Scott. 1977. A selected annotated bibliography of economic values of fish and wildlife and their habitats. Fargo, ND: Dept. Agric. Econ., North Dakota State Univ., 132 pp.
75. Leonard, R.I., E.J. Clairain, Jr.; R.T. Huffman, J. Jardy, L.D. Brown, P.E. Ballard, and J.W. Watts. 1981. Analysis of methodologies used for the

assessment of wetland values. Washington, DC: U.S. Water Resources Council, 68 pp.
76. Littlejohn, C. 1977. An analysis of the role of natural wetlands in regional water management. In: Hall, C.A.S. and J.W. Day, Jr. eds. Ecosystem modeling in theory and practice. New York: John Wiley and Sons, 451-476.
77. Loftin, L.K. 1988. Peat mining regulations and coastal water quality protection. In: Proc. of the symposium on coastal water resources. Minneapolis, MN: American Water Resources Assoc., Technical Publ. Ser., 845-852.
78. Lowrance, R.R., R.L. Todd, J. Fail, O. Hendrickson, R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34:374-377.
79. McArthur, B.H. 1989. The use of isolated wetlands in Florida for stormwater treatment. In: Fisk, D.W., ed. Wetlands: Concerns and successes. Bethesda, MD: American Water Resources Assoc. Technical Publ. No. TPS-89-3, 185-193.
80. May, J.P. 1989. Groundwater recharge potential of freshwater wetlands on Hilton Head Island, South Carolina. In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 1123-1139.
81. Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. New York: Van Nostrand Reinhold Company, Inc.
82. Motts, W.S. and R.W. Heeley. 1973. Wetlands and ground water. In: Larson, J.S., ed. A guide to important characteristics and values of freshwater wetlands in the northeast. Amherst, MA: Univ. of Massachusetts, Water Resources Research Ctr., 5-8.
83. Motts, W.S. and A.L. O'Brien. 1981. Geology and hydrology of wetlands in Massachusetts. Amherst, MA: Univ. of Massachusetts, Water Resources Research Center Publ. No. 123, 147 pp.
84. Niering, W.A. 1986. Scenic, cultural (heritage) and educational values of wetlands. In: Kusler, J.A. and P. Riexinger, eds. Proc. of the national wetlands assessment symposium. Chester, VT: Assoc. of State Wetland Managers Technical Rep. 1, 58-64.
85. Nixon, S.W.and V. Lee. 1986. Wetlands and water quality: A regional review of recent research in the United States on the role of freshwater and saltwater wetlands as sources, sinks, and transformers of nitrogen, phosphorus, and various heavy metals. Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station Technical Rep. Y-86-2.
86. Novitski, R.P. 1979. The hydrologic characteristics of Wisconsin wetlands and their influence on floods, streamflow, and sediment. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 377-388.
87. Novitski, R.P. 1982. Hydrology of Wisconsin wetlands. Madison, WI: Univ. of Wisconsin Extension Geol. and Natural History Survey Info. Circ. 40, 22 pp.
88. Oberts, G.L. 1981. Impact of wetlands on watershed water quality. In: Richardson, B., ed. Selected proc. of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 213-227.
89. Odum, E.P. 1979. The value of wetlands: A hierarchial approach. In: Greeson, P.E., J.R. Clark, and J.E.Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 16-25.
90. Odum, H.T. 1984. Summary: Cypress swamps and their regional role. In: Ewel, K.C. and H.T. Odum, eds. Cypress swamps. Gainesville, FL: Univ. Presses of Florida, 416-443.
91. Odum, H.T., J.S. McNight, L.H. Moore, and J.L. Van Beck. 1981. Optimization of economic use of southern bottomland hardwood forests. In: Clark, J.R. and J. Benforado, eds. Wetlands of bottomland hardwood forests. New York: Elsevier Scientific Publishing Co., 361-385.
92. Odum, W.E. 1982. Environmental degradation and the tyranny of small decisions. BioScience 32: 728-729.
93. Odum, W.E. 1988. Non-tidal freshwater wetlands in Virginia. Virginia J. of Nat. Resources Law 7:421-434.
94. Ogawa, H. 1982. Evaluation methodologies for the flood mitigation potential of inland wetlands. Amherst, MA: Univ. of Massachusetts. Dissertation, 219 pp.
95. Ogawa, H. and J.W. Male. 1986. Simulating the flood mitigation role of wetlands. J. of Water Resources Planning and Manage. 112(1): 114-128.
96. Ogawa, H. and J.W. Male. 1990. Evaluation framework for wetland regulation. J. Environ. Management 30:95-109.
97. Peterjohn, W.T. and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65(5):1466-1475.
98. Pratt, D.C. and N.J. Andrews. 1981. Research in biomass/special energy crops in wetlands. In: Richardson, B., ed. Selected proc. of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 71-81.
99. Reppert, R.T. 1981. Wetland values, concepts, and methods for wetlands evaluation. In: Richardson, B., ed. Selected proceedings of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 385-394.
100. Ryther, J.H., T.A. Debusk, M.D. Hansiak, and L.D. Williams. 1979. Freshwater macrophytes for energy and waste water treatment. In: Greeson, P.E., J.R. Clark, and J.E. Clark, eds. Wetland functions and values: The state of our understanding. Minneapolis, MN: American Water Resources Assoc. Technical Publ. No. TPS 79-2, 652-660.
101. Richardson, C.J. 1989. Freshwater wetlands:

Transformers, filters, or sinks? In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 25-46.
102. Richardson, C.J. and P.E. Marshall. 1986. Processes controlling movement, storage and export of phosphorus in a fen peatland. Ecol. Monogr. 56(4):279-302.
103. Rockfeller, L. 1975. Why wetlands are natural protective barriers against flooding. New York: Natural Resources Defense Council, Inc.
104. Sather, J.H., R.D. Smith, and J.S. Larson. 1990. Natural values of wetlands. In: Patten, B.C., ed. Wetlands and shallow continental water bodies, Vol. 1: Natural and human relationships. The Hague, the Netherlands: SPB Academic Publishing, 373-387.
105. Shabman, L.A. and S.S. Batie. 1978. Economic value of natural coastal wetlands: a critique. Coastal Zone Management J. 4:231-247.
106. Shabman, L.A. and S.S. Batie. 1979. A reply to the rebuttal on economic value of natural coastal wetlands: A critique. Coastal Zone Management J. 5:243-244.
107. Shabman, L.A. and S.S. Batie. 1980. Estimating the economic value of coastal wetlands: Conceptual issues and research needs. In: Kennedy, V.S., ed. Estuarine perspectives. New York: Academic Press, 3-15.
108. Shabman, L.A.and S.S. Batie. 1981. Basic economic concepts important for wetland valuation. In: Richardson, B., ed. Selected proceedings of the Midwest conference on wetland values and management. Navarre, MN: Freshwater Society, 431-443.
109. Sharitz, R.R. and J.W. Gibbons, eds. 1989. Freshwater wetlands and wildlife. Proc. of a symposium held at Charleston, South Carolina, March 24–27, 1986. Springfield, VA: NTIS DE90005384.
110. Smardon, R.C. 1983. The future of wetlands, assessing visual-cultural values. Totowa, NJ: Allanhead, Osmun and Co., Publs., Inc., 224 pp.
111. Tilton, D.L., R.H. Kadlec, and B.R. Schwegler. 1978. The ecology and values of Michigan's coastal wetlands. Ann Arbor, MI: Univ. Michigan, Dept. of Chemical Engineering.
112. Tiner, R.W., Jr. 1989. Recent changes in the extent of palustrine wetlands in the Chesapeake Bay region. In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 791-800.
113. Tiner, R.W., Jr. and J.F. Finn. Status and recent trends of wetlands in five mid-Atlantic states. Newton Corner, MA: U.S. Dept. of Interior, U.S. Fish and Wildlife Service, and U. S. Environmental Protection Agency, Region III., Philadelphia, PA, Cooperative Publ. 40 pp.
114. U.S. Environmental Protection Agency. 1983. Freshwater wetlands for wastewater management. Atlanta, GA: Rep. No. EPA 904/9-83-107.
115. U.S. Environmental Protection Agency. 1984. Literature review of wetland evaluation methodologies. Chicago, IL: U.S. EPA, Region V.
116. U.S. Fish and Wildlife Service, Dept. of Interior. 1980. Habitat evaluation procedures (HEP). Washington, DC: USFWS, Division of Ecol. Serv. ESM 102.
117. U.S. Fish and Wildlife Service, Dept. of Interior. 1984. Proc. of the national wetlands values assessment workshop. Fort Collins, CO: USFWS Publ. No. FWS-14-0009-82-033.
118. U.S. Fish and Wildlife Service, Dept. of Interior. 1990. Regional wetlands concept plan, northeast region. Newton Corner, MA: USFWS, Region V.
119. Virginia Dept. of Conservation and Recreation. 1990. The Virginia nontidal wetlands inventory. Richmond, VA: Division of Soil and Water Conservation, Dept. of Conserv. and Recreation.
120. Ward, J.V. 1989. Riverine-wetland interactions. In: Sharitz, R.R. and J.W. Gibbons, eds. Freshwater wetlands and wildlife. Springfield, VA: NTIS DE90005384, 385-400.
121. Whigham, D.F. and M.M. Brinson. 1990. Wetland value impacts. In: Patten, B.C., ed. Wetlands and shallow continental water bodies, Vol. 1: Natural and human relationships. The Hague, the Netherlands: SPB Academic Publishing, 401-421.
122. Whigham, D.F., C. Chitterling, and B. Palmer. 1988. Impacts of freshwater wetlands on water quality: A landscape perspective. J. Environ. Management 12(5):663-671.
123. Wilkinson, D.L., K. Schneller-McDonald, R.W. Olson, and G.T. Auble. 1987. Synopsis of wetland functions and values: Bottomland hardwoods with special emphasis on eastern Texas and Oklahoma. Washington, DC: U.S. Dept. of Interior, U.S. Fish and Wildlife Service National Ecology Center Biological Rep. 87(12).