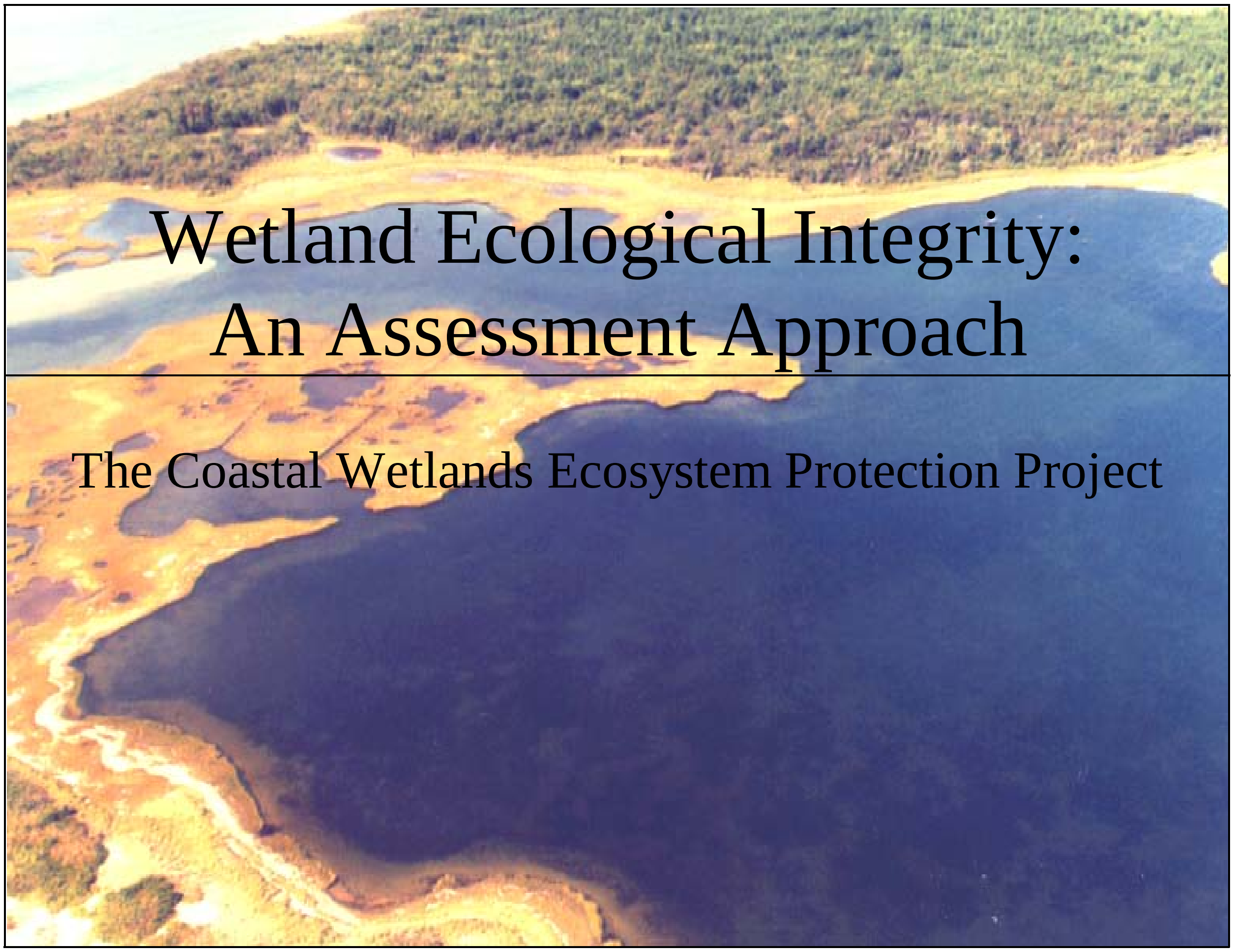
Wetland Ecological Integrity: An Assessment Approach

The Coastal Wetlands Ecosystem Protection Project



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Date:	**31 March 1998**
Principal Author:	**Bruce K. Carlisle, Massachusetts Coastal Zone Management**
Contributing Authors:	**Jan P. Smith, Massachusetts Coastal Zone Management** **Anna L. Hicks, University of Massachusetts** **Bryan G. Largay, University of California, Davis** **Samuel R. Garcia, University of California, Santa Cruz**
Coordinating Agencies:	**Waquoit Bay National Estuarine Research Reserve,** **Massachusetts Department of Environmental Protection**
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Executive Summary

Since July 1995, Massachusetts Coastal Zone Management has been engaged in a regional research and demonstration project sponsored by the National Oceanic and Atmospheric Administration's Coastal Services Center. The goal of the Coastal Wetland Ecosystem Protection Project is to develop, test, and refine a transferable approach for wetlands evaluation to determine the impacts of adjacent land uses and nonpoint sources (NPS) of pollution on the ecological integrity of these aquatic resources. Thirteen wetland study sites were identified in the Waquoit Bay watershed on Cape Cod in southeastern Massachusetts. These sites were selected to be representative of the three dominant types in the watershed--salt marshes, bordering riverine wetlands, and isolated depressional wetland--and of the major land uses types present: residential and commercial development, transportation, agriculture, and recreation. At each site, biological, chemical, and hydrological measurements were made in order to assess the relative ecological health and functioning of these wetlands. In addition, several rapid assessment methods and techniques were employed and the results were examined in light of actual on-site measurements. Through the development and implementation of this pilot project, project staff were able to evaluate the accuracy and effectiveness of an array of wetland evaluation methods and promote their inclusion in a transferable assessment approach.

Based on the analysis of the onsite biological, hydrological, and chemical measurements, there is discernable variation between study sites. The data indicate a pattern of ecological degradation associated with certain land uses and land use practices. Compared to control (or reference) study sites, wetlands with a higher degree and intensity of proximate land uses show a marked shift in biological species and community composition, dissimilar hydrology, and increased concentrations of nutrients, sediments, and pathogenic bacteria. Statistical analysis reveals very close correlations between the outputs of the rapid assessment methods and the field-based indicators.

Project results have enabled the authors to identify which wetland sites are exhibiting signs of ecological and functional impairment, to characterize what the adverse effects are, and to infer as to the potential sources or causes of impairment. This information can be utilized to guide decision-makers as they attempt to address NPS pollution and implement measures to mitigate existing problems and to prevent future ones. The Wetlands Health Assessment Toolbox (WHAT) approach has valuable applications for wetlands inventory and assessment in specific geographic areas (such as towns or watersheds); measuring and evaluating the success of wetland restoration, compensatory mitigation, or banking projects; and for examining and quantifying the impacts of new development and other land use activities on wetlands.

Part I of this document provides the introduction, background and scope for the project, setting the foundation for the detailed description of the assessment methods in Part II which includes the explanation of methods, data analysis, and results. Part III contributes a site-by-site discussion of the project results, makes observations on data patterns, and provides some recommendations for further development of the WHAT approach and management actions.

Part I: Background and Project Scope

Section 1. Introduction

This section provides an introduction to wetlands ecology, function, and values; briefly reviews the causes and types of wetland degradation, alteration, and impact; and introduces the rationale and impetus behind the Coastal Wetlands Ecosystem Protection Project. Some of the wetland ecology section has been adapted from the US Environmental Protection Agency (USEPA) document, *America's Wetlands: Our Vital Link Between Land and Water*.

The Importance and Diversity of Wetlands

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil for at least part of the growing season. The occurrence and flow of water (hydrology) largely determine how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favor the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils.

Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation, and other factors, including human disturbance. Indeed, wetlands are found from the tundra to the tropics and on every continent except Antarctica. Two general categories of wetlands are recognized: tidally-influenced wetlands and non-tidal (or inland) wetlands.

Coastal Tidal Wetlands

Coastal wetlands in the United States, as their name suggests, are found along the Atlantic, Pacific, Alaskan, and Gulf coasts. They are closely linked to estuaries, where sea water mixes with fresh water to form an environment of varying salinities. The salt water and the fluctuating water levels (due to tidal action) combine to create a rather difficult environment for most plants. Consequently, many shallow coastal areas are unvegetated mud flats or sand flats. Some plants, however, have successfully adapted to this environment. Certain grasses and grasslike plants (or graminoids, including sedges and rushes) that adapt to the saline conditions form the tidal salt marshes that are found along the Atlantic, Gulf, and Pacific coasts. Mangrove swamps, with salt-loving shrubs or trees, are common in tropical climates, such as in southern Florida and Puerto Rico. Some tidal freshwater wetlands form beyond the upper edges of tidal salt marshes where the influence of salt water ends.

Nontidal Wetlands

Inland wetlands are most common on floodplains along rivers and streams (riparian wetlands), in isolated depressions surrounded by dry land (for example, playas, basins, and "potholes"), along the margins of lakes and ponds, and in other low-lying areas where the groundwater intercepts the soil surface or where precipitation sufficiently saturates the soil (vernal pools and bogs). Inland wetlands include marshes and wet meadows dominated by herbaceous plants, swamps dominated by shrubs, and wooded swamps dominated by trees. Certain types of inland wetlands are common to particular regions of the country: bogs and fens of the northeastern and north-central states and Alaska; inland saline and alkaline marshes of the arid and semiarid west; prairie potholes of Iowa, Minnesota and the Dakotas; playa lakes of the southwest and Great Plains; and bottomland hardwood swamps of the south.

Many of these wetlands are seasonal and, particularly in the arid and semiarid West, may be wet only periodically. The quantity of water present and the timing of its presence in part determine the functions of a wetland and its role in the environment. Even wetlands that appear dry at times for significant parts of the year–such as vernal pools–often provide critical habitat for wildlife adapted to breeding exclusively in these areas.

Wetland Ecology and Functions

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs. An immense variety of species of microbes, plants, insects, amphibians, reptiles, birds, fish, and mammals can be part of a wetland ecosystem. Physical and chemical features such as climate, landscape shape (topology), geology, and the movement and abundance of water help to determine the plants and animals that inhabit each wetland. The complex, dynamic relationships among the organisms inhabiting the wetland environment are referred to as food webs.

Wetlands provide great volumes of food that attract many animal species. These animals use wetlands for part of or all of their life-cycle. Dead plant leaves and stems break down in the water to form small particles of organic material called "detritus." This enriched material feeds many small aquatic insects, shellfish, and small fish that are food for larger predatory fish, reptiles, amphibians, birds, and mammals.

The biological, chemical, and physical operations and attributes of a wetland are known as wetland functions. Some typical wetland functions include: wildlife habitat and food chain support, surface water retention or detention, groundwater recharge, and nutrient transformation. Distinct from these intrinsic natural functions are human uses of and interaction with wetlands. Society's utilization and appraisal of wetland resources is referred to as wetland values, which include: support for commercially valuable fish and wildlife, flood control, supply of drinking water, enhancement of water quality, and recreational opportunities.

A watershed is a geographic area in which water, sediments, and dissolved materials drain from higher elevations to a common low-lying outlet, basin, or point on a larger stream, lake, underlying aquifer, or estuary. Wetlands play an integral role in the ecology and hydrology of the watershed. The combination of shallow water, high levels of nutrients, and high primary productivity is ideal for the growth of organisms that form the base of the food web and feed many species of fish, amphibians, shellfish, and insects. Many species of birds and mammals rely on wetlands for food, water, and shelter, especially during migration and breeding. Wetlands' microbes, plants, and wildlife are part of global cycles for water, nitrogen, and sulfur. Furthermore, scientists are beginning to realize that atmospheric maintenance may be an additional wetlands function. Wetlands store carbon within their plant communities and soil instead of releasing it to the atmosphere as carbon dioxide. Thus wetlands help to moderate global climate conditions.

Water Quality

Wetlands have important filtering capabilities for intercepting surface water runoff from higher dry land before the runoff reaches open water. As the runoff water passes through, the wetlands retain excess nutrients and some pollutants, and reduce sediment that would clog waterways and affect fish and amphibian egg development. In addition to improving water quality through filtering, some wetlands maintain stream flow during dry periods, and many replenish groundwater.

Flood Protection

Wetlands function as natural sponges that trap and slowly release surface water, rain, snowmelt, groundwater, and flood waters. Trees, root mats, and other wetland vegetation also slow the speed of flood waters and distribute them more slowly over the floodplain. This combined water storage and braking action lowers downstream flood heights and reduces erosion. Wetlands within and downstream of urban areas are particularly valuable, counteracting the greatly increased rate and volume of surface water runoff from pavement and buildings. The holding capacity of wetlands helps control floods. Preserving and restoring wetlands can often provide the level of flood control otherwise provided by expensive dredge operations and levees.

Shoreline Erosion

The ability of wetlands to control erosion is so valuable that some states are restoring wetlands in coastal areas to buffer the storm surges from hurricanes and tropical storms. Wetlands at the margins of lakes, rivers, bays, and the ocean protect shorelines and stream banks against erosion. Wetland plants hold the soil in place with their roots, absorb the energy of waves, and slow the flow of stream or river currents along the shore.

Fish and Wildlife Habitat

More than one-third of the United States' threatened and endangered species live only in wetlands, and nearly half require wetlands at some point in their lives. Many other animals and plants depend on wetlands for survival. Estuarine and marine fish and shellfish, various birds, and certain mammals must have coastal wetlands to survive. Most commercial and game fish breed and raise their young in coastal marshes and estuaries. Menhaden, flounder, sea trout, spot, croaker, and striped bass are among the more familiar fish that depend on coastal wetlands. Shrimp, oysters, clams, and blue and Dungeness crabs likewise need these wetlands for food, shelter, and breeding grounds.

For many animals and plants, like wood ducks, muskrat, cattails, and swamp rose, inland wetlands are the only places they can live. Beaver may actually create their own wetlands. For others, such as striped bass, peregrine falcon, otter, black bear, raccoon, and deer, wetlands provide important food, water, or shelter. Many of the U.S. breeding bird populations--including ducks, geese, woodpeckers, hawks, wading birds, and many song-birds--feed, nest, and raise their young in wetlands. Migratory waterfowl use coastal and inland wetlands as resting, feeding, breeding, or nesting grounds for at least part of the year.

Wetland Loss and Degradation

In the 1600s, over 220 million acres of wetlands are thought to have existed in the lower 48 states. Since then, extensive losses have occurred, and over half of our original wetlands have been drained and converted to other uses (Dahl, 1990). The years from the mid-1950s to the mid-1970s were a time of major wetland loss, but since then the rate of loss has decreased.

In addition to these losses, many other wetlands have been degraded, although calculating the magnitude of the degradation is difficult. These losses, as well as degradation, have greatly diminished our nation's wetlands resources; as a result, we no longer have the benefits they provided. Recent increases in flood damages, drought damages, and the declining bird populations are, in part, the result of wetlands degradation and destruction.

Wetlands have been degraded in ways that are not as obvious as direct physical destruction or degradation (Table 1.1). Other threats have included chemical contamination, increased nutrient inputs and eutrophication (accelerated succession from low to high primary productivity rates), hydrologic modification, and sediment from air and water. Global climate change could affect wetlands through increased air temperature; shifts in precipitation; increased frequency of storms, droughts, and floods; increased atmospheric carbon dioxide concentration; and sea level rise. All of these impacts could affect species composition and wetland functions.

Human Development and Landscape Alteration

Human alteration to the natural landscape have the potential to exert significant direct and indirect influence on wetland ontogeny and processes. Changes to natural hydrological, chemical, and physical regimes have been documented as affecting the production and succession of a wetland's ecology, and therefore its functions and values **(Mitsch and Gosselink,1993; Booth and Reinelt 1993; Preston and Bedford, 1988.).**

During urbanization or development, pervious areas–those that permit the infiltration of precipitation through the ground–including vegetated and forested land, are lost. These natural areas are converted to land uses that increase the amount of impervious surfaces, such as roads, parking lots, and buildings. Impervious surfaces transform watershed hydrology by changing the rate and volume of runoff and altering natural drainage features, including groundwater levels. This, in turn, alters wetland hydrology and may adversely affect aquatic and riparian wetland habitat. Increases in population pressures from urbanization results in corresponding increases in pollutant loadings generated from a wide array of human activities.

Impacts to Water Quality: Pollutant Constituents

Both nationally and in Massachusetts, urban runoff and discharges from stormwater outfalls are some of the largest sources responsible for the non-attainment of water quality standards. Table 1.2 shows a breakdown of the individual pollutant constituents typically found in urban stormwater and the principle sources of runoff pollutants.

Impacts to Hydrology

Urban development of the natural landscape changes both the form and function of the natural downstream drainage system. Data from a host of sources demonstrate that the shift from undeveloped to developed areas results in substantial increases in runoff volume, thereby reducing the amount of rainfall available for groundwater recharge. Increases in peak runoff rates and volumes to stream channels intensifies streambank erosion and alters the natural deposition regimes (USEPA, 1983).

Physical, chemical, and biological data from King County, Washington demonstrate that consistent thresholds exist for aquatic ecosystem impacts from urbanization (Booth, 1993). Approximately 10 to 15 percent impervious area in a watershed typically yields demonstrable loss of aquatic system functioning, as measured by changes in channel morphology, fish and amphibian populations, vegetation succession, and water chemistry. Physical changes may result from direct alteration–riparian corridors are cleared, channels are straightened, logs are removed from channels. Indirect alteration results in increased flows from upstream development, increased sediment transport, increase bank erosion, and increased flood durations.

Table 1.1. Major causes of wetland loss and degradation

Human Actions	Natural Events
- Drainage	- Erosion
- Dredging and stream channelization	- Subsidence
- Deposition of fill material	- Sea level rise
- Diking and damming	- Droughts
- Discharge of pollutants	- Hurricanes and other storms
- Tilling for crop production	- Ice scour
- Logging	- Beaver
- Mining	
- Construction	
- Air and water pollutants	
- Changing nutrient levels	
- Grazing by domestic animals	

Table 1.2. Stormwater constituents and sources (Newton, 1989; Horner, 1992)

Stormwater pollutant constituents	Sources
- Pathogens/bacteria	- Construction sites
- Nutrients	- Street and parking lot pavement
- Sediments (total suspended solids)	- Motor vehicles
- Road salts	- Dry atmospheric deposition
- Biological and chemical oxygen-demanding substances	- Vegetation
- Thermal pollution	- Domestic animals, wildlife
- Metals	- Human wastes (failing septic systems, illegal connections)
- Synthetic chemicals	- Spills
- Polyaromatic hydrocarbons (PAHs)	- Litter
	- Salt, sand, and de-icing chemicals
	- Lawn fertilizers
	- Pesticides, herbicides

Wetland Assessment

Methods and techniques for wetland assessment in the United States have evolved rapidly over the last decade, with increased interest not only in the extent of our nation's wetland resources, but the quality of these resources. The first generation of wetland assessment techniques developed from a need for wetland functional assessment that was applicable to the national wetland regulatory program, or §404 of the Clean Water Act. The most widely used and adopted method was the Wetland Assessment Technique (WET) pioneered by Paul Adamus and the US Army Corps of Engineers in the early 1980s. Another generation of techniques, including the US Fish and Wildlife Service's Habitat Evaluation Procedures (HEP), the Evaluation for Planned Wetlands (Bartoldus et al., 1994), and several independent efforts from Connecticut (Ammann et al., 1986), New Hampshire (Ammann and Stone, 1991), and Oregon (Roth et al., 1993) furthered the wetland assessment field with improvements and new contributions for wildlife habitat and other functions. The most recent advances in wetland assessment involve specific wetland classification and functional modeling (hydrogeomorphic [HGM] approach) as well as watershed-specific risk ecological risk assessment (US Environmental Protection Agency/Office of Wetlands, Oceans, and Watershed's Ecological Risk Assessment case studies).

Biological, chemical, and physical indicators may be used to assess the ecological health of wetlands through multi-metric or index approaches adapted specifically for wetland ecosystems. An index is an analysis technique utilized to integrate a number of different variables or measurements into a single rank or score (see **Focus Box** in Section 2). For biological indices, such variables typically include: species diversity, community composition, and abundance of rare or pollution-tolerant species. In addition, the recent development of rapid assessment techniques has enabled the relatively swift evaluation and prediction of wetland functional capacity, biological communities, and susceptibility to degradation.

Section 2. Project Scope

The Coastal Wetlands Ecosystem Protection Project concept was borne by staff at Massachusetts Coastal Zone Management (MCZM) while researching and developing wetland related components of the state's Coastal Nonpoint Source Pollution Control Plan and was reinforced by ongoing efforts at the Waquoit Bay National Estuarine Research Reserve (WBNERR) to identify and quantify nonpoint source (NPS) pollution and its impacts to the Bay and by specific staff interests in the interconnections of wetlands, water quality, and aquatic habitat. Made possible through support from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center (CSC), the Coastal Wetlands Ecosystem Protection Project was launched with the primary goal of developing and testing an innovative and transferable approach for wetland assessment.

To develop the Wetland Health Assessment Toolbox (WHAT) approach, the project relied on a coordinated, inter-disciplinary strategy, utilizing the diverse skills and experience of the project staff, Technical Advisory Group, and other groups and individuals. The project was divided into two phases. This document covers Phase I only–the research for and development of the WHAT approach. The second phase is focused on the development of the methods and means for the transfer of the WHAT approach. The Phase II efforts–including training, technical assistance, and outreach–will be integral to realizing the effective implementation of wetland assessment efforts and NPS control strategies. Phase I of the project scope was comprised of:

Objective I: Inventory of wetland resources

- Gather and review existing data sources: MA Department of Environmental Protection interpreted aerial photos, town Conservation Commission delineations, US Fish & Wildlife Service National Wetlands Inventory data.
- Conduct preliminary on-site investigations: confirm inventory, obtain estimates of boundaries, preliminary assessment of wetland types and classifications (hydrogeomorphic factors).
- Select set of reference wetlands: from inventory, determine representative wetland types according to US Army Corps of Engineers' Hydrogeomorphic Classification framework.
- Map wetland resources: generate Geographical Information System (GIS) overlay of wetland study sites from interpreted aerial photos.

Objective II: Rapid assessments

- Evaluate and select methodologies: examine available techniques and indicators for assessing wetland functions, habitat, and sources of degradation; select appropriate methodologies.
- Conduct rapid assessments: using selected techniques/methodologies, perform assessments on wetland study sites.
- Compile data and analyze results: develop summary of assessment results, compare results between wetland study sites.

Objective III: Identification of nonpoint sources of pollution

- Gather and review data sources: GIS McConnel 1990 land use overlays (MassGIS, 1997), infrared aerial photos, stormdrain maps, shoreline surveys, and hydrological data.
- On-site investigations/confirm sources: develop comprehensive index of nonpoint sources and confirmed sources from interpreted aerial photos, water quality monitoring, additional shoreline surveys, and site inquiries.
- Data analysis: compile data, analyze results, generate NPS Index maps, examine results of investigation reports and water quality data.

Objective IV: Field-based investigations of ecological indicators

- Evaluate and select wetland ecological indicators: examine available indicators for quantifying/qualifying impairment and select appropriate indicators and methodologies.
- Develop appropriate Quality Assurance Plans (QAP): Utilize US Environmental Protection Agency-approved format, produce QAP, obtain sign-offs from all investigators, field staff, and laboratories.
- Conduct on-site investigations: utilizing selected indicators and methodologies, conduct onsite investigations of project study site wetlands.
- Compile data and analyze results: evaluate data to generate impairment index relative to reference wetlands.

Developing the transferable Wetland Health Assessment Toolbox was the ultimate goal of this pilot research demonstration project. Through the implementation of these Phase I objectives and tasks, the groundwork for the transferable WHAT approach was set. It is important to emphasize that the WHAT approach should be recognized as a collection of assessment methods and a framework for implementing them, rather than a stand-alone product.

The Wetland Health Assessment Toolbox

The Wetland Health Assessment Toolbox is a multi-component approach to wetland assessment developed by Massachusetts Coastal Zone Management with project partners: the University of Massachusetts/Amherst (The Environmental Institute and UMass Extension) and the Waquoit Bay National Estuarine Research Reserve. The WHAT approach has been designed to be utilized by groups and individuals interested in conducting evaluations of wetland ecological integrity for a host of different purposes. The results of this assessment approach will enable groups or individuals to identify wetland study sites that were exhibiting signs of adverse ecological effects and functional impairments, and, to some extent, to characterize the source(s) or causes(s) of the adverse effects. This information can be utilized to assist decision-makers as they attempt to address NPS pollution and habitat degradation. As discussed in Section 10, the WHAT approach has strong applications for the evaluation of wetland restoration or compensatory mitigation projects and for weighing the impacts of development on a specific site before and after the project has occurred.

The WHAT approach combines relatively simple and straight-forward rapid assessment methods with scientifically sound onsite fieldwork to produce a comprehensive evaluation of the ecological health of wetland study site. The WHAT emphasizes a team process, relying on the expertise of professionals from different disciplines. With proper training and guidance, though, each method and onsite field investigation can be successfully employed by any group or individual.

The rapid assessment methods and onsite field measurements utilized in the WHAT are listed in Table 2.1. For this project, additional detailed investigations of stormwater and groundwater hydrology were conducted at one wetland study site (WEA7).

The WHAT approach relies on the use of metrics and indices in data analysis and reporting. The **Focus Box** below defines and explains the use of metrics, indices and reference sites in a multi-metric assessment approach. A cumulative Wetland Ecological Condition score is the final assessment output, combining all of the above variables into one single quantitative value or rank. Statistical analysis may be employed to examine data patterns, correlations, significance, and use for predictive inquiry.

For additional information or to obtain comprehensive guidance information for a specific method, visit the WHAT site (currently under construction) on the world wide web at:

http://www.magnet.state.ma.us/czm/what.htm

or, contact the Project Manager:

Bruce K. Carlisle
Wetlands and Water Quality Specialist
Massachusetts Coastal Zone Management
100 Cambridge Street–Room 2006
Boston, MA 02202-0221.

Table 2.1. Wetland Health Assessment Toolbox

Rapid Assessment Methods	Developed by:
Nonpoint Source Index	Carlisle, B.K. and B.G. Largay
Habitat Assessment	Hicks, A.L.
Method for the Evaluation of Nontidal Wetlands	Ammann, A.P. and A.L. Stone
Method for the Evaluation of Vegetated Tidal Marshes	Cook, R.A., A.L. Stone, and A.P. Ammann
Ecological Indicator: Multi-Metric Approaches	**Developed by:**
Vegetation	Carlisle, B.K., S.R. Garcia, B.G. Largay, and J.P. Smith
Aquatic macro invertebrates	Hicks, A.L.
Water chemistry	Carlisle, B.K., B.G. Largay, and J.P. Smith
Hydroperiod	Carlisle, B.K. and B.G. Largay
Avifauna	J.P. Smith and B.K. Carlisle

Focus Box: Metrics, Indices, and The Reference Condition

Past studies in the assessment of biological integrity or water chemistry in water bodies have typically focused on a limited number of parameters or attributes that connect to a narrow range of perturbations (Barbour et al., 1994). Recent approaches in biomonitoring and ecological investigations have incorporated methods which examine an array of parameters or variables and incorporate responses from as many ecosystem levels as possible (Adamus, 1992). These methods are referred to as multi-metric approaches. *A metric is a parameter or variable which represents some feature, status, or attribute of biotic assemblage, chemical state, or physical condition.* In a multi-metric approach, several different metrics are chosen in order to effectively capture and integrate information from individual, population, guild, community, and ecosystem levels and processes. Metrics are selected based on literature reviews, historical data, and professional knowledge. The following are some examples of metric types from the different indicator protocols contained in the Wetland Ecological Health Toolbox:

Protocol	**Metric Type**	**Summary**
Biological	Taxa Richness	The diversity of species (taxa) from a population
Biological	Community Health	Proportionate composition of tolerant, sensitive, or invasive species
Physical	Change in Water Level	Measures similarities and differences in hydroperiod
Chemical	Ortho-Phosphates	Measures mean concentration of limiting nutrient in water

The quantitative output from each metric is then combined to produce an index. *An index is the aggregate of weighted metric scores that serves to summarize the biological, chemical, or physical condition.* The use of a control data set, or reference condition, with which to compare other sites in question to is a fundamental tenant of a multi-metric assessment approach. *The reference condition establishes the basis for making comparisons and for detecting impairments; it should be applicable to study sites on a regional scale.* The reference condition should be representative of sites at which minimal impacts exist (i.e. relatively pristine) or sites with existing conditions that are deemed to be the best attainable for a given region (i.e. heavily urbanized or agricultural). Reference conditions may be established by several means: the collection of *in situ* data, the use of historical data, employing a simulation model, or from expert or best professional opinion (Barbour et al., 1994).

The integration from various ecosystem level attributes is what gives the multi-metric approach its strength. The multi-metric approach is able to pick up perturbations that a more narrowly defined study may not; such an approach is also able to minimize weaknesses or variability of a single metric through the synthesis of the total array of metrics. Over the past decade, multi-metric approaches have been widely utilized for biological surveys of lakes, streams and rivers but have not been adequately explored for their use in wetland ecological assessments. Several recent efforts, such as the Coastal Wetlands Ecosystem Protection Project, have emerged to adapt current methods and develop new techniques. Each new application of these wetland assessment approaches provides an opportunity for testing and refinement.

Study Area

The project study area was the Waquoit Bay watershed in southwestern Cape Cod, and included parts of the towns of Falmouth, Mashpee, and Sandwich (Figure 2.1). Waquoit Bay is a shallow coastal lagoon representative of similar estuaries found in this coastal plain region. The Waquoit Bay watershed is 54 km^2 and its geology is characterized by unconsolidated glacial sands and gravel, while the hydrology is predominately driven by groundwater (Figure 2.2). Land cover and use in the watershed is mixed, and is best characterized as dominated by scrub oak/pitch pine forest and moderate to dense residential, with isolated areas of agriculture (cranberry bogs), recreation (golf courses), transportation, and commercial/industrial. Waquoit Bay and the aquatic resources of its watershed are exhibiting symptoms of acute eutrophication, such as fish kills, loss of eelgrass beds, nuisance macro algae blooms, and loss of species diversity. Sources of nutrients in the watershed include septic systems, fertilizers, atmospheric deposition, road runoff, boat waste, domestic animals, and wildlife. Bacterial contamination has led to the closure of shellfish beds. In addition, toxic pollution from the Massachusetts Military Reservation Superfund site has contaminated groundwater in the northwestern part of the Waquoit Bay watershed.

A high diversity of wetland hydrogeomorphic types is found within the watershed. Glacial depressions, which reach below the water table, are typically characterized by lacustrine fringe and depressional wetlands and are generally isolated with no, or minor, inlets or outlets. Historical anthropogenic activities have added surface hydrologic connections to enhance conditions for cranberry production or drainage. The lacustrine fringe and depressional wetlands of the Waquoit Bay watershed are hydrologically dominated by groundwater and precipitation and are characterized by vertical hydrodynamic fluctuations. Riverine wetlands, both channel and floodplain, are numerous on each of the two major tributaries to Waquoit Bay: the Childs River and the Quashnet River. Most of these wetlands have been historically altered for cranberry production and many are still in active agricultural use. Groundwater mapping efforts by the Cape Cod Commission indicate that the upper portions of the Quashnet and Childs receive groundwater discharge while the lower portions are mostly recharge areas. These riverine wetlands can be classified as having their hydrology driven by a range of water sources, depending on location within the drainage area, on seasonal water table fluctuation, and precipitation. The riverine hydrodynamics are unidirectional in flow. Fringing and pocket salt marsh wetlands are also located extensively throughout the watershed, with large areas found behind the South Cape barrier beach system in the Sage Lot Pond region. Primary impacts to salt marsh hydrology include filling for commercial or private development, restriction of tidal flow, and historical ditching conducted under the premise of mosquito control. The hydrology of salt marshes is dominated by the inundation by estuarine surface water, limited groundwater discharge, and the evapotranspiration of salt marsh plants. The salt marsh wetlands are driven by diurnal tidal cycles and are classified as exhibiting bidirectional hydrodynamics.

Figure 2.1. Locus map of Cape Cod and Islands, southeastern Massachusetts.

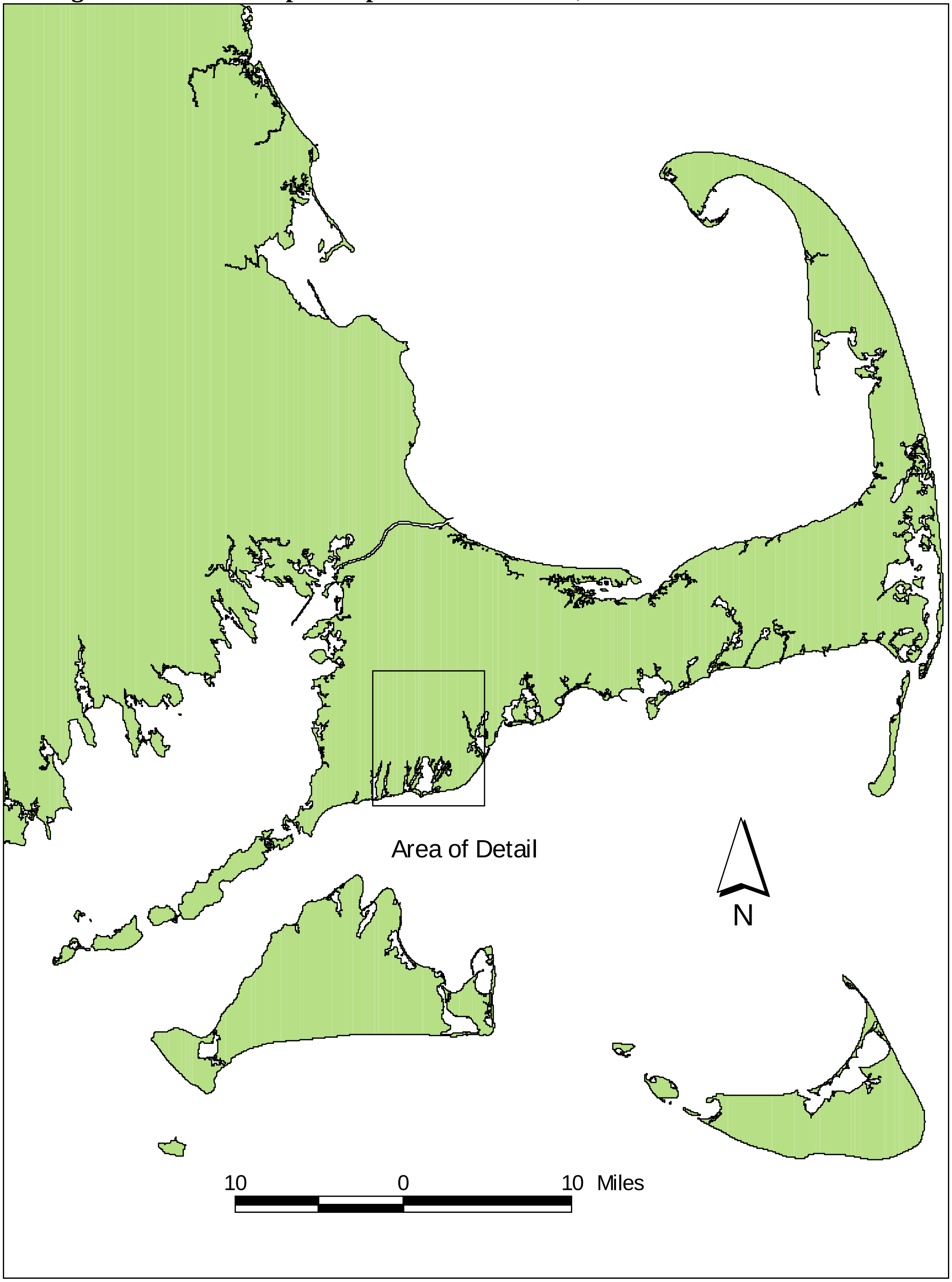
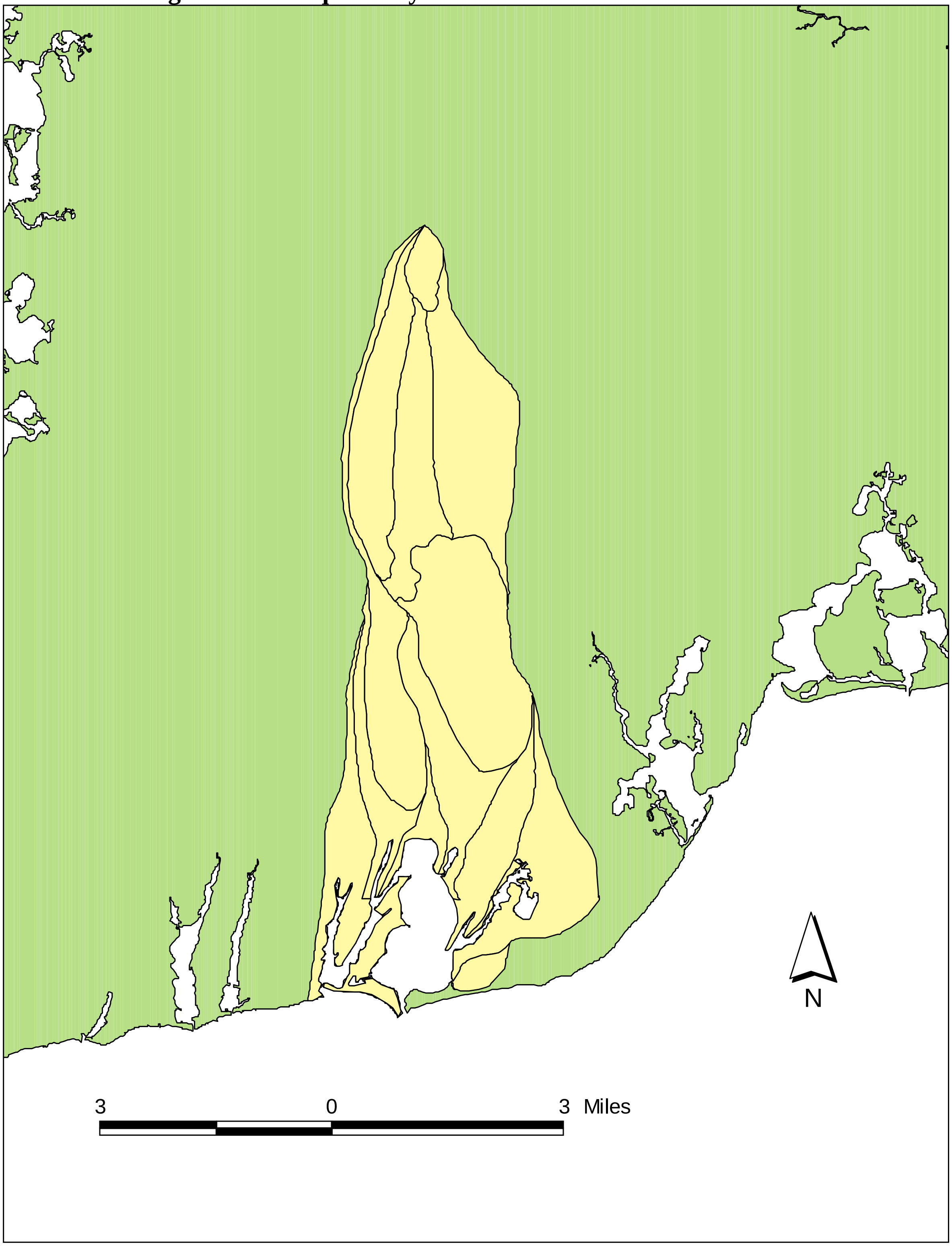


Figure 2.2. Waquoit Bay watershed and contribution areas.



Study Sites

The wetland study sites, or Wetland Evaluation Areas (WEAs), were chosen to be representative of each major hydrogeomorphic type of wetland present in this coastal watershed (isolated depressional, riverine/lacustrine fringe, and tidal salt marsh) and to capture a range of surrounding land use types and intensity (Table 2.2). For both the freshwater wetland study site group and the salt marsh study site group, reference wetlands, or controls, were carefully selected. These reference sites were characterized as having only natural land cover and low impact land use (recreation: walking trails and/or fire roads) within a 1000 meter zone of influence. The three reference sites, WEA2 and WEA3 for freshwater group and WEA10 for the tidal wetland group, were appraised to be wetlands which have been largely unaffected by anthropogenic activities and have little to no invasive land use within their 1000m zone of influence. Impacted study sites had within their 1000m zone of influence various human land uses, including four sites with direct storm drain discharges, seven sites with residential development, three sites with golf courses, and three sites affected by cranberry farming. Study sites ranged in size from less than one acre to approximately forty acres. Figure 2.3 displays the locations and size of the freshwater sites, and Figure 2.4 does the same for the salt marsh sites. During the course of the study, site WEA5, a riparian depressional wetland at the Quashnet Country Club, was removed at the request of the landowner.

Freshwater Sites

WEA2

One of two freshwater reference sites, WEA2, is an isolated depressional wetland located about 200 meters west of an old fire road and surrounded by several hundred acres of pitch pine and scrub oak forest. This wetland is approximately 6,824 m^2 (1.7 acres) and has a diverse plant population. The wetland is comprised of six main vegetative communities, which include a shrub swamp community dominated by *Lyonia ligustrina* (maleberry), a grassy flooded marsh dominated by *Dulichium arundinaceum* (three-way sedge) and *Glyceria striata* (fowl meadow grass), and an area of ponded water dominated by *Sagitaria latifolia* (big-leaved arrowhead) and *Eleocharis ovata* (blunt spike rush). The wetland is divided by a line of trees, *Pinus rigida* (pitch pine) and *Acer rubrum* (red maple), growing in a strip of elevated topography about five m wide by 20 m long. Water input to this site is dominated by precipitation and groundwater discharge. The wetland has loamy soils with a high content of organic material. An area of open water in this wetland varies considerably in size depending on local water levels and rainfall. The land uses in the 1,000 m zone of influence are conservation and open space, with no apparent sources of NPS pollution.

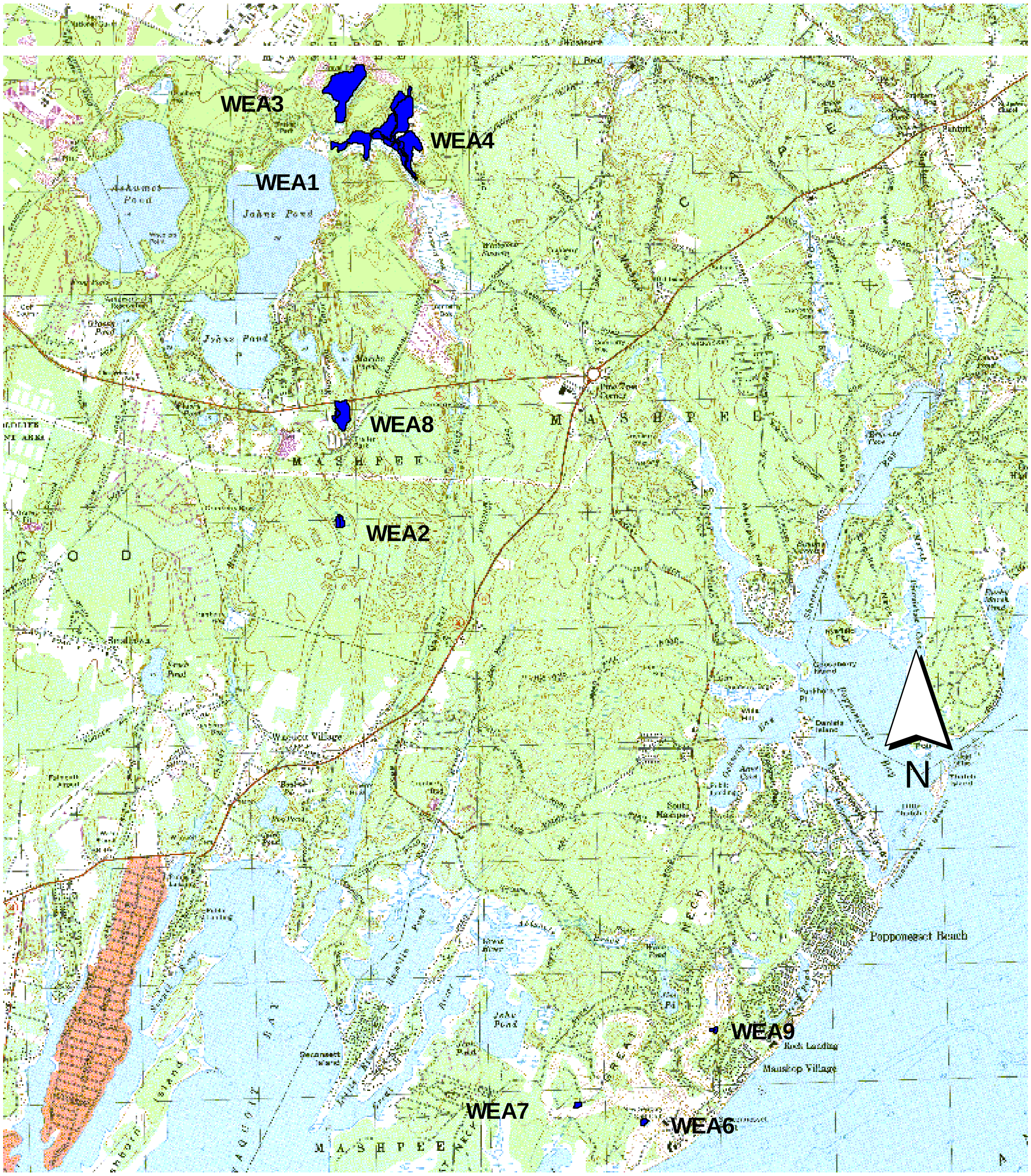
WEA3

Site WEA3, the second freshwater reference site, is a lacustrine fringe wetland located in the northern part of the watershed to the northeast of John’s Pond. The study site is a lacustrine fringe system about 79,865 m^2 (19.6 acres) in size and is characterized by fringing emergent marsh, pitch pine, and scrub oak forest. The shoreline is characterized by relatively short, steep banks. The aquatic/emergent community is dominated by *Juncus effusis* (soft rush) and *Decodon verticillatus* (swamp loosestrife) and there is ample presence of *Nymphaea odorata* (white water lily); the shrub community is dominated by *Vaccinium corrymbusum* (highbush blueberry) and *Clethra alnifolia*

Table 2.2. Wetland Evaluation Areas: Class, cover, and surrounding land use.

WEA	Subwatershed	Class	Cover Type	Land Use
WEA1	Quashnet	Riparian depressional	Emergent Shrub	Former cranberry bog, open space, dirt roads
WEA2	Quashnet	Isolated depressional	Emergent Shrub Forest	Open space, dirt road
WEA3	Quashnet	Lacustrine fringe	Emergent Shrub Forest	Military operations, open space, dirt roads
WEA4	Quashnet	Riparian fringe	Cranberry cultivation Emergent Shrub	Agriculture, irrigation, hydromodification
WEA6	Jehu Pond	Lacustrine fringe	Emergent Forest	Golf course, residential, stormwater disposal
WEA7	Flat Pond	Isolated depressional	Forest Shrub Emergent	Golf course, residential, stormwater disposal
WEA8	Quashnet	Lacustrine fringe	Emergent Shrub Forest	Residential, transportation, stormwater disposal
WEA9	Jehu Pond	Isolated depressional	Emergent Shrub Forest	Golf course, residential, stormwater disposal
WEA10	Sage Lot Pond	Tidal salt marsh	Emergent	Open space, dirt road
WEA11	Hamblin Pond	Tidal salt marsh	Emergent	Marina, residential, boating
WEA12	Eel Pond	Tidal salt marsh	Emergent	Residential, boating
WEA13	Eel Pond	Tidal salt marsh	Emergent	Residential, boating
WEA14	Jehu Pond	Tidal salt marsh	Emergent	Public boat ramp, residential, boating

Figure 2.3. Freshwater wetland study sites.



(sweet pepper bush); and the sapling/forest community is dominated by *Acer rubrum* (red maple). Soils at WEA3 are predominantly sands. Water input is driven by groundwater discharge and precipitation. The land use in the immediate area consists of open space and recreation, although it is important to note that the Massachusetts Military Reservation (MMR), a national superfund site, located about one kilometer to the north and west of this wetland and that contaminated groundwater plumes have been detected in the area of this site as well as WEA1 and WEA4. The majority of the 1,000 m. zone of influence is characterized by forest and natural vegetation. A dirt road leading to the wetland is gullied and eroding, and this may be a sediment source to a small portion of the wetland.

<u>WEA1</u>

WEA1 is a 32,063 m^2 (7.8 acre) riverine depressional type wetland, bordering the upper reaches of the Quashnet River. This wetland was utilized for active cranberry production but has been left fallow for at least 12 years (per conversation with local conservation officials). The Quashnet River exits John's Pond and enters the study site at its northwest edge and fills a network of relict ditches and channels. The surface hydrological connection to John's Pond is a manmade channel constructed to enhance cranberry irrigation and also resulting in the development of an anadromous herring run to the pond. Groundwater discharge within this marsh appears to constitute 20 percent of total river outflow. This wetland is comprised of five distinct vegetative communities. A community dominated by *Typha latifolia*(broad-leaved cattail) borders the stream, and an open water community in the slower moving parts of the stream is dominated by *Nymphaea odorata* (white water lily). Three separate emergent communities are present and are dominated *Scirpus cyperinus* (wool grass), *Spirea tomentosa* (steeplebush), and *Scirpus americanus* (three-square rush). Soils at WEA1 are dominated by sands and the hydrology is both groundwater and riverine flow driven. The land use surrounding WEA1 is primarily town conservation land and town-leased cranberry production (study site WEA4). This cranberry agriculture is downstream of WEA1 and should not contribute significant NPS pollution to this wetland. The most likely NPS source for this site would be the existing reservoirs of particulate-bound nutrients in the wetland soils–remnants of fertilizer usage for this former cranberry bog. As previously mentioned, groundwater plumes from the MMR Superfund site have been detected in the vicinity of this site.

<u>WEA4</u>

Study site WEA4 is an active cranberry bog located on the headwaters of the Quashnet River below the outlet of John's Pond and site WEA1 and occupies 46,841 m^2 (11.5 acres). This wetland is dominated by the cultivated *Vaccinium macrocarpa* (cranberry). Other vegetation species present in this wetland occur in cranberry ditches and in fringing shrub-scrub communities. Plants developing within the manipulated bog are periodically weeded and/or sprayed with herbicide. In addition, bank and ditch maintenance frequently result in physical disturbances, by removing existing vegetation and exposing bare soil. The vegetative community in these areas is very diverse, dominated by colonizing burr reed, sedges, rushes and grasses. Soils at WEA4 are mostly sands and the hydrology measurements indicate that 20-40 percent of the Quashnet flow originates within this site. The surrounding land use is predominantly forested and the main source of NPS pollution is from fertilizer and pesticide applications associated with cranberry production. Because of the presence of the MMR groundwater plume this bog was closed to harvest for the 1997 season.

WEA5

Study site WEA5 was removed from the research project at the landowners request.

WEA6

One of three study sites bordered by golf course land use, WEA6 is a 2,874 m^2 (0.7 acre) pond/deep marsh wetland located at the southeast edge of the Waquoit Bay watershed in the New Seabury planned development community. WEA6 is dominated by open water, and its fringing vegetation population is characterized by emergent herbaceous species–*Juncus effusis* (soft rush), *Phragmites australis* (common reed), and *Scirpus cyperinus* (wool grass)–as well as some shrubs and saplings. Soils are mainly sands and water input is groundwater discharge, precipitation, and stormwater discharge. WEA6 is bordered by two golf course fairways and greens with little and no buffer area between the manicured grass and the wetland edge. Bordering wetland and upland plants are frequently mowed, and the pond edge has been conspicuously filled in some areas. In addition, site WEA6 receives direct stormwater discharge from a dense residential subdivision (<1/4 acre lot size) located to the northwest of the site.

WEA7

Study site WEA7 is a 2,478 m^2 (0.6 acres) isolated depressional wetland located between a golf course and a large, dense residential subdivision. Catch basins along the residential streets in this area collect rainfall and snowmelt and discharge through a 16-inch diameter concrete drain pipe to the wetland. The vegetative survey identified three communities, an emergent section dominated by *Typha latifolia* (broad-leaved cattail), an herbaceous community dominated by *Carex sp.* (sedges), and a shrub/forest community dominated by *Clethra alnifolia* (sweet pepper bush) and *Acer rubrum* (red maple). Episodic flooding and subsequent dry down in this wetland may be inhibiting the succession into a complete forest cover. This wetland consists primarily of saturated soils of predominantly sands overlain by a fairly thick peat layer (1.0 m). Water inputs to WEA7 include groundwater discharge, precipitation, and stormwater discharge. This site is also connected to a downstream intermittent stream by a culvert that runs under the width of a golfcourse fairway. This stream flows to Flat Pond then onto Sage Lot Pond and into Waquoit Bay.

WEA8

Site WEA8 is a lacustrine fringe wetland 28,095 m^2 (6.9 acres) in size, located directly to the south of a two lane state highway (Route 151). The wetland consists primarily of open water with fringing emergent and shrub plant communities, and water sources are groundwater, precipitation, and stormwater discharge. A 16-inch diameter culvert empties to the wetland, but the contributing sources to this culvert could not be positively verified. Catch basins along Route 151 collect rainfall runoff, but it is not clear that they are connected to this storm drain. From remote sensing and topographic drainage inspections, the culvert likely serves a long narrow drainage area and a small wetland to the north of Route 151. Site WEA8 is also bordered to the west by a very dense single family residential area (trailer park), served by onsite septic systems. Dominant plant species include *Decodon verticillatus* (swamp loosestrife), *Clethra alnifolia* (sweet pepper bush), *Lyonia ligustrina* (maleberry), and *Acer rubrum* (red maple). Areal coverage of the open water by *Nymphaea odorata* (white water lily) is substantial (>90%) in the latter part of the growing season (July to October).

WEA9

Like WEA7, site WEA9 is an isolated depressional wetland, of similar size–2,671 m^2 (0.7 acres)– and is bounded by residential development and golf course land uses. Soils at this site consist of sands with significant peat and muck accumulation. Water inputs include groundwater discharge, precipitation, and stormwater discharge. Similar to site WEA7 also, this wetland receives direct discharge of untreated stormwater runoff from catch basins along the streets in this area. WEA9 is characterized by mixed cover types, with a forest community dominated by *Acer rubrum* (red maple) and *Salix discolor* (pussy willow), a shrub community dominated by *Clethra alnifolia* (sweet pepper bush) and *Decodon verticillatus* (swamp loosestrife), and an emergent herbaceous community dominated by *Scirpus cyperinus* (wool grass) and *Carex sp.*(sedges).

Salt Marsh Sites

WEA10

Site WEA10, located in a section of protected South Cape Beach State Park, is an excellent example of a healthy New England region salt marsh. Other than low-impact dirt fire roads and walking trails, WEA10 is isolated from immediate sources of NPS pollution, and was selected as the reference site for the salt marsh study group. WEA10 occupies 169,665 m^2 (41.6 acres). As typical of this region's salt marshes, the low marsh communities were dominated by *Spartina alterniflora* (smooth cordgrass), and several distinct high marsh communities were identified, including one dominated by *Juncus gerardii* (black grass) and *Distichlis spicata* (spike grass), one dominated by *Iva frutescens* (high tide bush), and one dominated by *Spartina patens* (salt hay grass) and *Limonium nashii* (sea lavender). Water flow is primarily from by tidal exchange, while groundwater discharge, precipitation, and freshwater surface flow from Flat Pond play lesser roles.

WEA11

Study site WEA11 is a very small (376 m^2, 0.1 acres) fringing salt marsh on the Little River, one of the fingers of Waquoit Bay. Historic shoreline development and corresponding fill and alterations have divided long fringes of bordering salt marsh into small isolated areas like this and several other of the salt marsh study sites. The Little River Marina occupies much of the zone of influence to this study site and low to medium density residential land use is also present. The vegetative communities at this site are a low marsh, dominated by *Spartina alterniflora* (smooth cordgrass), a high marsh dominated by *Spartina patens* (salt hay grass) and *Distichlis spicata* (spike grass), and an upland bordering community with *Iva frutescens* (high tide bush) and isolated stems of stunted *Phragmites australis* (common reed). The site has unrestricted tidal flushing and there was no evidence of channelization or ditching.

WEA12

Study site WEA12 is another small fringing salt marsh (1,308 m^2, 0.3 acres), located on Eel Pond. Like the other salt marsh study sites, unrestricted tidal exchange dominates the flow regime of WEA12. This site is situated within primarily medium density residential land use, with a public boat landing also present in the zone of influence. A dense stand of *Phragmites australis* (common reed) and *Toxicodendron radicans* (poison ivy) dominated the wetland from about the average high tide line up into the upland. Freshwater mounding from septic systems and former disturbance to wetland soils most likely created the conditions for the widespread colonization of *Phragmites.*

Other sources of NPS pollution in the zone of influence include erosion, stormwater runoff from the road and boat launch area, and pollutants associated with the septic systems of nearby houses. Also noted at this site, in the edges of the river near the low marsh and at the marsh at the boat ramp, was the widespread presence of thick, decomposing filamentous algal mats.

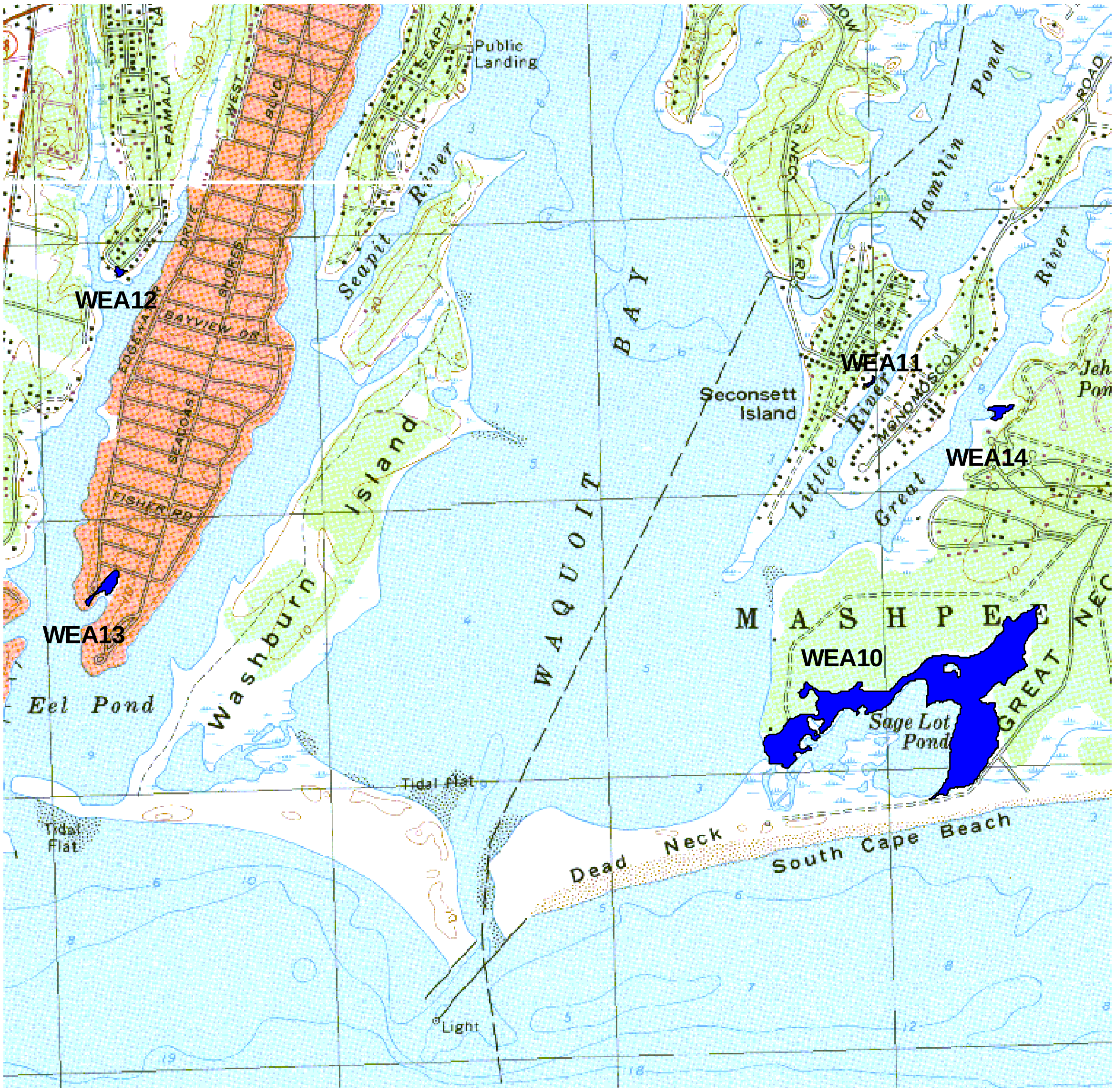
<u>WEA13</u>

Salt marsh study site WEA13, also located on Eel River, is characterized geologically as a pocket marsh rather than a fringing one. WEA13 occupies 4,142 m^2 (1.0 acre). Estuarine tidal exchange dominates the water flow. Medium density residential development surrounds this marsh, with several lawns directly abutting the high marsh fringe. For this site, septic system and lawn fertilizer inputs are the NPS pollutants of concern, although a small freshwater drainage, with stormwater runoff inputs, enters the marsh to the north. Similar to site WEA12, late summer visits to WEA13 confirmed the presence of large floating filamentous algal mats. Shorelines just to east and west of this site had been hardened with sea walls and docks. Tidal influence to this site was not observably restricted.

<u>WEA14</u>

The final salt marsh study site, WEA14, is a 3,254 m^2 (0.8 acres) pocket marsh located on the Great River. Land use in the 1,000m zone of influence includes low to medium density residential, including the 1996-1997 construction of a very large (6+ bedrooms) house immediately to the north (<50 meters) of the study site, and a public boat ramp and paved parking lot. Again, similar to sites WEA12 and WEA13, large floating filamentous algal mats were observed at the edges of this marsh. The vegetation population at this site is dominated by the low marsh *Spartina alterniflora* (smooth cordgrass), with abundant *Iva frutescens* (high tide bush) and *Distichlis spicata* (spike grass) in the high marsh areas.

Figure 2.4. Salt marsh study sites.



Part II: Wetland Ecological Assessment

The Wetland Health Assessment Toolbox (WHAT)

Section 3. Rapid Assessment Methodologies

The utilization of the following rapid assessment techniques was an important component of the Coastal Wetland Ecosystem Protection Project. As detailed in the Project Scope (Section 2), one of the major objectives of the project was to evaluate, select, and apply several rapid assessment methods in order to compare these results with the field-based indicator results. Based on this information, the suitability of these rapid assessment methods as part of an array of available wetland ecological assessment methods would be determined. As explained in each of the following subsections, these rapid assessment methods provide valuable information that both enhances the field based data and also serves as an aid to the interpretation of this data. In most cases, the relationships between the rapid assessment outputs and the individual indices is remarkably close.

Generally, rapid assessment methods are simple models which utilize existing information and basic field-based wetland and landscape observations to derive a generalized estimate of wetland conditions. These rapid techniques can be highly useful in that they can be applied very quickly and by most field personnel (given adequate guidance), and they are inexpensive. Currently, several rapid assessment methods are used in lieu of more intensive field-based assessments for state and federal wetland regulatory and restoration programs. In the Wetland Health Assessment Toolbox (WHAT), rapid assessment methods serve to compliment the field-based ecological indicators by aggregating basic information on wetland and landscape conditions–a necessary step for the data analysis and diagnosis of impairment causes. In addition, rapid assessment methods represent options for groups or individuals who lack sufficient resources to engage in more intensive, field-based wetland evaluation.

Habitat Assessment

Measuring impact on wetlands from cumulative nonpoint pollution and hydrological alterations within the wetland contribution area, or the zone of influence, requires a landscape approach. Wetlands need to be viewed within the context of a larger ecosystem, not just as "black boxes" (Burbridge, 1994; Euphrat and Warkentin, 1994). In such an approach, four groups of factors must be considered: the source of the impact (the drainage basin and the immediate surrounding landscape), the nature of the wetland as a sink (the characteristics of the wetland and how effectively they can mitigate impact); the logical geographic scale for planning and management (wetland, surrounding landscape, sub-drainage basin, whole watershed); and finally the biological integrity of the wetland.

The focus of the Habitat Assessment (HA) method is primarily to provide support for the aquatic macro invertebrate field-based indicator protocol. It provide necessary input on habitat integrity and quality for macro invertebrates, though it certainly has broad implications for other wetland biota. This HA method was adapted by A.L. Hicks (1996) from protocol developed by Plafkin et al. (1989) and Florida DEP (1996).

For the HA method, two groups of criteria are utilized: surrounding landscape characteristics and onsite wetland features. For each site a HA worksheet is completed by trained project staff personnel at least one time during the growing season. The HA field forms are contained below in Table 3.1

and Table 3.2. The landscape level characteristics that are evaluated are: the dominant land uses; the amount of impervious cover within the local sub-drainage basin (wetland contribution area); the amount of natural vegetation within the local sub-drainage basin; the ratio between the size of the wetland and the size of the local sub-drainage basin; and finally, the major sources of pollution. Using the HA field form, evaluators select from the scoring criteria columns (5-6, 3-4, 1-2, 0) the description that best describes the Wetland Evaluation Area (WEA) for each indicator. Evaluators use best professional judgement when examining the WEA in order to assign the scoring criteria at the higher or lower end of the spectrum (i.e. 5 instead of a 6).

For freshwater wetlands, the onsite descriptors of habitat quality are: degree of water level fluctuation, nature of any outlet restriction, rate of sedimentation, nature of the wetland substrate, vegetation diversity, degree of buffering from impacts, the intensity of human activities within the wetland, and finally an assessment of the available food sources for aquatic invertebrates. Additional salt marsh descriptors include: littoral alterations, plant community types, tidal fluctuation, freshwater discharges, channelization, wave action, sediment type, and degree of impact from human activities. The use of Cowardin wetland classes are employed in the HA method. This system was develop by Cowardin et al. 1979 to identify wetlands by specific characterizations including vegetation, soils, hydrology, salinity, and others. The Cowardin system has been widely accepted as the current national standard for wetland classification (the basis for the National Wetlands Inventory, for example), though adaptations of the Cowardin system are currently underway to incorporate additional abiotic features such as landscape position and landform type (Tiner, 1997).

For this project, the HA was completed during May 1996. The results of the HA are displayed in Table 3.3. The output score is a relative ranking of habitat quality on a scale of 100. A score of >80 is indicative of healthy wetland habitat conditions. More discussion of the use and output scores of the HA method is contained in Section 5 Aquatic Macro Invertebrates. Figure 3.2 and Figure 3.3 graphically display the results of each of the three rapid assessment methods applied.

Table 3.1. Freshwater wetland Habitat Assessment field form.

SCORING CRITERIA:	5-6	3-4	1-2	0	SCORE
LANDSCAPE Dominant land use	Forestry and open space	Low density residential or grazing	Medium-high density residential	Commercial, industrial, transportation	
%Impervious surface	< 5	5 - 10	11 - 20	> 20	
% Natural vegetation	>50	30 - 50	10 - 29	< 10	
Ratio wetland/drainage basin area	> 10%	6 - 10%	2 - 5%	< 2%	
Possible major sources of pollution	No discernable source	Septic sewage effluent	Fertilizers and pesticides from gardens, golf courses, agriculture.Sediments and de-icing salts	Industrial commercial effluent, urban storm water runoff	
WETLAND Water level fluctuation	Due to natural seasonal fluctuation	Some modification to natural hydrology through artificial control	Controlled by damming of the outlet	Fluctuation extreme and unseasonable due to dam release, or storm water run-off	
Outlet restriction	No outlet restriction	Outlet restriction > 30’	Outlet restriction 5 - 30’	Outlet restriction <5’	
Rate of sedimentation	No evidence of sedimentation	Evidence of shallowing processes near inlets and storm water drains	Sand accumulation evident with some vegetation growing on bars	Sand accumulation smothering vegetation and forming bars	
Nature of sediments	Composed of equal quantities of gravel, sand, silt/mud and organic matter	Predominantly silt/mud with organic material	Predominantly gravel, sand, with some silt/mud and organic material	Predominantly rocks, cobbles, gravel and sand with no silt or organic matter	
Vegetation diversity	> 4 Cowardin classes	4 Cowardin classes	2 - 3 Cowardin classes	< 2 Cowardin classes	
% Presence of a vegetated buffer of 100’width	> 80	50 - 80	20 - 49	< 20	
Food sources	Abundance of macrophytes, algae, periphyton, CPOM and FPOM	Some macrophytes, plus algae, periphyton, CPOM and FPOM	Some algae and periphyton, CPOM and FPOM	No macrophytes, no algae or periphyton, only some CPOM and FPOM	
Degree of human activities in wetland: fishing, swimming, boating, trails roads, trampling, shoreline modification, solid waste	No human impact	Low level with minimal impact	Moderate level, erosion noticeable, vegetation degraded in places	High level, wetland severely degraded and neglected	
				TOTAL SCORE:	

% (13 indicators, 78 maximum score) n/78 x 100

CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter

Table 3.2. Salt marsh Habitat Assessment field form.

SCORING CRITERIA:	5 - 6	3 - 4	1 - 2	0	SCORE
LANDSCAPE Dominant land use	Forestry and open space	Low density residential or grazing	Medium-high density residential	Commercial, industrial, transportation	
%Impervious surface	< 5	5 - 10	11 - 20	> 20	
% Natural vegetation	>50	30 - 50	10 - 29	< 10	
Ratio wetland/drainage basin area	> 10%	6 - 10%	2 - 5%	< 2%	
Possible major sources of pollution	No discernable source	Septic sewage effluent	Fertilizers, pesticides from golf courses, agriculture. Sediments and de-icing salts	Industrial commercial effluent, urban storm water runoff	
SALT MARSH Tidal fluctuation and degree of flushing	Natural tidal surges are unimpeded	Some modification to natural fluctuation due to artificial control	Controlled by constriction of the estuary outlet, or shoreline modification	Salt marsh cut off from normal tidal fluctuation	
Outlet restriction	No outlet restriction	Outlet restriction > 30’	Outlet restriction 5 - 30’	Outlet restriction <5’	
Rate of erosion	No evidence of bank erosion	Evidence of bank erosion (mussels disturbed,grass thinned,slumping)	Bank eroding processes well established	Severe bank erosion	
Nature of substrate at water/substrate interface	Composed of sand, silt/mud, or a mixture of both	Predominantly sand, or silt/mud with organic material	Predominantly organic peat with some sand and silt/mud	Predominantly rocks, cobbles, or peat	
Vegetation diversity	4 Cowardin classes	3 Cowardin classes	2 Cowardin classes	<2 Cowardin classes	
% Presence of a vegetated buffer of 100’ width	> 80	50 - 80	20 - 49	< 20	
Food sources	Abundance of macrophytes, algae, periphyton, CPOM and FPOM	Some macrophytes, plus algae, periphyton, CPOM and FPOM	Some algae and periphyton, CPOM and FPOM	No macrophytes, algae or periphyton, some CPOM and FPOM	
Degree of human activities in salt marsh: fishing, swimming, boating, trampling, shoreline modification, waste	No human impact	Low level with minimal impact	Moderate level, erosion noticeable, vegetation degraded in places	High level, wetland severely degraded and neglected	
				TOTAL SCORE:	

% conversion (13 indicators, 78 is maximum score) n/78 x 100

CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter

Table 3.3. Habitat Assessment results for freshwater and salt marsh wetlands.

Freshwater Site	HA Score	Salt marsh Site	HA Score
WEA2	94	WEA10	94
WEA3	90	WEA11	49
WEA1	80	WEA12	46
WEA4	47	WEA13	45
WEA6	46	WEA14	39
WEA7	46		
WEA8	75		
WEA9	53		

Nonpoint Source Index

Developed as a specific product of the Coastal Wetlands Ecosystem Protection Project, the Nonpoint Source Index (NPSI) method is to estimate the potential nonpoint source (NPS) pollutant contributions, or loadings, to Wetland Evaluation Areas (WEA) from surrounding land uses and landscape conditions.

Using this methodology, it is possible to gain an understanding of the potential sources of NPS pollution to a given wetland based on its position in the landscape, the types of land use surrounding it, and other factors including land use distances from the WEA and cover type. Due to the high variability in land use patterns and landscape characteristics, different wetland areas are subject to different levels of disturbance from human sources.

The NPSI is a planning-based method, and it should be emphasized that the results of this methodology are estimates only and should not be used for regulatory or non-planning efforts. The NPSI is intended to be used by individuals and groups who are engaged in local, regional, and state wetland protection and restoration planning as well as NPS identification and control. Like the citizen-based water quality monitoring, shoreline survey, and streamwalk models, this methodology has been designed to be a readily transferable and user-friendly approach, and, after a brief initial training, most individuals should be able to utilize this methodology regardless of their level of expertise. Some representative groups who would use this methodology are citizens, local officials, watershed organizations, regional planning groups, and state or federal environmental agencies.

Wetlands are typically located in low-lying areas of the landscape, causing them to act as receiving points for upland sources of sediment, nutrient, and other pollutants (Nixon, 1986). Although many wetland types are able to perform water quality-related functions, such as sediment trapping and nutrient uptake, pollutant loads entering a wetland may actually exceed its capacity to store, absorb, or transform them (Whigham, et al., 1988). In addition, while a wetland may do a good job of removing pollutants from upland sources, these pollutants may have adverse effects on other wetland functions and conditions such as flood storage and desynchronization, wildlife habitat and vegetation, production export, recreation, and successional state (National Research Council, 1991). As the type and intensity of proximate human land uses increases, the wetland area becomes subject to corresponding changes to its hydrology, nutrient and sediment regimes, and habitat quality. This compounding of insults to the natural ecological integrity of wetlands is referred to as cumulative impacts. The NPSI is a method that can help to better gauge, estimate, and rank the relative potential for cumulative impacts to different wetlands.

The NPSI methodology has been developed and refined based on primary data and field observations, extensive literature review, and professional opinion. Because no two wetlands are the same, nor are any region's or area's land use patterns and characteristics, this methodology has incorporated procedures to discriminate for important variables. In this perspective, it is important to state and clarify the central assumptions or tenants of this methodology.

Firstly, one of the primary factors affecting the outcome of this weighted index is the presence, state, and condition of three wetland zones of influence. The first zone of influence is the 30.48 meter (100 feet) buffer zone. In Massachusetts, this area is jurisdictional and issuing authorities have discretion regarding activities proposed in this buffer zone. The presence and condition of this upland zone or area directly adjacent to the wetland has significant influence on the health and functional integrity of the wetland. The second zone of influence is a 100 meter area directly adjacent to the WEA–more than twice the regulatory buffer zone. Multiple references substantiate the fact that for most wetlands and riparian areas, in terms of pollutant transport and wildlife habitat, an area larger than 100 feet must be considered (Desbonnet, et al., 1994; Castelle, et al., 1994; Gilliam, 1994; Groffman, et al., 1990). The final zone of influence is the wetland's contribution area, or watershed. Watershed management has become widely recognized as an important way to control NPS pollution (U.S. Environmental Protection Agency, 1993). A wetland watershed is the area on the land that contributes surface water and groundwater to the wetland. In regions like Cape Cod, Massachusetts, where soils are highly permeable, rainfall infiltrates rapidly and contributes to groundwater flow, while surface water flow occurs only across impervious surfaces such as roads and roofs, or where the ground surface intersects the water table to form a river or pond.

The second assumption recognizes that the production, transport and fate of NPS pollutants is influenced by a number of determinants, including the nature and type of land use, the physical characteristics typical of certain land uses, hydrological patterns of the watershed or contribution area of the WEA, and intercepting or attenuating conditions. Based on extensive literature and available data, generalized assumptions can be made about the relative contributions of NPS pollutants from specific land uses. Intensive uses such as commercial areas (malls and urban centers, for example) produce more NPS pollutants than low density residential uses (Horner, 1992). Through the development of relative land use pollutant loading coefficients, this methodology has attempted to incorporate many of these variables into evaluation procedures. Due to many variables, though, it is important to point out that actual conditions may vary from output results. The pollutant loading estimate values that have been assigned for each of the different "sources" or land use types must be recognized as educated estimates that are based on a number of different data sets, published literature values, best professional judgement, and loading coefficients currently employed in models, and management and regulatory schemes. It is important to remember that actual pollutant loads generated from the same land use types will vary. Again, it must be emphasized that this methodology is only intended to be used as a planning and a "broad-brush" identification method. Enforcement, remediation, and mitigation actions should not be undertaken based solely on the outcome of this methodology but rather on additional follow-up data collection and analysis.

As explained below in detail, the NPSI method examines the land use types in each zone of influence area, derives estimates of the extent of each land use type, applies land use loading coefficients, and derives an index score to indicate the relative potential for NPS production and transport to a given wetland. In addition, the NPSI also incorporates a rapid on-site evaluation component, completed with a field data sheet for each site (Table 3.4).

To derive the Nonpoint Source Index, several steps were necessary. First, the field worksheets for each WEA were completed, scores were totaled and then adjusted to a scale of 100. For each component of the NPSI method, higher index scores represent lower nonpoint source potential. Next, to complete the land use analysis components, wetland boundary and NPSI zones of influence were delineated and land use information was compiled. Due to the groundwater dominated hydrology of the region, the delineation of wetland watersheds was complex. Delineating surface water dominated watersheds is considerably simpler–generally accomplished by tracking and bisecting the topographical contour lines of hills surrounding the wetland. Ground-watershed delineation requires the investigation of groundwater movement and regional water table contours, which are difficult to map.

Wetland Ground-Watersheds and Capture Zones

Much of Massachusetts wetlands occur on highly permeable soils or are in contact with a groundwater aquifer. Waquoit Bay watershed overlies sandy soils and sediments tens of meters thick. Many of the lakes and wetlands in the watershed are surface water expressions of the water table.

Wetland watershed delineation in a groundwater dominated system involves estimating the degree to which groundwater flows towards the open water portions of the wetland, or whether flow bypasses the wetland by flowing beneath and/or around it. Groundwater bound for the wetland flows through the *capture zone*, which is a vertically oriented area that can be conceptualized as the rim of a funnel which directs water into the wetland. The configuration of the water table determines the origin of that groundwater which enters the capture zone. The goal of this analysis was to estimate the depth and width of the capture zone and use this information to delineate the watershed.

The elevation of the water table reflects the potential energy of the groundwater, and this energy dissipates as the water flows through sediment. Groundwater will often flow towards an area of open water because it provides a path of least resistance. Four major factors determine the extent to which groundwater is directed into wetlands and thereby the size of the capture zone:

- the size of the open water area in the wetland,
- the aquifer permeability and thickness,
- the wetland soil permeability and thickness, and
- whether streams enter or leave the wetland.

The open water area of the wetland is referred to in this analysis as a "pool"–even though this may actually be a lake, a river or a small water filled depression. Large pools, thin aquifers, highly permeable wetland soils and outflowing streams will all increase the wetland capture zone and, therefore, wetland watershed size. The size of the pool determines the energy savings offered by the flow path through the wetland. Aquifer thickness and permeability affect the energy cost of deep groundwater flowing up from the bottom of the aquifer to pass through the pool.

Table 3.4. Nonpoint Source Index method field worksheet.

Wetland Evaluation Area:		**Date:**
Nonpoint Source Index Zone of Influence Includes:	**(A) 30.48 meter buffer (100 feet), or**	**(B) 100 meter buffer**
	Estimated Size of NPSI Zone:	**Score:**
(1) **Development Density**	High (≥2 houses/acre)	Score = 0
	Medium (< 2 houses /acre, > 1 house/2 acres)	Score = 2
	Low (≤1 house/2 acres)	Score = 4
	No development in NPSI Zone	Score = 5
(2) **Sewage Disposal**	If served by sewer	Score = 5
	If served by septic, score same as (1)	Score =
(3) Are the **Roads** within the NPSI Zone...	mostly unimproved, dirt, gravel	Score = 4
	mostly 2-lane, paved	Score = 2
	mostly 4-lane paved	Score = 0
(4) Direct **Stormdrains** to wetland?	No	Score = 5
	Yes	Score = 0
(5) Evidence of direct **Runoff** or **Erosion** to wetland?	No	Score = 5
	Yes	Score = 2
(6) Are **Lawns** green and well-managed?	No	Score = 5
	Yes	Score = 2
(7) **Agricultural Type** in NPSI Zone is...	Row crops or nursery plants	Score = 2
	Orchards	Score = 3
	Cranberry	Score = 1
	Turf/Sod	Score = 3
(8) Are there signs of runoff from **Dairy/Livestock** holding area or pasture to WEA?	No	Score = 5
	Yes	Score = 0

(9) Do **Dairy/Livestock** animals have direct access to WEA?	No	Score = 5
	Yes	Score = 0
(10) Evidence of **Water Withdrawal** from WEA?	No	Score = 5
	Yes	Score = 1
(11) Evidence of **Pesticide** application?	No	Score = 5
	Yes	Score = 1
(12) Evidence of recent **Forest Cutting**?	No	Score = 5
	Yes	Score = 1
(13) **Marinas** present w/in NPSI Zone?	No	Score = 5
	Yes	Score = 1
(14) **Slips/Docks/Moorings** present w/in NPSI Zone?	No	Score = 5
	Yes	Score = 2
(15) Type/intensity of **Boating** use in NPSI Zone is ...	mostly powerboat	Score = 0
	mixed powerboat/non-motorized craft	Score = 2
	non-motorized craft only	Score = 4
(14) Evidence of recent **hydromodification** (channelization/fill/flow alteration) or long term impacts?	No	Score = 5
	Yes	Score = 0
(15) **Golf Courses** present w/in NPSI Zone?	No	Score = 5
	Yes	Score = 0
(16) **Sand/Gravel Extraction** present in NPSI Zone?	No	Score = 5
	Yes	Score =0

Wetland soils, such as muck and decomposed peat, can provide considerable resistance to water flow, effectively lengthening the shortcut through the pool. Wetlands with groundwater-fed streams will draw additional groundwater from the aquifer, while wetlands that detain surface water at levels higher than the water table may recharge the aquifer beneath, diverting the flow of groundwater away from the wetland.

Methods: Capture zone depth for freshwater wetlands

The first step in delineating the wetland watersheds was to determine the depth and width of the capture zones, which describes groundwater flow immediately up gradient from the wetland. The capture zone dimensions for the freshwater sites (WEA1 through WEA9) were determined by application of a mathematical model developed by the CSIRO Water Resources Branch (Townley et al., 1993; Nield et al., 1992; Townley and Davidson, 1988). Input parameters include the size of the pool, thickness of the aquifer, water table slope, aquifer and wetland soil permeability, surface water flows, and recharge rate. Parameters which describe the aquifer, such as its thickness and permeability, were drawn from local water resources reports (Barlow and Hess, 1993; Masterson et al., 1996; Cambarerri et al., 1992; Sasaki Associates Inc., 1983). Pool size and estimates of wetland soil permeability and thickness were determined using aerial photographs, field surveys and the Natural Resource Conservation Service's Soil Survey of Barnstable County (Fletcher, 1993). It is important to note that this model was designed for wetlands with pools that are large compared to the thickness of the aquifer. Its accuracy is likely to be higher for such wetlands such as WEA3 than for wetlands with smaller pools such as WEA7 or WEA2. This model also does not account for changes in pool size, so an average size was used.

Methods: Capture zone depth for salt marshes

Groundwater discharge to salt marshes is affected by the pattern of groundwater discharge to the marine receiving water (Waquoit Bay) and by the differences in density between salt and fresh water. The rate of groundwater discharge is typically maximized at the shore and decreases with distance into the bay. Salt marshes at the shore are in a position to receive a large portion of that groundwater discharge. This discharge is inhibited by the relatively low permeability of salt marsh peat, but the presence of springs and seeps indicates that peat is not uniformly impermeable. Capture zone depth was estimated by assuming that groundwater discharge is diverted neither up nor down by the salt marsh. The depth of the capture zone was estimated as the depth of the salt marsh peat measured near the center of the marsh, which ranged between 0.2 and 0.6 meters at the salt marsh study sites (WEA10 through WEA14).

Fresh groundwater floats above saline groundwater with relatively little mixing. In the Waquoit Bay system, this freshwater lens at the head of the bay tapers away from the shore (Cambarerri et al., 1992). This reduces the freshwater aquifer thickness and forces the groundwater to discharge to the estuary above. At the shore, the thickness of the freshwater lens is the effective thickness of the aquifer. At the head of Waquoit Bay the lens was measured by Cambarerri and others (1992) as approximately 3.0 meters. This thickness was used for all sites.

The assumption that groundwater discharge occurs at the fringing salt marshes is supported by salinity measurements of salt marsh porewater at both of the fringing marshes where wells were installed. These measurements indicated that at certain times at least 75 percent of the porewater was fresh.

<u>Capture zone delineation</u>

The regional water table maps illustrated that groundwater flow diverted towards the larger wetland study sites: WEA1, WEA3, WEA4, WEA8, and WEA10. Capture zone width was determined for these sites based on the water table maps. For the smaller freshwater sites: WEA2, WEA6, WEA7 and WEA9, the CSIRO model was used. This model indicates that capture zone width ranges from one to two times the width of the pool, depending on wetland soil permeability and the influence of other wetlands. The fringing salt marshes,WEA11 and WEA12 ,were assigned capture zone widths equal to the width of the marshes. Pocket marshes, WEA13 and WEA14, were assigned capture zones widths equal to approximately twice the marsh width because groundwater discharge tends to be focused at embayments.

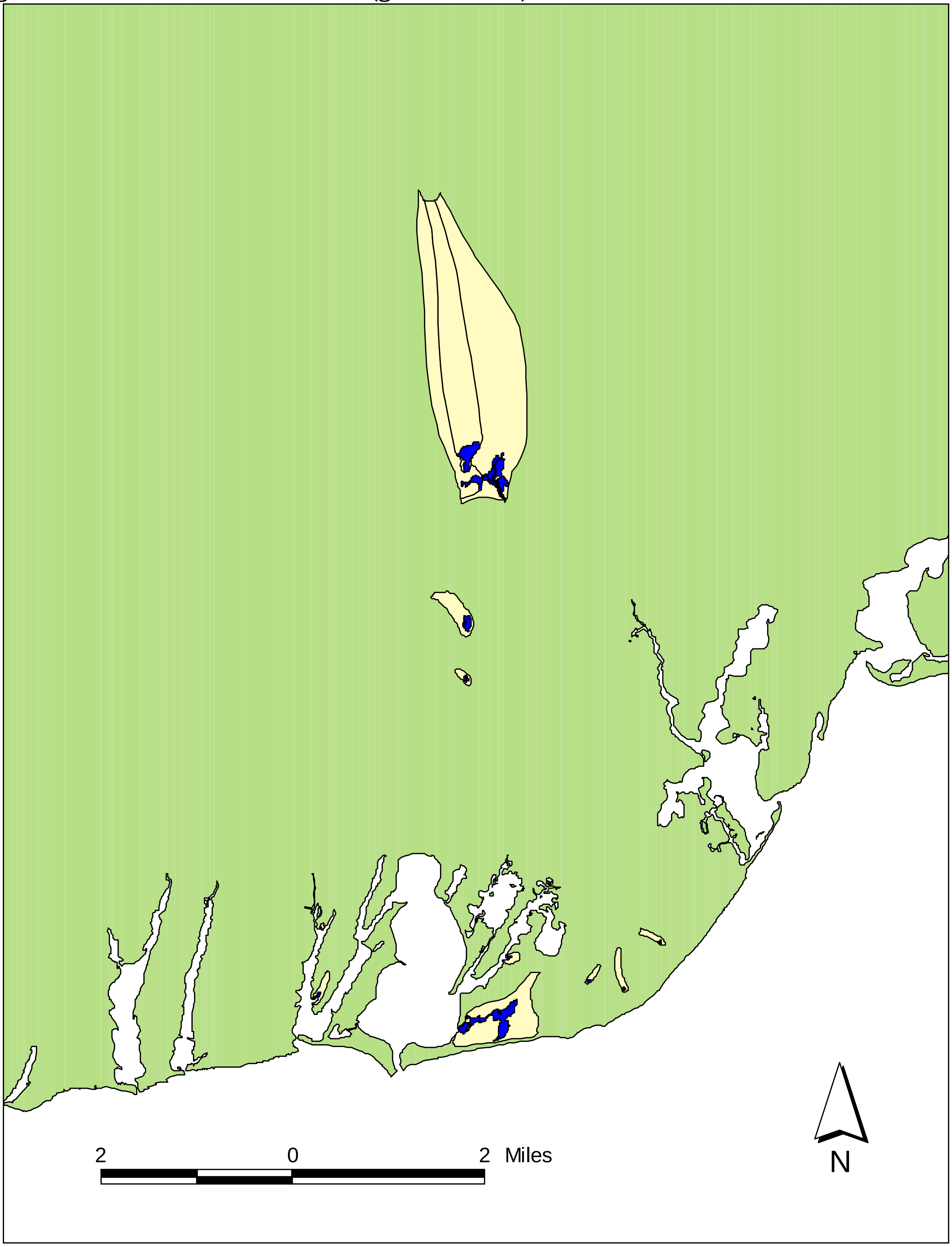
The up gradient length of the watershed was determined based on the distance from the wetland to the groundwater divide, which is analogous to the ridge line on a topographic map. The ratio of the depth of the capture zone to the depth of the aquifer is equal to the ratio of the up gradient length of the watershed to the distance to the groundwater divide. Maps of the regional water table by Cambarerri et al. (1992) and Sasaki Associates (1983) were used to determine the shape of the watersheds based on capture zone width and watershed length. The width of the watershed was set equal to the width of the capture zone unless water table contours indicated otherwise. Where these maps failed to provide sufficient resolution of the water table (i.e. for WEA11, WEA12, and WEA13) topography and insight from other studies were used to estimate the water table shape.

For all sites, the size of the watershed was primarily a function of pool size, the permeability of the wetland soils, and the distance to the groundwater divide. In regions with highly permeable sediments and gentle topography, wetlands with pools generally serve as flow through conduits for groundwater. Groundwater enters on the up gradient side of the wetland and discharges on the down gradient side. Sites WEA2, WEA3, WEA6, WEA7, WEA8, and WEA9 were found to be flow though wetlands. Sites WEA1, WEA4, and WEA10 are the source water for outflowing streams. These sites receive groundwater discharge from both sides, and the watersheds for these wetlands extend up gradient to the water table divide. The fringing salt marshes, WEA11 and WEA12, have small watersheds primarily because the wetlands are both small and located close to the local groundwater divide. The pocket salt marshes WEA13 and WEA14 have relatively larger watersheds because of their greater shoreline length, but these sites are also close to the local groundwater divide which limits watershed size. Figure 3.1 displays the ground-watersheds for each project WEA.

Geographic Information System Analysis for NPSI

For the purposes of this project, computer software programs were utilized to calculate the NPSI scores. Geographic Information System (GIS) software (ArcView 3.0a) enabled project staff to overlay wetland and zones of influence polygons over interpreted 1990 land use, query the geographic information, and to calculate specific areas of intersection. For each WEA, the extent of specific McConnell land use types was computed for each zone of influence: the 30.48 m buffer area, the 100 m buffer area, and the site wetland watershed. This data was then exported to

Figure 3.1. Watershed delineations (groundwater) for each Wetland Evaluation Area.



spreadsheet software (Excel 97) for the last analysis steps. For each of the 37 McConnell land use types in the GIS land use layer, specific NPSI loading coefficients were developed. Table 3.5 contains NPSI coefficients for only those land use types identified in the project area. Next, for each NPSI zone of influence, the area of each land use type identified was multiplied by the NPSI loading coefficient. These products were totaled and divided by the entire area of the specific zone of influence to derive a NPSI subtotal score for each zone. To illustrate, in the watershed zone of influence for site WEA7, four land use types were identified: forest, residential-1 (density is smaller than 1/4 acre lots), residential-3 (density is larger than ½ acre lots), and golf course, with a total area of 28,170 m^2. First, the forest land use area (1,441 m^2) and was multiplied by a NPSI coefficient of 1.00. Residential1 area (11,356 m^2) was multiplied by 0.36; residential-3 area (2,347 m^2) was multiplied by 0.75; and golf course area (13,026 m^2) was multiplied by 0.55. These four products were totaled to a sum of 14,454 and then divided by the total watershed area to derive the NPSI watershed subtotal score of 51.31. This process was repeated for each zone and for each site.

The final step in the NPSI method is to combine each of the scores from the rapid assessment field worksheet, the 30.48 m buffer zone, the 100 m buffer zone, and the wetland watershed. As previously explained, one of the major assumptions of this model is that the presence and condition of upland areas directly adjacent to the wetland have significant influence on the health and functional integrity of the wetland. For this reason, the subtotal scores for each NPSI component are weighted differently as they are combined to comprise the final NPSI score. The subtotal scores for each NPSI component, their relative weight, and the final NPSI scores are displayed in Table 3.6.

It is important to note that for others interested in implementing the NPSI method, neither GIS nor spreadsheet software is necessary–this method can be implemented using information that is easily obtained from maps and other sources. Once land use and wetland information is acquired, the NPSI analysis really only involves conducting some area estimates (such as the dot grid method) and performing some mathematical operations.

The NPSI results serve to provide a robust index of a wetland's relative potential to receive NPS pollutants from upland land use activities, to rank wetlands for prioritizing management actions, and to aid in the interpretation of other data. For example, sites with high NPSI scores–implying little NPS contribution potential–but low biological scores are probably exhibiting signs of ecological impairment due to habitat alteration. Section 9 describes the tight statistical correlation between the NPSI scores and other WHAT approach outputs.

Table 3.5. Land use types and NPSI loading coefficients.

McConnell Land Use 37 Code	Land Use Description	NPSI Loading Coefficient
1	cropland	0.36
3	forest	1.00
4	wetland	1.00
5	mining, land disturbance	0.30
6	open land	0.96
9	water recreation	0.85
10	residential 0	0.19
11	residential 1	0.36
12	residential 2	0.58
13	residential 3	0.75
14	salt marsh	1.00
15	commercial	0.20
16	industrial	0.36
17	urban open	0.85
18	transportation	0.20
20	water	1.00
21	woody perennial	0.70
23	cranberry bog	0.37
24	power lines	0.96
25	sandy beach	1.00
26	golf	0.55
27	salt marsh	1.00
29	marina	0.64
37	forest wetland	1.00

Table 3.6. NPSI subtotals and final scores for all study sites.

Site	30.48m Zone (weight x3)	100m Zone (weight x2)	Watershed Zone (weight x1)	Rapid Worksheet (weight x2)	Final NPSI Score
WEA2	100.00	100.00	100.00	98.86	**100**
WEA3	100.00	97.79	55.53	90.91	**92**
WEA1	73.90	85.05	59.97	84.09	**77**
WEA4	56.99	73.12	74.91	76.14	**68**
WEA6	64.28	58.49	54.02	73.86	**64**
WEA7	48.65	58.62	51.31	59.09	**54**
WEA8	93.23	80.61	81.87	76.14	**84**
WEA9	78.59	71.11	74.85	67.05	**73**
WEA10	99.77	99.39	98.67	98.86	**99**
WEA11	61.95	59.69	64.00	73.86	**65**
WEA12	58.00	58.00	58.00	65.91	**60**
WEA13	58.00	58.00	58.00	62.50	**59**
WEA14	91.83	81.05	82.13	59.09	**80**

Functional Evaluation

As discussed in Section 1, wetland functions are the physical, chemical, and biological processes and attributes of a wetland. Wetlands perform these unique functions independent of human society. Human society's valuation of wetland functions is best described as wetland values. Over the last two decades, for different purposes, a range of methods or approaches have been developed to determine and assess the relative level of functions that given wetlands perform. Distinct from direct field-based measurements and research of wetland characteristics, indirect or rapid functional assessments rely on relatively simple observations, calculations, and questions to come up with an estimation of wetland functions and values. Most of these rapid functional assessment methods are based on available literature and findings, and, as such, serve as wetland functional models. By inputting certain information, it is possible to gain a rough estimate of a wetland's ability to perform or provide specific functions and values.

For the Coastal Wetlands Ecosystem Protection Project, project staff reviewed a host of available functional assessment methodologies to select one that best suited the project needs. For this project, the functional assessment method needed to be current, peer-reviewed, applied in New England wetlands, and rapid (i.e. implemented by a trained project team member in a day or less). The following methods were evaluated for use:

- Method for the Evaluation of NonTidal Wetlands in Connecticut. Ammann, 1986.
- Wetland Evaluation Technique (WET), Volume II. Adamus, 1987.
- Method for the Comparative Evaluation of NonTidal Wetlands in New Hampshire. Ammann, 1991.
- A Hydrogeomorphic Classification for Wetlands. Brinson, 1993.
- Method for the Evaluation and Inventory of Vegetated Tidal Marshes in New Hampshire (Coastal Method). Cook et al., 1993.
- The Highway Methodology Workbook: Wetland Functions and Value, A Descriptive Approach. US Army Corps of Engineers, 1995.
- Evaluation for Planned Wetlands. Environmental Concern, Inc., 1996.

After review and evaluation, modified versions of the two New Hampshire methods were selected as the rapid functional assessment methodologies to be utilized. The following serves as a very brief explanation for this decision. The Connecticut method is basically an earlier version of the New Hampshire nontidal wetland evaluation, and the more current of these very similar methods was therefore selected. The WET method was not selected as it was somewhat dated and required three separate levels of evaluation: social significance, effectiveness and opportunity, and habitat suitability. The Evaluation for Planned Wetlands is a detailed and effective functional evaluation method but was exceedingly labor-intensive. Brinson's HGM method, currently embraced by the US Army Corps of Engineers as the national standard for functional assessment method, is in its formative stages with regional models for different wetland classes still under development and is not available for use. The Highway manual had appeal for being quick and straight-forward, but its output is qualitative, or narrative, and by design does not produce quantitative functional assessments.

The adaption of New Hampshire tidal and nontidal methods involved selecting the functions, or "functional values," to be evaluated, changing the scoring approach to exclude wetland size, and modifying the definition of the wetland evaluation unit. Both New Hampshire methods utilize the same evaluation format, requiring the evaluator to answer a number of questions both in the field and back in the office for each function. The questions pertain to a range of wetland and landscape physical, biological, and hydrological characteristics as well as other factors such as surrounding and in-wetland land use. Table 3.7 lists the functions as contained in the New Hampshire manuals and the functions which were evaluated for the purposes of this project. Table 3.8 contains an example of a single page of the New Hampshire method field manual. For each question and answer, the possible range of scores for the Functional Value Index (right-hand column) is from 0 to 1.0. To derive the score for each function, the Functional Value Index scores are averaged. According to the NH guidance, the higher the score, the greater degree to which the site exhibits the function in question.

The results of the modified New Hampshire method for both the freshwater wetlands are contained in Table 3.9 and the salt marsh functional assessment scores are in Table 3.10. Where a score is "NA" it is because this function is not being performed at the wetland in question and therefore should not be evaluated. The final NH method scores are the averages of all the individual function evaluations. The results of each of the three rapid assessment methods are graphically represented in Figure 3.2 and Figure 3.3.

Table 3.7. New Hampshire Method (tidal and nontidal) functional values evaluated.

NonTidal Method	Evaluated?	Tidal Method	Evaluated?
Ecological Integrity	Yes	Ecological Integrity	Yes
Wildlife Habitat	Yes	Shoreline Anchoring	Yes
Finfish Habitat	Yes	Storm Surge Protection	Yes
Educational Potential	Yes	Wildlife, Finfish, & Shellfish	Yes
Visual/Aesthetic Quality	Yes	Habitat	Yes
Water-Based Recreation	Yes	Water Quality Maintenance	Yes
Flood Control Potential	Yes	Recreation Potential	Yes
Ground Water Use Potential	Yes	Aesthetic Quality	Yes
Sediment Trapping	Yes	Education Potential	No
Nutrient Attenuation	Yes	Noteworthiness	
Shoreline Anchoring and	Yes		
Dissipation	No		
Urban Quality of Life	No		
Historical Site Potential	No		
Noteworthiness			

Table 3.8. Sample page from the NH nontidal wetland evaluation manual: Functional Value 1 (Ecological Integrity). From Ammann, 1991.

Wetland Name/Code:________		**Functional Value 1**
NEEDED FOR THIS EVALUATION:		**ECOLOGICAL INTEGRITY**
Zoning map	Method to calculate area	
SCS soils map	USGS topographic map or recent aerial photo	
305b Water quality report	Ruler or scale	

Evaluation Questions	Evaluation Criteria	Functional Value Index
QUESTIONS TO ANSWER IN	**OFFICE:**	
1. Percent of wetland having very poorly drained soils or Hydric A soils and/or open water.	A. More than 50 percent B. From 25 to 50 percent C. Less than 25 percent	1.0 0.5 0.1
2. Dominant land use zoning of wetland . Use current land use if different from what is zoned.	A. Agriculture, forestry, or similar open space B. Rural residential C. Commercial/industrial, high density resid.	1.0 0.5 0.1
QUESTIONS TO ANSWER IN	**FIELD:**	
3. Water quality of the watercourse, pond, or lake associated with the wetland.	A. High: Minimal pollution (meets or exceeds Class A or B standards B. Medium (below Class B standards)	1.0 0.5
4. Ratio of the number of occupied buildings within 500 ft. of the wetland to the total wetland area.	A. Less than 1 building/10 acres B. From 1 building/10 acres to 2 bldg./2 acres C. More than 1 bldg./2 acres.	1.0 0.5 0.1
5. Percent of original wetland filled.	A. Less than 10 percent. B. From 10 to 50 percent. C. More than 50 percent.	1.0 0.5 0.1
6. Percent of wetland edge bordered by a buffer of woodland or idle land at least 5000 feet in width.	A. More than 80 percent. B. From 20 to 80 percent. C. Less than 20 percent.	1.0 0.5 0.1
7. Level of activity within wetland as evidenced by litter, trails, etc.	A. Low level: few trails, sparse litter B. Moderate level: some trails or roads C. High level: many trails/roads, litter	1.0 0.5 0.1
8. Level of activity in upland within 500 feet as evidenced by litter, trails, residences, etc.	A. Low level: few trails, sparse litter B. Moderate level: some trails, residences C. High level: many trails/roads, residences	1.0 0.5 0.1
9. Percent of wetland plant community presently being altered by mowing, grazing, farming, or other (including invasive species)	A. Less than 10 percent B. From 10 to 50 percent C. More than 50 percent	1.0 0.5 0.1

Evaluation Questions	Evaluation Criteria	Functional Value Index
10. Percent of wetland actively being drained for agriculture or other purposes.	A. Less than 10 percent. B. From 10 to 50 percent. C. More than 50 percent.	1.0 0.5 0.1
11. Number of public road and/or railroad crossings per 500 feet of wetland (measured along long axis of wetland).	A. None B. One C. Two or more	1.0 0.5 0.1
12. Long-term stability.	A. Wetland appears to be naturally occurring, not impounded by dam or dike. B. Wetland appears to be somewhat dependent on artificial diking by dam, road, fill, etc.	1.0 0.5
Average Functional Value Index for Functional Value 1:	**(Average of third column.)**	

Table 3.9. Functional Evaluation scores for New Hampshire Method for freshwater sites.

Function	**WEA2**	**WEA3**	**WEA1**	**WEA4**	**WEA6**	**WEA7**	**WEA8**	**WEA9**
Ecological Integrity	1.00	0.94	0.76	0.58	0.63	0.58	0.65	0.61
Wildlife Habitat	0.81	0.80	0.71	0.56	0.44	0.27	0.51	0.59
Fish Habitat	NA	0.83	0.72	0.41	0.37	NA	0.52	0.43
Education Potential	0.6	0.71	0.85	0.60	0.48	0.25	0.23	0.36
Aesthetic Quality	0.84	0.75	0.78	0.62	0.58	0.34	0.42	0.62
Water-Based Recreation	NA	0.86	0.59	0.63	0.59	NA	0.27	0.36
Flood Control	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ground Water Use	0.88	0.53	0.43	0.43	0.53	0.53	0.56	0.50
Sediment Trapping	0.38	0.49	0.64	0.54	0.61	0.47	0.75	0.82
Nutrient Attenuation	0.40	0.54	0.56	0.70	0.73	0.58	0.78	0.78
Shoreline Anchoring	NA	0.67	1.00	0.50	0.37	NA	0.37	0.83
Average All Functions	**0.74**	**0.74**	**0.73**	**0.60**	**0.57**	**0.50**	**0.55**	**0.63**
Scale adjusted (x 100)	**74**	**74**	**73**	**60**	**57**	**50**	**55**	**63**

Table 3.10. Functional Evaluation scores for New Hampshire Method for salt marsh sites.

Function	**WEA10**	**WEA11**	**WEA12**	**WEA13**	**WEA14**
Ecological Integrity	1.00	0.55	0.48	0.54	0.59
Shoreline Anchoring	0.75	0.75	0.75	1.00	0.75
Storm Surge Protection	0.75	0.10	0.10	0.10	0.10
Wildlife & Fish Habitat	0.66	0.36	0.38	0.40	0.40
Water Quality Maintenance	0.83	0.70	0.70	0.70	0.70
Recreation Potential	0.67	0.57	0.52	0.48	0.64
Aesthetic Quality	0.86	0.43	0.47	0.50	0.63
Education Potential	0.74	0.51	0.51	0.37	0.66
Average All Functions	**0.78**	**0.50**	**0.49**	**0.51**	**0.56**
Scale Adjusted (x 100)	**78**	**50**	**49**	**51**	**56**

Figure 3.2. Final results of rapid assessment methods: freshwater sites.

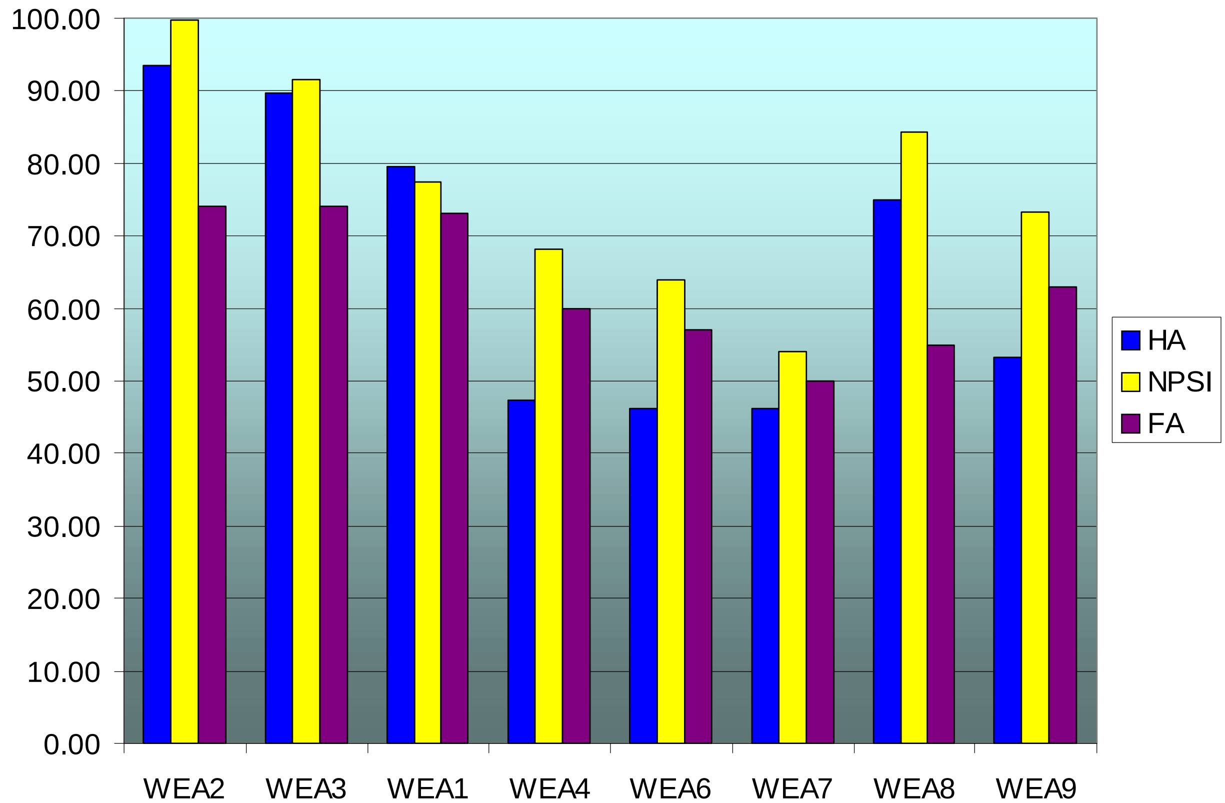
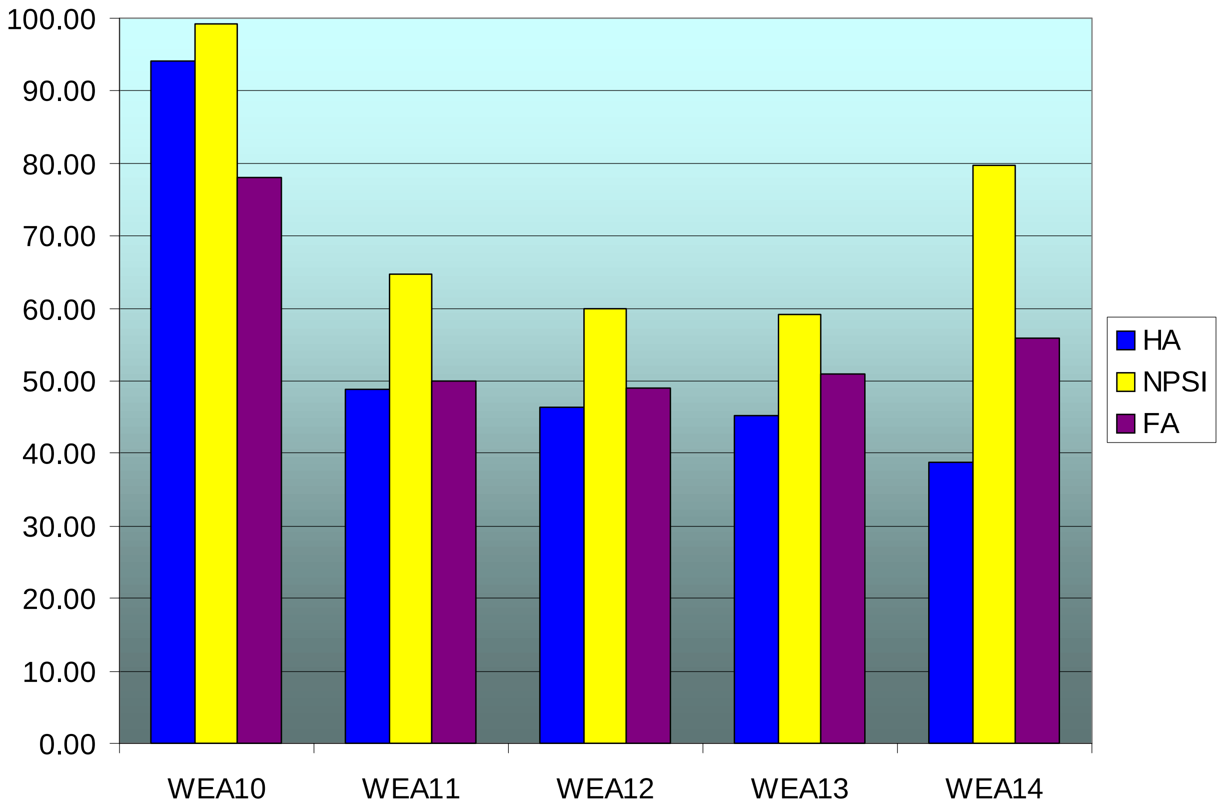


Figure 3.3. Final results of rapid assessment methods: salt marsh sites.



Section 4. Wetland Vegetation

Wetland vegetation, because of its relative stationary properties, may serve as a practical indicator of ecological stress (Hunsaker and Carpenter, 1990). Changes in wetland vegetative composition are community-level responses that integrate the effects of a wide range of ecological stressors. Community composition, species abundance, productivity, dynamics, structure, and health will change as environmental conditions shift (Shindler, 1987). Generally, such responses cannot be attributed to specific stressors without concurrent data on other factors such as hydrology or hydroperiod, water chemistry, and soil conditions. Vegetative indicators were used to assess ecological integrity through a multi-metric approach (see Focus Box in Section 2), taking into consideration the community assemblage, structure, and function of wetlands to derive an Index of Vegetative Integrity (IVI).

The development of the Index of Vegetative Integrity was based primarily on the existing biomonitoring index structures established by Karr (1981), Plafkin et al. (1989), and Hicks (1997), which incorporate metrics to address response mechanisms at the individual, population, and community levels. Wetland vegetation will respond to both physical and chemical stressors, including the hydrological alterations and increased nutrient inputs typically associated with human development of the landscape. In the Waquoit Bay watershed, the main land uses affecting wetland resources are the drainage and waste practices of medium to high density residential development, the stormwater management conventions of roads and highways, the siting and management of cranberry agriculture, and golf course construction and management. The Index of Vegetative Integrity incorporates specific functional attributes and metric scoring in an attempt to quantify these land use impacts on wetland plant species and communities.

Methods

The wetland vegetation investigations for this project required species identification and cover abundance assessment at all 13 Wetland Evaluation Areas. Two methods were selected for the vegetative cover analysis. Cover data was collected during the middle of the growing season in 1996 (late June to the middle of September). The vegetative cover abundance of 13 study sites was surveyed using plant community sampling protocols adapted from Tiner (1996) and Jackson (1995): an observation method and a plot sampling method.

The observation method was used only when it was possible to gain a thorough estimate of areal coverage from vantage points within or next to the wetland. This method was considered appropriate for use only for very small wetlands (1-2 acres), and only for marsh or shrub wetlands where it is possible to observe the entire wetland unit, or for mixed-cover wetlands, where the forested component is predominately open canopy. At least two evaluators walked through the wetland to familiarize themselves with the vegetative communities and species present. Next, a list of the individual species was made. When no new species were found, evaluators estimated the areal coverage of each species on the list. Evaluators then compared coverage values with one another and with standardized coverage charts and then revised estimates if necessary. To be as accurate as possible, areal estimates included the coverage of duff, leaves, bare ground, and open water, collectively designated as *other*. Areal estimates were adjusted during the analysis stage to account for the coverage of this *other* category.

The plot sampling method was the principal method utilized in this investigation, and was considered appropriate for larger wetlands and for wetlands with dense under and over story. The plot sampling method produces a comprehensive species list and an accurate assessment of areal coverage, or abundance. Similar to the general observation method, evaluators first determined the community structure of the study site and the dominant species present. Next the areal coverage for each community was assessed and then randomized plots were established in each distinct vegetative community. If a random plot siting occurred at the upland border where vegetation patterns were transitional, the plot was discarded and sited again. Plot size depended on the vegetative strata being assessed. The four strata groups are defined in Table 4.1.

Table 4.1. Wetland vegetation strata.

Strata:	**Defined As:**
Trees	Diameter at breast height greater than or equal to 12.7 centimeter (5 in.) and 6.1 meter (20 ft.) or taller
Saplings	Diameter at breast height less than 12.7 cm and 6.1 m or taller
Shrubs	Woody plants less than 6.1 m tall
Herbs	Non-woody (herbaceous) plants

A 9.14 m (30 ft.) radius circular plot was utilized for the tree and sapling strata, a 4.57 m (15 ft.) radius plot was used for the shrub stratum, and a 1.52 m (5 ft.) radius plot was used to evaluate the herb stratum. For trees, basal area for each tree was determined. Diameter at breast height was measured with a diameter tape at a height of 1.37 m (4.5 ft.) above the ground surface. Basal area was calculated using the formula: $BA = (3.1416) \times (dbh^2/4)$. Every plant present in the sampling plots was identified to species level, if possible. For each species in the sampling plot, areal coverage was estimated, compared to another evaluators' estimate and revised if necessary. As with the observation method, areal estimates took into consideration the coverage of duff, leaves, bare ground, open water, and non-target vegetation (i.e., herbaceous species in a shrub plot), and areal estimates were revised accordingly.

Of the thirteen study sites, vegetative cover of nine sites was assessed using the plot sampling method (WEA1, WEA2, WEA3, WEA4, WEA7, WEA8, WEA10, WEA12, WEA14) and four sites were suitable to be evaluated using the observation method (WEA6, WEA9, WEA11, WEA13). The average number of random sample plots per wetland was 7.33.

Data Analysis

Throughout this study, the freshwater and the salt marsh WEAs were evaluated and compared separately. Data obtained from each study site were entered into computer spreadsheet files (Excel 97), compiled, and metrics were generated as described below. Statistical analysis was completed primarily by computer statistics software (SPSS 6.0.1). For each plot evaluated, percent cover always totaled 100, but, as explained above, this cover percentage often included the category called *other*–duff, leaves, bare ground, and open water, and in the case of the plot sampling method, non-target vegetation types. Areal cover percentages, or abundance values, were then adjusted to account for the percentage of wetland cover occupied by *other*. When the *other* value was removed, the remaining plant species coverage totaled 100.

For this investigation, a community-based assessment approach was employed (see the following **Focus Box**). With this assessment method, individual vegetation species abundance values were adjusted according to the extent of each community in the wetland. This community-based approach results in a more accurate estimate of each species' relative abundance in the wetland, not just in the plot it was surveyed in.

After the abundance values were adjusted for community-weighting and for *other* coverage, two total species lists were compiled, one for the freshwater sites and one for the salt marsh sites. Each list includes the total wetland abundance value for each species at each WEA. From the total lists, each species was then assigned specific wetland vegetation attribute scores. Each wetland vegetation attribute and value is defined below. Section 12 (Appendix) contains the total species list and the attribute scores for each species identified in this project.

- **Persistent Standing Litter**. A species with a positive persistent standing litter attribute has a significant part of its above-ground biomass that remains standing during the dormant period until next growing season. All shrubs and trees are persistent. Examples of emergent plants with persistent standing litter are: *Typha latifolia* (broad-leaved cattail), *Scirpus cyperinus* (wool grass), and *Spirea tomentosa* (steeple bush). Species with persistent standing litter were assigned a score of 1; those that die back were assigned a 0. The attribute scores were based on literature, identification guides, and professional judgement.

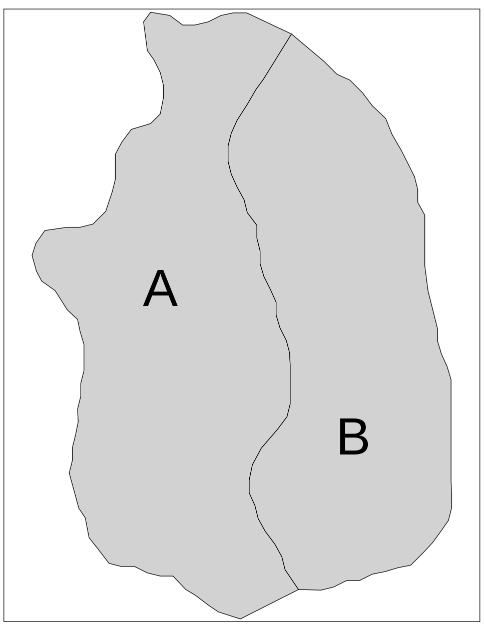
- **Opportunistic**. A species with a positive opportunistic attribute is able to tolerate a wide range of habitat types and conditions and is therefore well adapted to thrive in a variety of conditions. Opportunistic species will pioneer disturbed areas as well as compete advantageously in altered sites. Examples of opportunistic species are: *Sparganium eurycarpon* (great burreed), *Lysimachia terrestris* (swamp candle), and *Clethra alnifolia* (sweet pepper bush). Opportunistic species were assigned a score of 1; others assigned a 0. The attribute scores were based on literature, identification guides, and professional judgement.

- **Invasive**. A species with a positive invasive attribute is defined as an aggressive colonizer of natural and disturbed areas, often forming extensive monocultural stands. Invasive species are frequently alien, or non-native. Examples of invasive species are: *Phragmites australis* (common reed), *Decodon verticilattus* (swamp loosestrife), and *Toxicodentron radicans* (poison ivy). Invasive species were assigned a score of 1; others were assigned a 0. The attribute scores were based on literature, identification guides, and professional judgement.

Focus Box: Community-Based Method for Vegetation Survey

Depending on the method employed, surveying vegetation in the same wetland can actually produce different results. Plot sampling techniques can give very accurate estimates of a species dominance in the plot surveyed, but using this information to describe the entire wetland would result in erroneous evaluations. Transect sampling techniques, if utilized judiciously, would produce a more accurate picture of species abundance throughout the wetland but can be extremely labor-intensive. In addition, depending on the size of the wetland, an inadequate number or placement of transects would also produce misleading data.

The community-based assessment method used for this investigation relies first on an assessment of the specific communities in a wetland. Next, several vegetation plots are sited in each community in order to produce an accurate representation of the species present in the community being evaluated. Species abundance values can then be adjusted to reflect that community's relative areal coverage of the entire wetland. Consider this simplified example within a hypothetical wetland:



Wetland Plant Community A, in this example, occupies 60 percent of the wetland and can be characterized as an emergent community with three species: Species 1, Species 2, and Species 3. Wetland Plant Community B occupies 40 percent of the wetland and is a shrub sapling community with two species, Species 4 and Species 5.

Several plot surveys are conducted in community, and the abundance values for each species is identified. Consider that for one survey plot in Community A, Species 1 had area cover of 70 percent, Species 2 had cover of 20 percent and Species 3 had cover of 10 percent. For this survey plot, the total species abundance totals 100 percent. But Species 1 does not occupy 70 percent of the wetland. If the plot is representative of Community A (or if enough plots are surveyed in Community A), though, Species 1 can be assumed to occupy 70 percent of Community A. Therefore, to determine the abundance value of Species 1 for the entire wetland, its community abundance value (70 percent) is multiplied by Community A's extent in the wetland (60 percent). As a result of this adjustment, Species 1 is found to occupy 42 percent of the entire wetland. This same adjustment is conducted for the rest of the species surveyed in both communities (Species 2 through Species 5). The complete community-weighted wetland species list should total 100.

- **Wetness**. A ranking of a species relative affinity to hydric (wet) conditions. This attribute is taken directly from the USFWS National List. Attributes range from obligate (wetland dependent) to upland, based on the median probability of a species occurrence in a wetland. Wetness scores were assigned according to this scale: Obligate = 1.00, FacWet+ = 0.91, FacWet = 0.82, FacWet- = 0.71, Fac+ = 0.60, Fac = 0.50, Fac- = 0.71, FacUp+ = 0.29, FacUp = 0.18, FacUp- = 0.09, Upland = 0.00.

- **Flood Tolerance**. A ranking of a species tolerance to relative lengths of inundation. The attribute ranges from intolerant to very high tolerance. Intolerant species are killed by less than 3 days of inundation in a growing season, while species with very high tolerance can withstand a full growing season of inundation. This attribute is used only for <u>freshwater</u> species. Flood tolerance scores were assigned according to this scale: Very High = 1.00, High = 0.80, Medium = 0.60, Low = 0.40, Intolerant = 0.20. The values for this attribute were adapted from the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

- **Salinity Tolerance**. A ranking of a species' tolerance to saline conditions. The attributes range from intolerant to very high tolerance. Intolerant species will not survive salt water exposure, including occasional ocean spray. Species with very high tolerance will survive in tidal areas with twice daily inundation of salt water. This attribute is used only for <u>salt marsh</u> wetland species. Salinity tolerance scores were assigned according to this scale: Very High = 1.00, High = 0.80, Medium = 0.60, Low = 0.40, Intolerant = 0.20. The values for this attribute were adapted the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

- **Nutrient Status**. A ranking of a species affinity for areas with differing nutrient availabilities. Attributes range from species generally occurring in areas with low nutrient availability (as in bogs and isolated wetlands) to those species occurring in areas with disturbances or enrichment from fertilizer or wastewater. Nutrient status scores were assigned according to this scale: Bogs, lowest nutrients = 0.12; Sands, low nutrients = 0.23; Acid woods, till, and sandy loam = 0.34; Alluvial acid soils, enriched by flood deposits = 0.45; Sweet soils in calcareous areas = 0.56; Alluvial sweet soils = 0.67; Somewhat disturbed or partly enriched soils = 0.78; Disturbed or enriched soils = 0.89; Very disturbed and heavily enriched = 1.00. The values for this attribute were adapted from the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

The final data analysis step was to process the species, abundance, and attribute data into a set of metrics for each study site. Table 4.2 displays the Index of Vegetative Integrity metrics, the rationale for their use, the predicted response to impairment, and the method for metric value computation. Using the reference sites as the bench marks, attributes for each study site were compared and a relative metric score was computed according to the scoring criteria in Table 4.3 and Table 4.4. The metric scores were then totaled and transformed into a final IVI score.

Table 4.2. Index of Vegetative Integrity metrics.

Metric	Rationale	Response to Stressors	Metric Computation
Community Similarity	Resemblance of communities to reference site will shift as stressors increase	Decline	Total percent shared species
Taxa Richness	Total number of plant species will change as stressors increase	Variable	Absolute difference of total taxa
Persistent Standing Litter	Decomposition of vegetation provides important food chain support and habitat structure	Rise	Total abundance of species with a positive PSL attribute
Invasive	Increased presence of invasive species reduces habitat and other wetland functions	Rise	Total abundance of species with positive invasive attribute
Opportunistic	Opportunistic species will colonize or persist as habitat conditions are altered by stressors	Rise	Total abundance of species with positive opportunistic attribute
Wetness	Species composition will shift towards upland or obligate due to hydrologic stressors	Variable	Percent similarity of wet value weighted for abundance
Flood tolerance (freshwater sites only)	Species with higher flood tolerance will colonize or persist as duration of flooding changes	Variable	Percent similarity of flood tolerance value weighted for abundance
Salinity tolerance (salt marsh sites only)	Species with lower salinity tolerance will colonize or persist with change in tidal hydrology	Decline	Percent similarity of salinity tolerance value weighted for abundance
Nutrient status	Species composition will shift with nutrient enrichment and elevated eutrophication	Decline	Percent similarity of nutrient status value weighted for abundance

Results

A total of 86 freshwater wetland plant species and 25 saltmarsh plant species were identified in the project WEAs (see Appendix). Nearly half the freshwater species were found in more than one WEA. The freshwater species with the greatest total overall abundance values were: *Viburnum dentatum* (southern arrowwood), *Vaccinium macrocarpon* (cranberry), *Scirpus cyperinus*, *Nymphaea odorata* (white water lily), and *Lysimachia terrestris*. The species with the highest frequency of occurrence in WEAs were: *Acer rubrum* (red maple), *Sphagnum palustre* (sphagnum moss), *Vaccinium corrymbusum* (Highbush blueberry), *Clethra alnifolia*, *Lysimachia terrestris*, and *Polygonum punctatum* (water smartweed).

For the saltmarsh wetlands, 60 percent of the plant species were found in more than one WEA. The saltmarsh species with the greatest total overall abundance values were: *Spartina alterniflora* (smooth cordgrass), *Spartina patens* (salt hay grass), *Iva frutescens* (hightide bush), *Distichlis spicata* (spike grass), and *Phragmites australis*. One third of all the saltmarsh species were present in all of the WEAs. These species were: *Distichlis spicata*, *Iva frutescens*, *Salicornia europea* (common glasswort), *Spartina alterniflora*, and *Spartina patens*.

IVI scores for the freshwater wetland study sites ranged from a minimum of 46 to the maximum score of 100, with a mean of 60.94 and a standard deviation of 17.24. Table 4.5 lists both the metric and IVI scores for the freshwater sites; Figure 4.1 graphically displays the freshwater IVI results. Variability between freshwater sites was greatest for the Community Similarity Metric, the Opportunistic Metric, and the Nutrient Status Metric.

IVI scores for the salt marsh study sites ranged from a minimum of 38 to the maximum of 100, with a mean of 73.33 and a standard deviation of 23.31. Table 4.6 displays the final metric and IVI scores for the saltmarsh study sites; Figure 4.2 graphically displays the salt marsh IVI results Saltmarsh study sites displayed the most extreme variability in the Community Similarity Metric, the Decomposition Metric, and the Intrusion Metric. IVI scores for saltmarsh sites WEA12 and WEA13 also fell below the mean.

Inter-Annual Variation

To check the relative variation of the vegetation sampling method, five of the thirteen study sites were assessed again, following the exact same methodology described above, in June of 1997. In all five cases, the wetland plant species abundance values varied less than ten percent from the data obtained in 1996.

Table 4.3. Index of Vegetative Integrity metric scoring criteria: freshwater sites.

Score:	0	2	4	6	Standard Deviation
Community Similarity	<25	25-49	50-75	>75	25
Taxa Richness	>9	7-9	3-6	<3	3
Persistent Standing Litter	>89	77-89	65-77	<65	12
Invasive	>29	20-29	9-19	<9	10
Opportunistic	>75	63-75	50-62	<50	25
Wetness	<67	67-77	78-89	>89	11
Flood Tolerance	<85	85-89	90-95	>95	5
Nutrient Status	<34	34-55	56-78	>78	22

Table 4.4. Index of Vegetative Integrity metric scoring criteria: salt marsh sites.

Score:	0	2	4	6	Standard Deviation
Community Similarity	<40	40-59	60-80	>80	20
Taxa Richness	>6	5-6	2-4	<2	2
Persistent Standing Litter	>90	75-90	58-74	<58	16
Invasive	>33	17-33	1-17	<1	16
Opportunistic	>72	59-72	44-58	<44	14
Wetness	<88	88-91	92-96	>96	4
Salinity Tolerance	<70	70-79	80-90	>90	10
Nutrient Status	<58	58-71	72-86	>86	14

Table 4.5. Final metric and IVI scores for freshwater study sites.

Metric	WEA2	WEA3	WEA1	WEA4	WEA6	WEA7	WEA8	WEA9
Community	6	6	2	2	2	2	4	2
Taxa Richness	6	6	2	0	2	2	4	6
Persistent Standing Litter	6	4	4	2	2	4	6	0
Invasive	6	4	4	4	6	2	4	4
Opportunistic	6	4	2	6	0	6	6	4
Wetness	6	6	4	4	6	2	4	4
Flood Tolerance	6	6	6	6	6	2	4	6
Nutrient Status	6	6	6	2	4	6	4	6
Raw IVI Score	48	42	32	28	26	30	32	34
Final IVI Score	**100**	**88**	**67**	**58**	**54**	**63**	**67**	**71**

Table 4.6. Final metric and IVI scores for salt marsh study sites.

Metric	WEA10	WEA11	WEA12	WEA13	WEA14
Community	6	4	2	2	2
Taxa Richness	6	4	4	4	6
Persistent Standing Litter	6	6	2	4	4
Invasive	6	4	0	4	6
Opportunistic	6	4	4	0	4
Wetness	6	4	2	6	6
Salinity Tolerance	6	6	2	6	6
Nutrient Status	6	6	2	6	6
Raw IVI Scores	48	38	18	32	40
Final IVI Scores	**100**	**79**	**38**	**67**	**83**

Figure 4.1. Index of Vegetative Integrity: freshwater sites.

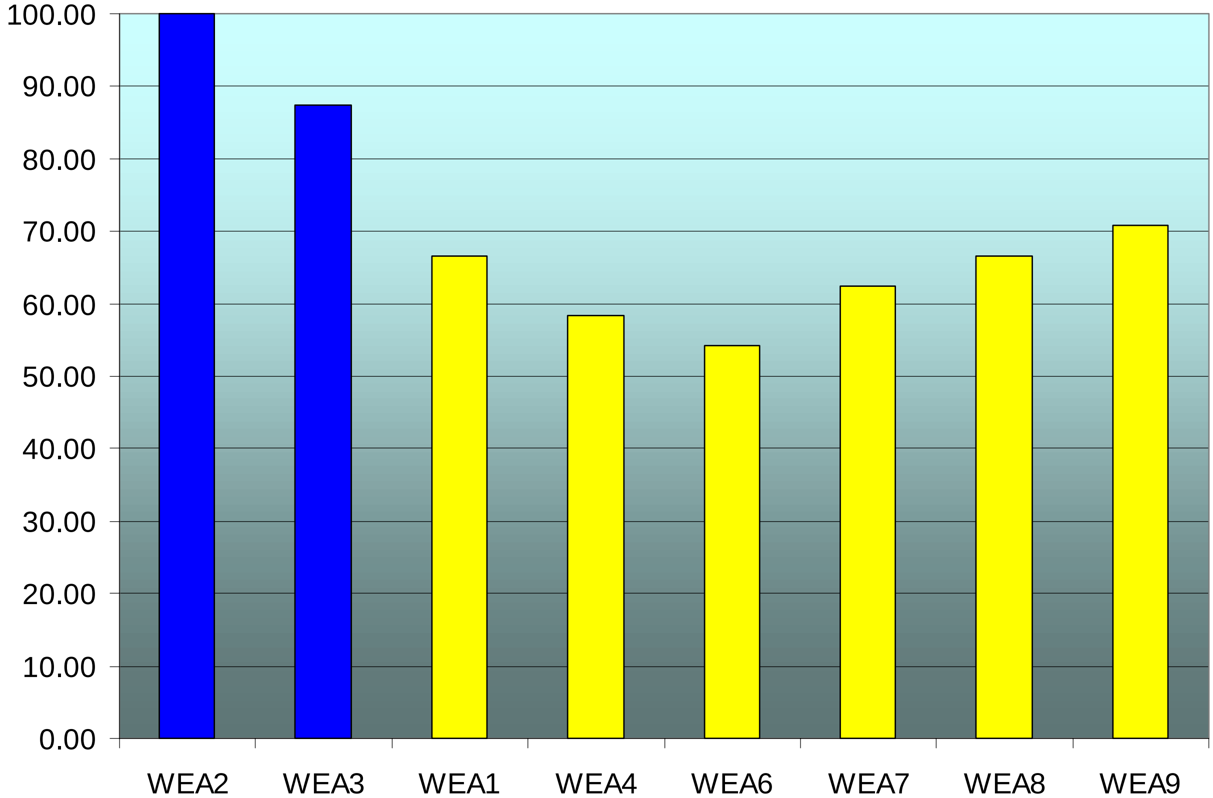
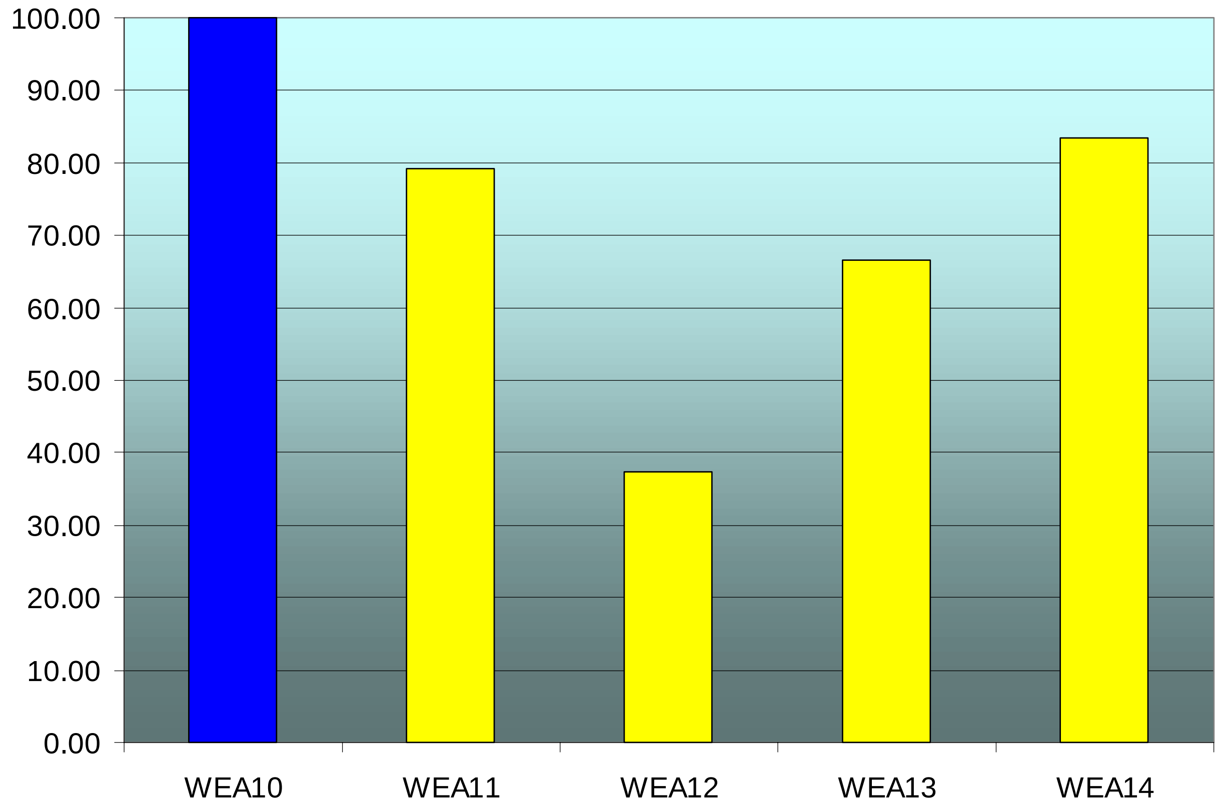


Figure 4.2. Index of Vegetative Integrity: salt marsh sites.



Section 5. Aquatic Macro Invertebrates

Aquatic invertebrate biomonitoring has historic roots in stream, river, and lake management programs, and is applied nationwide. Within the last five years or so attention has been turned to the application of aquatic invertebrate biomonitoring in wetland habitats. There is a growing consensus that any wetland assessment procedure needs to be based on data that represents a reference, or "minimally impaired" condition against which subject wetland(s) may be compared for degree of severity of impact. Normally this reference condition is established from pooled data gathered from a set of reference sites (Brinson and Reinhardt, 1996; Kentula et al., 1993; Yoder and Ranking, 1995). Reference sites must be representative of the natural conditions within the same geological and climatic setting together with the same hydrological regime as the subject wetlands (Brinson and Reinhart, 1996). Due to the high diversity of conditions within wetlands it is also desirable to consider similarities in vegetation classes.

A habitat assessment that incorporates both surrounding upland and wetland features is an important component of an invertebrate monitoring program. It is used to interpret the invertebrate sampling results, indicate the source(s) of impact, and provide a guide to best management practices that can be implemented to restore ecological integrity to a wetland.

Wetlands present special constraints that challenge the successful design of aquatic invertebrate sampling protocols. The constraints include: the complexity of wetland types, seasonality of hydrological regime, dense and resilient vegetation stands, lack of wetland data on invertebrate tolerance ratings, and minimal guidance as to suitable metrics and indices that will be sensitive and accurate in measuring wetland invertebrate community health.

The objectives of this study were to design aquatic invertebrate biomonitoring protocols for both freshwater and salt marsh wetlands, to test their application in the 13 selected wetlands within the Waquoit Bay watershed, and to record the biological condition of the project wetlands.

Methods

Samples of aquatic invertebrates were taken at each Wetland Evaluation Area (WEA) over three seasons: May 1996, August 1996, and May 1997. This allowed for seasonal variation to be measured, and provided an indication of inter-annual variation.

Within the freshwater wetlands, three randomly selected composite (D-Net and Sediment Corer) samples were taken as follows: The D-Net was held fully extended to the right hand side of the body, and starting at the surface of the water, a 180^{o} sweeping arc was prescribed, incrementally descending through the vegetation and the water column downwards to complete the sweep on the left hand side at the sediment interface. The net containing the sample was brought straight up to the surface for retrieval. The retrieved contents of the net were inverted over a bucket, and using a baster, all debris and invertebrates washed free of the net into the bucket. The net was carefully examined for any clinging organisms and vegetation, and removed with forceps to the bucket. The bucket contents were strained through a standard U.S. No. 30 brass sieve to remove water, and placed into a zip-lock bag, ensuring that no invertebrates were left on the sieve. Sediment samples were collected using a Wildco 5.5 cm diameter hand core sediment sampler.

Within the salt marshes, three randomly selected composite (rectangular frame, D-Net, soil auger) samples were taken at the low tide line on the bank and within the water and sediments as follows: a rectangular metal frame, 25 cm x 40 cm, was placed on the surface of the marsh bank, and all visible living organisms found within the frame were identified and counted; the water column and vegetation were sampled using a D-frame aquatic net that was held fully extended to the right hand side of the body at the water surface, and in an arching sweep pulled slowly downwards through the floating and attached marine vegetation and water column to rest at the sediment interface on the left hand side of the body. At that point the net was brought sharply to the surface for the retrieval of the contents. Sediment samples were collected using AMS 3 1/4" diameter sand auger.

Samples were bagged, preserved in 70 percent isopropyl alcohol, labeled, and returned to the laboratory for sorting, identification to family level, and enumeration, without subsampling.

Data Analysis

A multi-metric approach (see **Focus Box** Section 2) using reference condition was used to analyze the raw data. The metrics and indices utilized are listed in Tables 5.1 (freshwater) and Table 5.2 (salt marsh). The values for each metric/index (calculations are shown below) were derived from the average of three random samples for each site and scored according to the formulas in Table 5.3 (freshwater) and Table 5.5 (salt marsh). By referring to the predetermined Biological Condition Scoring Criteria in Table 5.4 (freshwater) and Table 5.6 (salt marsh), the metric scores were weighted, summed, and converted to a percentage to derive the final Invertebrate Community Index (ICI).

Table 5.1. Freshwater invertebrate community metrics and indices.

Metric/Index	Category	Rationale	Response to Stressors
Total Number of Organisms	Enumeration and community composition	Nutrient enrichment will usually support higher numbers of organisms. Toxicity and habitat degradation will reduce numbers.	Variable
% Contribution of Major Feeding Groups	Enumeration and community composition	A healthy community will have a balance between the various trophic groups.	Variable
% Contribution of Dominant Family	Enumeration and community composition	A healthy community will have a balanced composition between taxa, with more than 2 dominant groups.	Rise
Taxa Richness	Diversity	Diversity is a measure of community complexity, responds adversely to stress intensity.	Decline
EOT Richness (*Ephemeroptera, Odonata, Trichoptera*)	Diversity	Healthy systems have greater numbers of sensitive taxa and predator-guild organisms.	Decline
EOT/*Chironomidae* Ratio	Community health	Healthy systems have higher sensitive/predator to tolerant organisms ratios.	Decline
Other *Odonata/Coenagrionidae* Ratio	Community health	Healthy systems have higher sensitive to tolerant Odonate ratios.	Decline
% Tolerant / % Intolerant Ratio	Community health	Impacted systems have higher tolerant to intolerant organism ratios.	Rise
Family Biotic Index	Community health	Community's averaged tolerance value will rise with increasing stressors.	Rise
Community Taxa Similarity Index	Similarity to reference condition	Resemblance of taxa composition to reference will shift with stressors.	Decline
Community Trophic Similarity Index	Similarity to reference condition	Resemblance of trophic pattern to reference will shift with stressors.	Decline
Invertebrate Community Index	Summarized bioassessment	Overall community condition will decline with increasing degradation.	Decline

Table 5.2. Saltmarsh invertebrate community metrics and indices.

Metric/Index	Category	Rationale	Response to Stressor
Total Number of Organisms	Enumeration and community composition	Nutrient enrichment will usually support higher numbers of organisms. Toxicity and habitat degradation will reduce numbers.	Variable
% Contribution of Dominant Taxonomic Group	Enumeration and community composition	A healthy community will have a balance between the various trophic groups.	Rise
% Contribution of Dominant Trophic Group	Enumeration and community composition	A healthy community will have a balanced composition between taxa, with more than 2 dominant groups.	Rise
Taxa Richness	Diversity	Diversity is a measure of community complexity, responds adversely to stress intensity.	Decline
% Abundant / % Rare	Diversity	Ratio of common to rare families will increase with stressors.	Rise
% Capitellid polychaete worms	Community health	Numbers of organism rise with stressors; indicator of eutrophication.	Rise
% Palaemondedae shrimp	Community health	Numbers of organism rise with stressors; indicator of eutrophication.	Rise
Community Taxa Similarity Index	Similarity to reference condition	Resemblance of taxa composition to reference will shift with stressors.	Decline
Community Trophic Similarity Index	Similarity to reference condition	Resemblance of trophic pattern to reference will shift with stressors.	Decline
Invertebrate Community Index	Summarized bioassessment	Overall community condition will decline with increasing degradation.	Decline

The following is an explanation of the freshwater ICI metrics and indices:

- **Total Number of Organisms**
  The total number of organisms in each sample, summed, and averaged.

- **% Composition of Major Groups**
  (Total average density for each major group/Total average density of the sample) x 100. Groups include:
  Ephemeroptera, Odonata, Trichoptera, Chironomidae, Other Diptera, Coleoptera, Hemiptera plus *Homoptera, Lepidoptera, Amphipoda, Isopoda, Oligochaeta, Hirudinea, Gastropoda*, and *Pelecypoda*.

- **% Contribution of Dominant Family**
  The group with the highest percent representation.

- **Taxa Richness**
  The total number of identified aquatic macro invertebrate families present at each site.

- **EOT Richness**
  The total number of *Ephemeroptera, Odonata*, and *Trichoptera* (EOT)families present at each site.

- **EOT/*Chironomidae* Ratio**
  (Total average density of EOT/Total average density of *Chironomidae)*

- **Other *Odonates/Coenagrionidae* Ratio**
  (Total average density of other *Odonates*/Total average density of *Coenagrionidae*)

- **% Tolerant /% Intolerant Ratio**
  Tolerant organisms were those having a tolerance value (Hilsenhoff, 1988) from 7 to 10, and intolerant organisms were those having a tolerance value from 0 to 4.

- **Family Biotic Index**
  This index averages the various eutrophication tolerances of the families that make up the aquatic invertebrate community (adapted from Hilsenhoff, 1988)

- **Community Taxa Similarity Index**
  The degree of similarity between the reference condition and study site based on a comparison of dominant groups. The score is calculated by finding the absolute difference between the reference site and the study site for each family/group, then summing these values. This total is converted to the index score by dividing in half, and subtracting from 100. [100 - (Total Score/2)].

- **Community Trophic Similarity Index**
  The degree of similarity between the reference condition and the study site based on a comparison of the trophic groups (scrapers, filter collectors, gathering collectors, predators, shredders, piercers-herbivores, omnivores, mixed). As above, the absolute differences for each of these trophic groups were summed and converted [100-(Total Score/2)] to derive the Community Trophic Similarity Index.

- **Invertebrate Community Index**
  A multiple metric index, combining all the above metrics and indices into a single index value without losing the information from the original measurements (Davis, 1995). Using the reference condition, or model value–the average of the two reference sites WEA2 and WEA3–and project wetland data, the Biological Condition Score (n) was calculated for each metric and index as displayed in Table 5.3. The final ICI score was obtained by totaling the Biological Condition Score of the 12 metrics/indices and converting it into a percentage. 72 was the maximum possible score for the 12 metrics/indices, and the final ICI was totaled as: n/72 x 100.

Table 5.3. Freshwater wetlands ICI metric calculation.
(Modified from Plafkin, 1989)

Metric	Formula
Total Organisms	n/Model value x 100
Total Taxa Richness	n/Model value x 100
EOT Richness	n/Model value x 100
EOT/Chironomidae Ratio	n/Model value x 100
Family Biotic Index	Model value/n x 100
% Tolerant / % Intolerant	Model value/n x 100
% Contribution Dominant Family	Model value/n x 100
Other Odonata/Coenagrionidae Ratio	n/Model value x 100
% Chironomidae	Model value/n x 100
% Oligochaeta	Model value/n x 100
Community Taxa Similarity Index	n/Model value x 100 (or CTSI n)
Community Trophic Similarity Index	n/Model value x 100 (or CTSI n)

Table 5.4. Freshwater wetlands ICI metric scoring criteria
(Modified from Plafkin, 1989; Ohio EPA, 1991).

Score:	6	4	2	0
Total Organisms	>90	70-90	50-69	<50
Total Taxa Richness	>90	70-90	50-69	<50
EOT Richness	>90	70-90	50-69	<50
EOT/Chironomidae Ratio	>80	65-80	26-64	<25
Family Biotic Index	>90	70-90	40-69	<40
% Tolerant / % Intolerant	>80	65-80	25-64	<25
% Contribution Dominant Family	>70	50-70	30-49	<30
Other Odonata/Coenagrionidae Ratio	>80	65-80	25-64	<25
% Chironomidae	>90	70-90	50-69	<50
% Oligochaeta	>90	70-90	50-69	<50
Community Taxa Similarity Index	>64	50-64	35-49	<35
Community Trophic Similarity Index	>64	50-64	35-49	<35

The saltmarsh ICI metrics were calculated using the same methods as for freshwater wetland metrics except where noted below:

- **Total Number of Organisms**

- **Percent Contribution of Dominant Taxonomic Groups**
  (*Nemerta, Capitellida, Cossurida, Ctenodrilla, Eunicida, Orbiniidae, Phyllodocidea, Sabellida, Spionida, Terebelida, Amphipoda, Tanaidacea, Isopoda, Pelecypoda, Gastropoda, Thoracica, Decopoda Shrimps,* and other groups).

- **Percent Contribution Dominant Trophic Group**

- **Taxa Richness**

- **% Abundant/% Rare Ratio**
  This metric was adapted from Roberts et al. 1996. A salt marsh community characterized by a high percentage of rare taxonomic groups but not outbalanced by a high percentage of abundant groups may be presumed to be "close to pristine" condition. For each site, all taxonomic groups sampled were listed, and their occurrence was categorized as follows:
  Not registered (-); Rare (R) = 0 - 4; Common (C) = 5 - 49; Abundant (A) = >50.
  The frequency for each of the above categories was noted, and only the proportional percentages for R and A were calculated deriving the % Abundant /% Rare Ratio.

- **Community Taxa Similarity Index**

- **Community Trophic Similarity Index**
  The trophic categories used for this salt marsh protocol were:
  Carnivore (C), Deposit Feeder (DF), Grazer (G), Omnivore (O), Suspension Feeder (SF), and Mixed (M).

- **Invertebrate Community Index**

As with the freshwater sites, the Biological Condition Score (n) for the saltmarsh WEAs was calculated for each metric by the formulas contained in Table 5.5. Using the criteria in Table 5.6, the Biological Condition Score was then derived for each metric. These Biological Condition Scores were then summed and converted into a percentage to derive the final ICI score. 54 was the maximum score for 9 metrics/indices, so the final ICI score was: n/54 x 100.

Table 5.5. Salt marsh wetlands ICI metric calculation.
(Modified from Plafkin et al., 1989; Hicks, 1997)

Metric	Formula
Total Organisms	n/Model value x 100
Total Taxa Richness	n/Model value x 100
% Contribution Dominant Taxonomic Group	Model value/n x 100
% Contribution Dominant Trophic Group	Model value/n x 100
% Abundant / % Rare	Model value/n x 100
% Capitellida polychaete worms	Model value/n x 100
% Palaemonedae shrimp	Model value/n x 100
Community Taxa Similarity Index	n/Model value x 100
Community Trophic Similarity Index	n/Model value x 100

Table 5.6. Salt marsh wetland ICI metric scoring criteria.
(Modified from Plafkin et al., 1989; Ohio EPA, 1991)

Score:	6	4	2	0
Total Organisms	>90	70-90	50-69	<50
Total Taxa Richness	>90	70-90	50-69	<50
% Contribution Dominant Taxonomic Group	>70	50-70	30-49	<30
% Contribution Dominant Trophic Group	>70	50-70	30-49	<30
% Abundant / % Rare	>80	65-80	25-64	<25
% Capitellida polychaete worms	>90	70-90	50-69	<50
% Palaemonedae shrimp	>90	70-90	50-69	<50
Community Taxa Similarity Index	>64	50-64	35-49	<35
Community Trophic Similarity Index	>64	50-64	35-49	<35

Results

Sixty-two families were represented throughout the nine freshwater wetlands sampled. The most commonly occurring families were: *Chironomidae* (midges) and *Culicidae* (mosquitoes) from the order *Diptera*; *Coenagrionidae* (damselflies) from the order *Odonata*; *Lumbricidae* from the order *Oligochaeta* (worms); *Sphaeriidae* (finger nail clams) from the order *Pelecypoda*; *Gammaridae* from the order *Amphipoda* (scuds); *Asellidae* (sow bugs) from the order *Isopoda*. In May 1996, there were higher numbers of individuals in the orders *Ephemeroptera* (mayflies), *Hirudinea* (leeches), *Coleoptera* (beetles), and *Trichoptera* (caddisflies) than in August 1996. *Homoptera* (aquatic aphids) were very numerous in several wetlands in August 1996, although this group was not found in spring. No *Plecoptera* (stoneflies) were collected in either season.

Overall abundance of organisms was higher in August 1996 than in May 1996. Sites with the highest number of taxa (families) were WEA1 and WEA6, and those with the lowest were WEA7 and WEA2. In May 1996, there was no single outstanding dominant trophic group, with dominant percentages shifting from one wetland site to another. In August 1996, however, predators frequently out numbered the other trophic groups in most wetlands. All wetlands had more tolerant individuals than intolerant, regardless of season.

Seventy-two different taxa were sampled across the five salt marsh sites. The most common invertebrates were *Mercenaria mercenaria* (clams), *Modiolus demissus* (mussels), *Paleamonidae* (shrimp), *Balanas sp*. (barnacles), *Amphipoda* (mostly *Gammaridae*), and *Nassarius sp*. and *Littorina sp*. (snails). From the *Polychaeta* class, *Nereidae* and *Spionidae* were found in the greatest abundance. Sites with the highest taxa richness were WEA10 and WEA11, and those sites with the lowest were WEA13 and WEA12. Within the taxonomic groups, the seasonal variations that were most notable were the rise in the number of shrimps and the decline in the number of *Polychaete* worms.

Table 5.7 gives the average metrics and indices scores for the three seasons for the freshwater wetlands. Variability across sites was high for the following: Total Organisms, % Tolerant/% Intolerant Ratio, % *Oligochaeta*, Community Taxa Similarity Index, Community Trophic Similarity Index, and to a lesser degree, % Contribution Dominant Family, % *Chironomidae*, and Invertebrate Community Index. Freshwater sites with ICI scores below the mean (68.4) were, in descending order, WEA8, WEA1, WEA4, WEA9, and WEA7. Apart from reference sites WEA2 and WEA3, only WEA6 scored above the mean. Figure 5.1 displays a bar graph of the final freshwater ICI scores, as averaged over the three sampling seasons.

Table 5.8 gives the average metrics and indices scores for the three seasons for the salt marsh wetlands. Variability across sites was high for the following: Total Organisms, Community Taxa Similarity Index, Community Trophic Similarity Index, and to a lesser extent, # of *Palaemonedae* Shrimps, and Invertebrate Community Index. Apart from the reference site (WEA10) all other sites scored below the mean ICI score of 71.8. Figure 5.2 displays the ICI scores for the salt marsh WEAs, as averaged over 3 seasons.

Table 5.7. Freshwater wetlands ICI metrics and indices averaged over 3 seasons.

Metric/Index	**WEA2**	**WEA3**	**WEA1**	**WEA4**	**WEA6**	**WEA7**	**WEA8**	**WEA9**
Total Organisms	78	203	175	151	85	126	73	71
Total Taxa Richness	11	12	18	18	22	10	12	15
EOT Richness	4	2	2	1	7	0	4	2
EOT/Chironomidae Ratio	2.1	0.3	0	0.1	4.1	0.3	1.2	4.1
Family Biotic Index	6.8	7	6.8	7.3	7.3	7	7.6	7.7
% Tolerant/% Intolerant	15	61	96	32	8	79	27	64
% Contribution Dominant Family	55	70	43	39	30	64	59	41
Other Odonata/ Coenagronidae Ratio	9.7	1.3	0	0	0.1	0.7	1.6	1.7
% Chironomidae	25	39	37	19	11	1	47	6
% Oligochaeta	0	2	1	0	4	64	8	8
Community Taxa Similarity Index	100	100	37	28	36	5	54	32
Community Trophic Similarity Index	100	100	60	34	62	32	68	59
Invertebrate Community Index	**100**	**100**	**57**	**57**	**72**	**42**	**62**	**57**

Figure 5.1. Invertebrate Community Index scores: freshwater sites.

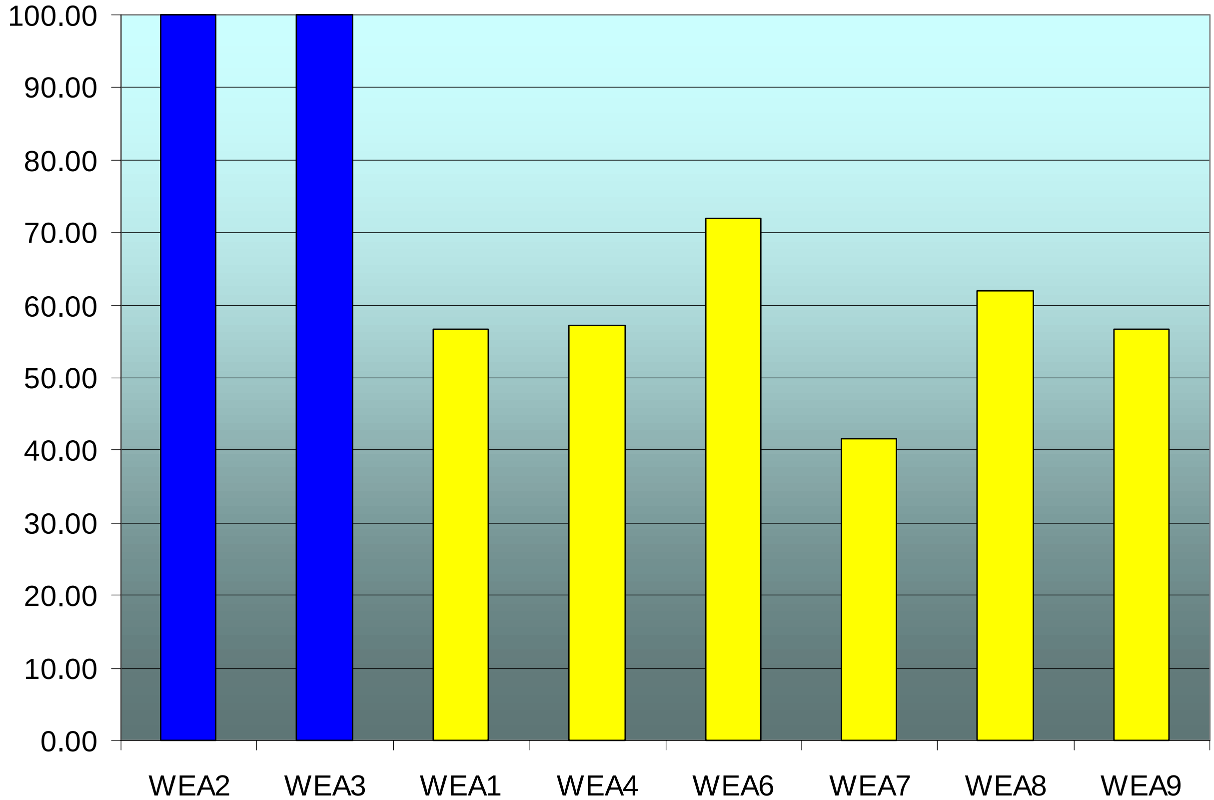


Table 5.8. Salt marsh wetlands ICI metrics and indices averaged over 3 seasons.

Metric/Index	WEA10	WEA11	WEA12	WEA13	WEA14
Total Organisms	193	65	119	93	131
Total Taxa Richness	28	23	18	18	20
% Contribution Dominant Taxa Group	50	46	53	52	46
% Contribution Dominant Trophic Group	57	45	54	48	39
% Abundant/% Rare	0.1	0	0.1	0	0.1
% Captellida Polychaeta	1	5	1	2	0
# Palaemonedae Shrimps	1	41	24	36	17
Community Taxa Similarity Index	100	43	65	53	46
Community Trophic Similarity Index	100	58	73	58	58
Invertebrate Community Index	**100**	**61**	**67**	**68**	**63**

As a summary of the status of each wetland, the ICI was graphed in correlation with the Habitat Assessment (HA) score in Figure 5.3. This allowed for a determination of whether the ICI score was due to poor habitat condition, a combination of poor habitat condition and some other stressor, or not related to poor habitat condition at all, but some other environmental stressor such as poor water quality. Figure 5.3 correlates the averaged ICI scores with the HA scores for all 13 wetlands. To interpret this graphical presentation of the results, the following guidelines are important to consider. The ICI scores are listed on the vertical X axis, and the HA scores are listed horizontally on the Y axis. On this graph, the shading of the area in which the site number is located serves to indicate whether the invertebrate community condition is due primarily to poor habitat [red shaded area], to stressors other than habitat (i.e. eutrophication or toxic contamination) [yellow shaded], or a combination of poor habitat and other stressors [green shaded]. For example, if a site receives a moderate ICI score but a low HA score, one can predict that the invertebrate community condition is most likely impaired due to poor habitat quality (see site WEA14). On the other hand, if a site scores a low ICI, indicating an impacted invertebrate community, but a high HA score, the condition is due, most likely, to stressors other than poor habitat, such as chronic nonpoint source pollution (see site WEA1).

Figure 5.2. Invertebrate Community Index scores: salt marsh sites.

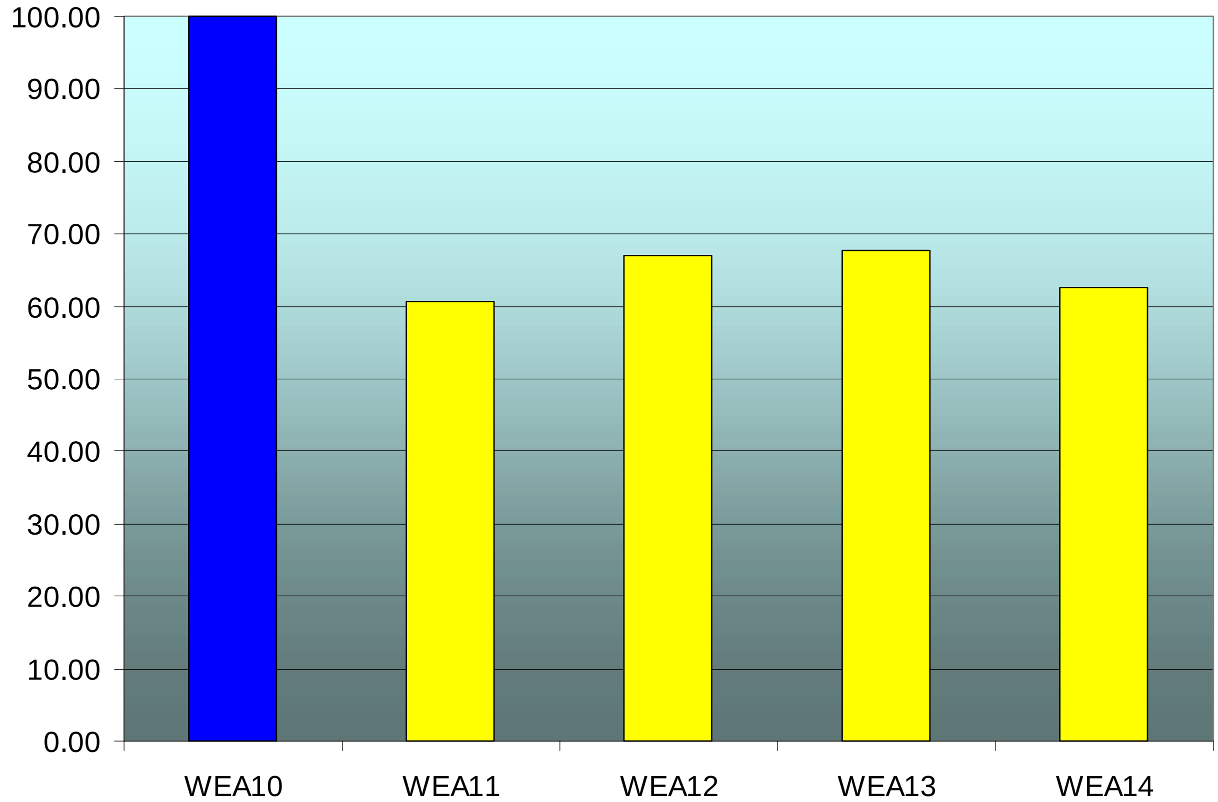
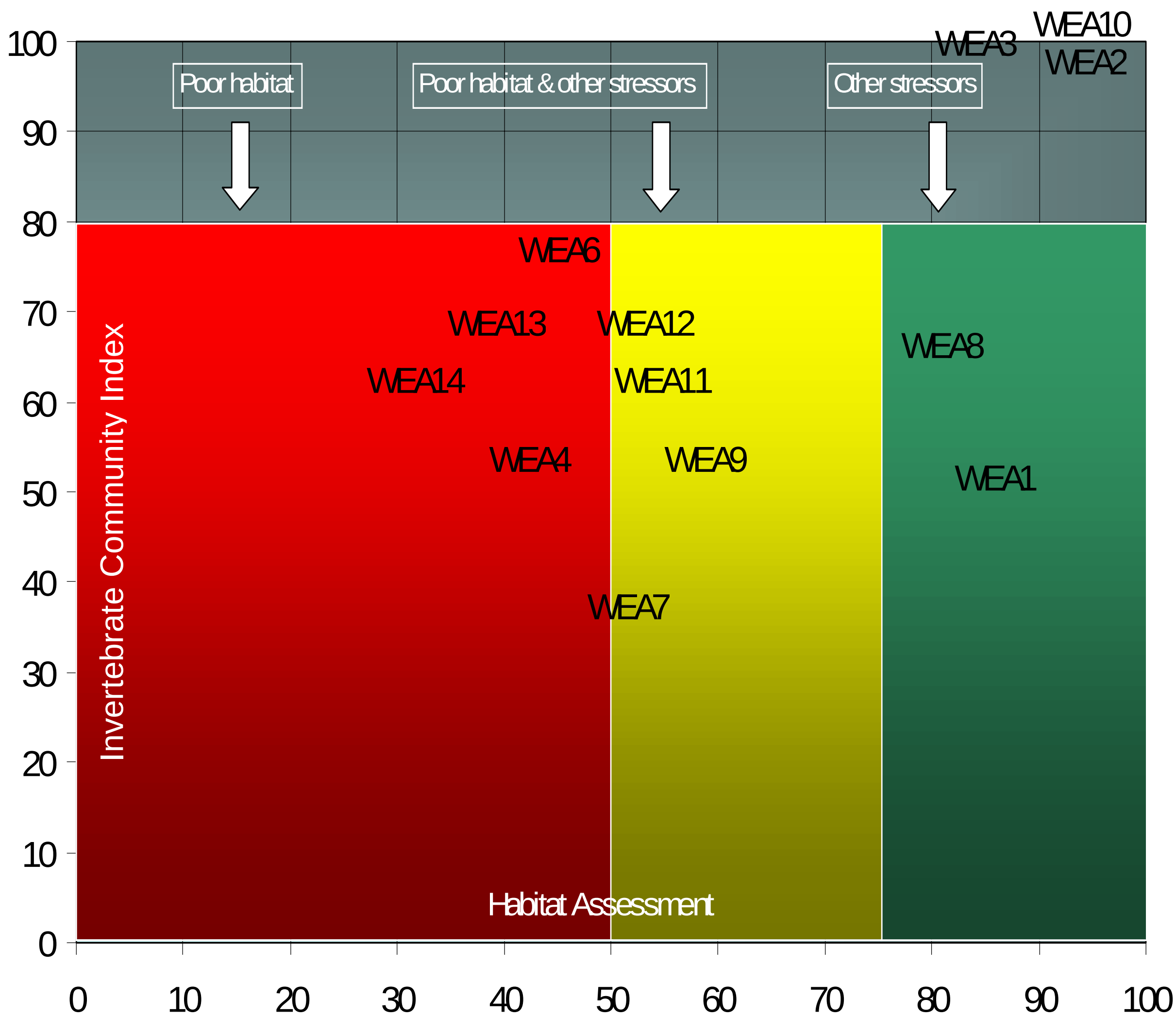


Figure 5.3. Graphic of ICI score versus HA score.



Seasonal and Inter-Annual Variation

The seasonal differences in ICI scores between May 1996, August 1996, and May 1997 are shown in Table 5.9 (freshwater sites) and Table 5.10 (saltmarsh sites). The ICI scores declined between May and August 1996 for most of the nine study (non-reference) sites, except WEA1 and WEA8, with the score unaltered for WEA11. Comparing the inter-annual variation for ICI scores calculated for May 1996, August 1996, and May 1997 reveals that the standard deviation is generally very low except for sites WEA6, WEA8 and WEA13, indicating that the overall variation (seasonally and inter-annually) was not significant.

It was generally assumed that wetland condition would deteriorate between spring and late summer due to higher temperatures, lower overnight dissolved oxygen concentrations, higher loads of nutrients from sewage discharge due to the increase in population over the holiday season, and the impact of management practices on the cranberry farm and golf courses. Toxicant levels were also expected to rise with increased road usage and applications of pesticides to lawns, golf courses and the cranberry bog. These impacts would be counter balanced to a marginal degree by the increased vegetation growth within the wetlands themselves, providing elevated water purification potential to each wetland, and increasing habitat opportunity for the invertebrates. WEA1's improved summer condition was due to vegetation growth, and the fact that it was in a protected habitat with minimal human impact. WEA8's condition also improved, possibly due to the difference in vegetation density between the two sampling seasons. All other wetlands' biological integrity declined over the intervening three months. The biological integrity of all the salt marsh sites declined between May and August, due to the same reasons as set out above for freshwater wetlands.

Table 5.9. Seasonal ICI scores: freshwater sites

Site	ICI May 1996	ICI August 1996	ICI May 1997	Standard Deviation
WEA1	53	61	56	4.04
WEA2	100	100	100	0
WEA3	100	100	100	0
WEA4	61	53	58	4.04
WEA6	72	61	83	11
WEA7	47	39	39	4.62
WEA8	50	72	64	11.14
WEA9	64	53	53	6.35

Table 5.10. Seasonal ICI scores: salt marsh sites

Site	ICI May 1996	ICI August 1996	ICI May 1997	Standard Deviation
WEA10	100	100	100	0
WEA11	63	56	63	4.04
WEA12	71	67	63	4
WEA13	67	78	58	10.02
WEA14	67	67	54	7.51

Section 6. Water Chemistry

As discussed in the introductory section, wetlands provide a multitude of functional roles in the natural landscape, including critical wildlife habitat and flood control, and water quality improvements. The ability of wetlands to serve as improver of water quality has been well documented (Mitsch and Gosselink, 1993; Meiorin, 1989; Whigham et al., 1988; Hemmond and Benoit, 1988; Brinson, 1988; Nixon, 1986). Due to their natural landscape positions and depositional characteristics, wetlands are commonly the receivers of anthropogenic sources of pollution. Unique biogeochemical conditions in wetlands create strongly reducing environments (low or no oxygen, anaerobic) that allow wetlands to assimilate or transform a wide array of pollutants, including nutrients, sediments, metals, and biological and chemical oxygen demanding substances. The ability of a given wetland to retain, absorb, or transform specific pollutants can be compromised, though, when the assimilative capacity of the wetland is surpassed. In addition, while a wetland may be performing water quality improvements by assimilating anthropogenic pollution, the effects of these pollutants on the ecology of the wetland and, therefore, on other wetland functions may be severe. Urban and agricultural runoff, sewage disposal practices, sedimentation from construction and forestry activities, and other sources of pollutants have the potential to significantly alter wetland biological communities and the subsequent food chains they support, reduce flood storage capacity, and impair drinking water supplies.

While many people become concerned over visible signs of eutrophication in lakes, ponds, streams, and coastal embayments, public recognition of wetland eutrophication is practically non-existent. In fact, public perception towards wetlands and water quality has been strongly towards treating all naturally occurring wetlands as disposal areas that are best suited for accepting waste and drainage.

The measurement of ambient wetland water chemistry has recently been regarded as one of the most useful tools available to wetland managers (Brown et al., 1990; Leibowitz, 1990; Hemond and Benoit, 1988). The comparison of ambient water chemistry of reference wetlands to study sites has strong potential to link pollutant concentrations to both surrounding or contributing land use as well as to biological responses.

The need for comprehensive water quality measurements should not be understated. Due to the high degree of natural variability found in wetland water chemistry, single samples or limited data sets may lead to inaccurate predictions or analyses. The naturally high spatial and temporal variability can be addressed by increasing sample size (data points) and by compositing samples. Cost effectiveness is a balancing concern here, though. Samples requiring laboratory analysis have associated costs that can quickly add up with number of stations and frequency of collection.

The objectives of this investigation were to sample each reference and study site at a frequency sufficient to obtain a representative perspective of ambient water chemistry, to compare these results between study sites in order to determine if differences in ambient pollutant concentrations existed, and to use the water chemistry data as an aid to interpret other data sets.

Finally, in order to better understand the relative contribution and pollutant concentrations of direct storm drain discharges, a storm event sampling component was added as part of this larger investigation. The objectives of the stormwater sampling component were to sample stormwater discharge over the course of three storm events, to obtain a representative pollutant concentrations of storm water discharge over time, and to analyze and present these results.

Methods

Water chemistry measurements were made at one or more stations at each wetland study site on a monthly basis for the 1996 growing season and bi-monthly for the 1996-1997 senescent period. Constituents that were sampled in this investigation include:

- Temperature (degrees C)
- pH
- Conductivity (uS)
- Salinity (ppt)
- Dissolved oxygen (mg/l)
- Total suspended solids (mg/l)
- Nitrate plus nitrite (mg/l)
- Ammonia (mg/l)
- Ortho-phosphate (mg/l)
- Particulate organic carbon and nitrogen (um)
- Total fecal coliform bacteria (number/100 ml)

In addition, stormwater sampling was conducted at one of four sites with direct stormwater discharges. From this stormwater data, an estimate of pollutant loading on an average storm basis was obtained.

All samples were collected with standard techniques as outlined in *Handbook for Sampling and Sample Preservation of Water and Wastewater* (EPA-600/4-82-029). All water chemistry sampling was completed in accordance with an approved Quality Assurance Project Plan (QAPP).

Measurements for temperature, conductivity, pH, and dissolved oxygen were obtained in the field with the use of a YSI 600 probe and data logger. Within one hour of beginning a sampling run, the YSI probe was calibrated in the laboratory using methods described in the *YSI 600 Multi-Parameter Water Quality Monitor Instruction Manual*.

For all other parameters, sample bottles were all acid-washed or pre-sterilized, with the exception of the 250 ml fecal coliform bottles which were autoclaved. Samples were collected by trained Project Team personnel. Sample identification information was completed at the time of sampling. Sample IDs included name, site, date, time, and assay. All samples were maintained on ice and in dark from collection in the field through transport directly to the laboratory where the chemical analyses were performed.

Sampling was coordinated so that samples were analyzed within QAPP-specified holding times. All dissolved nutrient constituents samples were filtered upon collection in the field. Particulate Organic Carbon and Nitrogen samples were filtered within 24 hours of collection. Bacterial samples were analyzed within 12 hours of collection.

Field data sheets were maintained by Project Team personnel to document each sampling event. The field data sheets record location, station, date, time of each sample, number of samples by constituent, number of QA samples, weather conditions, physical conditions, and other relevant information.

Samples were collected from pre-selected stations (selected based on representation of a particular wetland type and to encompass the range of environmental variability found within the system). Field duplicates (two independent samples from the same sampling site and depth) were collected during each sampling round to assess the natural variability of each parameter as well as variability introduced during the sampling and analysis process.

Dissolved nutrient (nitrate-nitrite, ammonium nitrogen, and ortho-phosphate) analyses were extracted from a single composite sample. In the field, the sample was extracted at the designated site sampling station, filtered (0.45 um), and placed on ice. The filtration process went as follows: Utilizing an acid-washed syringe, 60 ml of water was withdrawn from the composite sample. This volume was passed through the syringe and discarded. Another 60 ml was withdrawn and, utilizing an acid-washed filter housing, 30 ml was passed through the filter and discarded. Another 30 ml was injected into the 60 ml sample bottle, the bottle was rinsed, and the volume discarded. Finally, another 60 ml was withdrawn and passed through the filter into the 60 ml sample bottle.

Particulate nutrient samples remained unfiltered, collected in dark bottles, put immediately on ice and kept dark. These conditions of cold and dark were maintained from field collection through to analysis at the laboratory. Upon arrival at the laboratory, the POC/PON sample was filtered and refrigerated until analysis.

Samples for total fecal coliform bacteria were collected in separate, sterilized bottles and transferred to the laboratory the day of sampling for processing within 12 hours.

Samples for organics were collected in separate solvent-rinsed borosilicate glass containers with Teflon-lined caps and transferred to the laboratory the day of sampling for processing within 14 days.

Laboratory analyses methods and holding times are shown in Table 6.1.

Table 6.1. Analysis methods, matrices, references, and holding times.

Parameter	Matrix	Units	Method	Reference	Holding Time
Nitrate + Nitrite	water	uM	Autoanalyzer	a	48 hours
Ammonium	water	uM	Indophenol	b	24 hours
Total Dissolved Nitrogen	water	uM	Persulfate digestion	c	24 hours
Ortho-phosphate	water	uM	Molybdenum blue	d	24 hours
Particulate Organic Carbon/Nitrogen	particulates	uM	Elemental analysis	e	24 hours
Fecal Coliform Bacteria	water	CFU	Membrane filtration	f	12 hours
Total Suspended Solids	particulates	mg/l	EPA Method 160.2	g	12 hours
Total Petroleum Hydrocarbons	water	mg/l	EPA Method 415.1	h	14 days

a Lachat Autoanalysis procedures based upon the following techniques:
Wood, E., F. Armstrong, and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11: 87-96.

b Scheiner, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10: 31-36.

c D'Elia, C., P. Steudler and N. Corwin. 1977. Limnol. Oceanogr. 22:760-764.

d Murphy,J, and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31-36.

e Perkin-Elmer Model 2400 CHN Elemental Analyzer Technical Manual.

f Standard Methods for the Examination of Water and Wastewater, 18th Edition, 1992.

g Methods for Chemical Analysis of Water and Wastes, US EPA 600/4-79-020, Revised 1983. & Methods for the Determination of Metals in Environmental samples, June 1991 and Supplement I, May 1994.

h Test Methods for Evaluating Solid Waste, US EPA SW846, Third Edition 1986.

Data Analysis

Water chemistry data was entered into spreadsheet computer software (Excel 97). A multi-metric approach (see **Focus Box**, Section 2) using reference conditions was used to analyze the water chemistry data. Table 6.2 displays the Water Chemistry Index (WCI) metrics for wetlands, the rationale for their use, the predicted response to impairment, and the method for metric value computation. For this investigation and analysis, the average pollutant concentrations for each Wetland Evaluation Area (WEA) were utilized to obtain the metric scores. By referring to predetermined scoring criteria, contained in Table 6.3 and Table 6.4, metrics scores were obtained for each WEA. The metric scores were summed and then converted to a percentage (scale of 100) to derive the final Water Chemistry Index score.

Results

Table 6.5 displays the metric scores for each freshwater WEA. The range of WCI scores for freshwater sites was considerable, with a high of 100 and a low of 17, but the mean freshwater WCI score was 70.83. The median freshwater WCI score was 72.22, with a standard deviation of 27.98. Figure 6.1 graphically displays the final Water Chemistry Index scores for the freshwater WEAs.

The salt marsh metric scores are displayed in Table 6.6. Saltmarsh WCI scores did not vary as much as the freshwater sites, with the high salt marsh WCI score being 100 and the low 56. The mean WCI for saltmarsh WEAs was 74.44, the median 72.22, and the standard deviation was 16.48.

As discussed in Section 9, many of the study sites, both freshwater and salt marsh WEAs, demonstrated high concentrations of nutrients in shallow wetland groundwater. In addition, fecal coliform levels were consistently found to be significantly over human recreational contact levels at several sites, even after extended periods with no precipitation. Uniformly high total suspended solid concentrations were also detected at several freshwater and salt marsh WEAs.

Table 6.2. Metrics for Water Chemistry Index.

Metric	Rationale	Response to Stressors	Metric Computation
Specific Conductivity (Freshwater sites only)	Conductivity levels indicate presence of dissolved inorganic compounds	Rise	Absolute difference from reference value
Salinity (Salt marsh sites only)	Salt marsh biological communities are dependent on specific saline levels	Decline	Mean PPT for study site
Fecal Coliform Bacteria	Fecal coliform bacteria is harmful to human health	Rise	Mean CFU for study site
Total Suspended Solids	Reduce quality and availability of aquatic habitat, reduce clarity and sun penetration, increase rate of sedimentation	Rise	Mean concentration (mg/l) for study site
Otho-Phosphates	Accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site
Ammonia	Accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site
Nitrate/Nitrite	Potentially harmful to human health; accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site

Table 6.3. Water Chemistry Index metric scoring criteria: freshwater sites.

Score:	0	2	4	6	Standard Deviation
Specific Conductivity	>157	125-156	93-124	<93	32
Fecal Coliform	>200	100-199	50-99	<49	NA
Total Suspended Solids	>36	23-35	11-22	<10	13
Phosphorous	>0.20	0.11-0.19	0.10-0.03	<0.02	0.09
Ammonia	>1.03	0.55-1.02	0.09-0.56	<0.09	0.47
Nitrate + Nitrite	>2.28	0.16-2.27	0.04-1.15	<0.04	1.12

Table 6.4. Water Chemistry Index metric scoring criteria: salt marsh sites.

Score:	0	2	4	6	Standard Deviation
Salinity	<25	25.0-25.9	26.0-27	>27.0	1.3
Fecal Coliform	>100	50-100	30-49	<30	NA
Total Suspended Solids	>37.0	27.0-37.0	17.0-26.9	<17	10.0
Phosphorous	>0.10	0.08-0.10	0.06-0.07	<0.07	0.02
Ammonia	>0.12	0.08-0.12	0.04-0.07	<0.04	0.04
Nitrate + Nitrite	>0.06	0.05-0.06	0.03-0.04	<0.03	0.02

Table 6.5. Final metric and WCI scores for freshwater sites.

Metric	WEA2	WEA3	WEA1	WEA4	WEA6	WEA7	WEA8	WEA9
Specific Conductivity	6	6	4	6	2	2	4	4
Fecal Coliform	6	6	6	6	6	0	2	0
TSS	6	6	6	6	6	0	2	6
Phosphorous	6	6	2	4	4	0	4	4
Ammonia	6	6	6	6	6	0	4	6
Nitrate/Nitrite	6	6	0	4	4	4	2	4
Raw WCI Score	36	36	24	32	28	6	18	24
Final WCI Score	**100**	**100**	**67**	**89**	**78**	**17**	**50**	**67**

Table 6.6. Final metric and WCI scores for saltmarsh sites.

Metric	WEA10	WEA11	WEA12	WEA13	WEA14
Salinity	6	6	4	4	2
Fecal Coliform	6	6	6	6	4
TSS	6	6	2	6	2
Phosphorous	6	4	6	6	6
Ammonia	6	4	4	0	4
Nitrate/Nitrite	6	2	2	4	2
Raw WCI Scores	36	28	24	26	20
Final WCI Scores	**100**	**78**	**67**	**72**	**56**

Figure 6.1. Water Chemistry Index: freshwater sites.

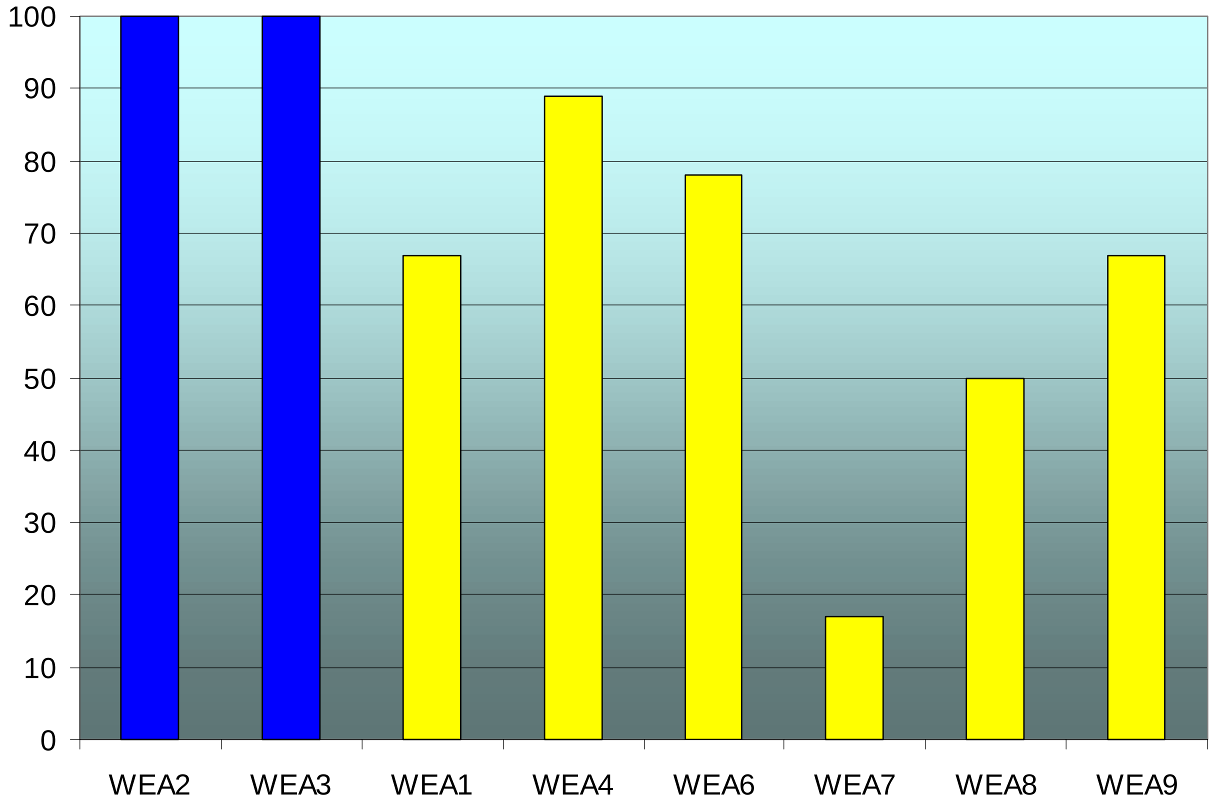
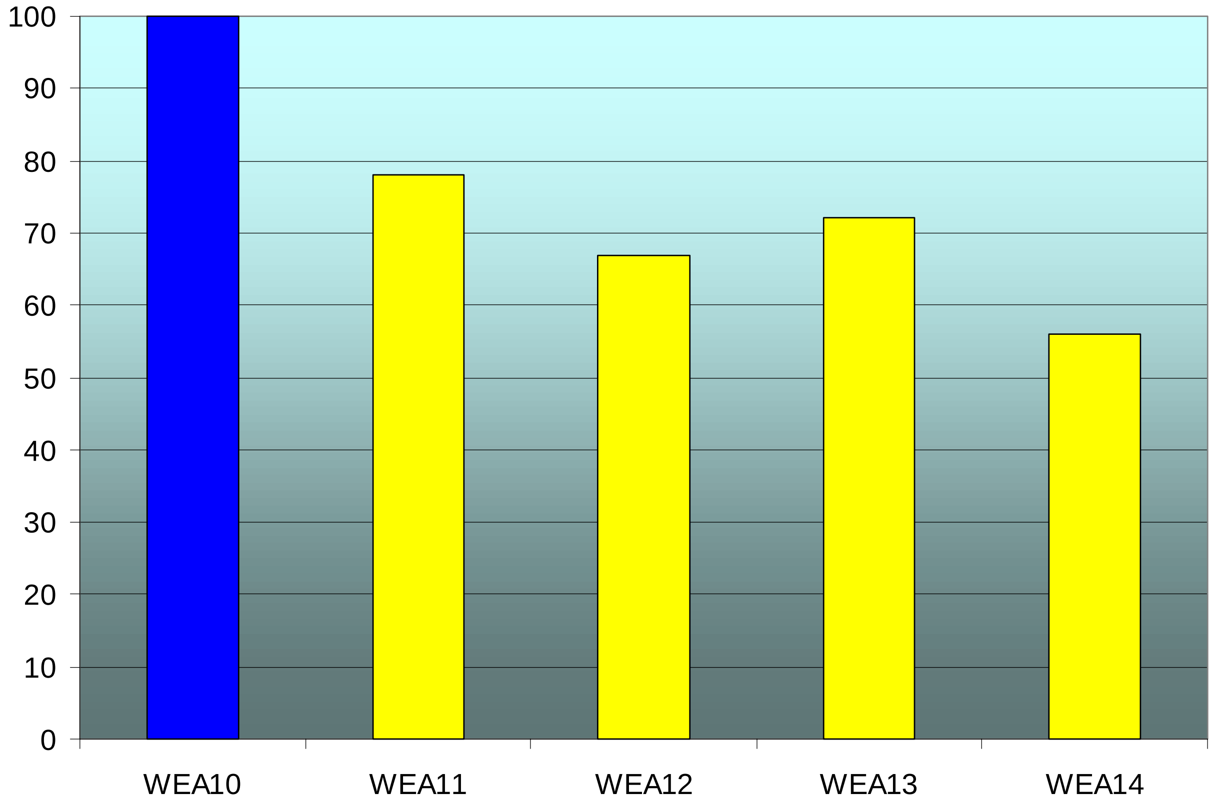


Figure 6.2. Water Chemistry Index: salt marsh sites.



Stormwater Results

A total of three separate storm events over the course of 1996-1997 were sampled. These events occurred on July 31, 1996; May 6, 1997; and June 22, 1997. Grab samples were taken manually directly from the storm drain discharge point. In all three cases, the first flush from the storm drain was captured and then samples were taken at regular intervals through the course of the storm event. The first flush refers to the initial discharge of stormwater that collects in the catch basins and drainage pipes and then overflows from this collection system to release from the outfall structure. Rainfall intensity and volume for these three storm events varied, but for each storm the total rainfall volume exceeded 0.5"–the minimum volume necessary to qualify as a rain event for this project. Total amounts of precipitation were obtained from a rain gauge at the Waquoit Bay National Estuarine Research Reserve and reading were confirmed by rainfall data collected by the MA Department of Environmental Management at the Long Pond Reservoir in Falmouth, MA.

From the data collected it is clear that pollutant concentrations in stormwater runoff are significantly higher than in ambient wetland surface and pore water. In some cases the stormwater runoff pollutant concentrations are several orders of magnitude greater. In addition, from stormwater flow and wetland water level data as well as regular observations, it became evident that sites receiving direct stormwater discharges were subject to much greater variations in wetland water level than reference sites and study sites with no direct discharge. Water levels at site WEA7, in particular, exhibited significant variability. Table 6.7 documents the mean, maximum, and minimum concentration for selected pollutants for the three storm events sampled, as well as the standard deviation.

Figures 6.3 through 6.6 serve to graphically display the concentrations of specific pollutants in stormwater runoff directly discharged to wetland study sites over the course of a rain event. Each line represents a single storm event at a unique site. Several graphs show only the results from two events. This is because nutrient analyses were completed only for two events, and data for another event has a couple TSS and fecal coliform values that were dramatic outliers–perhaps due to sample contamination (in the field or laboratory). These data were therefore eliminated from the analysis.

As a point of reference, a red line has been placed on each graph showing the ambient concentration of the pollutant averaged over all of the freshwater sites. This overall average--assimilating even the high ambient concentrations of certain study sites–is, in many cases, a fraction of the stormwater concentrations. Many of these figures also illustrate the first flush effect of stormwater runoff–that higher concentration of pollutants are typically contained in the first volumes of stormwater discharge.

Table 6.7. Pollutant concentrations of stormwater for three rain events 1996-1997.

	Mean	Maximum	Minimum	Standard Deviation
Specific Conductivity (uS/cm)	68.25	199.00	7.00	53.49
Total Suspended Solids (mg/l)	86.89	715.00	1.10	170.25
Fecal Coliform (#/100ml)	16,123	60,000	2	21,274.08
PO4 (um/l)	3.95	10.90	2.30	2.48
NH4 (um/l)	19.55	37.10	4.24	16.15
NO3/NO2 (um/l)	56.11	118.44	16.15	29.19

Figure 6.3. Average fecal coliform bacteria concentrations in stormwater discharges.

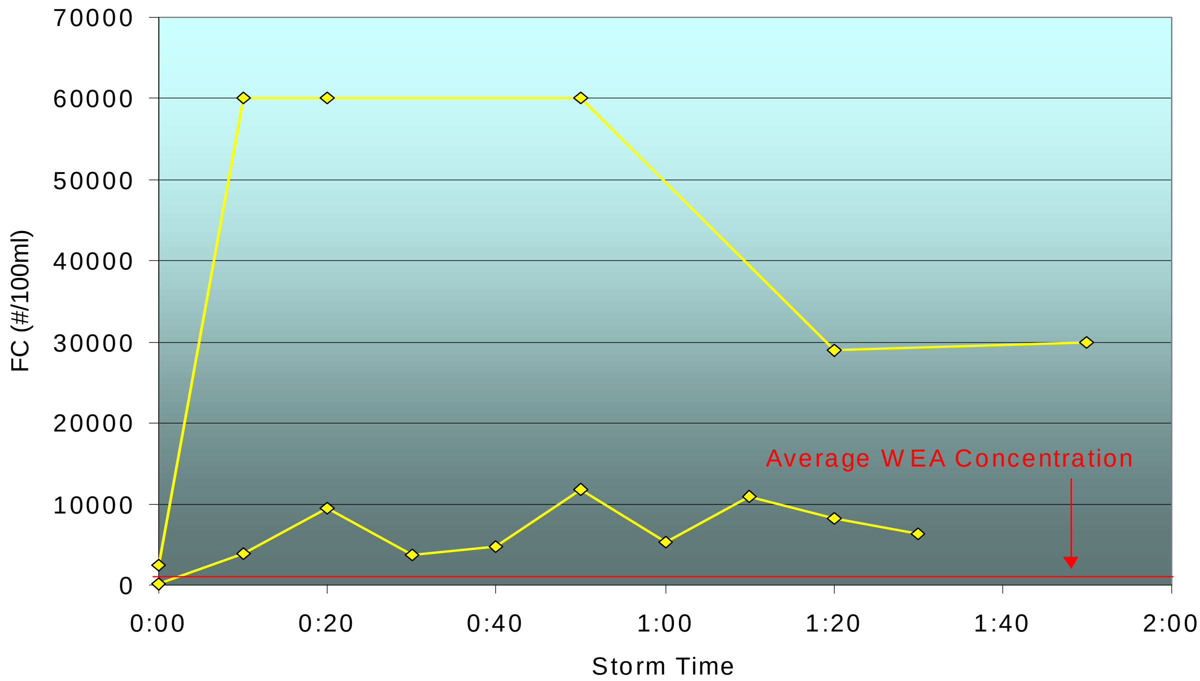


Figure 6.4. Average specific conductance of stormwater discharges.

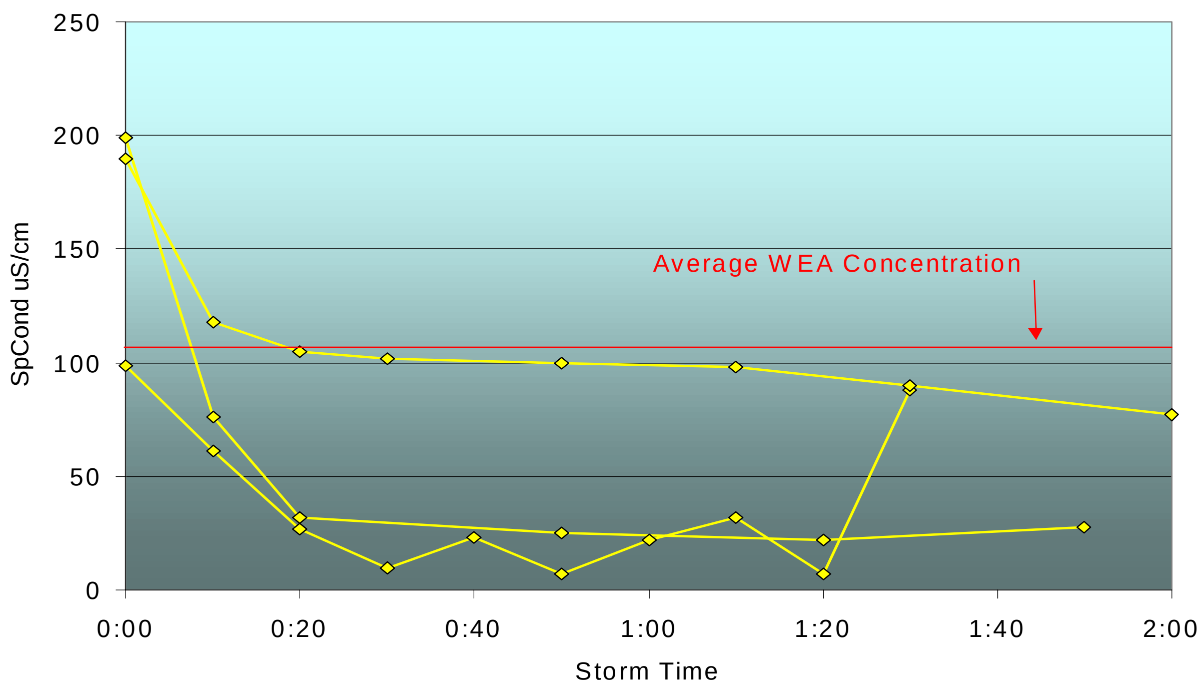


Figure 6.5. Average phosphorous concentrations in stormwater discharges.

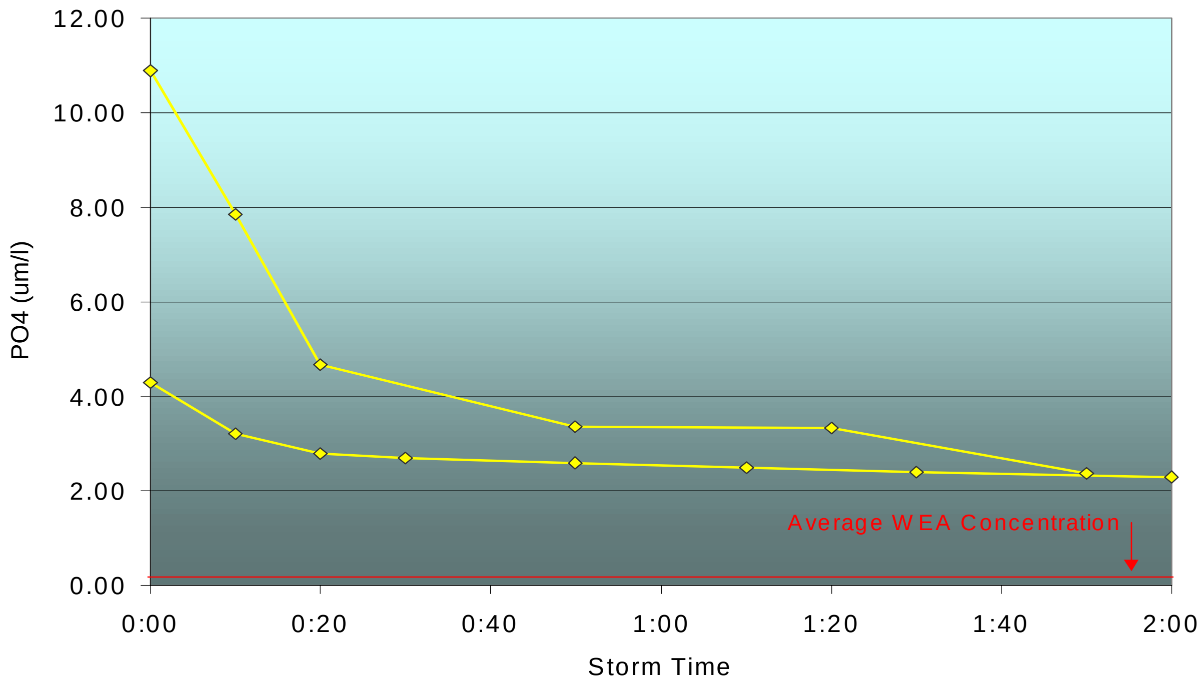
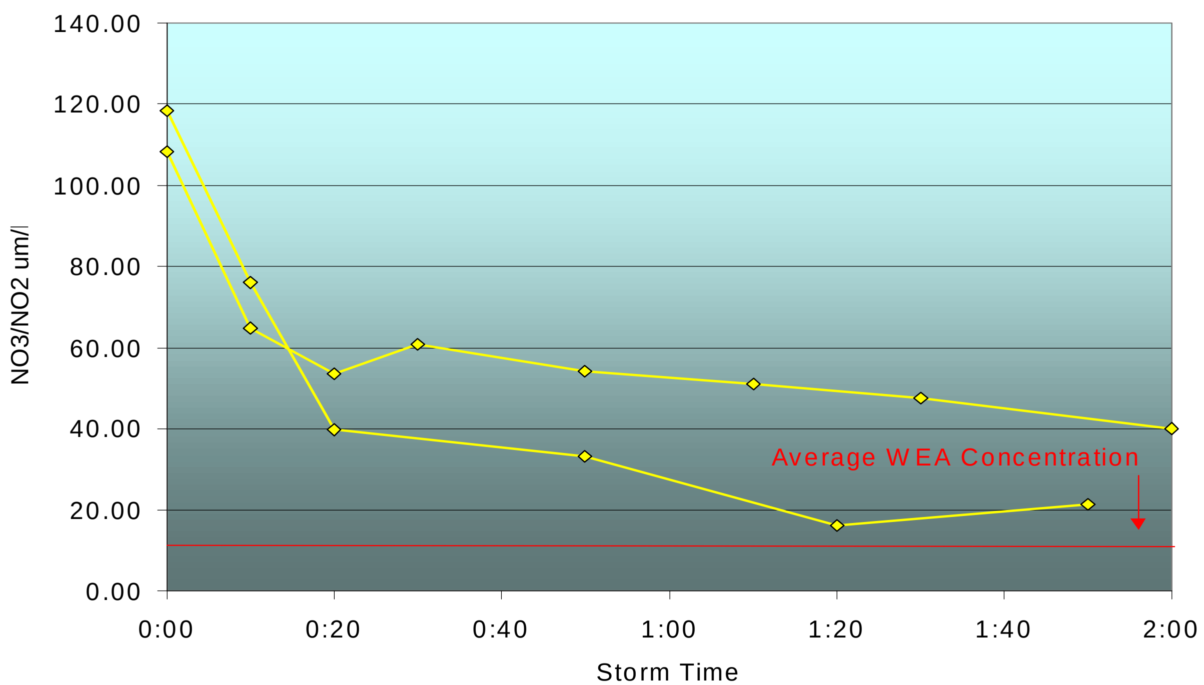


Figure 6.6. Average nitrate/nitrite concentrations in stormwater discharges.



Section 7. Wetland Hydroperiod

Hydrology is one of the strongest determinants for the establishment and maintenance of wetland types and processes. Anthropogenic impacts may alter wetland hydrologic regimes, and subsequently affect wetland hydroperiod, or the pattern of water level rise and fall over time. Wetland ecosystem response to hydrologic changes may be manifested in major habitat changes (through shifts in vegetation community abundance, diversity, and invasive/opportunistic species occurrence) as well as altered flood storage capacity and altered chemical properties (Mitsch and Gosselink, 1993; Taylor, 1993; van der Valk, 1981). The measurement of wetland water levels is important for the interpretation of most other indicators and data. The goals of the wetland hydroperiod investigation were to:

- Observe and measure the water level elevations in selected freshwater wetland evaluation study sites, approximately monthly over a growing season;
- Generate specific metrics from sample data;
- Compare metrics to other environmental data and assessment method results; and
- Analyze and present results.

The last part of Section 7 contains the summary report of a detailed investigation on wetland and groundwater hydrology. This component investigation was conducted at a single Wetland Evaluation Area (WEA) in order to accurately quantify the interaction between the wetland site and the water table aquifer, and thereby estimate the extent and dimensions of its watershed. The delineation of wetland watersheds, or contribution areas, is a necessary step in the comprehensive assessment of nonpoint source (NPS) pollution origins, transport, and fate to a wetland.

Methods

At each freshwater wetland study site, water levels were recorded five times during the 1996 growing season (May to September). These measurements generated four separate periods during which the water level changed or remained constant according to the hydrology of the wetland. For sites with permanent standing water, staff gauges with 0.5 centimeter increments were installed. At sites without permanent standing water, shallow groundwater wells were installed. Wells were made of 2 meter lengths of 5 cm PVC pipe. The bottom third of the well was drilled with 0.9 cm diameter holes on three planes around the PVC. Synthetic geotextile filter fabric was then wrapped and secured around the bottom third and the open well bottom. All water levels recorded were standardized to the surface of the wetland soil substrate.

WEA4 is not included in this analysis, due to repeated vandalization of the staff gauge and resulting lack of data. Water levels from salt marsh study sites were not analyzed as there are no tidal restrictions present for any site and data indicated normal tidal range and influence.

Data Analysis

Water level data were processed into a set of metrics for each study site, using spreadsheet computer software (Excel 97). Wetlands were grouped according to two broad hydrogeomorphic classes: small isolated depressional and deep marsh/lacustrine. WEA2 served as the reference site for the isolated depressional class, which included WEA1, WEA7, and WEA9. WEA3 was the control for the deep marsh/lacustrine fringe class which included WEA6 and WEA8.

Underlying this comparison is the assumption that components of the water budget (i.e. precipitation, groundwater discharge and recharge, surface water input and output, transpiration, evaporation) will be proportionate for wetlands of similar hydrogeomorphic classes and sizes. This assumption is reasonable given the small size of the Waquoit Bay watershed and the relative uniformity of the watershed soils. For example, we assumed uniform precipitation over the entire watershed.

The hydroperiod is the sum of the all the water budget components listed above. The hydroperiod should fluctuate in the same direction by a proportionate amount for wetlands of a given class. Alteration to the wetland or its contribution area may change one or more of the water budget components–such as adding stormwater inflow through a direct stormwater discharge or paving areas of the wetland contribution area–and, in turn, cause consequential trends in the wetland hydroperiod.

Table 7.1 displays the Hydroperiod Index metrics, the rationale for their use, the predicted response to impairment, and the method for metric value computation. For each study site, values were computed for each metric. By referring to the predetermined scoring criteria in Table 7.2, the metric attributes were scored, summed, and converted to a percentage to derive the final Hydroperiod Index (HPI).

Table 7.1. Metrics for Hydroperiod Index

Metric	Rationale	Response to Stressors	Metric Computation
Period Rise/Fall Similarity	During a given period, water level change in study sites should have the same direction as reference sites	Variable	Percent of measurement periods with same rise/fall direction as reference site
Period of Maximum Water Level	The period with maximum water level should be the same for study site as reference site	Variable	If maximum level occurs at same period in both reference site and study site, score= 1, if not score = 0
Period of Minimum Water Level	The period with minimum water level should be the same for study site as reference site	Variable	If minimum level occurs at same period in both reference site and study site, score= 1, if not score = 0
Mean Change in Water Level	Average change in water level for period of measurement should approximate reference site	Variable	Absolute difference in average water level change of study site from reference site over four periods during growing season
Total Change in Water Level	Total water level change over growing season should approximate reference site	Variable	Absolute difference in total water level change of study site from start to end of growing season from reference site
Hydroperiod Similarity	Hydroperiod of study sites should approximate reference site	Decline	Correlation coefficient of hydroperiod curves (r^2)

Table 7.2. Hydroperiod Index metric scoring criteria: freshwater sites

Metric	0	2	4	6	SD
Period Rise/Fall Similarity	1	2	3	4	1
Period of Maximum Water Level	0	NA	NA	1	NA
Period of Minimum Water Level	0	NA	NA	1	NA
Mean Change in Water Level	>13	9-13	4-8	<4	4
Total Change in Water Level	>60	41-60	20-40	<20	20
Hydroperiod Similarity	<.26	.26-.54	.53-.74	>.74	0.53

Results

HPI scores for the freshwater wetland study sites ranged from a minimum of 17 to a maximum of 100, with a mean of 69.05 and a standard deviation of 34.22. Table 7.3 lists both the metric and HPI scores for the freshwater sites; Figure 7.1 graphically displays the HPI results. Variability between freshwater sites was greatest for the Period of Minimum Water Level Metric, the Period of Maximum Water Level Metric, and the Hydrograph Similarity Metric.

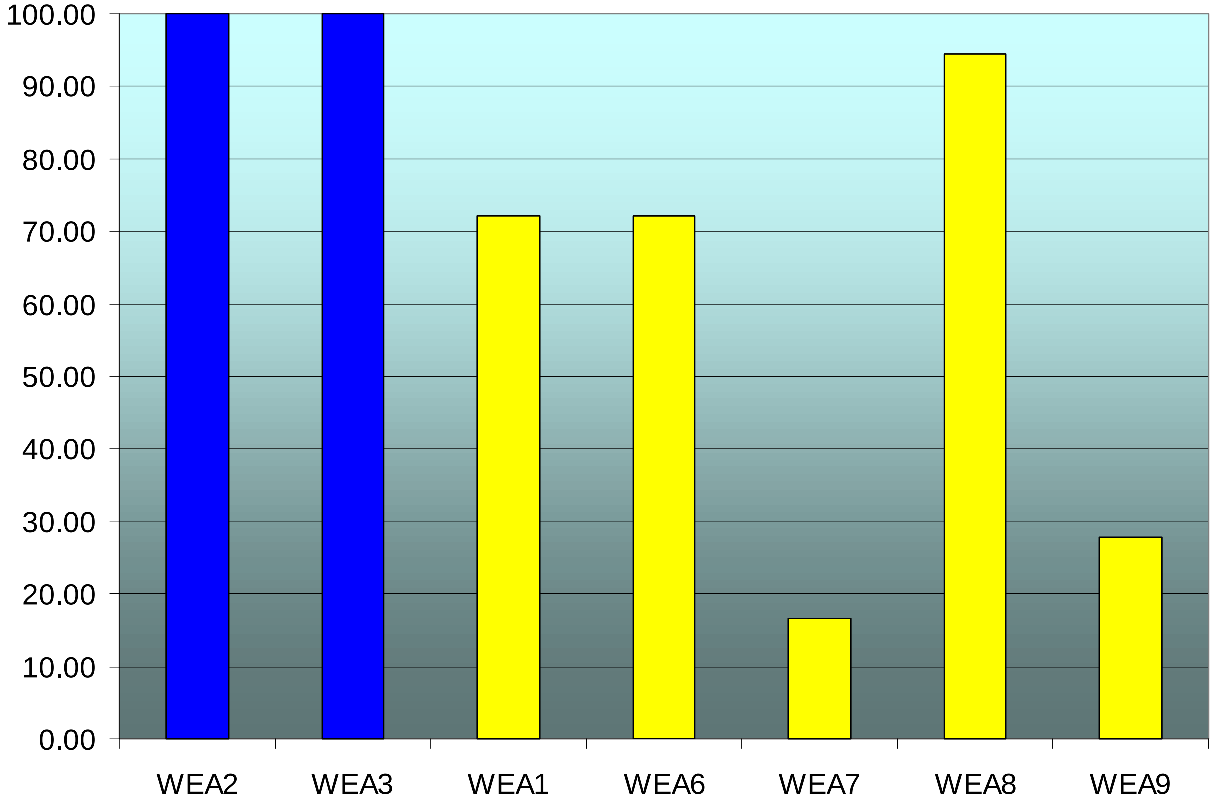
Sites receiving HPI scores below the mean were WEA7 and WEA9. These low scores can be attributed to strong dissimilarity to the reference sites for periods of maximum and minimum water levels as well as to exhibiting distinctly different hydroperiod curves. The hydrology of study sites WEA7 and WEA9 was strongly influenced by the presence of stormwater outfalls, both of which drained substantial areas of impervious surfaces. During and after rainfall events, water levels in these wetlands would increase rapidly. In comparison, water levels in reference and other study sites would gradually increase in response to precipitation patterns as rainfall permeated surrounding contribution areas, temporarily raised local water tables, and flowed into the receiving wetlands as shallow subsurface groundwater.

The hydroperiod of the deep marsh/lacustrine wetlands is closely linked to the regional water table level, while the smaller isolated depressional type wetland are more vulnerable to variations of site specific conditions. For the same net input of the budget water, water levels in the deep marsh/lacustrine class will not shift as dramatically as will the levels in depressional wetlands.

Table 7.3. Final metric and HPI scores for freshwater sites.

Metric	WEA2 (ref.)	WEA1	WEA7	WEA9	WEA3 (ref.)	WEA6	WEA8
Period Rise/Fall Similarity	6	4	2	2	6	4	6
Period of Maximum Water Level	6	6	0	0	6	6	6
Period of Minimum Water Level	6	6	0	0	6	0	6
Mean Change in Water Level	6	4	2	4	6	6	6
Total Change in Water Level	6	4	2	4	6	6	6
Hydroperiod Similarity	6	2	0	0	6	4	4
Raw HPI Score	36	26	6	10	36	26	34
Final HPI Score	**100**	**72**	**17**	**28**	**100**	**72**	**94**

Figure 7.1. Hydroperiod Index: freshwater sites.



The Groundwater Hydrology of an Isolated Depressional Wetland

Similar to the stormwater investigation summarized in Section 6, a groundwater hydrology study was conducted as a special component of the Coastal Wetlands Ecosystem Protection Project. This investigation of wetland and groundwater hydrology was implemented in order to accurately quantify the interaction between a wetland and the water table aquifer and thereby estimate the extent and dimensions of the watershed to a specific Wetland Evaluation Area (WEA). The delineation of wetland watersheds, or contribution areas, is a necessary step in the comprehensive assessment of nonpoint source (NPS) pollution origins, transport, and fate to a wetland. The investigation consisted primarily of a hydrogeologic analysis, including field measurements of hydraulic head, hydraulic conductivity, and stratigraphy for the purpose of calculating groundwater flow using Darcy's Law.

The study site for this investigation, WEA7, is a small (2478 m^2) red maple swamp located 0.7 km from Nantucket Sound in the Great Neck area of Mashpee, Massachusetts. See study site description in Section 2 for more detail. An extensive water table aquifer underlies this WEA. Field measurements were made of the hydrostatic head and hydraulic conductivity within and beneath the wetland and in the aquifer. These measurements were used to calculated the vertical flow rate of groundwater between the aquifer and the wetland.

The area of the wetland watershed was found by comparing the rate of replenishment of groundwater at the land surface to the rate of groundwater discharge to the wetland. The land area required to supply this groundwater discharge is the groundwater watershed or groundwater contribution area of the wetland. The rate of groundwater flow between the wetland and aquifer was compared to measurements of streamflow and estimates of evapotranspiration in order to gain insight into other hydrologic processes at work in the system and to check the validity of these methods and calculations.

Field Methods

WEA7 is essentially a surface water expression of a regional water table aquifer, and is located at the landward edge of a regional discharge area where groundwater discharges to estuarine embayments. An intermittent creek exits WEA7 and flows to Flat Pond, which connects in turn to Sage Lot Pond, Waquoit Bay and Vineyard Sound. The major components of the wetland water balance include groundwater flow, evapotranspiration, and intermittent surface water inflow from a stormwater drainpipe and outflow to the channelized drainage creek.

The surface of the swamp is a mosaic of low hummocks and swales; soils consist mostly of peat and mucky fine to medium sands up to 2 m deep. Fine to coarse sands over 100 m deep comprise the glacial outwash and ice contact deposits that underlie the site (Masterson et al., 1996). The unconfined aquifer extends from the water table at 1 m above sea level to a depth of about 35 m below sea level where there exists an interface between salt and fresh groundwater (Sasaki Associates Inc., 1983). The elevation of the aquifer water table tends to change gradually over the course of a year and is generally highest in the spring and lowest in mid-fall. For the purpose of this document, groundwater discharge refers to that groundwater which flows from the aquifer to the wetland, the water table refers to the free water surface in either the wetland or the aquifer, and the aquifer head refers to the sum of the elevation and the pressure head of water in the aquifer.

Forty wells and stage staffs were installed in the wetland and surrounding upland. The wells were nested such that one well screen was positioned at the water table while another penetrated 1 m or more past the peat layer and into the aquifer. The pair of one shallow and one deep well is referred to as a well nest, although certain well nests included multiple deep or shallow wells. Wells construction was PVC pipe, and well screens consisted of prefabricated 10 slot PVC, hack sawed slots, or holes drilled and covered with geotextile fabric. Wells were installed by driving the well with either a well hammer or by hand, by auguring a hole with a bucket or screw auger, or by a combination of these methods. The well annulus was backfilled with parent material, fine sand and bentonite clay in order to seal the screened interval from other layers. Well positions and elevations were surveyed using an autolevel, stadia rod and compass.

Head measurements were taken periodically over the course of 14 months, beginning in July of 1996. Heads were measured using a roughened steel tape and chalk. Measurements were repeated at a given well until successive measurements were within 1.0 mm of each other.

A bucket auger was used to extract sediment cores to depths of up to 3 m at ten points within the wetland. For each distinctive soil layer, the texture, approximate organic material content, color and other qualities were noted in the field. Soil samples were collected from five of the cores for reference purposes. A probe staff, which consisted of a 2 cm diameter pointed metal rod with depth graduations marked on it, was used to measure the thickness of the peat and mucky sand layers and the depth to the dense sand underlying the wetland. Probe measurements were made at 30 points near ten well nests within the wetland. A driller's log from a monitoring well installed for a local water resource investigation (Sasaki Associates Inc., 1983) was used to describe the aquifer sediments to a depth of 6 m. At the end of the field study, wells which had been driven into the ground were withdrawn and the type of sediment at the well screen was recorded as an indication of whether the well penetrated through the organic soils to sand.

Hydraulic conductivity was measured at 17 wells using slug tests conducted and analyzed according to the method of Bouwer and Rice (1976). Multiple tests were conducted at each well, and tests which produced erratic data were discarded. The remaining values for each well were arithmetically averaged. Slug tests were conducted in wells screened at different depths in order to characterize the hydraulic conductivity of three major types of sediment in this system: wetland peat, aquifer sands, and the transitional sediments in between.

Data Analysis

At each of the nine well nests, Darcy's Law was used to calculate vertical water velocity between the aquifer and the wetland surface:

$$q = K*dH/dz$$

where

q is the Darcy Velocity, with units of length/time [L/T],
K is the hydraulic conductivity [L/T], and

dH/dz is the vertical head gradient [unitless].

Inputs to this calculation included the vertical head gradient measured between the deep and shallow well and the hydraulic conductivity values assigned to the sediments between the deep well and the ground surface. Where head data was unavailable for one of the wells at a specific nest, a value was assigned based on the heads measured at wells screened in similar sediments and positioned at adjacent well nests.

For each well nest, an average vertical hydraulic conductivity was calculated as the harmonic mean hydraulic conductivity of the sediments between the deep well screen and the ground surface. This averaging calculation is based on the thickness and hydraulic conductivity of each layer and gives more weight to low conductivity layers. The three major layers of sediment: wetland peat, transitional and aquifer sands, were assigned values for thickness based on bore hole or probe staff data. Each layer was assigned a hydraulic conductivity value based on slug test measurements. In the absence of stratigraphic or slug test data at a specific well nest, values for thickness and hydraulic conductivity were estimated based on measurements made at adjacent well nests.

The Darcy velocity at each nest was transformed into a volumetric flow rate by multiplying the Darcy velocity by the area assigned to that well nest:

$$Q = q*A$$

where

Q is the volumetric flow rate [L^3/T],
q is the Darcy velocity [L/T], and
A is the area assigned to the well nest [L^2].

Areas of the wetland surface were assigned to the well nests based on the proximity of the area to the nest, and the similarity of the soils and plant cover in the area to those at the nest site.

Groundwater which flowed into the wetland was defined as groundwater discharge, and that which flowed from the wetland into the aquifer was defined as groundwater recharge. For each date of measurement, the total rate of groundwater discharge and recharge were calculated.

The total watershed area was determined based on the principle of continuity (mass is conserved and water is incompressible), and the rate of recharge to the aquifer. An annual average groundwater discharge rate was calculated based on representative dates.

Provided that there is no change in the amount of water stored in the aquifer or the wetland, the groundwater which discharges to the wetland is replenished by water recharged to the aquifer over the area of the watershed. This recharging water, referred to here as aerial recharge, is equal to the difference between precipitation and losses such as evapotranspiration, runoff, and storage in unsaturated zone. In the Waquoit Bay watershed, the aerial recharge rate is 0.49 m/year (Barlow and Hess, 1993). The effects of mixing in the aquifer were neglected.

Dividing the average groundwater discharge rate by the aerial recharge rate gives the area of the watershed:

$$W = Q_{ave}/R,$$

where

W is the wetland watershed area [L^2],
Q_{ave} is the average groundwater discharge rate [L^3/T], and
R is the aerial recharge rate [L/T].

The width of the watershed was estimated based on the horizontal hydraulic gradient between the wetland and well nests positioned on either side of it. The watershed width was assumed to remain constant along the entire watershed length. The watershed length was obtained by dividing the watershed area by its width.

The Priestley-Taylor (Dingman, 1994) method was used to estimate daily potential evapotranspiration. Inputs to this model include daily mean temperature and solar radiation. All climate data was obtained from the Long Pond Reservoir, Falmouth Weather Station, located 11 km from the site. The presence of saturated soils and open water permitted the assumption that actual evapotranspiration was equal to potential evapotranspiration. Any influence of the plant community on evapotranspiration was neglected.

The discharge of the intermittent outflowing stream was determined by measuring the velocity of flow through the channel and multiplying that velocity by the channel area. Across the channel cross section, seven velocity measurements were made at each of four stations, according to the method of Dunne and Leopold (1978) for measuring discharge without a flow meter.

Results

Table 7.4 displays the summary results for the groundwater hydrology investigation at site WEA7. Four main groundwater flow regimes were observed: high discharge, low discharge, high recharge, and flow through. The groundwater flow regime was largely determined by the elevation of the aquifer water table, except when the outlet creek was obstructed. The aquifer water table rose when substantial aerial recharge occurred, both on a seasonal basis during the winter, and on a short term basis following extended rainfall. Evapotranspiration and surface water drainage caused the wetland water table to generally be lower than the aquifer water table, which directed groundwater discharge into the wetland. Groundwater flow rates were highest in the center and near the up gradient edge of the wetland; these areas were the sites of highest hydraulic conductivity.

The aquifer head beneath the wetland followed the level of the aquifer water table, and at times was higher than the water table in the wetland. On two dates (12/20/96, 11/3/96), artesian pressures were observed in wells that penetrated the aquifer beneath the wetland. During these times significant groundwater discharge occurred across the entire area of the wetland. Table 7.5 shows values for groundwater discharge for each of seven dates, groundwater recharge, the number of days since the last major rainfall event, the elevation of the water tables and the evapotranspiration rate.

By the end of the summer, after a sustained period of little rain, the water table in both wetland and aquifer fell to low levels, and interaction between the wetland and the aquifer was minimal. After isolated storm events, however, the wetland filled with stormwater runoff and recharged the aquifer. The rate of recharge following high stormwater runoff events increased considerably when the drainage creek was blocked with debris, preventing surface water outflow. When the water tables in both the aquifer and the wetland were at intermediate levels, groundwater discharge occurred on the up gradient (northeast) side of the wetland and recharge occurred on the down gradient (southwest) side. Figure 7.2 illustrates the basic water budget components and four typical flow regimes observed at WEA7, with the configuration of the water table and the flow of water through the wetland.

The annual average groundwater discharge to the wetland was 16 m^3/day. This value was calculated as the average of the daily discharge for three dates. For the purpose of this analysis, the results from 12/20/96, 8/20/96 and 9/6/97 were chosen as representative of the periods January through April, May through August, and September through December, respectively. The average watershed area (groundwater contribution area) determined by the recharge method was 11700 m^2, based on an aerial recharge rate of 0.49 m/y. The watershed width, as measured by horizontal head gradients, changed over time and was larger on dates with high discharge. The average width was estimated at 80 m; the up gradient watershed length was calculated to be 146 m. Over this land area, recharge from precipitation was sufficient to supply the average groundwater discharge to the wetland.

Daily estimation of evapotranspiration for the years of 1996 and 1997 yielded rates ranging from 0.1 to 8.9 mm/day. The average evapotranspiration rate for the period was 3.23 mm/day, while the average daily precipitation for that period was 3.29 mm/day. Over the area of the entire wetland, the average daily evapotranspiration flux was 7.9 m^3/day and the average daily precipitation flux was 8.2 m^3/day. Streamflow out of the wetland was difficult to measure because of the small size of the channel (under 50 cm wide and 3 to 8 cm deep) and because of the presence of detritus. A discharge rate of 180 m^3/d (0.074 cfs) was measured on 12/21/96, following a period of 3.6 cm of rain over the course of 4 days. The hydraulic conductivity of wetland peat had a log normal distribution with a range of 2.7e-3 to 1.5e-1 m/day (n=11); transitional sediments had a range of 1.5e-1 to 7.9 e-1 m/day (n=3); aquifer sediments had a range of 4.8 e-1 to 7.1e+0 m/day (n=4).

Discussion

This field investigation illustrated the importance of groundwater and evapotranspiration in the water budget of an isolated depressional wetland, and the influence of intermittent surface water flows on the groundwater regime. During winter and spring months when the aquifer water table was high and evapotranspiration small due to low temperatures, groundwater discharge dominated the wetland water budget. At these times, groundwater discharged to the wetland and exited through the drainage channel. During the summer season, when precipitation was infrequent, groundwater

Table 7.4. WEA7 site description and results summary.

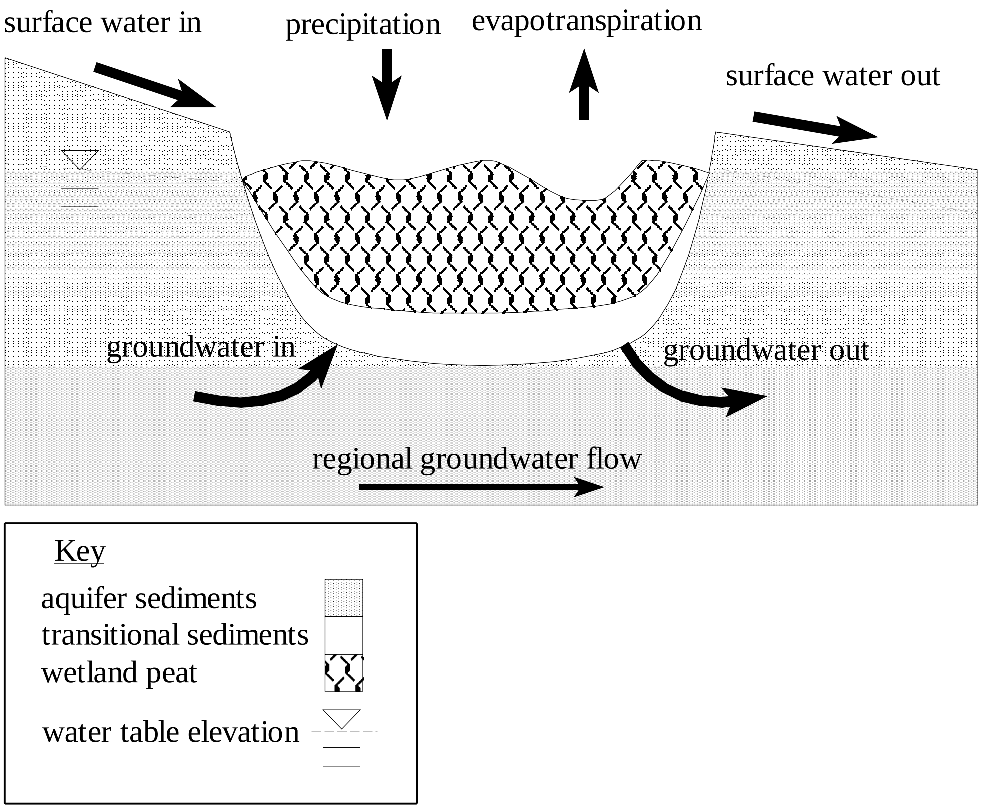
Location	Mashpee, Massachusetts
Hydrogeomorphic Class	Isolated Depressional
Wetland Area	2478 m^2, 0.6 acres
Watershed Area	11700 m^2, 2.9 acres
Mean Daily Groundwater Discharge (in)	15.9 m^3/day, 6.4 mm/day-unit area
Mean Daily Groundwater Recharge (out)	0.3 m^3/day, 0.1 mm/day-unit area
Mean Daily Precipitation	8.2 m^3/day, 3.29 mm/day-unit area
Mean Daily Evapotranspiration (estimated)	7.9 m^3/day, 3.23 mm/day-unit area
Unmeasured Components of Water Budget	Stormwater discharge inflow, Surface outflow

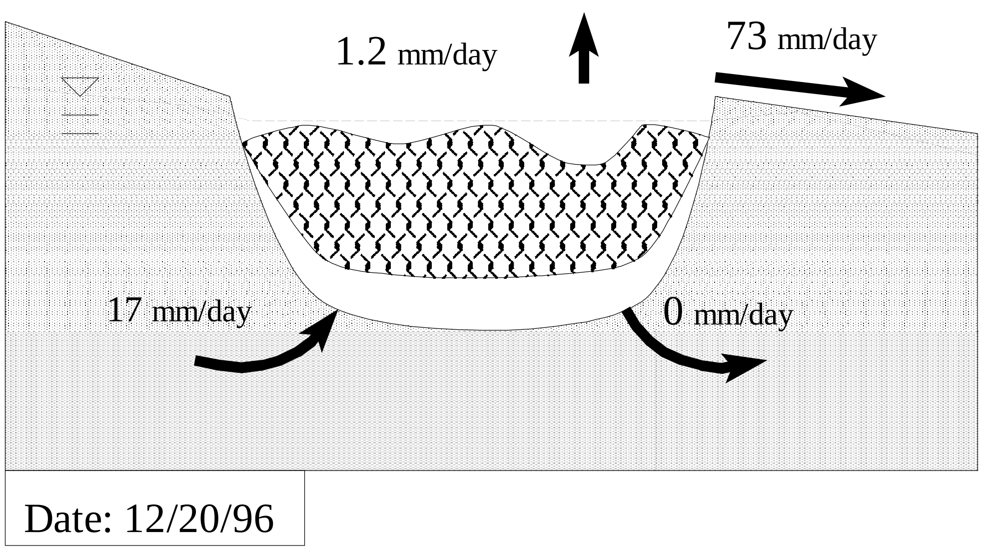
Table 7.5. Summary of daily water flow for WEA7.

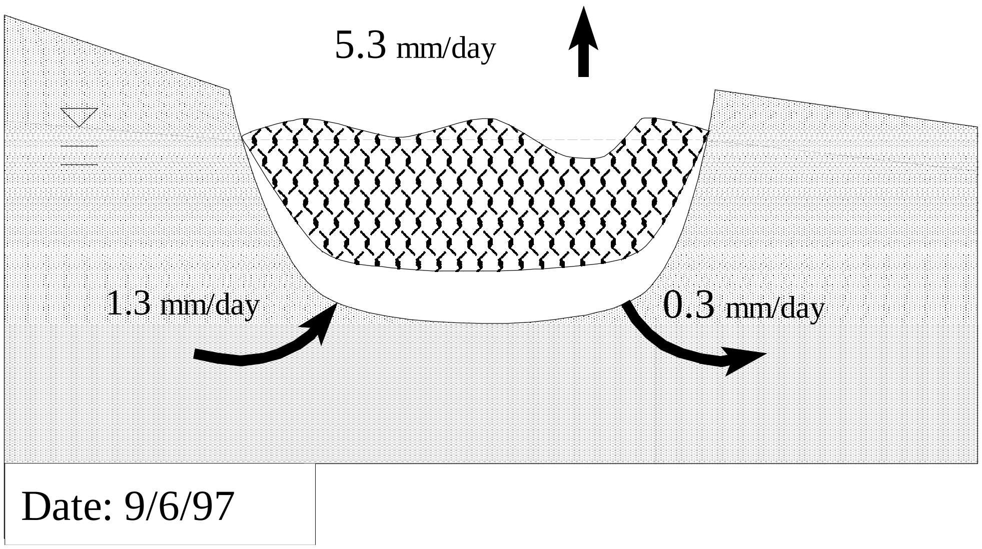
Date:	9/6/97	12/20/96	11/3/96	9/10/96	9/4/96	8/20/96	8/16/96
Groundwater discharge (m^3/day)	-3.3	-41.8	-65.1	0.0	0.0	-2.5	0.0
Groundwater recharge (m^3/day)	0.8	0.0	0.0	23.1	38.9	0.0	2.2
Evapotranspiration rate (m^3/day)	13.2	3.1	6.0	6.8	11.6	17.8	14.8
Days since last storm event*	3	1	6	2	2	7	3
Height of wetland water table (cm)$^+$	90	105	103	132	125	82	88
Height of aquifer water table (cm)$^+$	93	129	144	119	105	84	87

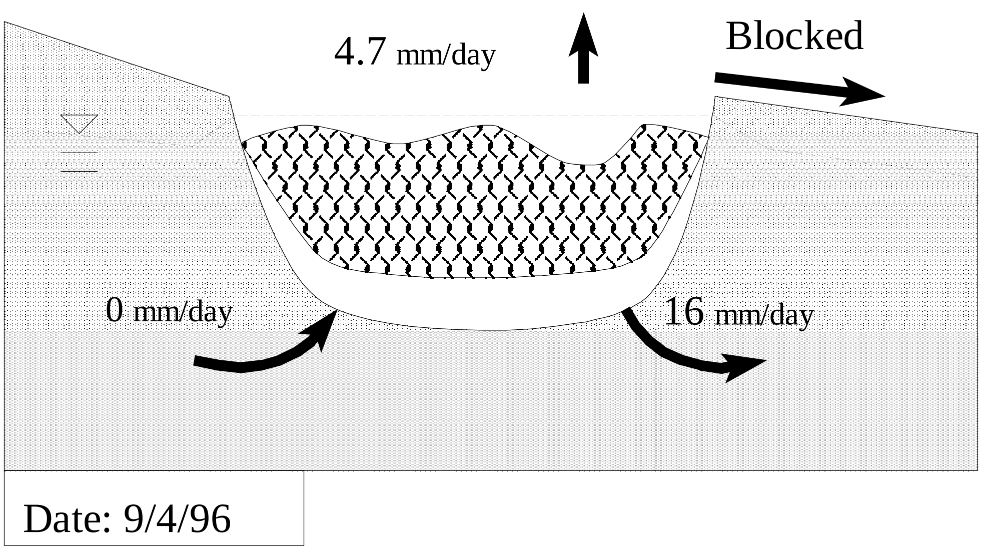
* A storm event is defined as rain in excess of 1.0 cm.
$^+$ Representative elevation of the water table above mean sea level.

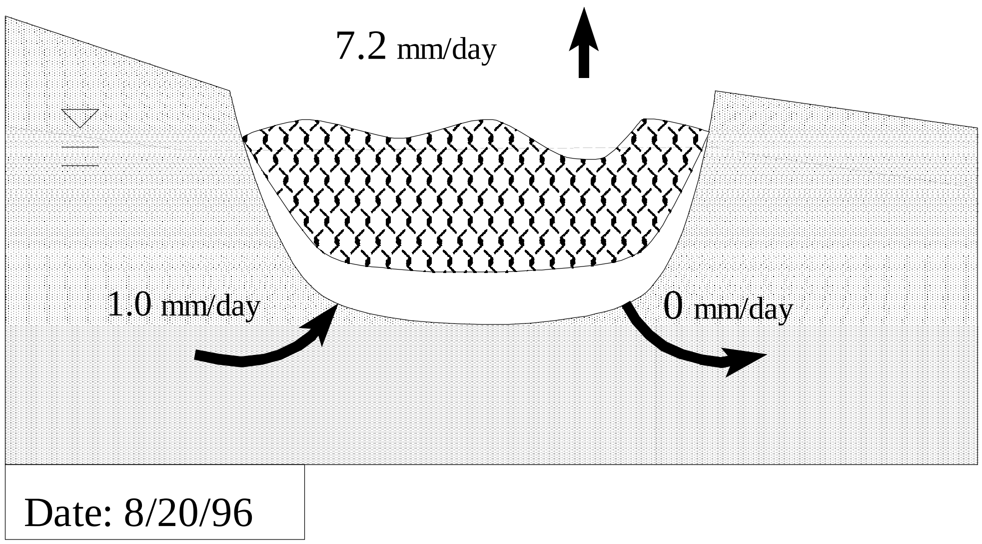
Figure 7.2. Components of the wetland water balance and four typical flow regimes at WEA7.






5.3 mm/day
1.3 mm/day
0.3 mm/day
Date: 9/6/97


4.7 mm/day
Blocked
0 mm/day
16 mm/day
Date: 9/4/96


7.2 mm/day
1.0 mm/day
0 mm/day
Date: 8/20/96

discharge was insufficient to meet the evapotranspirative demands of the wetland, and the soil began to dry out. During these dryer months, rain events temporarily reversed the flow of groundwater, refilling soil pores and directing recharge down into the aquifer. The flow of water through the aquifer directly beneath the wetland was approximately 170 m^3/d, based on data from previous water resources investigations in the area (Sasaki Associates Inc., 1983). The average groundwater discharge to the wetland was less than ten percent of that value.

The delineation of the watershed based on the recharge method produced a watershed 80 m wide and 146 m long that extends up gradient from the wetland according to the regional water table. Precipitation falling and recharging the aquifer over this area was sufficient to account for the average groundwater discharge to the wetland. Other sources of recharge such as septic systems and irrigation were neglected in this analysis, but they could impact both the rate of aerial recharge and the configuration of the aquifer water table.

When calculated on the basis of short term measurements, the watershed area was larger during periods of high discharge and smaller during periods of low discharge, but it is important to realize that the size of the watershed changes more rapidly than water flows through it. For the watershed based on the average discharge rate, the travel time to the wetland for a parcel of water entering at the up gradient limit of the watershed is about 2 years. This large travel time is the reason why for management purposes it is more appropriate to consider an annual average watershed rather than one based on more transient hydrologic conditions such as those following a storm event. The travel time and distance may also be important with respect to the degradation and mixing of pollutants in the aquifer.

Large storm events had the effect of elevating both the aquifer and wetland water tables, however the wetland water table would fall faster because of surface drainage. After these events groundwater flow was temporarily directed towards the wetland from the upland areas on all sides, and from as far as 15 m down gradient from the wetland. These local flow systems occurred over relatively short distances and involved high horizontal head gradients, and so pollutants and water may have been transported to the wetland before the flow pattern dissipated. Land uses adjacent to a wetland will potentially affect influent groundwater chemistry and/or the rate of groundwater discharge even if those land uses occur on the down gradient side on the wetland. For management purposes the wetland watershed should encompass these areas.

The watershed generated using these field techniques was 40 percent larger in area than that found using the method which incorporates the CSIRO capture zone model (Townley et al., 1993; Nield et al., 1992; Townley and Davidson, 1988) employed as part of the Nonpoint Source Index rapid assessment method described in Section 3. The watershed delineated through this field investigation was wider (80 m as opposed to 26.4 m) and shorter (146 m as opposed to 298 m), but the size and general proportions of the two watersheds are somewhat similar. The differences are largely due to the focus of the CSIRO capture zone model on only the open water portion of the wetland, while at the study site discharge was also observed in the saturated soil portions of the wetland. The authors of the CSIRO model (Townley et al., 1993) specifically acknowledged that the model was designed around wetlands dominated by open water rather than saturated soil. Additionally, the small size of the wetland compared to the aquifer thickness is at the bottom of the published range of input values for the CSIRO model, which may have led to some error in its application.

For the purposes of watershed delineation, the impervious surfaces which contributed stormwater to the wetland must not be neglected. Stormwater runoff discharge into the wetland was not specifically quantified during this study, but it had an important short term impact on wetland hydrology. Each large storm event raised the water level in the wetland by 5 to 25 cm and increased the inundated area by over 300 percent. Over the course of three to seven days, this water would exit the wetland primarily through the drainage creek and secondarily by groundwater recharge. When the drainage creek was blocked with debris, storm events resulted in a longer period and higher level of flooding. Adept watershed management must consider both the surface watershed and groundwater watershed of the specific site in question.

The streamflow measured on 12/21/96 illustrated the wetland's response to stormwater inputs when the aquifer water table was high: stormflow passed through the wetland relatively rapidly. In contrast, when the water table was lower, such as during the summer months, stormwater collected in the wetland, reversed the flow of groundwater, and infiltrated into the wetland soil. Under this scenario, there may occur longer stormwater contact times with plant roots and the benthic habitat. In contrast to surface water flows, rates of groundwater discharge changed gradually in time. Wetlands such as WEA7 which have been modified to receive surface water inputs (i.e. stormwater) may be impacted by the increased frequency and level of flooding. Baseline data was unavailable to test that hypothesis in this case. Stormwater delivered sediment into the wetland, and at the sediment core site close to the stormwater outfall, deposits of stormwater sediments were 40 cm thick.

It is often desirable to rapidly assess whether groundwater is a significant component of a wetland water budget. Field indicators of groundwater discharge include: seeps and springs at the break in slope between the wetland and the upland; reddish-brown (iron oxidizing) bacterial growth in shallow flowing water; temperature anomalies e.g. portions of the wetland surface that remain unfrozen in winter; areas of flowing water which persist after extended periods of little rain; green vegetation in an otherwise brown landscape; deposits of certain minerals (e.g. carbonates or gypsum); chemical indicators such as altered pH or specific conductivity; and, in extreme cases, upwelling currents in open water. Office based indicators of groundwater discharge include the relative elevations of the wetland and the local water table based on water table maps or the levels of water in wells near the site. In summary, the steps necessary to qualitatively assess the relationship between groundwater and a wetland include the following:

- A review of hydrogeology of the area permits the identification of the regional groundwater system and the depth to the water table.

- Deep and shallow wells permit measurement of the wetland water table and aquifer head in order to determine the direction of groundwater flow. Relative water levels, as determined using a manometer, may suffice for this purpose. Water levels should be observed over the course of long term fluctuations of the aquifer water table.

- Characterization of the wetland and aquifer sediments, both in texture and thickness, permits the estimation of sediment hydraulic conductivity.

- Estimation of the magnitude of the other components of the water budget permits their comparison with the groundwater flow rate.

These initial steps will allow for the estimation of the rate and direction of groundwater flow, and the relative importance of groundwater to the hydrology of the wetland.

Section 8. Avifauna

Birds can complement the use of plants, aquatic invertebrates, and other organisms as bioindicators of wetland quality, particularly at the landscape scale (Adamus and Brandt, 1990; Adamus, 1992). As longer-lived and generally wide-ranging or migrant indicators, birds may serve to reflect the larger, cumulative landscape-level impacts that may not be as discernable in other biological endpoints, such as invertebrates or vegetation. Habitat requirements for birds are generally well known. Wetland dependency in birds varies greatly from species that spend their entire lives in wetlands to those who use wetlands to feed or nest or for a seasonal duration, such as migration. Since birds are relatively easy to census, it is possible to include them as an indicator of wetland health to complement other indicators. Avifauna operate at a landscape level scale, and by including bird censuses into wetland ecological assessment, the overall evaluation scope broadens to incorporate issues of habitat fragmentation and cumulative impacts.

Disadvantages in or obstacles to the use of avifauna as an indicator of wetland health are several. The presence of an avian species in a wetland implies, but does not necessarily establish, specific usage of the wetland in question. Variability–both temporally and spatially–has been documented to be very high for wetland habitats, and data linkage of impaired avian communities to a specific stressor is difficult. In addition, survey work requires repeated site visits, and some species are more easily detected than others. For secretive bird species, the use of broadcast vocalizations may be necessary (Gibbs and Melvin, 1993).

Methods

Point counts were selected as the sample method, using visual and auditory cues. Expert observer(s) sat quietly from a vantage point where all of the wetland could be viewed. All species and individuals were counted and recorded by the observer, as they were heard or seen demonstrating any activity in the wetland or in a 100-foot buffer area. Counts were conducted for a period of 20 minutes, broken into four five-minute sample intervals. All individuals were counted, with an effort made not to duplicate individuals to the extent possible. An additional 10 minutes were allotted to allow the observer to walk slowly along the perimeter of the wetland in order to detect any species not tallied in the 20 minute count. Several sites were visited on the same day, with census beginning at approximately 6:00 AM and ceasing at approximately 8:30 AM in order to capture peak activity. Broadcast vocalizations were not employed for this effort but may be in future work.

Freshwater sites were sampled during the breeding season in May, June, and July in order to capture peak breeding usage, while saltwater sites were sampled in late August to capture migrating shorebird usage, since saltmarsh habitats are known to have comparatively fewer breeding species. Most freshwater sites were visited several times (average 1.75 census visits or 8.75 sample intervals per site), while salt marsh sites were visited only once.

Because of staff resource issues and time constraints, the sample size and subsequent data set for the avifauna investigation did not meet project targets. As such, it is with reservation that we present the following results. The authors do feel the data analysis methods described below hold regardless of sample size, but emphasize that results may shift with more robust data.

Data Analysis

Avifauna data were entered into spreadsheet computer software (Excel 97). A multi-metric approach using reference conditions (see Focus Box, Section 2) was used to analyze this data. Table 8.1 displays the Avifauna Index metrics for wetlands, the rationale for their use, the predicted response to impairment, and the method for metric value computation. For this investigation and analysis, raw abundance values were employed for species, not density-weighted values. By referring to predetermined scoring criteria in Table 8.2 and 8.3, the metrics were scored, summed, and converted to a percentage to derive the final Avifauna Index (AVI).

Observations of neotropical migrants included those seen or heard in the upland buffer zone adjacent to the wetland. Because of their sensitivity to habitat disturbance, the presence alone of neotropical migrants is an indicator of habitat quality. Resident species were defined as those that are non- or partial migrants that can be found at any month of the year. Because wetlands frequently freeze in the winter, resident species are normally forced to be habitat generalists for the food and shelter they require, and habitat quality is of lower importance. Tolerant species are essentially a subset of resident species that have adapted to living in disturbed habitats with active human presence. Finally, wetland-dependent species are those that feed and breed exclusively in wetlands.

Table 8.1. Avifauna Index metrics.

Metric	Rationale	Response to Stressors	Metric Computation
Taxa Richness	Feeding and breeding response based on habitat quality and food supply	Decline	Difference from reference site total taxa
% Neotropical Migrants	Migrants are generally sensitive to habitat quality and are habitat specialists	Decline	Percentage of total species
% Resident Species	Resident species less sensitive to habitat quality and tend to be generalists	Rise	Percentage of total species
% Tolerant Species	Tolerant species are generalists that have adapted to human-altered habitats and landscapes	Rise	Percentage of total species
Wetland-Dependent Species	Species with habitat requirements that tie them exclusively to aquatic habitats	Decline	Number of species

Table 8.2. Avifauna Index metric scoring criteria: freshwater sites.

Score:	6	4	2	0
Taxa Richness	<2	2-5	6-9	>9
% Neotropical Migrants	>40	30-40	20-29	<20
% Resident Species	<30	30-40	41-50	>50
% Tolerant Species	<20	20-30	31-40	>40
Wetland-Dependent Species	>5	3-5	1-3	<1

Table 8.3. Avifauna Index metric scoring criteria: salt marsh sites.

Score:	6	4	2	0
Taxa Richness	<5	5-10	11-15	>15
% Neotropical Migrants	>40	30-40	20-29	<20
% Resident Species	<30	30-50	51-70	>70
% Tolerant Species	<20	20-40	41-60	>60
Wetland-Dependent Species	>5	4-5	1-3	<1

<u>Results</u>

A total of 51 species were identified in freshwater study sites. Nearly 68 percent of the freshwater site species were found in more than one study site. The freshwater study site species with the greatest total overall abundance values were: *Agelaius phoeniceus* (Red-winged Blackbird). The species with the highest frequency of occurrence in study sites *were: Carduelis tristis* (American Goldfinch) [100%] and *Turdus migratorius* (American Robin) [100%].

AVI scores for the freshwater wetland study sites ranged from a minimum of 27 to a maximum of 93, with a mean of 64.17 and a standard deviation of 24.93. Table 8.4 lists both the metric and AVI scores for the freshwater sites; Figure 8.1 graphically displays the freshwater AVI results. Variability between freshwater sites was greatest for the % Tolerant Species, % Resident Species, and Wetland Dependent Species metrics. AVI scores for freshwater sites WEA4,WEA6, WEA7 and WEA9 fell below the mean.

A total of 42 species were cataloged in the saltmarsh sites. Nearly 53 percent of the bird species were found in more than one site. The species with the greatest total overall abundance values in saltmarsh sites were: *Larus argentatus* (Herring Gull). *Hirundo rustica* (Barn Swallow) [100%] and *Cardinalis cardinalis* (Northern Cardinal) [100%] species were present in each study site.

AVI scores for the salt marsh study sites ranged from a minimum of 20 to a maximum of 93, with a mean of 46.67 and a standard deviation of 29.06. Table 8.5 displays the final metric and AVI scores for the saltmarsh study sites, and Figure 8.2 graphically displays the AVI scores. Saltmarsh study sites displayed the most extreme variability in the % Neotropical Migrant Species and % Resident Species metrics. AVI scores for saltmarsh sites WEA11, WEA12, and WEA13 fell below the mean.

While the results appear to be generally consistent with the metric analyses for other indicators, the data are not sufficient to demonstrate differences with a high degree of confidence. Wetland size and habitat richness strongly affect species richness. Accounting for these factors in the index protocol is difficult. Additional metrics for species and individuals density might be appropriate.

Table 8.4. Final metric and AVI scores for freshwater sites.

Metric	WEA2	WEA3	WEA1	WEA4	WEA6	WEA7	WEA8	WEA9
Taxa Richness	6	4	4	2	6	6	6	6
% Neotropical	6	6	6	6	4	2	6	2
% Residents	6	6	6	2	2	0	4	2
% Tolerants	6	6	6	2	2	0	4	0
Wetland Dependents	2	2	6	4	4	0	4	0
Subtotal	26	24	28	16	18	8	24	10
Final AVI Score	**87**	**80**	**93**	**53**	**60**	**27**	**80**	**33**

Table 8.5. Final metric and AVI scores for salt marsh sites.

Metric	WEA10	WEA11	WEA12	WEA13	WEA14
Taxa Richness	6	2	4	2	4
% Neotropical	6	0	2	0	2
% Residents	6	0	2	0	2
% Tolerants	4	2	2	2	4
Wetland Dependents	6	4	2	2	4
Subtotal	28	8	12	6	16
Final AVI Score	**93**	**27**	**40**	**20**	**53**

Figure 8.1. Avifauna Index: freshwater sites.

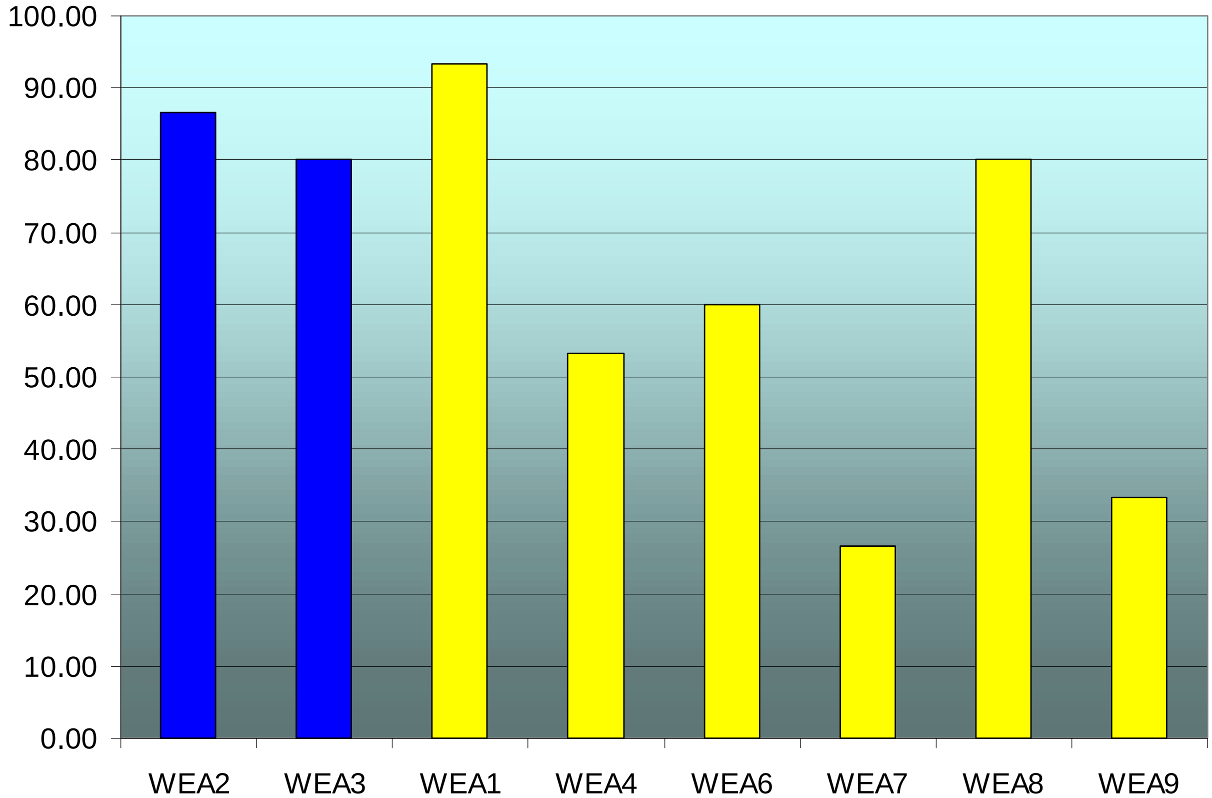
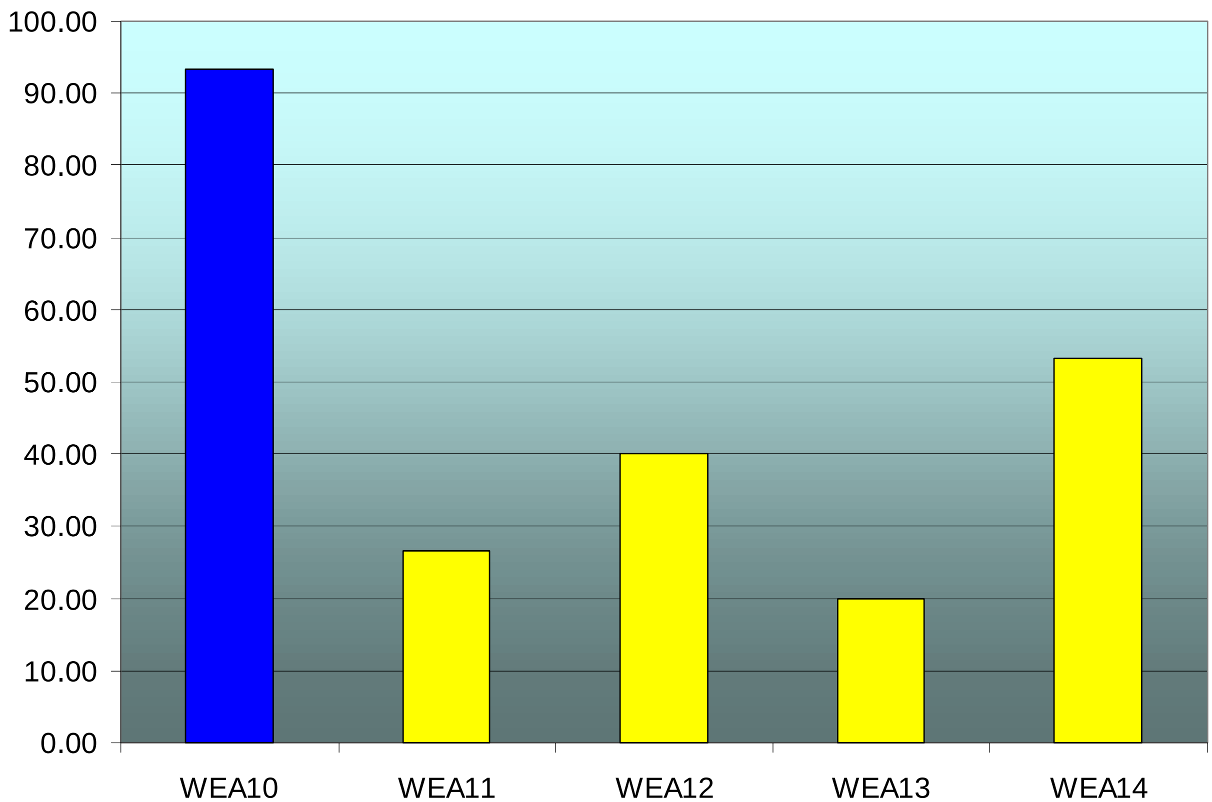


Figure 8.2. Avifauna Index: salt marsh sites.



Part III: Discussion and Conclusion

The Wetland Ecological Condition

Section 9. Discussion: Wetland Ecological Condition

In the attempt to develop a comprehensive approach to evaluate the health–or ecological integrity–of wetlands it became evident that the use of one single indicator or assessment method would not give as thorough or holistic a picture of wetland quality as would the application of several diverse indicators, specifically selected to represent distinct components of the ecological web. In addition, while many of the rapid assessment methods available do consider a wide array of wetland functions and landscape conditions, these summarizing models are only surrogates for actual field-based investigations and data collection. The Wetland Health Assessment Toolbox (WHAT) approach as employed and described in this project centers on the application of a suite of wetland assessment methods so as to yield a comprehensive understanding of the ecological health of the evaluation site(s) as well as the apparent causes of impairment.

While advocating for as complete an assessment as is realistically possible, the authors do not intend to convey that groups and individuals must replicate the investigation described in this report in order to engage in meaningful wetland assessment work. Instead, the purpose of this project was to examine, adapt, and develop wetland diagnostic tools so that groups or individuals could pursue wetland qualitative evaluation through an array of options, and select those that fit their needs, resources, skills, and budgets. For more information on the WHAT approach, visit the world wide website (currently under construction) at:

http://www.state.ma.us/magnet/czm/what.htm

The discussion in this section begins with an explanation of how each of the individual assessment components assemble to produce the summarizing Wetland Ecological Condition. A review of each wetland site is then presented, demonstrating how the assessment methods function to decipher specific ecological impairments and potential causes.

Index Totals: The Wetland Ecological Condition

The Wetland Ecological Condition (WEC) is an integrative score, summarizing the component field-based indices and rapid assessment models. As the final quantitative value, it provides an index or ranking of a wetland study site relative to the reference wetland condition. This point must be clearly emphasized and understood by those employing this and similar assessment approaches that rely on the use of the reference condition as the baseline for comparison. The output score, or rank, of any such index, must be understood as a relative score–relative only to the reference condition to which it was compared against. This means that one hypothetical study site with its own reference domain cannot be compared to another study site unless the same reference domain was employed for the analysis. In addition, caution must be exercised when evaluating and discussing the outputs of reference-based assessments. It may be difficult to make comparisons from one study site to another, outside of the reference context. For example, stating that study site WEAX is more impaired than WEAY is only valid when qualified. It would be more appropriate to state that WEAX exhibits more impairment of its biological or physical components than site WEAY when compared to the reference domain as established by site WEAZ.

While the Wetland Ecological Condition score serves to integrate all of the WHAT ecological indicators and rapid assessment methods, its quantitative output should be viewed as a general ranking score, and should be used in the proper context. The final WEC scores should be supported by descriptive narrative which summarizes the results provided by each of the component assessment methods. The site by site discussion in this section, demonstrates how the data and information generated by the Coastal Wetlands Ecosystem Protection Project can be employed to decipher biological, chemical, or physical impairments and to generate diagnoses as to the potential sources and causes for these impairments.

Tables 9.1 and 9.2 display the final Wetland Ecological Condition scores for the freshwater and salt marsh Wetland Evaluation Areas (WEAs), with all of the component indices and rapid assessment method scores. The Wetland Ecological Condition is simply derived–it is the weighted average of all the field-based ecological indicator protocols and the rapid assessment methods. To reflect the importance of obtaining on site field measurements, the ecological indicator indices are weighted twice the values of the rapid assessment methods. Figures 9.1 and 9.2 graphically display the final WEC scores.

Table 9.1. Final Wetland Ecological Condition, component indices, and rapid assessment scores for freshwater sites.

	WEA2	WEA3	WEA1	WEA4	WEA6	WEA7	WEA8	WEA9
Field-based Indicators:								
Index of Vegetative Integrity	100	88	67	58	54	63	67	71
Invertebrate Community Index	100	100	57	57	72	42	62	57
Water Chemistry Index	100	100	67	89	78	17	50	67
Hydroperiod Index	100	100	72	NA	72	17	94	28
Avifauna Index	87	80	93	53	60	27	80	33
Average field-based indices	*97*	*94*	*71*	*64*	*67*	*33*	*71*	*51*
Rapid Assessments:								
Habitat Assessment	94	90	80	47	46	46	75	53
Nonpoint Source Index	100	92	77	68	64	54	84	73
NH Functional Evaluation	74	74	73	60	57	50	55	63
Average rapid assessments	*89*	*85*	*77*	*58*	*56*	*50*	*71*	*63*
Wetland Ecological Condition	**95**	**91**	**73**	**62**	**63**	**39**	**71**	**55**

Table 9.2. Final Wetland Ecological Condition, component indices, and rapid assessment scores for salt marsh sites.

	WEA10	WEA11	WEA12	WEA13	WEA14
Field-based Investigations:					
Index of Vegetative Integrity	100	79	38	67	83
Invertebrate Community Index	100	61	67	68	63
Water Chemistry Index	100	78	67	72	56
Avifauna Index	93	27	40	20	53
Average field-based indices	*98*	*61*	*53*	*57*	*64*
Rapid Assessments:					
Habitat Assessment	94	49	46	45	39
Nonpoint Source Index	99	65	60	59	80
NH Functional Evaluation	78	50	49	51	56
Average rapid assessments	*90*	*55*	*52*	*52*	*58*
Wetland Ecological Condition	**96**	**59**	**53**	**55**	**62**

Figure 9.1. Wetland Ecological Condition scores: freshwater sites.

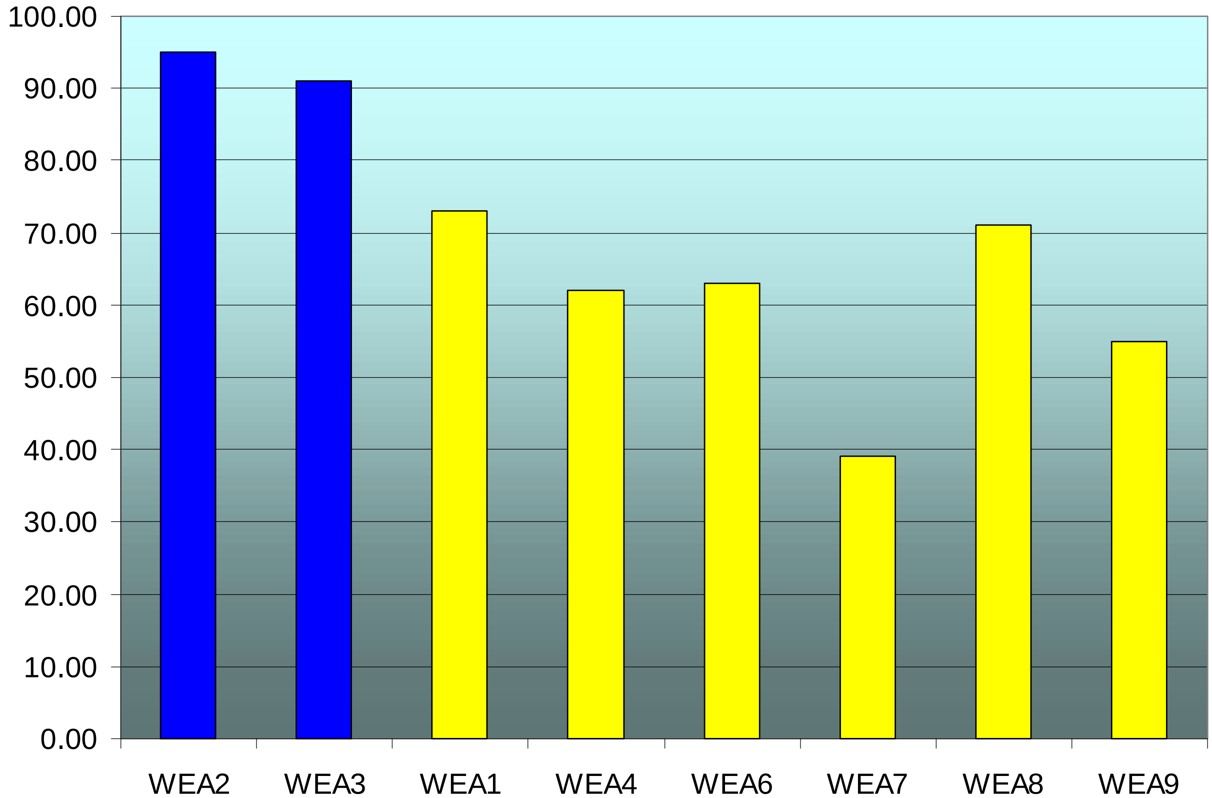
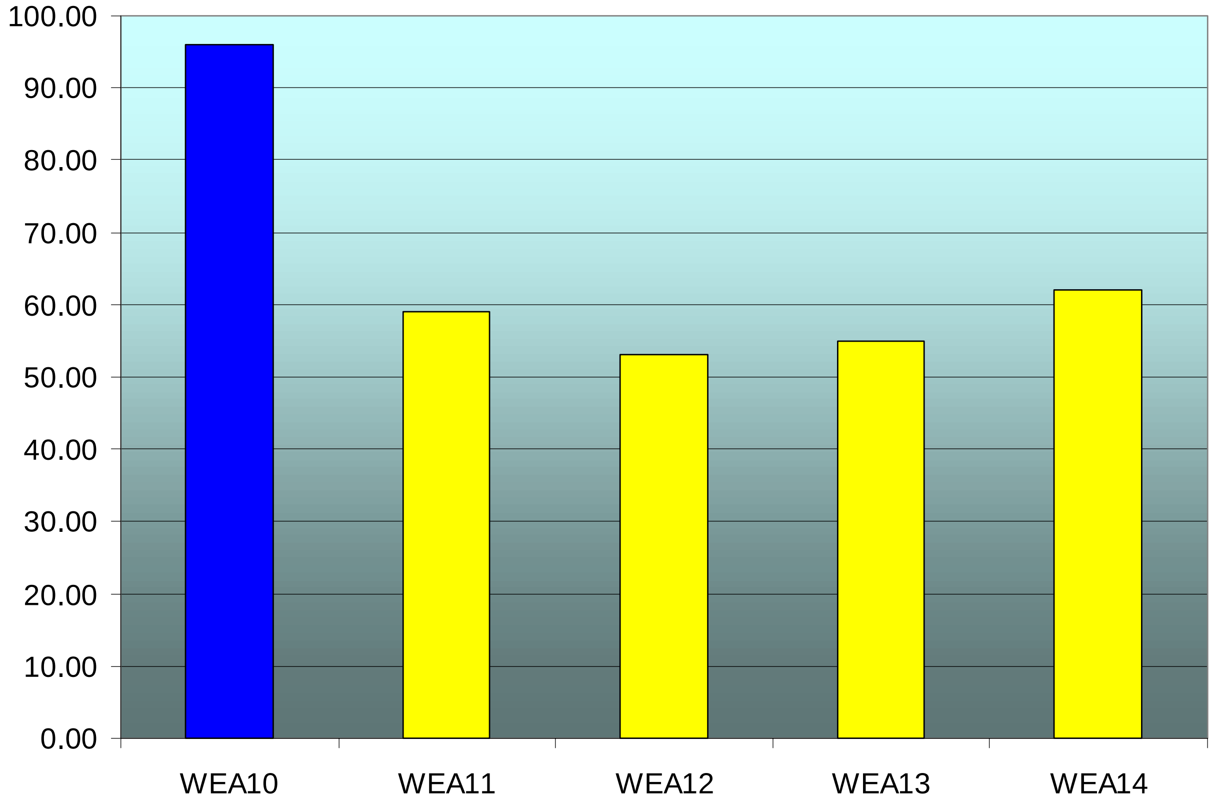


Figure 9.2 Wetland Ecological Condition scores: salt marsh sites.



Freshwater Wetland Evaluation Areas: Discussion of Results

WEA2

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA2	94	100	74	100	100	100	100	87	**95**

With a cumulative Wetland Ecological Condition (WEC) score of 95, WEA2 has no discernable evidence of alteration. The biological communities appear healthy and diverse., and physically, natural hydrologic patterns prevail–there is no evidence of hydrological modification. Soils are rich in organic content. The vegetation communities are diverse, contain very few invasive species, and have a low abundance of opportunistic species. Plant species present also have low nutrient status and normal flood tolerance values. Wetland water chemistry exhibits low nutrient concentrations, low fecal coliform counts, and low total suspended solids. There is an abundance of food sources for the aquatic macro invertebrate population. This site did not support a high diversity of invertebrate taxonomic groups, nor the greatest abundance of organisms compared to the other wetlands. Families sampled were surface dwellers such as *Hemiptera*, *Coleoptera*, and *Homoptera*–organisms well adapted to the low dissolved oxygen levels of certain wetland types, highly mobile, and able to follow the receding water levels during seasonal low water. Four families of *Odonates* indicated that conditions were highly suitable for this generally sensitive order, despite the very low dissolved oxygen levels recorded in summer months. *Odonates* have special adaptations that allow them to inhabit water and substrates with low dissolved oxygen level. From this assessment, the overall ecological condition of WEA2 is unimpaired. WEA2 is an excellent candidate for a long-term reference site.

WEA3

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA3	90	92	74	88	100	100	100	80	**91**

Reference site WEA3 also exhibits little to no adverse alteration from human land use and nonpoint source (NPS) pollution. WEA3 received an overall WEC score of 91. Some recreational fishing and boating occurs within WEA3, and the only discernable pollution source is the erosion from a dirt access road down to a small sandy beach area, which affects only a small portion of the site. The plant communities of WEA3 did not score as high in the Index of Vegetative Integrity (IVI) as the other freshwater site WEA2, primarily due to the moderate abundance of the invasive and persistent *Decadon verticillatus* along the emergent fringe zone of this predominantly open water wetland. Water chemistry data for WEA3 does not indicate any marked degradation, with low phosphorous and nitrogen concentrations, low total suspended solids, and fairly low fecal coliform bacteria counts. WEA3 has no visible anthropogenic hydrologic alterations, is permanently flooded throughout the year, and is little affected by seasonal low water levels. The invertebrate data indicates that WEA3 is affected by seasonal variations in habitat quality–either by the availability of food sources or the increasing water temperature and decreasing water quality. The exceptional abundance of organisms in August 1996 was due to the presence of extremely high numbers of semi-aquatic aphids (*Homoptera*) that represented 94 percent of the total community and skewed the results accordingly.

The most affected metric was % Tolerant/% Intolerant Ratio. These aphids–with a tolerance value of 8–accumulated in hoards on the water surface in summer, and were therefore able to avoid low dissolved oxygen and high temperature characterizing the water column in this season. These species were completely absent in the spring 1996 and 1997 sampling. Instead, *Chironomidae*–with a tolerance value of 6–were the major taxonomic group, constituting 74 percent of the May community and more representative of normal wetland conditions. Summer water quality appeared to adversely affect diversity of *Odonates*, only *Coenagrionidae* were present, and even these in low numbers. Grouped together, these results suggested that seasonality greatly affected the composition of the community at this site. Toxic groundwater plumes from the Massachusetts Military Reservation have been documented proximate to this and two other study sites. While microtox water and sediment and aquatic toxicology tests run by the US Environmental Protection Agency (USEPA) Region I Laboratory for this project failed to pick up any sediment or water column toxicity, it is uncertain what, if any, ecological impact this up-gradient hazardous waste site may be having–or will have–on the ecological integrity of this and sites WEA1 and WEA4.

WEA1

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA1	80	77	73	67	57	67	72	93	**73**

WEA1 reflects its history as a formerly active and productive cranberry bog, mostly through the latent stores of nutrients in its soils. At the outset of the project, study site WEA1 was appraised to be in relatively healthy condition, apparently recovering from its former agricultural use, as indicated by its diverse vegetation and bird usage. On-site sampling, however, demonstrated notable differences from reference conditions primarily in the biological and chemical indices. Site WEA1 received a WEC score of 73. While the vegetative communities are diverse with moderate interspersion of emergent herbaceous and scrub/shrub species, the communities are quite dissimilar from either reference site and have a high abundance of opportunistic species, especially *Typha latifolia*. Notably high nutrient concentrations were revealed from the pore water chemistry data, and according to the invertebrate data, the biological condition of WEA1 was moderately impaired. Some of this site's Invertebrate Community Index (ICI) metrics (Total Number of Organisms, Total Taxa, Family Biotic Index, % Contribution Dominant Family, % *Chironomidae*, % *Oligochaeta*) scored as well as the reference condition. EOT/*Chironomidae* Ratio, % Tolerant/% Intolerant Ratio, Other *Odonata/Coenagrionidae* Ratio, Community Taxa Similarity Index, and the Community Trophic Similarity Index all scored well below the reference condition, indicating a very different resident community at WEA1. August 1996 invertebrate samples appeared to be less impaired than either May 1996 or 1997. Overall impairment of the invertebrate community may be due to eutrophication of the waters rather than due to habitat condition. The previously mentioned MMR plumes cannot be discounted either, though, again, USEPA toxicity tests could not confirm suspected ecological impact. Site WEA1 receives significant groundwater discharge and has a contribution area with no impervious area–two factors that would account for relatively stable water levels (with no sharp peaks or troughs), which closely resemble those of the reference sites.

WEA4

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA4	47	64	60	58	57	67	NA	53	**62**

The active cranberry bog is a significantly altered and manipulated wetland system. Project data reveal that the biological communities and the water quality levels are impaired, but not as severely as initially expected. Study site WEA4 received a WEC score of 62. Though the dominant plant community is the cultivated cranberry (*Vaccinium macrocarpon*), there are diverse species thriving in a large unaltered area in the northwest corner of the site and in the banks, ditches, and channels. WEA4 scores poorly in the IVI primarily because of its dissimilarity to reference site plant communities, its large abundance of species with high nutrient status, and its high taxa richness value–probably the result of constant disturbance. Water chemistry data indicate nutrient concentrations higher than reference sites, especially nitrate nitrogen and less so phosphorous, but similar suspended solids and fecal coliform measures. The water quality of WEA4 is influenced considerably by significant groundwater discharge and by the swiftly flowing Quashnet River main channel. WEA4'sHabitat Assessment (HA) score suggested that the invertebrate community should be impacted by poor habitat condition, but the biological condition of this site was consistently found to be moderately impaired. The site metrics that scored as well as the reference condition were: Total Organisms, Total Taxa Richness, % Tolerant/ % Intolerant, % Contribution Dominant Family, % *Chironomidae,* Family Biotic Index, and % *Oligochaeta*. The remaining metrics and indices (EOT Richness, EOT/*Chironomidae* Ratio, Family Biotic Index, Other *Odonata/ Coenagrionidae* Ratio, Community Taxa Similarity Index, and Community Trophic Index were well below reference condition. Invertebrate community integrity in both May 1996 and 1997 was better than August 1996, and the invertebrate biomonitoring indicated that WEA4 was more impaired than WEA1, the recovering cranberry bog.

WEA6

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA6	46	54	57	54	72	78	72	60	**63**

Study site WEA6 is subject to considerable human alteration from ongoing maintenance of the surrounding golf course and from stormwater disposal from nearby residential development. WEA6 received an overall WEC score of 63. Ambient surface water chemistry reveals slightly elevated nutrient levels, but total suspended solid levels are very low. With adequate water quality as reflected by the relatively high Water Chemistry Index (WCI) score, the low biological index scores, as described below, must be due, primarily, to poor and altered habitat quality. At the boundaries of site WEA6, bordering wetland and upland plants are frequently mowed, and the pond edge has been conspicuously filled in some areas. WEA6 scores poorest for its vegetative integrity as its dominant species are ones with either invasive (*Phragmites australis*), opportunistic (*Salix discolor, Scirpus cyperinus*, and *Juncus effusus*), or high nutrient status attributes. For the invertebrate communities, habitat quality is low due to the lack of aquatic vegetation (consisting mostly of a few attached submergent species) in the open water. The HA score indicated the invertebrate community would be affected by relatively poor habitat condition. May 1996 sampling detected slight impairment of the invertebrate community as compared to the reference conditions. The biotic condition had deteriorated in August 1996, and the overall summarized assessment of the ICI is somewhat impaired**.** ICI metrics and indices that were equal to or better than reference condition were Total Taxa (Diversity), EOT, EOT/*Chironomidae* Ratio, % Tolerant/% Intolerant, % Contribution Dominant Family, and % *Chironomidae.* ICI metrics and indices that were far below reference standard were Total Organisms, Other *Odonata*/*Coenagrionidae*, % *Oligochaeta*, Community Taxa and Community Trophic Similarity Indices. In general it appeared that the minor invertebrate community impact at WEA6 is not due to eutrophication, but rather to habitat condition–such as less buffer and fringe vegetative growth, sandy substrate, and reduced food sources.

WEA7

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA7	46	54	50	63	42	17	17	27	**33**

Sandwiched between dense residential development and an active golf course, site WEA7 is a severely impaired isolated depressional wetland. WEA7 received some of the lowest index scores for each field-based protocol as well as the rapid assessment methods. With a cumulative WEC score of 33, WEA7 can be considered as the most ecologically impaired freshwater site in the series. Although heavily vegetated with hydrophytic plants throughout the wetland itself, WEA7 lacks a distinct buffer area to protect it from a wide array of nonpoint sources of pollution present in its contribution area (in the form of direct stormwater discharges, septic sewage contribution, fertilizers, and pesticides). WEA7 has very poor water quality as indicated by an extremely low WCI score, with elevated nutrient levels. High levels of fecal coliform bacteria were also consistently found in this study site. The wetland vegetation survey identified three primary communities, an emergent/open water section dominated by *Typha latifolia*, an herbaceous community dominated by *Carex sp.*, and a shrub/forest community dominated by *Clethra alnifolia* and *Acer rubrum*. This wetland has a large diversity of plant species which can be attributed to highly variable water levels (resulting from the collection and discharge of runoff from a highly impervious catchment area) and the very high concentrations of nutrients. Episodic flooding and draining in this wetland may be inhibiting the succession into a complete forest cover. Though site WEA7 is subject to dramatic water level fluctuations and has very high ambient nutrient concentrations, its vegetative population, as indicated by the IVI, does not appear to be reflecting these stresses as strongly as anticipated. Highly variable water levels observed in WEA7 were exhibited by a low Hydroperiod Index score. In all six of the hydroperiod metrics, WEA7 demonstrated strong dissimilarity to the reference condition. With a low HA score, it was anticipated that the invertebrate community would reflect impairments due to both poor habitat and water quality. Although moderately impaired for both seasons, the Invertebrate Community Index of WEA7 was worse in August 1996 than in May 1996 and 1997. Total Taxa (Diversity), Family Biotic Index, % Contribution of Dominant Family, and % *Chironomidae* were equal to or better than the reference condition. Total Organisms was somewhat comparable. The remaining metrics and indices were well below reference. Of the taxa present, *Oligochaeta* (worms) formed the dominant group. The presence of large numbers of worms suggests that the driving forces of this wetland's invertebrate community condition are the low oxygen levels, the soft organic substrate, the rapidly fluctuating water table, the lack of sustained open water during the summer, and very high nutrient levels. Ironically, this wetland has a sign on its upland edge informing the local community that it is a "protected" wetland. Apparently the wetland itself was established in a conservation restriction during the development of the surrounding planned residential community. While protected on paper from actual fill and development, the ecological condition of WEA7 illustrates the fact that wetlands cannot be truly protected unless the surrounding landscape is protected and/or managed in accordance with best watershed management practices to reduce NPS pollution and to maintain natural hydrological regimes.

WEA8

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA8	75	84	55	67	62	50	94	80	**71**

Characterized predominantly by open water with fringing emergent and shrub vegetation, study site WEA8 generally has a wide buffer area of natural vegetation between the wetland its surrounding land uses. The direct stormwater discharge to the site, though, was unaffected by the presence of any buffer zone and, in fact where Route 151 bordered WEA8 to the north, there are areas where this vegetated zone was less than several meters. In addition, the impacts of the sewage disposal practices of the dense trailer park to the northwest of the site are not clearly manifested in its chemical and biological properties. For most of the field-based indices, WEA8 exhibited scores that were above the mean and within a standard deviation from the reference scores. With an overall WEC score of 71,WEA8 ranks above all other freshwater WEAs, except WEA1. The vegetation and invertebrate indicators were influenced by the late season dominance of the invasive *Decodon verticillatus* and abundant *Nymphaea odorata*, both of which provide poor habitat for the freshwater insect species. The abundance of the invasive vegetation species, the poor Community Similarity metric score, the low Flood Tolerance, and the significant presence of plant species with affinity for enriched sites all contributed to the low final IVI score received by WEA8. According to the WCI, WEA8 did not correspond well with the reference condition. Average nutrient concentrations at this site were varied with particularly high concentrations of nitrate nitrogen, and suspended solid measurements were consistently high at this study site. For the ICI, in both May 1996 and 1997, biological condition was not as high as was recorded in August 1996. Wetlands are able to improve water quality through the uptake of nutrients and toxicants by vegetation production, and, as previously stated, there was abundant floating and emergent growth in August that was not present in May. Overall the wetland biological condition of study site WEA8 can be viewed as somewhat impaired. ICI metrics that were equal to or better than the reference condition were Total Taxa (Diversity), EOT Richness, EOT/Chironomidae Ratio, % Tolerant / % Intolerant Ratio. Metrics and indices that were somewhat below reference were % *Chironomidae*, Community Taxa Similarity Index, and Community Trophic Similarity Index. Those that were well below reference were Total Organisms, Family Biotic Index, Other *Odonata/ Coenagrionidae* Ratio, and % *Oligochaeta*. In May, *Chironomidae* made up 85 percent of the community. In August, *Diptera* other than *Chironomidae* formed the major group, and another significant part of the population was composed of *Coenagrionidae Odonates*. This shift in composition is a clear indicator of improved condition.

WEA9

	HA	NPSI	FE	IVI	ICI	WCI	HPI	AVI	**WEC**
WEA9	53	73	63	71	57	67	28	33	**55**

The overall WEC value of 55 indicates that site WEA9 is exhibiting symptoms of ecological impairment. As a depressional wetland crowded by active residential, transportation, and recreation (golf course) land uses, WEA9 is subject to a variety of pollution sources and hydrologic modifications. The direct stormwater discharge to WEA9 can be reasonably attributed as the single most deleterious land use impact, providing a massive conduit for upland pollutants and dramatically influencing the site's water level. Biologically, site WEA9 exhibited varied status, as the plant communities did not appear to be as impaired as the invertebrate and avian indicators. WEA9 is characterized by mixed cover types, with a forest community dominated by *Acer rubrum* and *Salix discolor,* a shrub community dominated by *Clethra alnifolia* and *Decodon verticillatus*, and an emergent herbaceous community dominated by *Scirpus cyperinus* and *Carex sp.* The moderate IVI score was influenced primarily by the lack of shared species with the reference site and the large abundance of species with persistent standing litter. For water quality, site WEA9 demonstrated significantly elevated fecal coliform bacteria levels but did not indicate significant nutrient loading. The HA score forecasted that there would be some impairment to the invertebrate community due to poor habitat. For the invertebrate populations, biological condition continued to deteriorate from somewhat impaired in May 1996 to moderately impaired by August 1996 and May 1997. ICI metrics and indices that were equivalent to or better than reference condition were Total Taxa Richness, EOT/*Chironomidae* Ratio, % Contribution Dominant Family, and % *Chironomidae*. EOT Richness was somewhat similar to reference, and the other metrics and indices (Total Organisms, % Tolerant/% Intolerant, Family Biotic Index, Other *Odonata*/*Coenagrionidae* Ratio, % *Oligochaeta*, Community Taxa Similarity Index, and Community Trophic Index) were all well below the reference standard.

Salt Marsh Wetland Evaluation Areas: Discussion of Results

WEA10

	HA	NPSI	FE	IVI	ICI	WCI	AVI	**WEC**
WEA10	94	99	78	100	100	100	93	**96**

Reference site WEA10, as the basis for which other salt marsh study sites are compared, is a healthy and productive coastal wetland system. WEA10 received an overall WEC value of 96. Aside from recreation and some commercial shell fishing, WEA10 has a contribution area with no land use activity that would contribute to the impairment of its ecological integrity. Tidal influence from Waquoit Bay into Sage Lot Pond was unrestricted. The only evident factor that would adversely affect habitat quality would be the few remnant linear ditches most probably dug under historical mosquito control work programs. The salt marsh vegetation communities at WEA10 were free from invasive species. Water chemistry for this site indicates that fecal coliform levels were low with the exception of a single spike which raised the average for the site. TSS levels and nutrient concentrations were low. As supported by its ICI score, WEA10 had a healthy and diverse invertebrate population. In sum, because it is the largest salt marsh area in the Waquoit Bay watershed and because it is located in protected conservation land, WEA10 is also an excellent candidate as a long-term reference site.

WEA11

	HA	NPSI	FE	IVI	ICI	WCI	AVI	**WEC**
WEA11	49	65	50	79	61	78	27	**59**

As with the other salt marsh sites, study site WEA11 has been adversely affected by development and land use patterns that have fragmented a long linear fringing salt marsh into small, isolated remnant pieces. Additionally, the ongoing land use activities in its contribution area, including a large marina, residential development, and heavy boat usage, degrade the ecological condition of WEA11 by generating NPS pollution and transforming habitat quality. WEA11's WEC score is 59. There has been considerable bank erosion and salt marsh slumping at WEA11 from boat handling, and the placement of large shellfish seeding grates at the toe of the salt marsh bank in the subtidal zone. Despite its small size, the marsh had a diverse vegetation cover, tidal flow was unrestricted, and there was no channelization or ditching. The near shore sediments were composed of sand and anaerobic mud. There was an abundance of attached algae to provide a food base for the aquatic invertebrates, although the growth suggested eutrophication of the water column. The HA score indicated there would be considerable impairment to the biological community due to poor habitat condition. Water chemistry indicates consistently low TSS and fecal coliform concentrations, and only slightly elevated nitrate levels. The final IVI score for WEA11, with relatively high scores for all the IVI metrics. The ICI score indicated a marginally impaired invertebrate community. Seven of the ICI metrics and indices were below reference condition, with three (% Contribution Dominant Taxa Group, % Contribution Dominant Trophic Group, and % Abundant/% Rare Ratio) scoring equal or better than the reference. In May 1996 and 1997, *Amphipoda* were the dominant group, whereas *Decapoda* were in August 1996. Although this shift indicated decreasing habitat condition during summer, the overall ICI for both seasons remained the same. Impact was predominantly related to poor habitat condition rather than impaired water quality.

WEA12

	HA	NPSI	FE	IVI	ICI	WCI	AVI	**WEC**
WEA12	46	60	49	38	67	67	40	**59**

Study site WEA12 exhibits significant ecological impairment. Both degraded habitat quality and chronic pollution problems adversely affect this small salt marsh fringe on Eel Pond, the western arm of Waquoit Bay. WEA12 received an overall WEC score of 59. The primary land use responsible for the degradation of site WEA12 is likely the failing or poorly functioning septic system of residential development situated just beyond its upland edge. A dense stand of *Phragmites australis* and *Toxicodendron radicans* dominated the wetland vegetation population and strongly influenced the final IVI. Water chemistry data confirmed suspected high nutrient concentrations, especially in wetland pore water. TSS levels were the highest of all salt marsh study sites. Fecal coliform samples taken from a shallow ground water well transect at the wetland/upland edge revealed consistently high populations, giving credence to the assumption that the septic system directly adjacent to the study site was poorly functioning. The HA score was poor and indicated that the invertebrate community would be adversely affected. Near shore sediments were composed of sand, peat, and muck. Filamentous algae, as well as marine algae floating mats, provided a rich source of food for invertebrates. The seasonal ICI score deteriorated between May and August 1996, but the overall assessment of the invertebrate community indicated this site was not severely impacted by residential land use and boating activities. This situation is likely the partial influence of unrestricted tidal flushing, as the marsh fronts a broad expanse of Eel Pond. WEA12 scored as well as, or better than, the reference condition for these metrics and indices: % Contribution Dominant Family, % Contribution Trophic Group, % Abundant/% Rare Ratio, and % *Capitellida*. The other metrics and indices were somewhat below (Total Number of Organisms and Community Taxa Similarity Index) or well below (Total Taxa Richness, # *Palaemonedae* Shrimp) the reference condition.

WEA13

	HA	NPSI	FE	IVI	ICI	WCI	AVI	**WEC**
WEA13	45	59	51	67	68	72	20	**55**

Study site WEA13, with a WEC score of 55, shows indications of degraded ecological quality attributed to both NPS pollution and habitat alteration. Surrounded on three sides by residential development, WEA13 has no functional buffer between the salt marsh and upland land uses. In addition, adjoining open water is actively utilized for recreational boating. Several of the waterfront properties had constructed rock walls, boat slips, and mooring piers, and these structural modifications to the natural shoreline configuration altered tidal flow and decease habitat quality. Nearshore sediments were composed of sand, silt, and muck. By August 1996, a thick mat of filamentous algal growth had covered the open water/sediment interface, suggesting advanced eutrophication, probably as a result of the nearby nutrient loading. Water chemistry data at this site confirmed high nutrient concentrations in wetland pore water. WEA13's relatively low IVI score appears to be most influenced by the notable extent of disturbance/colonizer species, such as

Distichlis spicata and *Salicornia sp.*. The ICI assessment indicated a moderately impaired invertebrate population with a seasonal decline from May to August. The ICI metrics and indices that scored equivalent to or better than reference condition were: % Contribution Dominant Taxa, % Abundant/% Rare Ratio, % *Capitellida* and % *Amphipods*. Those somewhat below reference condition were Total Number of Organisms, Total Taxa Richness, % Contribution Dominant Trophic Group, and those well below reference condition were # *Palaemonedae* Shrimp, Community Taxa Similarity Index, and Community Trophic Similarity Index. A few freshwater insects (*chironomids* and several *odonate* larvae) were observed in samples collected at this site in May 1996. Subsequent salinity readings confirmed the presence of significant freshwater discharge at the marsh bank and intertidal zone.

WEA14

	HA	NPSI	FE	IVI	ICI	WCI	AVI	**WEC**
WEA14	39	80	56	83	63	56	53	**62**

WEA14 received an overall WEC score of 62. Similar to the other salt marsh study sites, WEA14 exhibits symptoms of ecological degradation from both nonpoint sources and direct physical alteration. Residential development and boating activities dominated the surrounding land uses and there was little protection afforded by a minimal upland vegetated buffer. Nonpoint sources of pollution to WEA14 would consist of septic sewage discharge, polluted groundwater discharge, fertilizer and pesticide applications, stormwater runoff from impervious surfaces, and boating fuel and oil leaks. A public boat ramp was located within the western edge of the marsh. Rainfall runoff from a large parking lot was able to travel directly to the study site via this boat ramp. There were several linear mosquito control ditches in the marsh. Near shore sediments were mostly anaerobic mud with little sand, and there was a thick growth of filamentous algae attached to all substrates. Organic floating mats were abundant in the open water close to the salt marsh bank, suggesting an advanced stage of eutrophication. The vegetation population at this site is significantly dominated by the low marsh *Spartina alterniflora*, with large abundance of *Iva frutescens* and *Distichlis spicata*. WEA14's IVI score indicates that its wetland vegetation population most closely resembles the reference site. WEA14 received high scores for all the IVI metrics but Community Similarity. Nutrient, fecal coliform, and TSS concentrations at site WEA14 were only slightly more elevated than the reference site. The HA score indicated significantly impaired habitat condition. The invertebrate community at WEA14 was somewhat impaired, with the biotic condition deteriorating over the course of the summer season. ICI metrics and indices that were equal to or better than reference condition were: % Contribution Dominant Family, % Contribution Dominant Trophic Group, % Abundant/% Rare Ratio, and % *Capitellida*. Total Taxa Richness was somewhat similar to reference condition, and the remaining metrics and indices were far below.

Statistical Examination of Results

As described in the project scope, one aspect of the Coastal Ecosystem Protection Project was to evaluate the performance and strength of several rapid assessment methodologies (see Section 2). In certain applications, rapid assessment methods serve two roles. They contribute important–or, in some cases, integral–supplementary information and data to another investigation component of the wetland evaluation. The Habitat Assessment method, for example, provides the means to gather and input critical habitat characteristic, both of the wetland and of the surrounding landscape, to the Invertebrate Community Index and other multi-metric protocols. Another role of rapid assessment methods, though, is to offer an alternative evaluation technique when the option to collect and analyze on-site, field-based data is unavailable due to resource or time constraints. It is possible for groups or individuals who are interested in conducting some level of wetland ecological assessment to use accessible rapid assessment methods not as a substitute for, but as an alternative to, field-based investigations.

For both of these purposes, it is important to confirm that the rapid assessment methods being employed function as expected. By implementing the Nonpoint Source Index and New Hampshire Function Evaluation methods, for example, can we arrive at a finding about the relative health of a given wetland that would approximate a finding derived from field-based measurements and analysis? In order to verify that these methods do perform as anticipated, it is necessary to examine the extent to which the scores or outputs from these rapid assessment methods relate to the scores and outputs of the field-based ecological indicators. What are the relationships between the rapid assessment methods and the field-based measurements? What is the interdependence between these two groups–do they covary–that is, vary together? By computing a measure of association between these two groups, it is possible to examine their relationships.

Correlation coefficient analysis is a statistical technique used to compute the measure of association between two variables. To compute this measure, the Pearson product-moment correlation coefficient was used. Pearson's correlation coefficient is a measure of covariation; it measures the linear relationship between two variables (Sokal, 1995). The equation used to derive Pearson's correlation coefficient generates a value between +1.00 and -1.00. The size and sign of the correlation indicate the strength and nature of the relationship. A positive relationship indicates a direct association–high scores for one variable connect to high scores for another. A negative, or inverse, relationship results when a high score from one variable relates to a low score for another. Although there is no established principle for what constitutes a strong or weak relationship, we can follow general guidelines. We know that a correlation coefficient of (+)1.00 indicates a perfect relationship–that is, every value for one variable covaries identically with the value of another variable. Correlation coefficients above 0.75 indicate a very strong relationship between variables, while coefficients from 0.40 to 0.75 imply a moderate relationship. For this analysis, coefficients below 0.40 are considered weak.

In Table 9.3 and 9.4, correlation coefficients matrices are displayed for the freshwater and salt marsh WEAs. From these matrices, we can examine the measures of association between variables–in this case, each of the rapid assessment methods and field-based indices utilized in the WHAT approach.

Table 9.3. Correlation matrix for final index and rapid assessment scores: freshwater sites.

	IVI	ICI	WCI	HPI	AVI	HA	NPSI	FE
IVI	1.00	0.79	0.51	0.52	0.46	0.84	0.86	0.73
ICI		1.00	0.80	0.79	0.60	0.74	0.82	0.71
WCI			1.00	0.72	0.53	0.48	0.66	0.75
HYD				1.00	0.90	0.81	0.82	0.57
AVI					1.00	0.83	0.76	0.69
HA						1.00	0.93	0.79
NPSI							1.00	0.77
FE								1.00

(Pearson coefficients *r*)
Strength of relationship:

(black)	perfect	1.00
(dark grey)	strong	0.75 to 0.99
(light grey)	moderate	0.40 to 0.74
	weak	0.01 to 0.39

Table 9.4. Correlation matrix for final index and rapid assessment scores: salt marsh sites.

	IVI	ICI	WCI	AVI	HA	NPSI	FE
IVI	1.00	0.53	0.52	0.59	0.58	0.80	0.74
ICI		1.00	0.85	0.86	0.97	0.81	0.95
WCI			1.00	0.58	0.93	0.58	0.76
AVI				1.00	0.83	0.95	0.94
HA					1.00	0.80	0.93
NPSI						1.00	0.95
FE							1.00

(Pearson coefficients *r*)
Strength of relationship:

(black)	perfect	1.00
(dark grey)	strong	0.75 to 0.99
(light grey)	moderate	0.40 to 0.74
(white)	weak	0.01 to 0.39

By examining the correlation coefficient matrix for the freshwater sites, we can develop several inferences about the evaluation techniques. For one, we can see that none of the relationships between the evaluation techniques, both rapid assessment methods and field-based measurements, are considered weak. In fact, many of the correlation coefficients are above 0.75–indicating excellent covariance. We can also see that both the NPSI and the HA methods generally have very strong relationships with most of the ecological index protocols. The NH Functional Evaluation method does not exhibit as strong association with the ecological index protocols but still demonstrates very good correlation. The following combination of evaluation techniques utilized for the freshwater WEAs, in particular, have very strong relationships:

- HA : IVI
- NPSI : IVI
- NPSI : ICI
- NPSI : HYD
- HA : HYD
- HA : AVI

The salt marsh correlation coefficient matrix reveals similar patterns in the association of these evaluation techniques. Again, none of the relationships between these techniques is considered weak. Even more so than the freshwater WEAs, the salt marsh evaluation techniques exhibit very strong associations, or covariance. For the salt marsh sites, all of the rapid assessment methods have tight correlation to the ecological index protocols. The following combination of evaluation techniques utilized for the salt marsh WEAs have very strong relationships:

- HA : ICI
- HA : WCI
- HA : AVI
- NPSI : IVI
- NPSI : ICI
- NPSI : AVI
- FE : ICI
- FE : AVI

In sum, this statistical correlation analysis verifies the cumulative strength of the WHAT approach and component evaluation techniques. It also demonstrates the rapid assessment methodologies, for the most part, are able to generally predict patterns of ecological degradation or impairment, as evidenced by the field-based ecological index protocols. With future transfer and implementation of the WHAT approach, this type of confirmation analysis will be necessary to ensure that the assessment methods are robust enough to continue to detect trends in wetland ecological and functional impairment.

Section 10. Conclusion & Recommendations

The evaluation of wetland quality is a challenging and complicated task. In many circumstances and for a host of different reasons, environmental professionals, land use planners, resource managers, and others are faced with the need to assess wetland health. Since the means for engaging in meaningful wetland assessment are not fully developed, are not accessible, or are not affordable, the evaluation of wetland quality has been widely overlooked and omitted. As a result, land use planning and resource management decisions affecting wetlands are frequently being made with incomplete and inadequate information.

The desire to explore and build on available wetland assessment tools and to develop new techniques was borne by the authors and partner organizations through ongoing work in nonpoint source (NPS) pollution control planning, wetlands protection and restoration, biomonitoring, and remote sensing. Through support by the National Oceanic and Atmospheric Administration's Coastal Services Center, the Coastal Wetlands Ecosystem Protection Project was launched with the primary goal of developing and testing an innovative and transferable approach for wetland assessment.

Nearly three years in the making, the Wetland Health Assessment Toolbox (WHAT) approach presented and described in this report is the product of a coordinated, multi-disciplinary process to cultivate an innovative approach for wetland evaluation. The WHAT approach is an amalgamation of relatively simple, straight-forward rapid assessment methodologies, with scientifically sound on-site fieldwork, which are concurrently employed to produce a comprehensive evaluation of the ecological condition of a wetland study site.

To summarize, the rapid assessment tools utilized in the Wetland Ecological Assessment Method include a nonpoint source pollution index, a habitat assessment model, and a wetland functional assessment protocol. The onsite field-based indicators are comprised of wetland vegetation, aquatic macro invertebrates, surface and pore water chemistry, hydrology and hydroperiod, and avifauna. Metrics and indices are employed in data analysis and reporting. A cumulative Wetland Ecological Condition, is the final assessment output, combining all of the above variables into a single score or ranking. Statistical analysis is employed to examine data patterns, determine significance, and for predictive inquiry.

To attempt to recreate the tasks and objectives of the Coastal Wetlands Ecosystem Health Project would arguably be an arduous and costly venture. But through the piloting and testing of these assessment tools, and the subsequent cataloguing and illustration of their implementation, it is hoped that comprehensive wetland assessment will become more readily accessible to a wider range of different groups. The focus of this report, therefore, is to describe the project and its results, not to provide a recipe for the application of the WHAT approach. The outreach and technical assistance transfer component will be a World Wide Web based site, where potential users and those with varying degrees of interest in wetland assessment can learn more about the WHAT approach and how they could employ some or all of the assessment tools described here.

The results of this project appear promising. Three reference wetland sites and 10 wetland study sites located throughout the Waquoit Bay watershed in southeastern Cape Cod, Massachusetts were evaluated using the methods and techniques described in this report. Based on this analysis, it has been demonstrated that nonpoint sources of pollution as well as habitat alterations are causing varying degrees of biological, physical, and chemical impairments at study sites. Poor stormwater management practices, inadequate siting and/or functioning of onsite septic systems, runoff from impervious roads and parking areas, commercial cranberry cultivation, golf course construction and maintenance, and direct habitat destruction and fragmentation are the most significant causes of wetland degradation as evidenced by project findings. Statistical correlation indicates that the individual field-based indices correspond very well with one another and with the rapid assessment methodology results.

Data and information generated by this project can be used as baseline information for long-term studies observing wetland ecological responses to various forms of disturbance over multiple seasons. More applications of this approach method are necessary, though, particularly in other regions and watersheds with different geology, hydrology, and land use patterns. Work has recently been initiated to implement the WHAT approach in two watersheds in northeastern Massachusetts. Future applications of the WHAT approach are fundamentally necessary to contribute to the expansion of the various metric attributes database. Periodic peer review and subsequent edits to this database will be required in order for it to be as accurate and as current as possible.

Observations: Patterns of Results

Through the characterization and evaluation of each of the 13 wetland study sites in the Waquoit Bay watershed, a sufficient estimate of the ecological condition of each of the sites has been obtained. The results of the WHAT approach have identified specific freshwater and saltmarsh wetlands that are manifesting symptoms of ecological degradation from both nonpoint sources of pollution as well as habitat alteration from current or historical land uses.

In this investigation, several land use types have emerged as being notably deleterious to wetland ecological integrity. In particular, wetland sites that are subject to direct stormwater discharges from residential development and road runoff, exhibit the highest degree of biological, chemical, and physical impairment (the lowest cumulative Wetland Ecological Condition ranking). In addition, the aggregate nutrient load from residential onsite septic systems and fertilizer use (residential, commercial, and golf courses)–which move relatively liberally through the dominant sandy glacial outwash soils–are contributing to discernible signs of acute eutrophication. Finally, both active and historical (10 years former) agricultural cranberry cultivation–with its associated ditching, sand filling, water manipulations, fertilizer and pesticide applications–creates both NPS pollution problems and severe habitat modifications.

Another important pattern emerging from this project is that small wetlands, especially isolated depressional types, are more susceptible to land use impacts. With less areal extent, biological communities have more restricted mobility ranges, pollutant loads become concentrated, and hydrological shifts become very pronounced. Isolated depressional wetlands are most vulnerable as they are not able to export aggregated pollutant loads to downstream systems as readily. The only avenue for pollutant export in this class of wetlands, would be through groundwater recharge or through the uptake, sequestering, or transformation through biological endpoints. Wetland systems with surface water hydrological connections, especially riverine systems, will not retain as much contributing area pollutant loads, depending on the hydrological patterns of the site.

Another observation is that hydroperiod–or wetland water level–for most of the freshwater sites, was generally strong similarities between sites. This may be due to the underlying geology of the watershed and its groundwater driven hydrology. It seems that wetland sites would be much more susceptible to natural variation between sites if the wetlands were not well buffered by groundwater. In surface water dominated systems, the periodicity of flooding depends on many factors: the size of the watershed, the slope and roughness of the watershed, and the size and cross-sectional shape of the wetland. In addition, factors such as the quantity and behavior of inflowing and outflowing surface water will have a major impact on water levels. Surface water dominated systems also magnify variations in precipitation because the runoff is not delayed and buffered by flowing through the ground.

Finally, all the salt marsh sites, with the exception of the reference site, were surrounded by similar types of land uses. Therefore, it was the intensity of the specific land use, not the type, which appeared to account for discrepancies in biological populations. Tidal influence and the presence of freshwater seeps from upland sources seemed to affect a study site's ability to attenuate NPS loads. Fringing saltmarsh sites with a high degree of open water exposure demonstrated less impairment to the invertebrate communities, as opposed to pocket-type sites with small drainage ditches. Significant size differences between the reference site and the study sites may influenced results.

Management Implications and Recommendations

The management implications of this assessment approach are numerous. The Wetland Ecological Assessment Approach, with its inherent components, has strong potential application for:

- the identification of possible wetland restoration sites,
- the measurement of restoration success,
- the evaluation of mitigation banking or compensatory mitigation projects, and
- the comparison of the impacts of a project (such as a subdivision development) on a specific site before and after the project has occurred.

For existing wetland sites, the WHAT approach assessment tools can be utilized to identify degraded sites, and the information generated from this evaluation can be utilized by decision-makers as they prioritize which sites would be candidates for mitigation and restoration efforts. While in most cases it is not possible to relocate or cease existing development and land uses, there are structural and non-structural methods, or Best Management Practices, which, when implemented, can reduce pollutant loading to wetlands and diminish other potential impacts.

For wetlands currently with no or low intensity proximate land uses, the results of this project suggest that preventative management should be vigorously pursued in order to protect wetlands ecology.

Using ecological assessment methods, local, state, and federal planners should be able to identify wetlands with high Wetland Ecological Condition scores (or component index scores)–implying high ecological and functional value–and seek to acquire and protect these sites in perpetuity. For wetland sites currently with, or predictably subject to, new development proposals in their zones of influence, actions must be taken to prevent avoidable impacts. During site planning and project reviewing stages, for example, decision makers should require that development proposals retain sufficient buffer area of natural vegetation between new development and wetlands, implement aggressive stormwater management practices, reduce impervious areas, decrease or eliminate fertilizer use, and have acceptable onsite sewage treatment technology.

In sum, the WHAT approach has significant potential for extensive use as wetland analysis tool. The WHAT approach can be used to measure impairment due to land uses within the watershed, inventory the condition of wetlands within a planning authority's domain, evaluate the success of remediation, monitor the progress in created/restored wetlands, conduct before-and-after studies, and perform risk assessment as the basis for watershed management actions. The WHAT approach has been successfully applied to selected study site wetlands in the Waquoit Bay Watershed and has been able to register their current biological, physical and chemical conditions and indicate whether impairment, if present, was due primarily to NPS impacts or poor habitat quality, or due to a combination of both. In addition, it appears that the WHAT approach is sufficiently sensitive to detect the change in environmental conditions between spring and fall and does not appear to fluctuate statistically from one year to another.

As anticipated, the results of this project raise difficult environmental management issues but also point to areas of land use planning, wetland resource protection, and NPS control where new assessment tools and corresponding information can help to change ineffective policies and promote new approaches. In addition, as the Coastal Wetland Ecosystem Protection Project progressed from the early planning stages–including study site selection and review of assessment tools–to the more technical field based sampling and detailed data analysis steps, many lessons were learned.

Towns, municipalities, regional planning groups, watershed associations, and state resource planners and land managers should incorporate wetland assessment as an integral part of their ongoing natural resources inventory efforts. Tracking wetland acreage or quantity has important benefits, but we have not yet begun to adequately consider wetland health and ecological functioning. By engaging and completing an inventory of wetland in a certain area, information is obtained that enables decision makers to prioritize pristine wetlands for aggressive protection, select sites for restoration, and identify sites to continue to track for future actions.

An ambitious training and technical assistance program should be established to introduce groups and individuals to the concept of wetland assessment and to train them in the use of rapid assessment tools and ecological indicators. The WHAT approach is suitable for use by trained wetland professionals with basic experience in aquatic entomology, water chemistry, hydrology, and wetland ecology. Alternatively, a group leader can coordinate individuals with these specific skills to form a joint assessment team. Many of the skills necessary to conduct a comprehensive wetland evaluation can be acquired through classroom and field based training. Volunteers can gradually acquire specific skills and still participate in comprehensive assessment, working as team members.

Effective stormwater management, protective site planning, and specific on-the-ground nonpoint source control "best management practices" must be more widely implemented if the current status of wetland and water bodies is going to be maintained, at the least, or, ideally, improved. Recent Massachusetts' and federal efforts to provide policy and technical guidance on stormwater management represent a significant step towards addressing ongoing and cumulative wetland and water quality degradation. New stormwater policies and standards are subject to fairly steep learning curve as planners, engineers, and regulators become familiar with new concepts in stormwater management and technologies. Nonetheless, if the implementation of these and other available mechanisms are not vigorously pursued and enforced, the current trend of ecological degradation will not cease. Other examples of NPS management measures include sediment and erosion control, limitations on impervious cover, fertilizer and pesticide management, and pollution prevention planning.

There is little protection given to a wetland by managing activities only in its jurisdictional area of regulatory programs. Sources and causes of ecological degradation can originate from distance well beyond the jurisdictional 100 foot buffer zone. To engage in meaningful wetland protection strategies, efforts must be taken to protect or manage its upland watershed, or contribution area. In addition to direct land acquisition, there are a host of other land use and site planning tools available to local, regional, and state planners to manage wetland contribution areas. Wetland bylaws, stormwater management standards, transfer of development rights, cluster zoning, and septic systems codes are all examples of management tools that can be employed or enforced to achieve wetland protection goals.

More attention and emphasis should be placed on localized wetland restoration efforts. State and federal support and guidance for wetland restoration is at an all time high, and policy makers are setting optimistic goals for wetland acres restored and backing these goals with new and enhanced sources of funds. It is often at the localized level that the most information about the location, extent, and health of wetland resources exists. In Massachusetts, local Conservation Commission are the primary implementors of wetland protection regulation. Through the course of their work, Conservation Commissions review numerous permit applications, conduct site visits, and approve mitigation plans. With thorough advance planning, local officials could direct compensatory mitigation efforts toward the restoration of priority degraded wetlands. In addition, local planners could also work proactively to propose wetland restoration projects and seek financial and technical support.

As groups and individuals start to implement wetland assessment efforts for inventory purposes, to analyze restoration projects, and to gauge the effectiveness of NPS and stormwater management measures, the use of wetland reference sites will be necessary as the basis for comparison. Through coordination with other groups, and perhaps a lead agency, a robust data set of wetland reference sites could be established. Ideally, this reference data set would include wetlands of different classes, types, and sizes and would eventually contain sites throughout geologic regions or major watershed basins. In order to be effective and adaptable, care would have to betaken to ensure that methodologies are compatible and strict quality control is implemented. In fact, an excellent project for Massachusetts or other states would be to identify and establish reference sites on state or federally protected lands in a selected number of watersheds, with one or two years worth of data collection and analysis.

Finally, similar to the establishment of a long-term wetland reference site database, future wetland assessment projects would contribute to the continued building and refinement of the wetland biological attribute database. Metric attributes as described in the sections on wetland vegetation, aquatic macro invertebrates, and avifauna need to be expanded to include species not captured in surveys for this project and attribute values must reflect the most accurate professional judgement as possible. The further development of this biological attribute database would qualify as a high priority research project with significant applicability and benefits.

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Appendix: IVI Metric Attribute Values for Plant Species Surveyed

Salt Marsh Species

Genus	Species	Common	PSL	Invasive	Opportunistic	Wet	Nutrient	Salinity
Aster	subulatus	high aster	1	0	0	N/A	N/A	N/A
Aster	tenuifolius	low aster	1	0	0	N/A	N/A	N/A
Baccharis	halimifolia	groundsel tree	1	0	0	0.82	0.230	0.80
Carex	sp	sedge	N/A	N/A	N/A	N/A	N/A	N/A
Chamaecyparis	thyiodes	atlantic white cedar	1	0	0	1.00	0.120	0.20
Cuscuta	gronovii	love vine	1	0	1	0.82	N/A	0.40
Distichlis	spicata	spike grass	0	0	1	0.91	0.340	1.00
Iva	frutescens	marsh elder	1	0	0	0.91	0.340	0.80
Juncus	gerardii	black grass	0	0	0	0.91	0.340	1.00
Limonium	nashii	sea lavender	1	0	0	1.00	0.230	1.00
Parthenocissus	quinquefolia	virginia creeper	1	1	1	0.18	0.340	0.20
Phragmites	australis	common reed	1	1	1	0.82	1.000	0.60
Plantago	maritima	seaside plaintain	1	0	0	0.00	0.340	0.60
Rosa	palustris	swamp rose	1	0	1	1.00	0.340	0.20
Rosa	rugosa	rugosa rose	1	0	1	0.09	0.230	0.60
Salicornia	europaea	common glasswort	0	0	1	1.00	N/A	1.00
Salicornia	virginica	woody glasswort	0	0	1	1.00	N/A	1.00
Salsola	kali	saltwort	0	0	1	0.18	N/A	0.80
Solidago	sempervirens	seaside goldenrod	1	0	1	0.82	0.340	0.80
Spartina	alterniflora	smooth cordgrass	1	0	1	1.00	0.340	1.00
Spartina	patens	salt hay grass	0	0	0	0.91	0.340	1.00
Suaeda	linearis	sea-blite	0	0	0	1.00	N/A	0.80
Toxicodendron	radicans	poison ivy	1	1	1	0.50	0.340	0.20
Triglochin	maritimum	shore arrowgrass	1	0	1	1.00	0.340	1.00

Freshwater Species

Genus	Species	Common	PSL	Invasive	Opportunistic	Wet	Nutrient	Salinity
Acer	rubrum	red maple	1	0	0	0.50	0.8	0.340
Agrotis	scabra	tickle grass	0	0	1	0.50	0.4	0.340
Ambrosia*	artemisiifolia	ragweed	1	1	1	0.18	0.4	0.670
Aronia	prunifolia	purple chokeberry	1	0	0	0.82	0.4	0.340
Aulacomnium*	Moss sp.		N/A	N/A	N/A	N/A	N/A	N/A
Barbarea	vulgaris	wintercress	0	1	1	0.18	0.4	0.340
Boehmeria	cylindrica	false nettle	0	0	0	0.91	0.4	0.340
Calamagrotis	canadensis	bluejoint grass	0	0	0	0.91	0.6	0.340
Carex	intumescens	swelled sedge	0	0	0	0.91	0.4	0.430
Carex	lurida	lurid sedge	0	0	1	1.00	0.6	0.560
Carex	scoparia	broom sedge	0	0	1	0.82	0.4	0.560
Carex	sp.	sedge	N/A	N/A	N/A	N/A	N/A	N/A
Carex	stricta	tussock sedge	0	0	0	1.00	0.6	0.450
Carex*	atlantica	sedge	0	0	0	N/A	N/A	N/A
Cephalanthus	occidentalis	buttonbush	1	0	1	1.00	1	0.340
Clethra	alnifolia	sweet pepperbush	1	0	1	0.60	0.4	0.340
Cyperus	dentatus	flat sedge	N/A	N/A	N/A	N/A	N/A	N/A
Cyperus	strigosus	umbrella sedge	0	0	1	0.82	0.4	0.340
Decadon	verticillatus	water willow	1	1	1	1.00	0.6	0.430
Dulichium	arundinaceum	threeway sedge	0	0	0	1.00	0.6	0.230
Eleocharis	obtusa	blunt spikerush	0	0	1	1.00	0.6	0.340
Eleocharis	ovata	ovate spikerush	0	0	0	1.00	0.6	0.340
Epilobium	leptophyllum	narrowleaf willowweed	0	0	1	1.00	0.4	0.340
Galium	tinctorium	bedstraw	0	0	0	1.00	0.4	0.340
Glyceria	striata	fowlmeadowgrass	0	0	1	1.00	0.4	0.340
Hypericum	gentianoides	pineweed	0	0	1	0.00	0.4	0.230
Hypericum	multilum	lg. st.johnswort	0	0	1	0.82	0.4	0.340
Ilex	galbra	inkberry	1	0	0	0.71	0.4	0.230
Ilex	verticillata	winterberry	1	0	0	0.91	0.6	0.340
Impatiens	capensis	jewelweed	0	0	1	0.82	0.4	0.450
Juncus	canadensis	canada rush	0	0	1	1.00	0.6	0.230
Juncus	effusus	soft rush	0	0	1	0.91	0.4	0.340

Genus	Species	Common	PSL	Invasive	Opportunistic	Wet	Nutrient	Salinity
Juncus	filiformis	threadlike rush	0	0	1	0.82	0.6	0.230
Juncus	marginatus	shore rush	0	0	0	0.82	0.4	0.340
Kalmia	augustifolia	sheeplaurel	1	0	1	0.50	0.4	0.230
Leucothoe	racemosa	fetterbush	1	0	0	0.82	0.6	0.340
Lycopus	uniflorus	water horehound	0	0	1	1.00	0.4	0.340
Lyonia	ligustrina	maleberry	1	0	1	0.82	0.4	0.230
Lysimachia	terrestris	swamp candles	1	1	1	1.00	0.6	0.340
Magnolia	virginiana	laurel magnolia	1	0	0	0.91	0.4	0.340
Nymphaea	odorata	water lily	0	0	0	1.00	0.6	0.560
Nyssa	sylvatica	blackgum tupelo	1	0	0	0.50	0.6	0.230
Onoclea	sensibilis	sensitive fern	1	0	1	0.82	0.6	0.340
Osmunda	cinnamomea	cinnamon fern	0	0	0	0.82	0.6	0.340
Phragmites	australis	common reed	1	1	1	0.82	0.6	1.000
Pinus	rigida	pitch pine	1	0	0	0.18	0.4	0.230
Pinus	strobus	white pine	1	0	1	0.18	0.4	0.340
Poaceae*	unknown	grass	N/A	N/A	N/A	N/A	N/A	N/A
Polygonum	punctatum	water smartweed	0	0	1	1.00	0.6	0.450
Polygonum	sagittatum	arrowleaved tearthumb	0	0	1	1.00	0.6	0.340
Pontederia	cordata	pickerelweed	0	0	1	1.00	0.6	0.560
Populus	grandidentata	lg.toothed aspen	1	0	0	0.09	0.4	0.340
Populus	tremula	quaking aspen	1	0	0	0.18	0.4	0.340
Puccinellia	pallida	alkali grass	0	0	0	N/A	0.6	0.340
Quercus	rubra	nrth. red oak	1	0	0	0.09	0.4	0.340
Rhododendron	viscosum	swamp azelea	1	0	0	1.00	0.4	0.340
Rosa	palustrus	marsh rose	1	0	1	1.00	0.6	0.340
Rubus	sp.	bramble	N/A	N/A	N/A	N/A	N/A	N/A
Rumex	crispus	curled dock	1	1	1	0.18	0.4	0.560
Rhynchospora	capitellata	beak rush	N/A	N/A	N/A	N/A	N/A	N/A
Sagittaria	latifolia	arrowhead	0	0	1	1.00	0.6	0.430
Salix	bebbiana	bebb’s willow	1	0	1	0.82	0.4	0.340
Salix	discolor	pussy willow	1	0	1	0.82	0.6	0.340
Sassafras	albidum	sassafras	1	0	1	0.09	0.4	0.340
Scirpus	americanus	three square	0	0	1	1.00	0.6	0.340
Scirpus	cyperinus	woolgrass	1	0	1	0.91	0.6	0.560

Genus	Species	Common	PSL	Invasive	Opportunistic	Wet	Nutrient	Salinity
Scirpus	validus	great bullrush	0	0	0	1.00	0.6	0.340
Smilax	herbacea	carrion flower	1	0	1	0.50	0.4	0.560
Smilax	rotundifolia	greenbrier	1	0	1	0.50	0.4	0.340
Solanum	dulcamara	bittersweet	1	1	1	0.40	0.4	0.340
Solidago	hispida	goldenrod	1	0	0	0.00	0.4	0.230
Sparganium	eurycarpon	brd.fruited burreed	0	0	1	1.00	0.6	0.450
Sphagnum	palustre	sphagnum moss	0	0	0	1.00	0.6	0.120
Spirea	tomentosa	steeplebush	1	0	1	0.82	0.4	0.230
Spirodela	polyrhiza	water flaxseed	0	0	0	1.00	0.8	0.340
Thelyopteris	thelyopteroides	marsh fern	0	0	0	0.91	0.6	0.340
Toxicodendron	radicans	poison ivy	1	1	1	0.50	0.6	0.340
Triadenum	virginicum	marsh st.johns wort	0	0	0	1.00	0.6	0.340
Typha	latifolia	brd.leaf cattail	1	1	1	1.00	0.6	0.670
Vaccinium	corymbosum	highbush blueberry	1	0	0	0.71	0.4	0.340
Vaccinium	macrocarpon	lg.cranberry	1	0	0	1.00	0.6	1.000
Viburnum	dentatum	sthn. arrowwood	1	0	1	0.50	0.6	0.230
Vitis	sp	grape	N/A	N/A	N/A	N/A	N/A	N/A