Water Resources Management Plan

CAPE COD

National Seashore • Massachusetts

WATER RESOURCES MANAGEMENT PLAN

CAPE COD NATIONAL SEASHORE

MASSACHUSETTS

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Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

This plan charts a course for Cape Cod National Seashore water resources management and planning for the next 10 years. The overall goal is to resolve many of the uncertainties regarding the interaction between people and the National Seashore water resources in ways that sustain or restore the environmental health.

In 1981, the first Water Resources Management Plan was developed for the Cape Cod National Seashore. Its intent was to: 1) describe the state of information available at that time; 2) encourage a spirit of cooperation between the National Park Service and local municipalities and residents; and, 3) clearly articulate water resources management goals for the National Seashore. Eighteen years later, the present report attempts to update those goals with new information to create an action plan for public involvement in the protection of Cape Cod's freshwater resources. This action plan comprises two broad goals: first, the protection of ground and surface water quality and quantity, and second, the restoration of the natural hydrography and estuaries. It further includes six objectives:

1) to provide a detailed survey of existing information on the National Seashore's water resources;
2) to identify and discuss current and potential water resource problems and issues;
3) to clarify the legislative mandates of the National Park Service in the local and regional context;
4) to improve and encourage communication with appropriate state and regional agencies;
5) to identify and discuss viable management actions to address water resource management issues; and,
6) to develop an overarching water resources management program.

The first step, developing an up-to-date overview of the current state of National Seashore water resource information, is presented in Chapters One through Four of this report. Chapter One develops the context for National Seashore water resources concerns. Chapter Two summarizes the state of our knowledge regarding climate, soils, geology, and ground water. Chapter Three focuses on surface biotic and abiotic features with emphasis on the ponds, streams, and estuaries. (The report does not attempt to summarize knowledge on environments that are considered marine, i.e., neither freshwater nor brackish.) Chapter Four describes the human uses of the environment and how those uses affect the natural environment.

In defining this plan, six water resource areas of concern were identified. These are: 1) ground water withdrawal impacts; 2) water resource contamination from non-point pollution sources; 3) confirmed and potential contamination sites; 4) cultural impacts to pond water quality and biota; 5) park infrastructure management; and, 6) impacts from tidal restrictions. Chapter Five investigates ground water withdrawal issues from the perspective of impacts on surface waters and their biota and of human supply needs. Chapter Six examines non-point source pollution in both a local and regional context. Chapter Seven focuses on potential contamination from underground storage as well as other localized sources of toxic contamination. Chapter Eight examines the critical conflict between recreational demand for the unique resources of the National Seashore and the need to protect those resources from overuse or abuse. Chapter Nine assesses existing water supply and wastewater disposal within the National Seashore for their impact on water quality and quantity. Lastly, Chapter Ten reviews the efforts and remaining uncertainties in restoring tidal flow to historically restricted estuaries.

From this review of the natural and human environment and the more detailed examination of six specific major issues, Chapter Eleven sets forth a plan for developing the information necessary to continue to safeguard the environment, while recognizing the needs surrounding human participation in that environment. This plan provides a complex matrix of information gathering and implementation of programs that enhance National Park Service operation in the National Seashore; informs and encourages agencies and municipalities to also improve their practices as they relate to National Seashore water resources; and, informs and encourages the general public, residents and visitors to take an active part in the protection of these resources.

Cape Cod National Seashore is unusual within the national park system in that it was established after the area had been settled for more than 300 years; therefore, the opportunity to set aside wilderness or to assume responsibility for a large private holding was not an option. In creating a viable water resource management plan, park management must deal with many jurisdictions including those of the six outer Cape towns, Provincetown, Truro, Wellfleet, Eastham, Orleans, and Chatham, and of the state.

While 59 percent of the land is owned by the National Park Service, more than 30 percent within the National Seashore boundary is under the jurisdiction of other public entities, and nearly four percent is privately owned. Preserving the National Park Service mandate can, therefore, be challenging among so many other jurisdictional and management objectives. This plan provides a review of those jurisdictional interests and historical precedents and suggests methods for improved education and communication among the many land management interests.

Environmental research and management have shown that National Seashore water resources are both fragile and complex. Increased understanding of the complexity and sensitivity of the ecosystem is critical to wise management. Therefore, another major thrust is to maintain and expand the knowledge ofNational Seashore water resources.

Surface freshwater resources on the Cape include kettle ponds, seasonally-flooded wetlands, bogs, freshwater marshes, and dune ponds. Kettle ponds are permanently-flooded water bodies formed in ice-block depressions left in the landscape after the last glaciers melted about 12,000 years ago. There are 20 permanently-flooded kettle ponds within the National Seashore that range from 3 to 90 acres and 6 to 60 feet deep. There are 55 documented seasonally-flooded wetlands (vernal ponds) within the National Seashore that vary in size from small habitats to larger systems that occupy several acres. Freshwater marshes are located in river drainages, pond shores, and wetlands that were once salt water, but are now fresh water due to the placement of dikes and tide gates that prohibit tidal influences in the marsh. Dune ponds are small, shallow depressions that form between dunes on barrier spits and extend below the water table. These ponds are part of a larger wetlands complex that includes bogs, marshes, and floating peat islands. Bogs are poorly drained wetlands that have a floating mat of vegetation on their surface made up of sphagnum moss and cranberries, for example. The Atlantic white cedar community, which is a tree swamp, establishes itself under specific conditions that are rare on the Cape.

Very little is known about the interdunal bogs and vernal ponds. Wetland mapping and classification are outdated, and the impacts of water level change have not been evaluated. The National Seashore needs to update geographic information system maps of existing wetlands and develop a monitoring program for seasonally-flooded wetlands and for water level changes in the Atlantic white cedar swamps, interdunal ponds and ephemeral wetlands.

The Herring and Pamet rivers represent the two major stream systems on the lower Cape. The Herring River estuary has been greatly altered by 20th century diking and drainage for the purposes of mosquito control, flood protection, and improved travel corridors. The upper Pamet River, located in Truro, was a salt marsh estuary until it was diked around 1860.

Pilgrim Lake, once a coastal lagoon, was diked off from tidal flow by railway construction about 1870. This action transformed this body of water from a salt water bay to the present 344-acre brackish, shallow, eutrophic lake.

Estuarine salt marshes are one of the most valuable and productive ecosystems found anywhere, providing important nursery habitat to fish and shellfish. Almost all of the estuarine systems on the National Seashore have been altered to some extent by dikes and tide gates, reducing their productivity and habitat values. Salt marshes on the lower Cape are located at Hatches Harbor, Pamet River, Nauset Marsh, Provincetown's West End, and the lower Herring River (Wellfleet).

The Cape's water resources support a wide variety ofplants, fish, reptiles, amphibians, and mammals. There is a need for baseline surveys of the biotic and abiotic water resource environment including an inventory of aquatic macrophytes, amphibian and reptile populations, and kettle pond benthic invertebrates.

Most surface water resources on the lower Cape depend directly upon ground water. The Cape Cod aquifer system consists of six distinct ground water lenses or flow cells, which support both coastal and inland resources. Inland resources, such as kettle ponds, vernal pools and bogs, depend entirely on yearly and seasonal ground water levels to maintain their particular ecosystems. Fluctuations in the water table, due to either natural recharge variation or ground water withdrawals, are directly felt by these resources. Coastal resources, such as streams and estuaries depend on aquifer discharge to maintain yearly and seasonal flow rates and to regulate water chemistry.

Water withdrawals and water pollution can threaten the natural and human environment. Population growth and development are major considerations in maintaining water quality and quantity on Cape Cod. Population densities in America's coastal areas are growing faster than the rate of the general population, and Barnstable County, which encompasses Cape Cod, is growing faster than any of the mainland Massachusetts counties. The human population of the lower Cape is also entirely dependent on the ground water for private and municipal water supply. For this reason, the U.S. Environmental Protection Agency has designated this water source a "sole source aquifer", that is a water source which supplies greater than 50 percent of the drinking water to its service area, with no alternative should the source become contaminated.

Population and housing density increases in lower Cape communities have increased demand and simultaneously degraded local ground water quality to the extent that some communities are considering new public supply well locations. Only two of the lower Cape aquifers presently contain public water supply wells. The Pamet lens supports four permanent, large volume, public water supply sites. Chequesset lens has no large volume public water supplies and only one small volume public well supplying approximately 30 households. National Seashore lands are often viewed as prime sites for withdrawing high quality drinking water; however, the National Park Service mandate to "preserve and protect" may cause the National Seashore to have a different perspective on appropriate use than other entities. Current drinking water planning focuses on salt water intrusion; the National Seashore and the Massachusetts Department of Environmental Protection would prefer that all impacts resulting from ground water withdrawls be considered.

There are three, primary ground water withdrawal concerns facing the National Seashore as development continues and the demands for new private and public water wells increases. First, excessive ground water withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the ground water volume may be depleted to a point where salt water intrudes and contaminates the fresh ground water.

While much is known, more study is needed to assess the consequences of current or future development, particularly for maintaining adequate water quality for human consumption or adequate water quantity and quality for surface water resources. Efforts should be made to analyze existing ground water modeling to determine areas of increased water quantity and quality data needs, as well as test the feasibility of using models for investigating local impacts and evaluating the entire outer Cape ground water system.

The National Seashore as well as the Commonwealth of Massachusetts and local agencies recognize that the contamination of water resources by septic system leachate poses a great threat to the long-term health of the hydrologic environment of the Cape. Organic, inorganic, and biological pollutants can enter ground water through septic system leach fields. On the lower Cape, homes and businesses generally rely on private septic systems for wastewater disposal. Increases in housing density and the number of actively used on-site septic systems have been directly linked to increases in nitrate concentrations in the ground water on the lower Cape. Due to the proximity of private water supply wells and septic systems and the nature of the porous sand and gravel aquifer, there is great concern that as population growth on the outer Cape continues and the use of on-site wastewater disposal systems increases, occurrences in cross contamination of clean drinking water supplies will also increase. There needs to be a balance between the human impacts of development and the health of the environment.

Ponds and estuaries can also be degraded by pollutants that come from septic effluent. Eutrophication, the increased production of plants, phytoplankton, and macroalgae in surface waters, can result from nutrient loading. Eutrophication not only alters the native ecosystem, but also decreases its recreational value to humans. The addition of phosphorus to freshwaters via contaminated ground water discharge is a primary management concern ecologically, although it presents no major human health concern. Phosphorus introduced to the ponds via septic system runoff has the potential to increase algal production and reduce the natural clarity of the pond waters. Similar effects result from nitrogen discharge to estuaries.

To reduce nutrient loading and eutrophication, alternative wastewater treatment technologies need to be researched and tested on a case study basis. Some alternative wastewater disposal methods include: alternative technologies for private septic systems; cluster or package treatment plants for selected areas; and, increased on-line sewerage.

Additionally, underground storage tanks pose a threat to the quality of both ground and surface waters on the outer Cape. The majority of the tanks hold fuel oil and range in size from 200 to 2,000 gallons. Organic pollutants derived from landfills and leaking underground storage tanks as well as urban and septic leachate pose a serious threat to the integrity of clean drinking water supplies and natural resources.

Atmospheric deposition of acidity and metals is another significant source of non-point pollution. Cape Cod ponds are naturally very low in pH and therefore acid neutralizing capacity. Forty percent of Barnstable County ponds have little to no acid neutralizing capacity, a higher percentage than any other county in Massachusetts. Although a survey of mercury in National Seashore ponds has not been completed, preliminary results show a strong relationship between low pH and elevated methyl mercury levels in fish tissue. A recent study shows that sport fish in some ponds have mercury accumulations. These preliminary findings suggest that atmospheric deposition of mercury is a threat to the National Seashore's surface waters. The National Seashore should monitor mercury deposition at specific sites and evaluate mercury levels in sediments of freshwater ponds. Top predator fish tissue should be monitored in both fresh and estuarine environments. Information collected should be used to evaluate mercury pathways and determine management alternatives.

Road runoff, including salt and petrochemicals, as well as surface runoff and infiltration from lawns and golf courses may also be important sources of contamination. These non-point sources are presently a minor threat, but may become significant with increased development of the outer Cape.

The plan identifies two areas with regard to potential major contamination. The first involves historic landfills in the vicinity of the National Seashore. The proposed action focuses on understanding the continuing pollution from those landfills and their impact on surface and ground waters. The second concerns heightened preparation for and awareness of potential toxic contamination from National Seashore or private facilities and operations.

Inorganic and organic pollutants derived from landfills, leaking underground storage tanks, septic effluent, and urban runoff on the lower Cape pose a serious threat to clean drinking water and to ponds, rivers and estuaries located within the National Seashore. The intimate connection between the Cape's ground water and surface water compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the region's sand and gravel aquifer. There are five landfills located on the lower Cape, all of which have the potential to impact the freshwater resources within the National Seashore. Four of these (Truro, Wellfleet, Eastham, Orleans) are inactive landfills; the fifth (Provincetown) is capped. Both Provincetown and Truro landfills are located within the National Seashore boundaries and have contamination plumes emanating from their containment areas. The Wellfleet landfill abuts the National Seashore boundary and has a plume that travels southwest toward the Herring River.

Water that enters a landfill, usually in the form of rain and snow, comes into contact with buried wastes and forms leachate or dissolved waste. This leachate can contain toxic chemicals from commercial and household wastes. Often, the leachate leaves the landfill and follows the ground water flow, potentially entering recharge zones for water wells or surface water resources.

The five landfills on the Cape are monitored by wells and the contamination plume at each site has been mapped. According to reports generated from this monitoring, surface and ground waters both inside and outside of National Seashore boundaries may have been impacted. Landfill contamination may have negatively affected waters in Duck and Bennet ponds, the Pamet River, Provincetown Harbor, as well as several of the aquifers. National Seashore personnel need to continue to monitor landfill plumes, as well as review and evaluate the study design of past plume monitoring. Literature on landfill capping should be reviewed and the best techniques identified in preparation for capping the uncapped landfills. Contaminant discharge into surface waters should be assessed and a forum for dialogue on contamination issues should be established.

To be better prepared for potential hazardous waste spills, National Seashore personnel should conduct an inventory of septic systems and storage tanks on homes located on or near surface water resources and should also prepare an emergency response plan in case of spills or leakages of contaminants within National Seashore boundaries.

Recreational impacts continue to threaten the water quality of kettle ponds in the National Seashore, nearly all of which are used for recreation and have shoreline residences. The highly permeable nature of the sand and gravel aquifers on the Cape combined with septic system runoff of nutrients, particularly phosphorous, has the potential to cause eutrophication of the ponds.

Historic fisheries management, including stocking and liming, have affected pond waters. For example, an anadromous fish run between Gull Pond and Higgins Pond is maintained by artificial means to promote recreational fishing. The impacts of this on other pond organisms and water quality are unknown. National Seashore managers must gain an understanding of the ecological impact of the Gull Pond sluiceway before it can be managed. A study should be completed which will model the trophic structure and nutrient status of Gull Pond with and without river herring.

On some kettle pond shorelines, foot traffic has caused soil erosion and damaged rare plants. In most cases, revegetation is the most practical method of mitigating problems of heavy soil erosion around pond shorelines. However, the 20 kettle ponds within the National Seashore suffer from impacts related to multi jurisdictional ownership and access which cannot be mitigated completely by revegetation. The area that surrounds the kettle ponds contains roads and access points that are maintained by both the National Park Service and local communities, as well as ones that have been informally created by visitors seeking alternative access to remote portions of the ponds.

No plan currently exists that provides an integrated approach to the recreational management of the kettle ponds within National Seashore boundaries. A kettle pond recreational management plan needs to be developed by a pond management committee which would consist of all involved organizations. Outreach programs should be developed which would inform the public as well as continue public participation.

The National Seashore is encouraging and collaborating on restoring the natural tidal environment of estuaries, reversing many decades of well-intentioned but environmentally damaging efforts to drain and alter these systems. In the process of restoration, there are many issues regarding how these systems originally functioned; how best to arrive at restored systems that resemble the unaltered systems as closely as possible; and, how to make the transition in an environmentally safe and culturally sensitive manner.

Salt water marsh estuaries are a primary natural resource feature of Cape Cod National Seashore. Since the early 1900s, intertidal and estuarine resources on the Cape have been greatly altered by diking and drainage, turning brackish waters with a marine influence into freshwater wetlands and upland habitats. Diking affects over 10 percent of the remaining coastal marshes in New England as well as a portion of nearly all the salt marshes on the lower Cape. Salt marsh diking degrades and eliminates estuarine habitat for many native plant and animal species, including fish, shellfish and crustaceans. Restoration has been proposed for each of these diked areas; however, development within the diked areas makes restoration more complicated. Actual restoration of tidal flow has begun in Hatches Harbor in Provincetown, with research and discussion continuing for Herring and Pamet rivers, and Pilgrim Lake.

Ponds, streams and estuaries are often ground water discharge points, and because of this connection, estuaries, rivers, and ponds are susceptible to contamination from ground water discharge that contains pollutants. Ground water discharge containing high concentrations of nutrients, predominantly from septic leachate, has led to the eutrophication of portions of Waquoit Bay, Cape Cod, and many other coastal ecosystems worldwide. Tidal flushing is the primary mechanism for removal of nutrients, specifically nitrogen from coastal surface waters. In the absence of tidal flushing, nutrients introduced to coastal water bodies can remain in the system, increase algal production, and promote eutrophication.

Limited supplies of fresh water on the Cape make water conservation an important part of water resource management for the park as well as for towns on the lower Cape. Further, the National Seashore, in its role as an environmental steward and educator, has a responsibility to lead the way in development, use and demonstration of water conservation techniques.

It is critical that the National Seashore improve its own facilities to reflect long-range water resource management goals and objectives. Analyzing ages and types of septic systems as well as the amount of use that each facility receives is essential to determining the efficiency of the park's water usage. Also, there are private properties within the National Seashore boundary that have underground storage tanks and septic systems that can add to the contamination threat within the park.

Regardless of ownership, all development in the National Seashore has the potential to impact public water resources. For this reason, it is important to assess the contamination potential of all properties, regardless of ownership status, within the park.

The National Park Service needs to continue to fill a critical role as educator by modeling water conservation strategies at the National Seashore. Water conservation within the park has occurred to some degree. Low flow shower heads have been installed in all of the houses that are owned and occupied by the National Park Service and low flush toilets have been placed in some of the seasonal homes. Funding is a major barrier to park wide implementation of water conserving devices. The National Seashore could use their properties to showcase water conservation for the public. The homes could include alternative septic systems, modem water conservation devices, xeriscaping, pervious outdoor surfaces and rooftop rainfall collectors. Alternatively, a model home could be created which does all of the above, plus serves as a location for public education programs about water conservation.

This Water Resources Management Plan focuses on the protection of outer Cape freshwater resources including ponds, ground water, and estuaries. Without the cooperation and participation of Cape residents in the solution for these complex problems, effective management of water resources is impossible.

Information exchange with the public could provide a critical tool for the park to promote water resource solutions. The park could publish a newsletter, as well as create an interactive web page. A Cape Cod Institute could be established, which would be patterned after the successful Yellowstone Institute. This institute would provide classes and the opportunity for scientists and the general public to work together to understand and solve water resource management issues.

This plan proposes the establishment of a water resources management program which includes residents and local governments. The four components of this programs are to establish: 1) a cooperative forum among local government agencies and the National Park Service; 2) a community extension program that involves education, research and planning; 3) a comprehensive database that improves the accessibility of water resources information; and, 4) a research program that increases knowledge of the water resources on the National Seashore.

In conclusion, this Water Resources Management Plan updates the previous effort of 1981; identifies priority issues for continued research, management and outreach for the next decade; and, suggests a number of specific projects to address all of these issues.

Chapter One: The Water Resource Management Plan

The purpose of this Water Resource Management Plan is to guide and support the National Park Service's decision-making process as it relates to the protection, conservation, use, and management of Cape Cod National Seashore's water resources. The Cape Cod National Seashore Water Resource Management Plan is intended to provide guidance for management decisions for the next decade by: 1) providing an analysis of existing information, and 2) recommending preferred actions that will increase ecosystem knowledge to resolve uncertainties and conflicts. This water resource management plan will evaluate what is known and chart a cost-effective course toward learning what is unknown.

A New World Discovered

One of the first "known" environments in the New World, the outer or lower Cape is still imperfectly understood by scientists, managers and planners intent on understanding its special nature. Cape Cod, Massachusetts and the Cape Cod National Seashore (Figure 1.1) are a naturally complex environment, created by glaciers and subject to natural change caused by storms, fires and droughts. Nature, through these and other dynamic processes, has created a place which people enjoy. People visit the National Seashore because it preserves a portion of the Cape in its near natural state, providing opportunities for hiking, biking, photography, sightseeing, boating, fishing, hunting, beach combing, birding, and other recreational uses.

Partners in Conservation

In 1961, approximately half of the land mass of the outer Cape was granted national park status and named the Cape Cod National Seashore (Appendix A). It encompasses 44,600 acres of which 16,900 acres are water. The National Park Service manages 26,031 acres with the remaining 18,569 acres within the National Seashore boundary consisting of interspersed private and public lands in six established Massachusetts communities, the towns of Chatham, Orleans, Eastham, Wellfleet, Truro, and Provincetown (Figure 1.2). The Cape Cod National Seashore set national precedence by incorporating residents into the land management process through what is referred to as the "Cape Cod Formula". Establishment of Cape Cod National Seashore set in motion not only a process of resource

Figure 1.1: Regional Location and Cape Cod National Seashore Boundary

Sources: shorelines and boundaries from USGS DLG data (1977)with updates from aerial photos (1991)

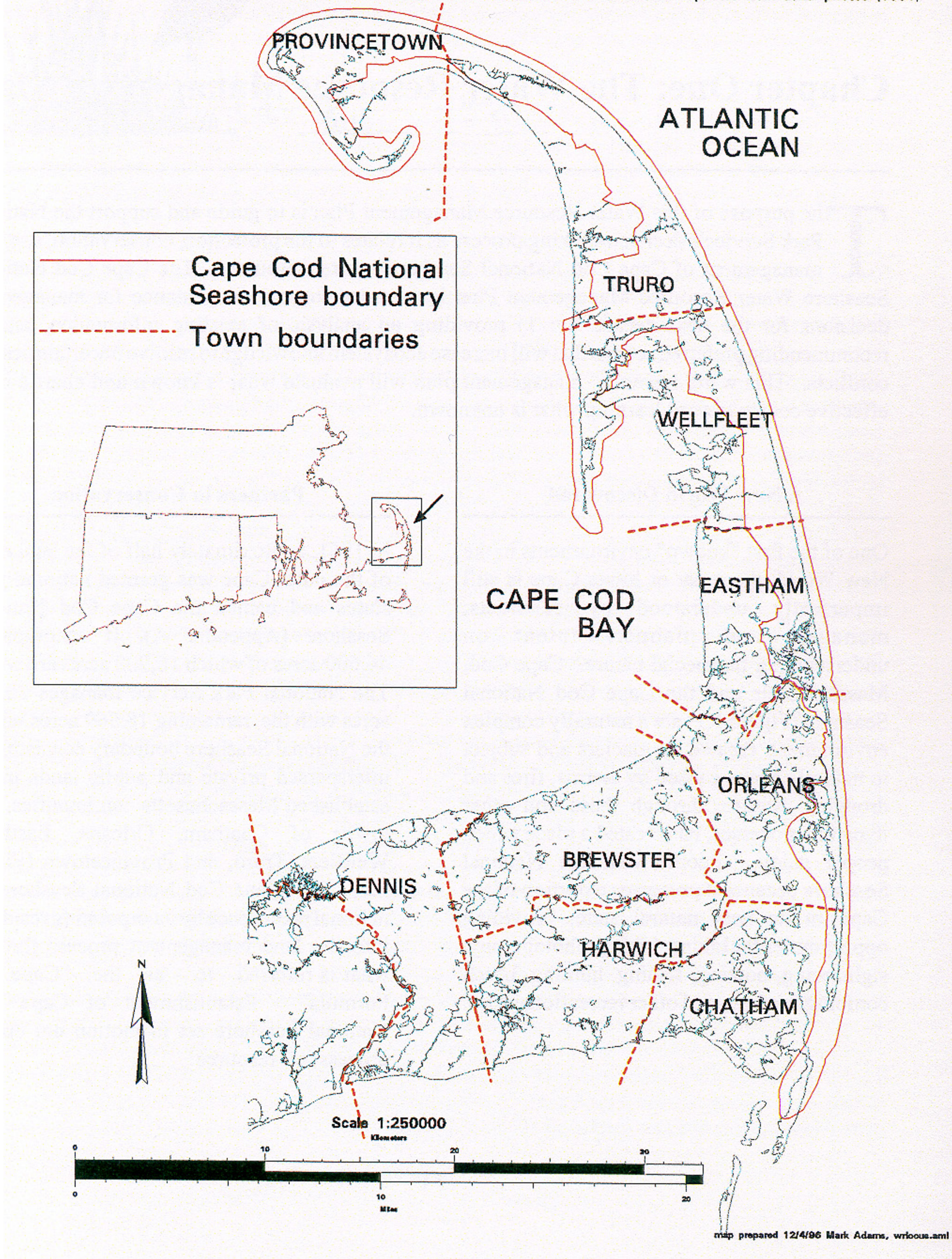
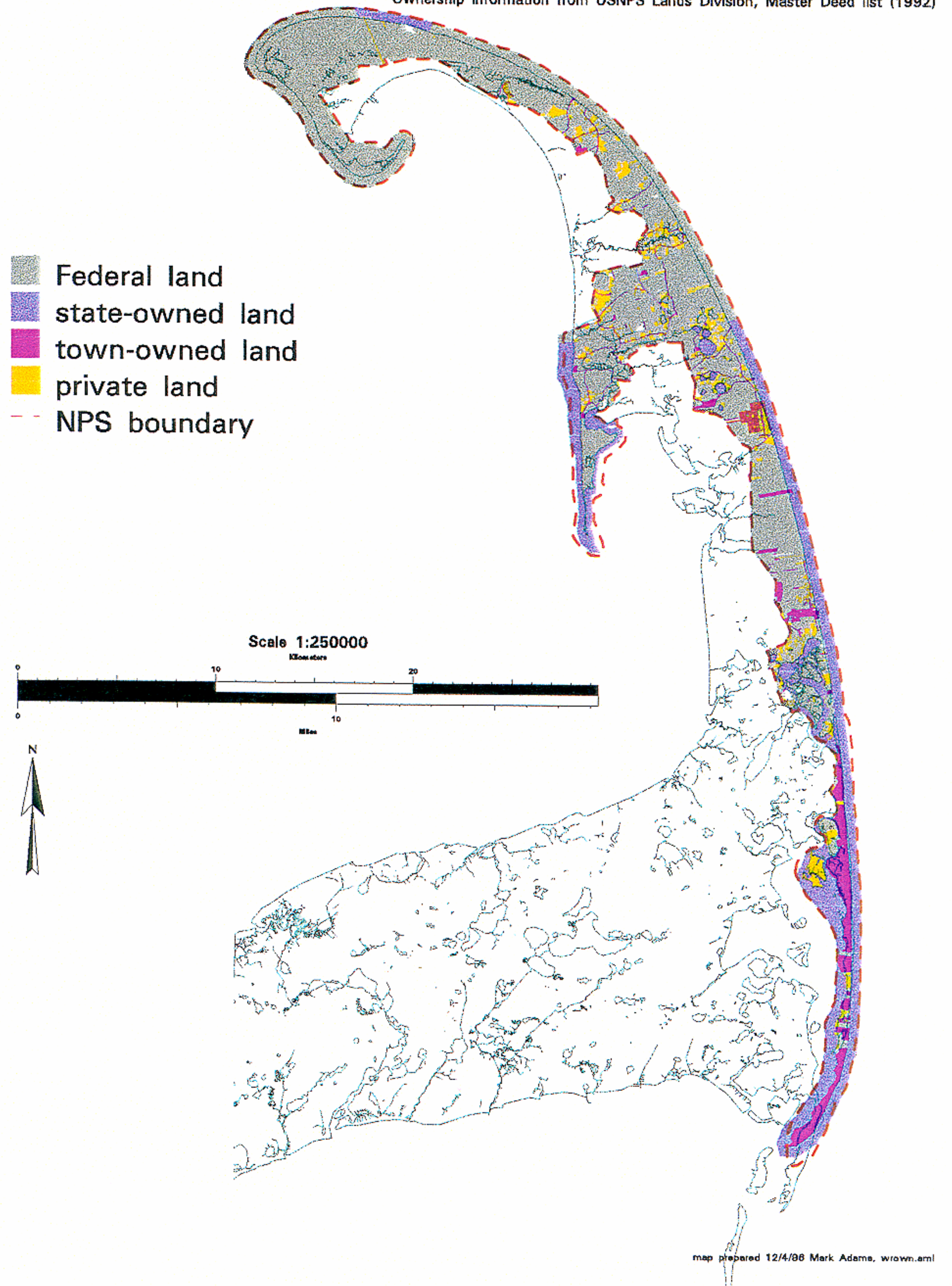


Figure 1.2: Land Ownership within NPS Boundaries Cape Cod National Seashore

Sources: shorelines and boundaries from USGS DLG data (1977) with updates from aerial photos (1991)
Ownership information from USNPS Lands Division, Master Deed list (1992)



The Water Resources Management Plan will provide the basis for:

understanding the hydrologic character and aquatic biota of the National Seashore;

mitigating pollutant impacts from within and outside the National Seashore;

cooperating in management with neighboring communities and other agencies and organizations over uses of water resources located within the National Seashore and those outside the Seashore with influence on resources within the park;

protecting naturally occurring aquatic communities and the public health;

resolving jurisdictional questions over the National Seashore's water resources; and,

integrating water resources management with daily National Seashore operations and future planning.

protection and conservation, but also a mechanism for community participation, thus making the residents of the outer Cape stakeholders in the conservation of their own lands. The partnership formed between the residents, local governments and the National Park Service now offers great opportunities as well as challenges in the use and protection of natural resources.

The Original Water Resources Management Plan — 1981

The Cape Cod National Seashore published the Analysis of Water Resource Management Alternatives in 1981 as part of a larger process to complete a Water Resource Management Plan (Mitchell and Soukup, 1981). The report was written to encourage public participation in the review of suggested water resource management alternatives. The document was also intended to clearly illustrate the water resource management goals of Cape Cod National Seashore for the public.

The issues covered in the 1981 document were ground water quality and quantity, kettle ponds, Gull Pond Sluiceway, Pilgrim Lake, water and marsh areas near the Herring River Dike, and wetland protection. All of these management issues are relevant today, presenting many of the same challenges that existed in 1981.

The preface for the 1981 document states that, "In some cases, the management objectives of the National Park Service may not completely coincide with the objectives of all other Cape groups and citizens; however, there are also many common objectives for the preservation of the outer Cape's water resources" (Mitchell and Soukup, 1981, p. ix). This statement is true today as well. In 1981, the report on water resources served as a tool for communication between the public and the National Park Service. The 1999 Water Resources Management Plan is not only a tool for communication, but also an action plan for public involvement in the protection of the Cape's freshwater resources.

The Challenge

The federal mandate of the National Seashore encompasses two conflicting goals of resource protection and public access. Cape Cod National Seashore must exist with the apparent contradiction between serving as a major attraction to people and protecting the National Seashore lands and waters in as natural a condition as possible. These conflicting goals pervade a wide range of issues from beach access to ground water use. This conflict has become increasingly pertinent as Cape Cod has come under enormous development pressure in the past two decades. Most of that pressure has occurred on the upper Cape towns located west of Chatham in Barnstable County, but demographic trends suggest that the pressure will increase on the outer Cape (see Figure 1.2), in part because of the existence of the Cape Cod National Seashore.

Due to these circumstances, the Cape Cod National Seashore Water Resources Management Plan must reconcile opposing pressures by identifying alternatives and recommending actions that protect the characteristics of the water resources.

General Management Objectives

The following are management objectives (National Park Service, 1998) that reflect the enabling legislation of Cape Cod National Seashore (Public Law 87-126) and its mission to protect the natural resources of the National Seashore while enabling the public to gain a greater appreciation for the environment.

1. Seek to understand, foster, and maintain native biological and physiographic diversity to sustain thriving, dynamic natural communities and systems. Within these standards, protect water resources through a cooperative, balanced approach to water use management.

2. Encourage commitment to the stewardship of the buildings, places, activities, and artifacts of Cape Cod that best exemplify its traditional character, and conserve them to ensure their continuing contribution to the culture of Cape Cod, in collaboration with local communities.

3. Allow natural processes to continue unimpeded in natural zones, including the action of wind and water, and neutralize the effects of human intervention where it has adversely affected natural systems.

4. Provide opportunities for a diverse range of quality experiences that are based on the resources and values of Cape Cod, with consideration for sustainable practices, traditional uses, and the purposes of the National Seashore.

5. Stimulate and then satisfy a public desire to understand the natural and cultural resources and the history and sociology of Cape Cod through the primary interpretive themes identified for the National Seashore.

6. Collaborate with local communities and other stakeholders to address common issues and to promote a stewardship ethic for the National Seashore.

Water Resources Management Plan Objectives

Consistent with the above National Seashore General Management objectives, the Water Resources Management Plan has two goals: 1) the protection of ground and surface water quality and quantity as well as adjacent wetlands, and 2) restoration of the natural hydrography and estuaries in consultation with affected municipalities. These goals will be accomplished through the following objectives:

1. to provide a detailed survey of existing information on the National Seashore's water resources;
2. to identify and discuss current and potential water resource problems and issues;
3. to clarify the legislative mandates of the National Park Service in the context of operation within the local and regional frameworks;
4. to improve and encourage communication with appropriate local state and regional agencies;
5. to identify and discuss viable actions addressing water resource management issues; and,
6. to develop an overarching water resources program.

Relationship to Other Planning Efforts

Many water resource management issues are a direct result of the complex pattern of multiple land ownership within the National Seashore and the activities that occur on and adjacent to these lands. The following is a brief description of other planning efforts or plans on the lower Cape that could have an effect on the management of water resources on the National Seashore.

Lower Cape Water Management Task Force

The task force, formed in 1992 comprises members from the Cape Cod Commission, Cape Cod National Seashore, and the towns of Eastham, Wellfleet, Truro, and Provincetown and is working towards a long term plan for the sustainable use of ground water resources. The primary goal of the Task Force "is to provide a decision-making tool which contains information, options, and recommendations regarding water supply planning for the region and respective towns" (Sobczak and Cambareri, 1996). Since the hydrological environment does not recognize political boundaries, the Task Force has examined water supply options from a resource-based perspective, using hydrological boundaries only. The Task Force report, released in 1996 (Sobczak and Cambareri, 1996), includes well location suitability, current and projected water use, current and projected water quality data, and cost information associated with the addition of wells and distribution systems.

Cape Cod Commission Regional Policy Plan

This plan outlines the regulations and minimum standards set for water quality within Barnstable County. The Cape Cod Commission presents this information for the use of town governments on the lower Cape (Cape Cod Commission, 1991).

Provincetown Master Plan

The 1988 Provincetown Master Plan addresses the problem of growth management and how it relates to adequate water supplies. Recognizing the need to limit growth in the area, the plan states that the goal of Provincetown is to live within the limits of the town's resources. Specific to the National Seashore, Provincetown's plan addresses water quality and quantity issues (Town of Provincetown, 1988).

Truro Comprehensive Plan

The water resources section of the Truro comprehensive plan highlights the role that the town intends to play in the area of water quality. The goals target ground water protection and sustainable withdrawal of ground water supplies. The plan (Town of Truro, 1994) outlines Truro's water resource policies which are in accordance with the Cape Cod Regional Policy Plan.

Wellfleet Local Comprehensive Plan The Wellfleet Local Comprehensive Plan (Town of Wellfleet, 1996) highlights water resources. An inventory of all water resources within Wellfleet is described which includes 13 kettle ponds located within the National Seashore. Goals and policies that relate to water resource management target wellhead protection areas, recharge areas, impaired areas, and potential water supply areas. Non-point source pollution threats to water resources are discussed and an implementation program for management is summarized.

Eastham Comprehensive Plan

This plan (Town of Eastham, 1996) outlines Eastham's goals for meeting minimum performance standards, which are modeled primarily after the Regional Policy. Issues concerning land use, growth management, and natural resources are addressed. The natural resources section highlights water resource protection and management. Wellhead protection, contaminated areas, recharge areas, and potential water supply areas are discussed also in this section.

Identification of Water Resource Issues

Six water resource issues provide the focus of this Water Resource Management Plan. The list of issues was derived from meetings between the National Park Service staff and University of Massachusetts planning team as well as from many past meetings between the National Park Service and the public. The issues are: 1) ground water withdrawal impacts; 2) water resource contamination from non-point sources; 3) confirmed and potential contamination sites; 4) recreation impacts to pond water quality; 5) Cape Cod National Seashore infrastructure; and, 6) impacts of diked estuaries. These six issues are summarized in this section and discussed in detail in chapters five through ten. In addressing these issues, the park is provided with a means to holistically approach the resolution of present conflicts. Selection of these six issues for principal focus does not presume that other issues do not or will not have importance. Elements of this plan provide a mechanism to address other issues.

Issue 1: Impacts of Ground Water Withdrawal

The majority of the available fresh water on the lower Cape is ground water. The ground water resource directly supports most of the lower Cape's surface waters - ponds, streams and wetlands. The human populations of the lower Cape are also entirely dependent on the ground water for private and municipal water supply. For this reason, the U.S. Environmental Protection Agency has designated this water source a "sole source aquifer" and must review any federally funded projects within the aquifer's watershed. The "sole source" designation is granted on the basis of a water supply source being needed to supply greater than 50 percent of the drinking water to its service area where there is no reasonable alternative should the source become contaminated (Massachusetts Department of Environmental Management, 1994).

Population and housing density increases in lower Cape communities have increased demand and simultaneously degraded local ground water quality to the extent that some communities are considering new public supply well locations. Since the National Seashore occupies a large percentage of the lower Cape land area and contains protected open space, National Seashore lands are often viewed as prime sites for withdrawing high quality drinking water. It is a delicate issue to balance water supply needs against a park mandate to protect all natural resources, including the ground water resources vital to maintaining surface water ecosystems (Sobczak and Cambareri, 1996).

Large-scale ground water withdrawals change the local water balance and the rate and pattern of ground water flow, resulting in impacts to ground water dependent ecosystems (Martin, 1993). There are three primary ground water withdrawal concerns facing the National Seashore as development continues and the demand for new private and public water wells increases. First, excessive ground water withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the ground water volume may be depleted to a point where salt water intrudes and contaminates the fresh ground water (Sobczak and Cambareri, 1995). The combination of an extremely vulnerable sole source water supply and the rapid growth rate on the lower Cape makes for a serious situation and requires a comprehensive resource protection and management program (Zoto, 1988).

Issue 2: **Water Resource Contamination from Non-point Sources**

The National Seashore as well as the Commonwealth of Massachusetts and local Cape Cod agencies recognize that contamination of water resources by septic system leachate poses a great threat to the long-term health of the hydrologic environment of the Cape. There needs to be a balance between the human impacts of development and the health of the environment. On the lower Cape, homes and businesses generally rely on private septic systems for wastewater disposal. Ponds, estuaries, and ground water can all be degraded by pollutants that come from septic effluent. For almost two decades, various reports have documented increases in nitrate concentrations in the ground water on the lower Cape and have directly linked the elevated levels with increases in housing density and the number of actively used on-site septic systems (Frimpter and Gay, 1979; Persky, 1986; Noss, 1989; Goetz et al., 1991; Cambareri and Sobczak, 1995). The Massachusetts Department of Environmental Protection has documented that faulty private septic systems are the largest contributor of pollutants to inland and coastal surface water bodies in the state (Sit, 1995). Careful land-use planning and multi-jurisdictional cooperation are necessary to mitigate this problem.

Another significant source of non-point pollution is acid deposition. Cape Cod ponds are naturally very low in pH and therefore acid neutralizing capacity. Forty percent of Barnstable County ponds have little to no acid neutralizing capacity, a higher percentage than any other county in Massachusetts (Godfrey et al., 1996). Despite reductions in acid deposition in New England since the late 1980s, pond pH's on the lower Cape have not significantly changed. Although a survey of mercury in National Seashore ponds has not been completed, preliminary results and a statewide survey have shown a strong relationship between low pH and elevated methyl mercury levels in fish tissue.

Road runoff, including salt and petrochemicals, as well as surface runoff and infiltration from lawns and golf courses may also be important sources of contamination. These non-point sources are presently a minor threat, but may become significant with increased development of the outer Cape.

Issue 3: Confirmed and Potential Point-Source Contamination Sites

Inorganic and organic pollutants derived from landfills, leaking underground storage tanks, septic effluent, and urban runoff on the lower Cape pose a serious threat to clean drinking water and to ponds, rivers and estuaries located within the National Seashore. The intimate connection between the Cape's ground water and surface water compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the region's sand and gravel aquifer. There are five landfills located on the lower Cape, all of which have the potential to impact the freshwater resources within the National Seashore. According to past research reports, some surface waters both inside and outside the National Seashore may have already been degraded (Cambareri et al., 1989; Frolich, 1991; Urish et al., 1993; Winkler, 1994).

Issue 4: Cultural Impacts on Pond Water Quality and Biota

Nearly all of the 20 kettle ponds located within the National Seashore boundary are used for recreation. Shoreline erosion and historic fisheries management, including stocking and liming, have affected pond waters. For example, an anadromous fish run between Gull Pond and Higgins Pond is maintained by artificial means to promote recreational fishing; however, the impacts of this are unknown. On some shorelines, rare plants have been affected by foot traffic.

While many pond management issues are obvious, management authority is not. There are several agencies and many landowners that have some control over access and management. A coordinated system for multi-jurisdictional management has not yet been established.

Issue 5: Cape Cod National Seashore Infrastructure

The infrastructure of the National Seashore is susceptible to the same inefficiencies experienced elsewhere. It is important that the National Seashore serve as a premier example of pro-active thinking and improves its facilities to reflect the goals and objectives stated in this Water Resources Management Plan. Analyzing ages and types of septic systems as well as the amount of use that each facility receives is essential to determining the efficiency of the park's water usage. Also, there are private properties within the boundary of the National Seashore that have underground storage tanks and septic systems that can add to the contamination threats within the park. Management of these properties is important to the preservation of many park resources. Additionally, non-point source pollution within the National Seashore needs to be identified and managed in order to ensure the long-term health of the hydrologic environment.

Issue 6: Ecological Impacts of Tidal Restriction

The importance of salt marsh estuaries to the Cape Cod National Seashore as a primary natural resource feature has been highlighted continuously in the 35-year administrative and legislative history of the park (National Park Service, 1998). Since the early 1900s, intertidal and estuarine resources on the Cape have been greatly altered, turning brackish waters with a marine influence into freshwater wetlands and upland habitats as is the case at Herring River, Pamet River, Hatches Harbor, and Pilgrim Lake. It is estimated that diking affects over 10 percent of the remaining coastal marshes in New England as well as a portion of nearly all the salt marshes on the lower Cape (National Park Service, 1998). Salt marsh diking degrades and eliminates estuarine habitat for many native plant and animal species, including fish, shellfish and crustaceans with economic and recreational value. Restoration has been proposed for each of these diked areas; however, development within the diked areas makes restoration more complicated. Partial or complete tidal restoration could re-establish native estuarine environments.

Management Strategy

Many issues regarding the use of water resources have developed since the formation of Cape Cod National Seashore in 1961. These six issues represent management challenges that have been relevant since then. These issues can also be found in several other plans from local governments and the Cape Cod Commission, as well as in 1981 National Park Service report on water resource management alternatives (Mitchell and Soukup, 1981; Town of Truro, 1994; Sobczak and Cambareri, 1996; Town of Eastham, 1996; Town of Wellfleet, 1996; Town of Provincetown, 1988). This plan recognizes that in order to move forward on many of these issues, there needs to be a cooperative framework for management in the area of water resources. Committing to water resource management expertise at Cape Cod National Seashore is a vital component of this framework. However, this endeavor can be strengthened through the participation of lower Cape towns and Cape residents and visitors in water resource programs, such as water quality sampling and ongoing discussions concerning water quality and quantity. There needs to be close integration of water resources management with understanding of the natural resources and the people of the Cape. Thus, this plan continues the spirit of the Cape Cod Formula, supporting a cooperative relationship into the future.

An Action Plan for the Future

This Water Resources Management Plan focuses on the protection of outer Cape freshwater resources including ponds, ground water, and estuaries. These water resources are used by humans for drinking water and recreation and support the native biota. Residents of the outer Cape, both within and outside the National Seashore, are a focal point of this plan. Without their cooperation and participation, effective management of water resources is impossible.

For this reason, this plan proposes the establishment of a water resources management program which includes residents and local governments to effectively manage water resources on the outer Cape. The four components of this program are:

- a cooperative forum among the local government agencies and the National Park Service for water management decisions;
- a community extension program that involves the public in education, research and planning;
- data management that improves the accessibility of information regarding water resources; and,
- a research program that increases knowledge of the water resources on the National Seashore.

The implementation of the water resource management program has been broken down into three time periods: 0 to 400 days, 400 days to 5 years, and 5 years to 10 years. The first 400 days provides the National Park Service with time for planning and organizing before implementation begins. Actual implementation and execution of the water resources management program should occur between 400 days and 5 years. Specific actions are discussed in the plan with their corresponding management issue. For example, the portion of the program related to septic systems is included in Chapter Six. During this time, research and community projects will begin. In the final 5 to 10 year time period, the program will continue activities related to water resource management, specifically the research projects that require several years to complete. These research activities, as well as all proposed actions, are described fully in project statements listed in Chapter Eleven.

First 400 Days of the Water Management Program

Develop a consistent policy to guide complex choices. The initial step would be a review of founding legislation and existing policy in other parks with comparable problems. The second step would be a review of current policy and practice by the National Seashore and others involved in management of Cape Cod resources.

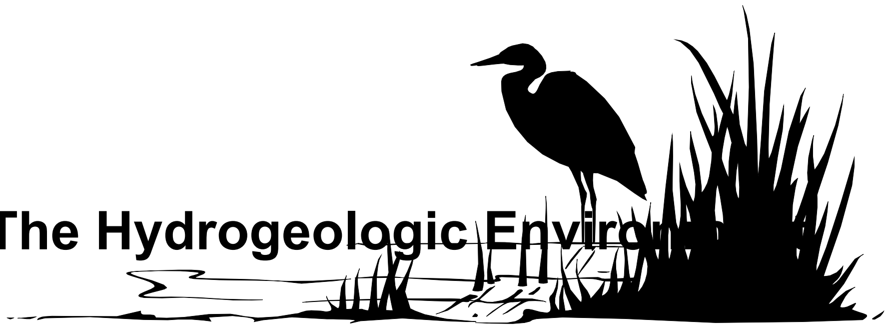
Establish a committee that includes the Cape Cod National Seashore, Cape Cod Commission, Massachusetts Coastal Zone Management, six towns in the National Seashore, Massachusetts Department of Environmental Protection, Massachusetts Divisions of Marine Fisheries and Fisheries & Wildlife, and Massachusetts Audubon. This committee represents all parties that have a stake in future water resource management on the outer Cape including those with governmental jurisdiction. The first goal is to develop a memorandum of understanding between all the agencies that acknowledges the need for management efforts that complement each other. The agreement should focus on developing a consensus for sustainable management and should holistically consider the short-term and long-term impacts on the development of water resources.

Begin community extension work to involve residents in water resource protection. Hold a workshop with the Massachusetts Water Resources Authority on water quality and consumption issues. The National Seashore should be a participant but not a leader in this workshop. A group of residents and representatives from the National Seashore should be established to develop a newsletter as a tool for communication between the National Seashore and the residents and visitors of the outer Cape. Develop an action plan that involves residents in management and/or research activities, e.g. water sampling, education, and water use monitoring. Environmental education is a critical part of water resource protection. The current environmental education program presented to local schools should be evaluated and revised to emphasize a water resource protection component.

Develop a comprehensive water resource database that is manageable, consistent and compatible with other National Park Service databases. This database should consolidate data into a format that is easily retrievable and easily updated. The plan for the database should include geographic information system data layers as well as U.S. Geological Survey water sampling data, National Park Service research and monitoring data sets, and park facilities monitoring data.

Research and planning projects should be prioritized and funding secured on the basis of the project's priority. Projects should be discussed and prioritized by the Cooperative Program Committee. An evaluation should be made to determine what is currently being done by all agencies and what role the National Park Service can play in existing projects.

Chapter Two: The Hydrogeologic Environment



Cape Cod is a peninsula 440 square miles in area, developed from deposits of the last glaciation that separated Cape Cod Bay from the Atlantic Ocean. The peninsula runs 40 miles east-west from the Massachusetts coast into the Atlantic Ocean before turning to run 25 miles north-south. The upper Cape, or inner Cape, is the east-west portion of the peninsula, closest to the Cape Cod Canal and mainland Massachusetts. Cape Cod National Seashore is located on the north-south portion of the peninsula known as the lower or outer Cape. There is no exposed bedrock anywhere on Cape Cod. Depth to bedrock ranges from about 200 feet near the Cape Cod Canal to more than 900 feet in Truro (Oldale, 1980; 1992). Bedrock, therefore, plays little importance in the existing topography of National Seashore lands. Rather, glacial landforms and marine reworking of those landforms are evident everywhere.

The Cape Cod National Seashore consists of approximately 44,600 acres of uplands, ponds, wetlands and tidal lands. Inland, the National Seashore is dominated by rolling plains. The shoreline is dynamic in nature. It exhibits both cliffs, where storms are actively eroding the inland plains, and barrier beaches where the eroded material is redeposited. Strong coastal winds work the redeposited material into dunes. The dunes and associated wetlands on the lower Cape are one of the most distinctive visual landscapes of Massachusetts (Smardon,1972; Fabos, 1983).

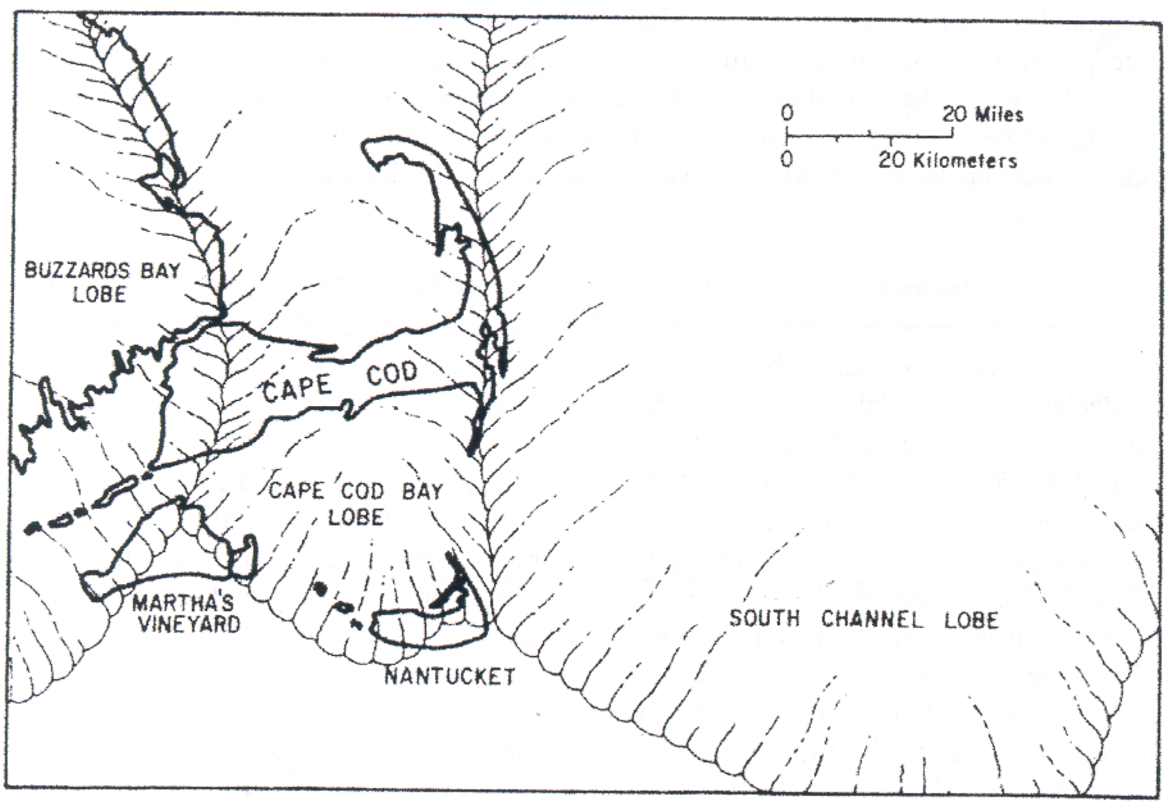
Geology

Most of Cape Cod was shaped by the last great glaciation in North America, the Wisconsin glacial stage of the Pleistocene, approximately 75,000 to 10,000 years ago. A vast ice sheet (the Laurentide ice sheet) advanced south from northern New England and Canada and transported eroded rock debris scoured from the underlying Paleozoic crystalline bedrock until it reached its southernmost limit at Martha's Vineyard and Nantucket Island. Late in this time period, the coalescing Buzzard's Bay, Cape Cod Bay, and South Channel glacial lobes of the Laurentide ice sheet deposited the glacial drift that now comprises much of Cape Cod (Oldale, 1980; 1992) (Figure 2.1).

The glacial history of the Cape Cod area was rapid in geologic terms. The minimum radiocarbon age of material found in the glacial drift indicates that the ice had reached Cape Cod more than 21,000 years ago. The maximum advance of the Laurentide ice sheet in the New England area is marked by the terminal moraines on Martha's Vineyard and Nantucket. At the time of maximum ice advance, sea level was about 300 feet lower than its present level, and the coastal plain extended far to the south of Cape Cod, out to the present edge of the continental shelf. South of the ice margin, meltwater streams flowed across the coastal plain to the sea (Oldale, 1980; 1992) (Figure 2.1). Retreat of the ice must have begun earlier than 18,000 years ago as the ice is thought to have retreated as far north as the Gulf of Maine by that time. This means that the ice had vanished from the Cape Cod area in less than 3,000 years and that most of Cape Cod's glacial landforms were created within about 1,000 years. Individual features may have formed in as little as several hundred years (Oldale, 1992).

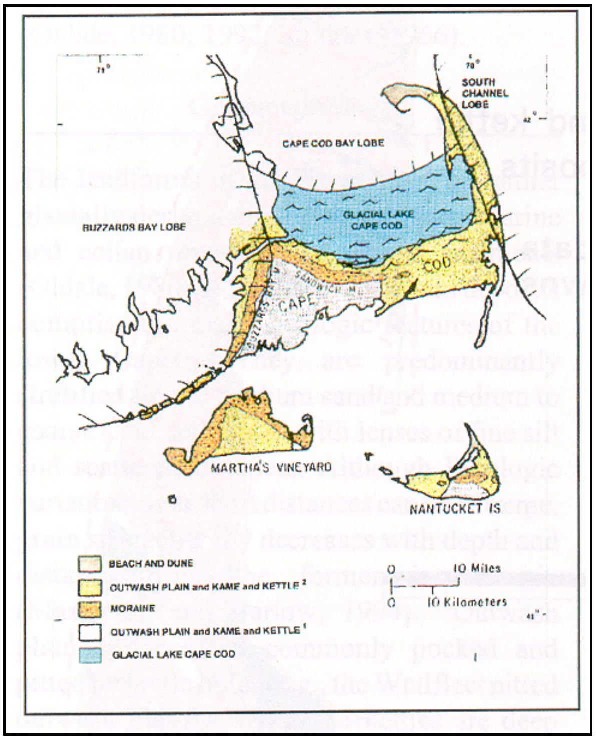
Through the interpretation of landforms, the relative timing of depositional events during glacial retreat has been fairly well determined. Forward progress of the ice sheet was often balanced by melting at the leading edge, so that the ice front maintained its position (ablation) even as it began to retreat. While the ice front was stationary, frequent warm periods caused large amounts of water to melt from the glaciers. The meltwater from the Buzzards Bay Lobe and Cape Cod Bay Lobe carried huge quantities of sediment from the glacier. This sediment formed the gently sloping outwash plains of stratified drift, several miles long, that now comprise much of the inner Cape (Oldale, 1992) (Figure 2.2). Minor re-advances of the ice sheets formed

Figure 2.1. Lobes of the Late Wisconsin Laurentide Ice Sheet During its Maximum Advance in the Cape and Islands Region (Oldale, 1981).



the thrusted Buzzards Bay and Sandwich Moraines located along the north and west margins of the upper Cape (Figure 2.2). No moraine deposits have been identified on the lower Cape.

Figure 2.2. Glacial Lake Cape Cod (Adapted from Oldale, 1992).

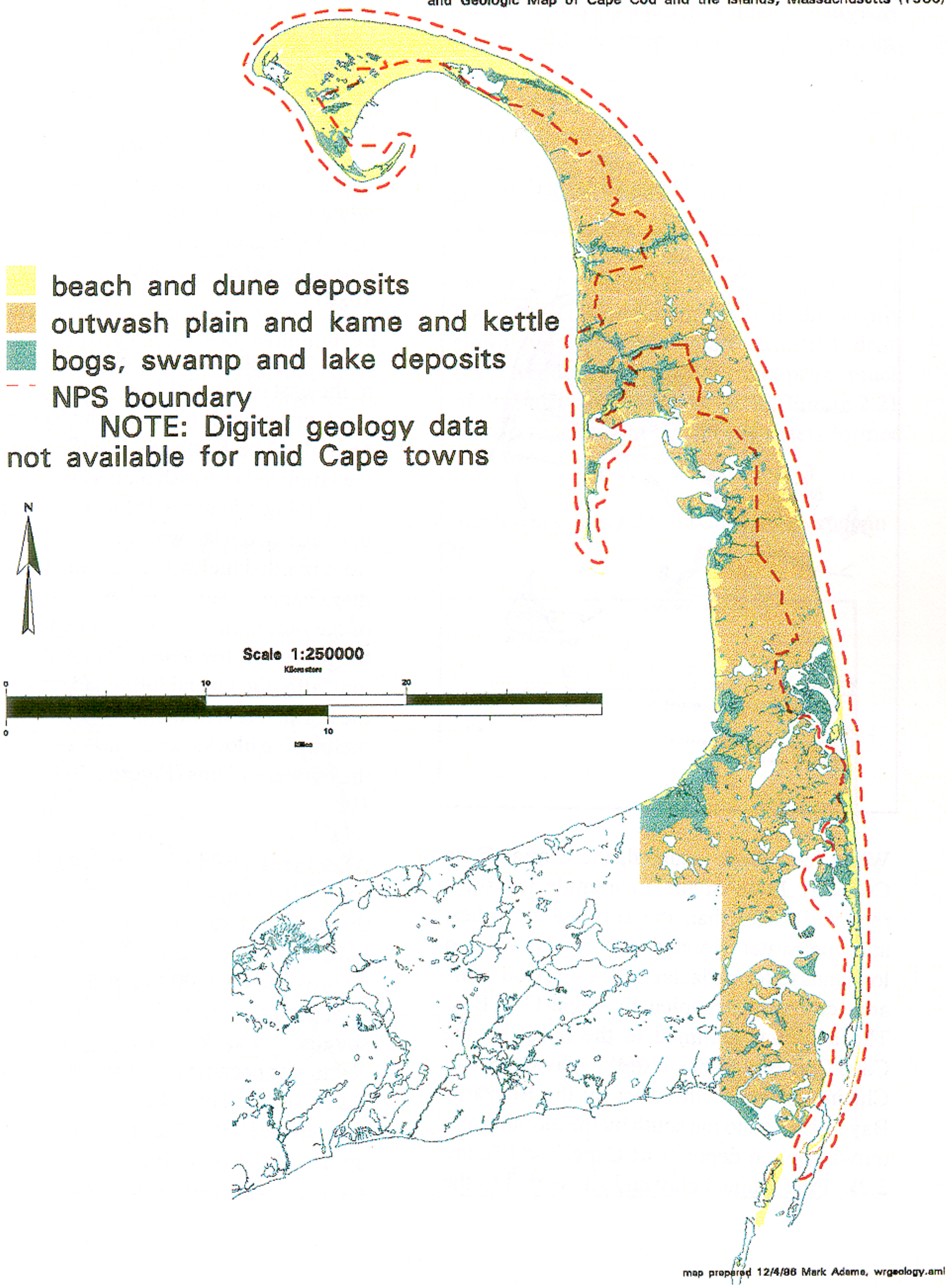


When ice retreat resumed, the central Cape Cod Bay Lobe of the Laurentide ice sheet retreated faster than the surrounding lobes, and meltwater flooded the newly vacated lowlands to form glacial Lake Cape Cod in the area currently occupied by Cape Cod Bay. The lake was dammed to the north by the Cape Cod Bay Lobe, to the east by the South Channel Lobe, to the west by the Buzzards Bay Lobe, and to the south by the moraine and outwash plain deposits of Cape Cod (Figure 2.2). Fine grained clay and silt settled to the lake bottom leaving behind seasonal bands which together represent annual layers or varves as evidence for the lake in the Cape Cod Bay area. The lake periodically broke through the moraine and outwash deposits and partially drained. The escaping water left eroded lowlands, one of which would later be exploited for the construction of the Cape Cod Canal. The lake drained for the last time when both the Cape Cod Bay Lobe and the South Channel Lobe retreated far enough to allow the water to escape to the ocean (Oldale, 1980).

Later stagnations of the South Channel Lobe to the east of Glacial Lake Cape Cod allowed the four outwash plains of the lower Cape to be built. The Eastham, Wellfleet, Truro and the Highland outwash plains are the dominant morphologic features of the lower Cape. This outwash material was built up by deposits from braided meltwater streams flowing west into Glacial Lake Cape Cod. Isolated blocks of ice buried in the outwash deposits of both the inner and the lower Cape melted slowly, long after the glacial lobes had retreated far to the north. As sediments collapsed around the melting ice blocks, kettle holes formed within the outwash plains (Figure 2.3) (Oldale 1980; 1992).After the last of the ice had retreated from the area, winds deposited eolian layers on top of the drift and sea level rose nearly 300 feet (Masterson and Barlow, 1994). Approximately 6,000 years ago, sea level rose high enough to flood Vineyard and Nantucket sounds. Marine reworking of the glacial sediments became an important process. The coastline was smoothed as glacial headlands were eroded back. Marine scarps were formed by the attack of storm surge waves, and the sediment was carried by long-shore drift to

Figure 2.3: Generalized Geology Cape Cod National Seashore

Sources: from USGS Geologic Quadrangle Maps of the United States, 1968,1970,1971, and Geologic Map of Cape Cod and the Islands, Massachusetts (1986)



form bars and spits. In the early period of deglaciation, sea level rise was about 50 feet per 1000 years. From 6,000 to 2,000 years ago, when most of the ice sheets had vanished, sea level rise had slowed to about 11 feet per 1000 years. Since then sea level rise has been approximately 3 feet per 1000 years. At the current rate of sea level rise, Cape Cod will continue to battle the waves for about another 5,000 years before succumbing to the sea (Oldale, 1980; 1992; Strahler, 1966).

Geomorphology

The landforms of the lower Cape are either glacially derived or a product of later marine and eolian reworking of glacial sediments (Oldale, 1980; 1992). Outwash plain deposits comprise the major geologic features of the lower Cape. They are predominantly stratified fine to medium sand and medium to coarse sand and gravel with lenses of fine silt and scattered boulders. Although lithologic variations over short distances can be extreme, grain size generally decreases with depth and distance from the former ice margin (Masterson and Barlow, 1994). Outwash plain surfaces are commonly pocked and pitted by kettle holes (e.g., the Wellfleet pitted outwash plain). When the kettles are deep enough to intersect the water table, a pond is formed. Thus pond level provides a close approximation of the water table. A kettle pond in Wellfleet yielded the oldest radiocarbon dated material at 12,000 years. (Winkler, 1985). This date, as much as 5,000 years after the ice retreated north, indicates that the buried ice blocks may have persisted for several thousand years after the glaciers retreated (Oldale, 1980; 1992).

Small streams and rivers, like the Pamet River, currently occupy oversized valleys within the outwash plains. The valleys were likely cut by ground water springs contacting the land surface at a time when a large pro-glacial lake, formed by large volumes of trapped meltwater, supported higher water tables. Later, with glacial retreat, catastrophic lake drainages enlarged the channels. Today, the streams appear undersized for the older valleys (Oldale, 1980; 1992).

The portion of Truro north of High Head and all of the Provincetown land area are not glacially derived. These areas consist of material derived from coastal erosion of the glacial outwash plains, transported northward, and redeposited by marine and eolian action as a series of recurved sand spits and dunes during the last 6,000 years (Ziegler et al., 1965).

Soils

The soils on the lower Cape are relatively young, having formed since the end of the last glaciation approximately 16,000 to 18,000 years ago. They exhibit only slight alteration of the original parent sand and gravel material and are well drained (U.S. Soil Conservation Service, 1993). Depth of soils on the Cape range from just a few inches in new dune and beach areas of the Province Lands to several feet in others; however, average depth is less than 6 inches. The soil on lower Cape Cod is predominantly a podzol, characteristic of climates that are both cold and humid. Cold temperatures inhibit bacteria and promote frost action, while humid conditions leach water soluble materials downward and support the growth of a vegetative cover (U.S. Soil Conservation Service, 1993; Oldale, 1992). A podzol soil profile typically consists of an upper organic layer undergoing decay, a middle layer of mixed humus and mineral grains, and a lower layer of mostly mineral grains (Oldale, 1992). The historic cultivation and burning of the land on the lower Cape, the associated current abundance of conifers, and the near shore ammonium loss through cation exchange with sea salts create acidic and nutrient poor soil conditions which contribute to stunted vegetative growth (Barnstable County Soil Survey, 1993; Brownlow, 1979; Blood et al., 1991; Valiela et al., 1997).

Soil type on the Cape is very important because it has a direct relationship to the rate at which infiltrating waters are purified. Soils which are coarse and sandy are highly permeable and allow effluent waters to travel quickly over large distances. Low organic matter and clay content provide little contaminant removal through soil sorption or cation exchange. Low organic content of the soils also decreases bacterial immobilization of nutrients as well as denitrification of nitrate-nitrogen. As a result, Cape Cod ground water is susceptible to contamination (Brownlow, 1979). According to the Barnstable County Soil Survey General Soil Map (1993), there are three principle soil types on the lower Cape: (1) *Carver* soil is characteristic of outwash deposits. It is the most common soil type on the lower Cape and is a poor filter for septic systems, sewage lagoons, and sanitary landfills.; (2) *Hooksan-Beaches-Dune Land* soil is characteristic of wind-blown deposits found in the Province Lands and on beaches. It is a poor filter for septic systems, sewage lagoons, and sanitary landfills.; (3) *Ipswich-Pawcatuck-Matanuck* soil is poorly drained and limited to lowland areas (e.g., the Pamet River, Little Pamet River, Herring River and Salt Meadow) (Figure 2.4). It has flooding and ponding potential when used for septic systems, sewage lagoons, and sanitary landfills.

Topography

The topography of the lower Cape between Orleans and North Truro is defined by four pitted outwash plains and is fairly flat. The maximum elevation is 120 feet above sea level at Highland Light. The high ground occurs on the sand cliffs on the Atlantic shore and slopes gradually down to the west. On a local scale, topographic highs and lows are marked by knobs and kettles within the outwash plains. This topography is characteristic of the lower Cape. Kettle holes form inland freshwater ponds, wetlands, and coastal bays and marshes when their depth is below the existing water table (Oldale, 1992).

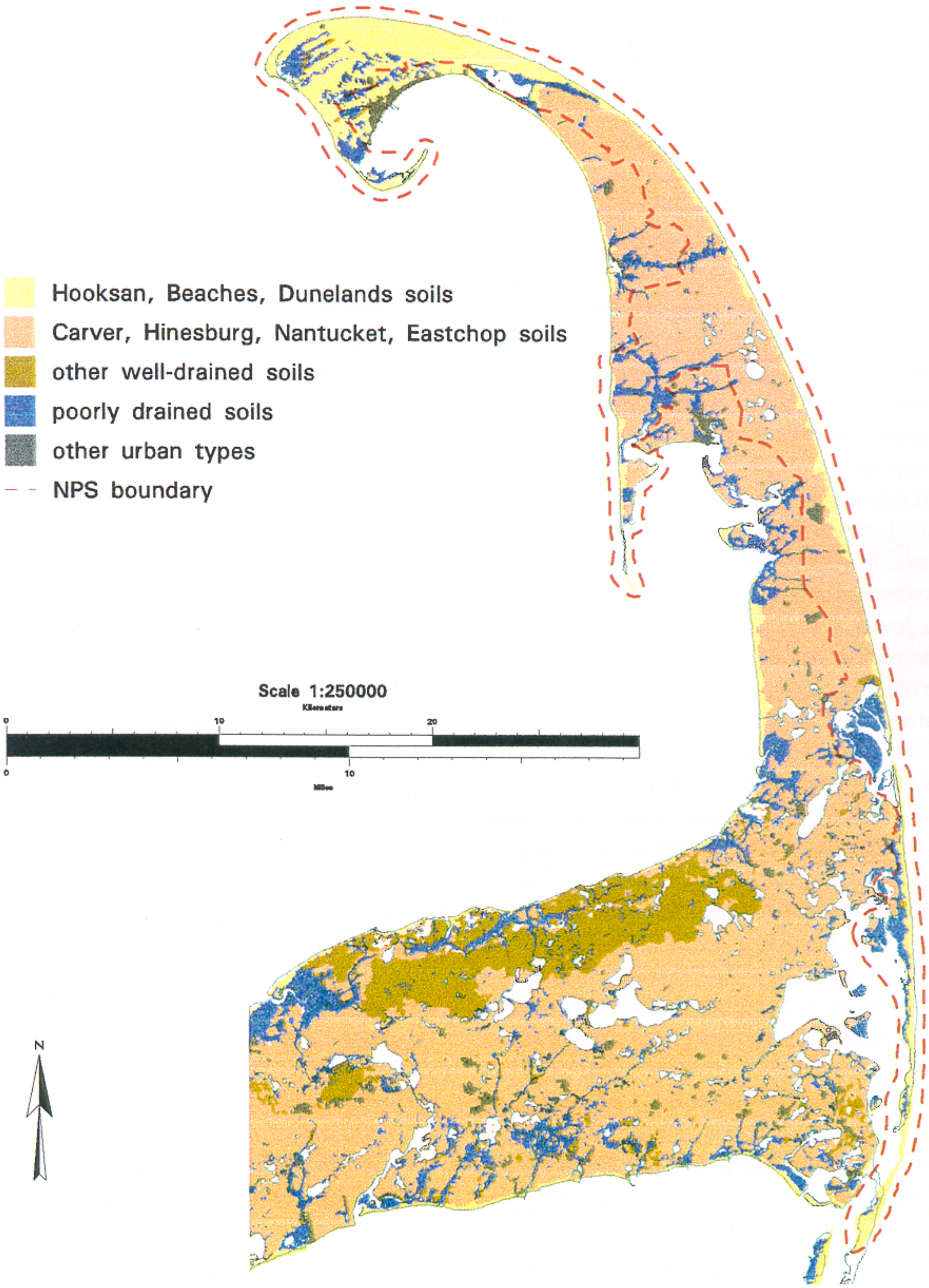
Climate

Cape Cod has a north temperate maritime climate that is characterized by well defined summer and winter seasons. Summer temperatures reach average highs of 77.5 degrees Fahrenheit and average lows around 61 degrees Fahrenheit. The winter months range from an average of 38 degrees Fahrenheit to 24 degrees Fahrenheit (Urish et al., 1993). Due to the moderating effects of the ocean, the Cape temperatures are on average two to three degrees Fahrenheit cooler in the summer and several degrees warmer in the winter compared to mainland temperatures. The average growing season, between the first and the last killing frosts, is 200 days, considerably longer than most inland locations (Strahler, 1966). Average precipitation on Cape Cod varies from about 40 inches per year on the lower Cape to 45 inches per year near the Cape Cod Canal. In the 1960s and1970s, total annual precipitation on the lower Cape ranged from a low of 26.5 inches to a high of 66 inches.

Water Resources Management Plan

Figure 2.4: Generalized Soil Types
Cape Cod National Seashore

Sources: from USDA Soil Conservation Service, Soil Survey of Barnstable County, Massachusetts, 1993



Winds on the Cape, predominantly from the northwest in the fall and winter and southwest in the summer, impact the formation of the lower Cape significantly as they are the primary building force for dune fields. When winds from the northeast bring storms, east facing shorelines can suffer from significant erosion produced by the energy of the storm (Brownlow, 1979).

GROUND WATER

The Hydrologic Cycle

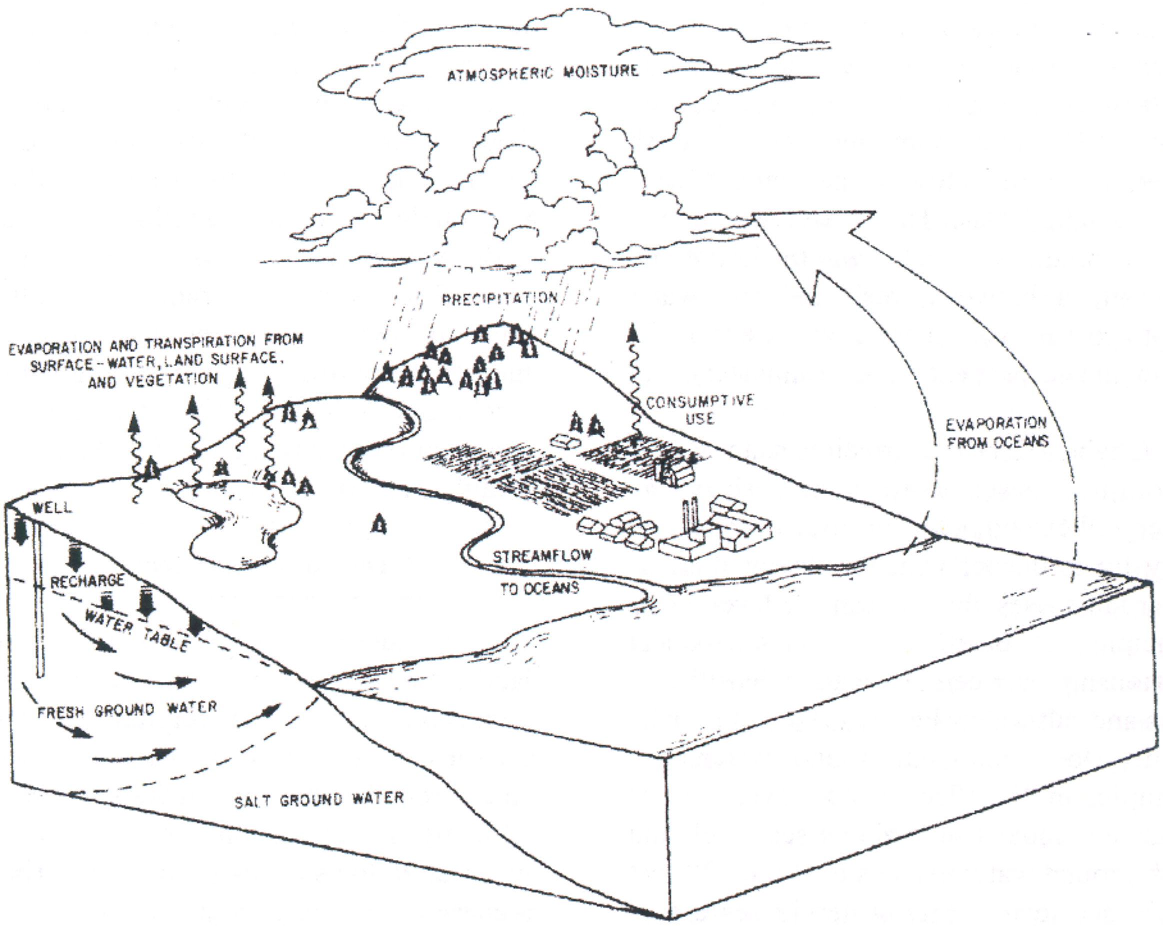
About half the precipitation falling on the lower Cape is returned directly to the atmosphere by evaporation and by plant transpiration (See Figure 2.5). The remaining half rapidly infiltrates the permeable sand and gravel stratified drift of the lower Cape outwash plains, where it fills the voids between unconsolidated mineral grains. On the lower Cape, all ground water has local precipitation as its source. As evidenced by the absence of any significant surface drainage features, less than 1 percent of all precipitation collects as overland runoff to streams and ponds (Wilson and Schreiber, 1981; LeBlanc et al., 1986). Once in the subsurface, the water flows down gradient between the pore spaces in the sedimentary deposits, and under the influence of gravity, it eventually enters the ocean (Oldale, 1992; Nemickas et al., 1989) (Figure 2.5). Water evaporates from the ocean surface to atmospheric water vapor, which condenses to fall again as rain or snow.

Hydrogeology

Geologic materials that are saturated with abundant freshwater are called aquifers. The ability of a material to hold and transmit water is largely dependent on its porosity, that is the number, size, and interconnectedness of the pore spaces between particles. Deposits consisting primarily of large sized sand and gravel particles (e.g., outwash deposits) transmit more water than deposits of finer grained silt and clay size deposits (e.g., lake deposits). Well sorted, stratified sediments (e.g., outwash deposits) are not so easily compacted and are described as having a high hydraulic conductivity or transmissivity (Fetter, 1994). Poorly sorted sediments of mixed grain sizes (e.g., till) have a poor capacity to transmit water because the smaller particles fill the voids between the larger particles.

The thick, glacial sand and gravel outwash plain of the lower Cape can be thought of as a huge sponge with a large capacity for water storage. Precipitation on the land surface easily percolates down through the soil until it comes to a level saturated with water. This level is the water table. Pore space above the water table, where water and air mix, is known as the unsaturated zone. Below the water table is the ground water or saturated zone, where all pore space is completely filled by water. An unconfined aquifer is one in which the water table forms the upper boundary (Freeze and Cherry, 1979). A confined aquifer is one that lies between two layers of geological material having very poor capacity to transmit water, such as silt and clay. Unconfined aquifers occur near land surface, whereas confined aquifers tend to occur at depth. Most of the ground water on the lower Cape occurs under unconfined conditions, although there are small areas of confinement in the vicinity of localized silt and clay lenses (Strahler, 1966). Lenses of silt and clay commonly exhibit conductivities of less than 1 foot per day creating a serious impediment to vertical flow (Martin, 1993).

Figure 2.5. The Hydrologic Cycle. Fresh water on the Cape depends solely on the precipitation that falls locally. There is no underground river bringing fresh water to Cape Cod (Oldale, 1992).



The outwash deposits present by far the best opportunities for ground water development on the lower Cape. They are not only thick, but consist of sand and gravel which has high hydraulic conductivities of 100 to 500 feet per day and provides excellent well yields. In these conditions, two foot diameter wells with a 10 foot screened length commonly yield 250 to 1000 gallons per minute (LeBlanc et al., 1986; Guswa and LeBlanc, 1981).

Thousands of years of melting glacial water and precipitation have built up four distinct subsurface reservoirs of fresh ground water hundreds of feet thick on the lower Cape. Since fresh water is less dense than salt water, rain infiltrating the subsurface rests atop and depresses the surface of the salt water. In each of the lower Cape's four aquifers, a lens-shaped body of fresh water exists, which is thickest at its center. A vertical cross section of the lower Cape's aquifers would show that the fresh and salt waters meet on a surface that starts near the shoreline and slopes steeply down below the center of the peninsula from both sides (Figure 2.5). The upper surface of the freshwater lens, defined by the water table, is convex up and the lower surface, defined by the fresh water-salt water interface, is convex down. The maximum thickness of fresh water, therefore, is toward the center of each lens (Oldale, 1992). The top of the aquifer is marked by the water table and the bottom by the contact between fresh and salt water (depth to bedrock on the lower Cape is far below the deepest extent of fresh water).

The Ghyben-Herzberg principle states that in unconfined coastal aquifers, the fresh ground water will extend below mean sea level about forty times deeper than the height that the water table rises above mean sea level. This principle is based on a mathematical relationship between the relative densities of fresh and salt water (Fetter, 1994), and can be applied to Cape Cod ground water. For example, in Wellfleet, water levels in the ponds are about 8 feet above sea level, and fresh ground water extends to about 320 feet below sea level. Freshwater lenses are as much as 200 feet thick in Truro, 250 feet thick in Wellfleet, and 275 feet thick in Eastham (Oldale, 1992).

The water table on the lower Cape is not a perfectly horizontal surface, but has a gentle slope or hydraulic gradient. Ground water moves slowly down slope under the influence of gravity. The lower the hydraulic conductivity of the materials through which the water seeks to travel, the greater the energy required to accomplish that movement and the steeper the resultant slope of the water table. Flow through the very highly conductive materials of the lower Cape outwash plains requires very little hydraulic gradient. Therefore, the slope of the water table is less steep than it would be in less conductive materials. The highest ground water levels occur in the center of each ground water lens and create a linear band of high water table along the center of the outer Cape. The hydraulic conductivity in localized areas of silt and clay may be several orders of magnitude less and produce a steeper hydraulic gradient (Oldale, 1992). Ground water flows slowly and radially from higher areas to lower areas down-gradient towards the perimeter of the aquifer where it finally discharges to the sea, salt water bays, inlets, canals and streams (Figure 2.5) (Oldale, 1992; Strahler, 1966).

Ground Water Recharge

Ground water recharge occurs over the entire land surface of the lower Cape. The highly permeable soils allow precipitation access to the subsurface equally in all areas. However, since ground water flows radially from water table highs near the center of the aquifers to water table lows at the perimeters, principal recharge areas are generally near the centers of the ground water mounds. Ground water originating in these areas will spend more time in the aquifer than that originating near the periphery of the aquifer. In recharge areas, flow is predominantly downward. Most ground water recharge on the lower Cape occurs during the late fall, winter and spring when precipitation is high and evapotranspiration is low (Guswa and LeBlanc, 1981). Recharge has not been directly measured, but an average rate of 18 inches per year has been used by most previous investigators. This estimate is based on the empirical Thornthwaite method (Thornthwaite and Mather, 1957) which relates recharge to climatological data.

Essentially, the average yearly recharge is equal to the average yearly precipitation less that lost to evapotranspiration and direct overland runoff. On the lower Cape, annual recharge variability does tend to follow annual precipitation variability. The lower Cape, along with the rest of the northeast, suffered a drought in the mid-1960s from which it recovered in the 1970s. The years from 1964 to1966 experienced the least precipitation and show record low water levels. The years from 1972 to 1973 were unusually wet and show record high water levels (Guswa and LeBlanc, 1981; LeBlanc, 1986).

Recharge may be locally reduced due to small scale variability of evapotranspiration and the presence of man-made impermeable surfaces. High evapotranspiration occurs over ponds and other areas where the water table is close to or at the surface. Pond evapotranspiration rates are estimated to be about 28 inches per year on the lower Cape. Therefore, net aquifer recharge under ponds is about 12 to 16 inches per year depending on the local precipitation rate (Guswa and LeBlanc, 1981). Impermeable surfaces such as pavement and roofs channel precipitation directly to storm drains, streams, and the ocean. Wastewater treatments plants, though not presently operational nor even proposed for the National Seashore towns, also decrease recharge if effluent is directly discharged into the ocean. Artificial runoff is a net loss of recharge (Ryan, 1980).

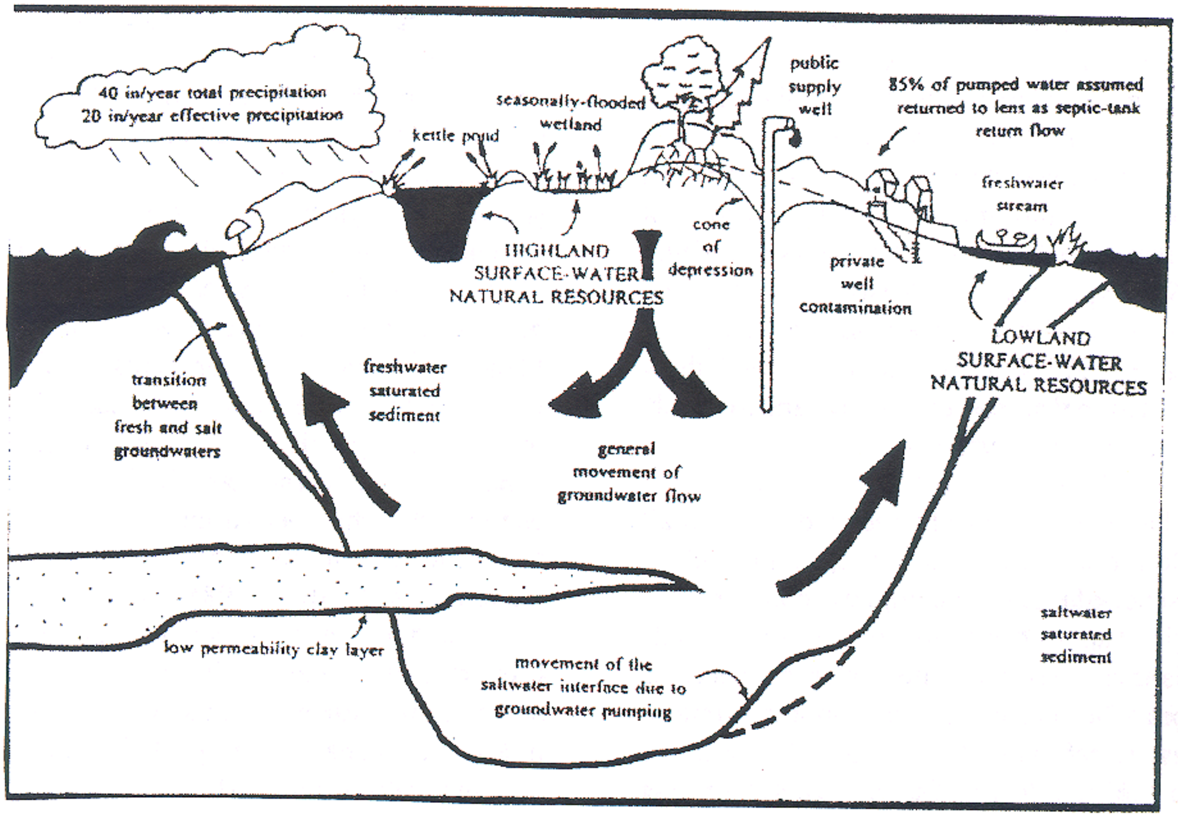
Ground Water Discharge

Any water entering the aquifer will eventually leave the aquifer as ground water discharge to streams, wetlands, wells, springs, and the ocean near the lateral boundaries of the aquifer (Massachusetts Department of Environmental Management, 1994). In addition, discharge by evapotranspiration can be significant in ponds and low lying areas when the water table is very near the surface and plant roots reach the saturated zone. In discharge areas flow is predominantly upward (Figure 2.6) (LeBlanc et al., 1986). Many specific ecosystems in these areas are dependent on sustained ground water discharge volume. Stream flow is also maintained by fresh ground water discharge. Estuary and marsh environments depend on fresh ground water input to maintain the proper salinity, pH, and water chemistry (Martin, 1993). Freshwater discharge to high energy shoreline environments, although insignificant in terms of salinity balance and water levels (Martin, 1993), does control the position of the fresh water-salt water interface (Fetter, 1994), and likely influences near-shore pore water chemistry and related interstitial fauna (Portnoy, 1996, personal communication, National Park Service).

Ground Water Levels

The altitude of the water table is controlled by a variety of factors: proximity to discharge areas, areal distribution of recharge, artificial recharge, proximity to pumping wells, hydraulic conductivity of the sediments, and seasonal and long-term recharge variability. Ground water fluctuations are generally smallest near the shore and greatest inland. In contrast, coastal areas are the most responsive to the loading and unloading effects of diurnal tidal fluctuations. Tidal influences cause fluctuations of fresh ground water levels similar to, but more subdued than, those of the sea water. Tidal effects dissipate rapidly away from the coast. An observation well 500 feet

Figure 2.6. Inland/Coastal Surface to Water Natural Resource Relationships (modified from Sobczak and Cambareri, 1995).



from Wellfleet Harbor exhibited tidal effects one-sixth those experienced in the harbor (LeBlanc et al., 1986). Seasonal high levels occur in early spring and low levels in the fall.

Unless they are perched on low permeability sediments, the vast majority of the lower Cape's ponds and wetlands are connected hydraulically to the ground water flow system and are an expression of the water table at that location. Compared to other parts of the aquifer, water table elevations across ponds are relatively flat because there is little resistance to flow. Water table contours follow the natural gradients of the pond, bending up at the up-gradient end and down at the lowest gradient of the pond. This shape focuses ground water inflow into the up-gradient ends of ponds and disperses pond water outflow to the surrounding aquifer at the down-gradient ends. Consequently, ponds are often areas of ground water through-flow (Barlow, 1994a).

The Flow System

The Cape Cod aquifer system consists of six distinct ground water reservoirs called ground water lenses or flow cells. The land area over each flow cell constitutes its recharge area. The lenses are separated from each other by bays, marshes, streams and glacial outwash valleys which constitute the discharge areas. Four of these flow cells are located on the lower Cape (Figure 2.7). Each flow cell is characterized by a ground water mound.

Under natural conditions, the flow cells or ground water lenses, are physically in contact with each other but hydraulically separate. Ground water elevations, movement, and water quality in one flow cell do not affect neighboring flow cells (Martin, 1993), though some interconnections may develop at times of extreme drought or other stress on the aquifer system (Guswa and LeBlanc, 1981). Under natural conditions, a ground water lens is assumed to be in a state of dynamic equilibrium. The equilibrium is dynamic because seasonal and annual fluctuations in precipitation and recharge result in corresponding fluctuations in water level and discharge. Over the long-term, however, the amount of water entering the lens as recharge is balanced by the amount leaving as freshwater discharge; the natural system is balanced (Sobczak and Cambareri, 1995). Vertical boundaries of the lower Cape flow cells are the water table at the top and the freshwater/saltwater interface at the bottom.

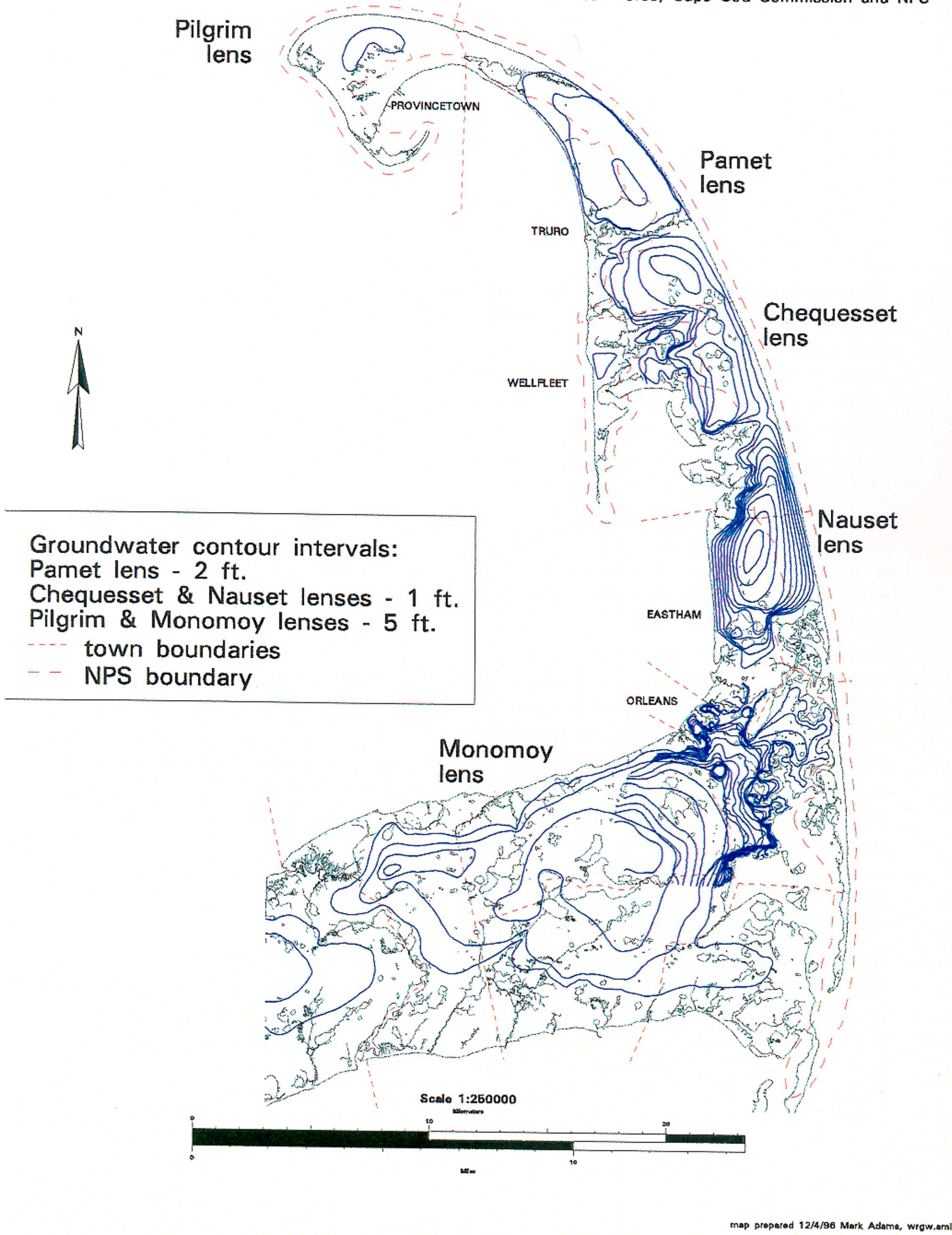
The U.S. Geological Survey and Cape Cod Commission use different names to describe the six flow cells on the Cape. The Cape Cod Commission nomenclature follows in parentheses and is used predominantly in this report. The West Cape (Sagamore) flow cell underlies the towns of Barnstable, Bourne, Falmouth, Mashpee, Sandwich and Yarmouth; the East Cape (Monomoy) flow cell underlies the towns of Orleans, Brewster, Chatham, Harwich, Dennis, Yarmouth, and the southern part of Eastham; the Eastham (Nauset) flow cell underlies the northern part of Eastham, the southern part of Wellfleet, and 38 percent of the areal extent of the lens is within the National Seashore; the Wellfleet (Chequesset) flow cell underlies northern Wellfleet, southern Truro, and 70 percent of the areal extent of the lens is within the National Seashore; The Truro (Pamet) flow cell contains northern Truro and 54 percent of the areal extent of the lens is within the National Seashore; the Provincetown (Pilgrim) flow cell underlies very northern Truro, Provincetown, and 80 percent of the areal extent of the lens is within the National Seashore (Figure 2.7). Only the Sagamore, Monomoy, Pamet, and Chequesset cells currently contain public water supplies (Oldale, 1992).

Nauset Lens

The Nauset lens is the southern-most of the lower Cape flow systems (Figure 2.7). No public water supplies are currently located here. The aquifer consists of an upper, 100 foot thick unit of sand and gravel above a greater than 300 foot thick lacustrine unit of fine to very fine sand, silt and clay. The fresh water-salt water interface is within the fine-grained unit 200 to 300 feet below sea level and well above the bedrock contact. The conductivity contrast between the coarse and fine unit is considered so great that in models of this lens, very little water flows through the fine grained unit (Barlow, 1994b).

Figure 2.7: Groundwater Lenses Cape Cod National Seashore

Source: Lower Cape Cod Groundwater Task Force, Cape Cod Commission and NPS



The southern edge is at the Town Cove and Boat Meadow River area just north of the Eastham / Orleans border and the northern limit is at Blackfish Creek. The land surface over the Nauset lens is approximately 3 miles across at its widest point and 7 miles long. The average maximum ground water elevation is 18 feet above mean sea level (Massachusetts Department of Environmental Management, 1994). Ground water elevations have fluctuated a maximum of 5.5 feet from the wettest season to the driest season on record (1975 to 1987) (Janik, 1987; Massachusetts Department of Environmental Management, 1994).

Chequesset Lens

The Chequesset aquifer is immediately north of the Nauset lens (Figure 2.7). It lies beneath the southern third of Truro and the northern two-thirds of Wellfleet. The southern Boundary is at Blackfish Creek and the northern boundary is the Pamet River. Geologic conditions are similar to the Nauset lens. There are currently no large volume public water supplies and only one small volume public well supplying approximately 30 households in the Coles Neck area of Wellfleet. The land surface over the Chequesset lens is approximately 3 miles across at its widest point and 6 miles long. The average maximum ground water elevation is 8 feet above mean sea level (Massachusetts Department of Environmental Management, 1994). The annual range of ground water levels in the Chequesset lens is approximately 2 to 3 feet (Cambareri, 1986). Ground water elevations have fluctuated a maximum 6 feet from wettest to driest season on record 1978 to1987 (Janik, 1987).

Pamet Lens

The Pamet lens is immediately north of the Chequesset lens (Figure 2.7). It lies beneath the northern two-thirds of Truro. The Pamet lens also has a similar geologic setting as the Nauset and Chequesset aquifers. The southern boundary is Pamet River and the northern boundary is the Pilgrim Lake and Salt Meadow area. The land surface over the Pamet lens is approximately 2.75 miles across at its widest and 6 miles long. Average maximum elevation of the water table in the Pamet aquifer is 6 feet above mean sea level (Mass. Department of Environmental Management, 1994). The annual range of ground water levels in the Pamet lens is approximately 2 to 3 feet (Cambareri, 1986). Maximum ground water fluctuation has been 3.5 feet between the wettest and driest periods on record 1973-1987 (Janik, 1987). The Pamet lens is the only lower Cape aquifer currently utilized for large volume public water supply. The Pamet lens serves as the water supply for the Towns of Truro and Provincetown, the North Truro Air Force Base Station (now closed) and the National Seashore (Cambareri, 1986). It is the most sensitive of the lower Cape's aquifer systems due to its small size, its equilibrium with surrounding sea water, and the withdrawal demands placed upon it (Massachusetts Department of Environmental Management, 1994).

Pilgrim Lens

The Pilgrim lens is the farthest north of the lower Cape flow systems (Figure 2.7). It underlies Provincetown and extends south to the Pilgrim Lake / Salt Meadow area in Truro. The land area over the Pilgrim lens is approximately 3 miles across at its widest and 7 miles long. The average maximum water table elevation is 5 feet above mean sea level (Mass. Department of Environmental Management, 1994). It is the only lower Cape aquifer not contained within glacial outwash deposits. Marine reworking of the lower Cape highlands has created a recurved spit covered with eolian sand dunes. This material constitutes the aquifer matrix. The Pilgrim lens has naturally high levels of iron, manganese and chloride, perhaps resulting from the formation and subsequent burial of many wetland areas as sand accumulated at the tip of Cape Cod. The poor water quality and the very high development density in Provincetown account for the absence of any public or private drinking water withdrawal from the Pilgrim lens. Instead Provincetown imports its water supply from the Pamet lens (Cambareri, 1986). The Pilgrim lens has been omitted from most ground water studies due to its lack of existing or potential drinking water supplies.

Ground Water Contamination

Ground water on the Cape is withdrawn from shallow sand and gravel aquifers that are susceptible to contamination from anthropogenic sources (Oldale, 1992). The generally shallow depth to the water table minimizes the time and distance required for contaminants to reach the ground water. Once in the subsurface, contaminants tend to move in a plume shape following ground water flow patterns. Contaminants are spread by advection, physical transport in the direction of ground water flow, and dispersion, mixing of the dissolved components with the surrounding water in three dimensions. The movement of contaminants is retarded by adsorption, the process by which dissolved components in the ground water adhere to particles in the aquifer matrix, and both chemical and biochemical reactions between the contaminant and other aquifer components (LeBlanc, 1984). Ion exchange, the process by which ions in the ground water substitute for similarly charged ions in the aquifer matrix, is the most common of chemical and biochemical reactions. The sandy soils of the lower Cape are low in organic content and have a poor capacity for attenuating contaminants by either adsorption or ion exchange (Weiskell et al., 1996; Zoto and Gallagher, 1988). A 1984 study of a sewage plume at Otis Air Force Base on the upper Cape, concluded that conservative ions such as boron, sodium, and chloride move rapidly through the subsurface under the influence of advection and dispersion (LeBlanc, 1984). Phosphorus was found to be greatly restricted by adsorption. Nitrogen in the form of ammonium was biochemically oxidized to nitrate through a reaction with dissolved oxygen in the ground water. Nitrogen in the form of nitrate moved freely through the subsurface under the influence of advection and dispersion (LeBlanc, 1984).

There are three principal types of pollutants impacting the ground water resources of the lower Cape: organic, inorganic, and biological. Organic pollutants contain carbon in their structures and are generally related to the petroleum products or solvents that are ubiquitous in modern, industrial society. Possible mechanisms for entrance to the ground water range from leaking underground storage tanks and illegal dumping to the use and disposal of household cleaning supplies and septic system cleaners (Janik, 1987; Cape Cod Planning and Economic Development Commission, 1978). Inorganic pollutants are those that do not contain carbon in their structure. The most common inorganic pollutants in Cape Cod ground water are ammonium (NH_4), nitrate (NO_3), sodium

(Na), and phosphorus (P). These components can enter the subsurface through septic system waste water, landfills, and road runoff. Nitrate and sodium are the two most prevalent inorganic pollutants in Cape Cod ground water (Janik, 1987). Biological pollutants include viruses, bacteria, and protozoans associated with human fecal matter. The biological pollutant most tested for is coliform bacteria, whose presence may indicate the presence of pathogenic organisms. Ground water contamination issues specific to the outer Cape are discussed in later chapters.

Chapter Three: Watershed Characteristics

The combination of Atlantic coastal plain, maritime, and boreal influences on the Cape provide a unique environment. This once unforested area has given way to forests of pitch pine and heathlands, a rare ecosystem, wooded swamps and freshwater marshes in the riparian areas, and grasslands on the dunes. Areas of vegetation that are not directly influenced by tides or salt water and are well elevated above ground water are referred to as uplands (Godfrey et al., 1978). The upland communities described by Godfrey et al. (1978) include grasslands and meadows, shrublands and thickets, woodlands and forests.

VEGETATION

Forests

The forests, which cover approximately half of the Cape (Figure 3.1a-c), are predominantly pitch pine (*Pinus rigida*), a principal species in the maritime forests and an invader of old fields previously dominated by hardwoods (Brownlow, 1979). Other tree species (Table 3.1) include black oak (*Quercus velutina*) and white oak (*Quercus alba*) which along with the pitch pine, grow in the podzoic soils (Brownlow, 1979) and eventually succeed the pine woodland with suppression of fire (Godfrey et al., 1978). The understory of the pitch pine forests includes several species of shrubs including low bush blueberry (*Vaccinium vacillans*), bear oak (*Quercus ilicifolia*), and black huckleberry (*Gaylussacia baccata*) (Godfrey et al., 1978).

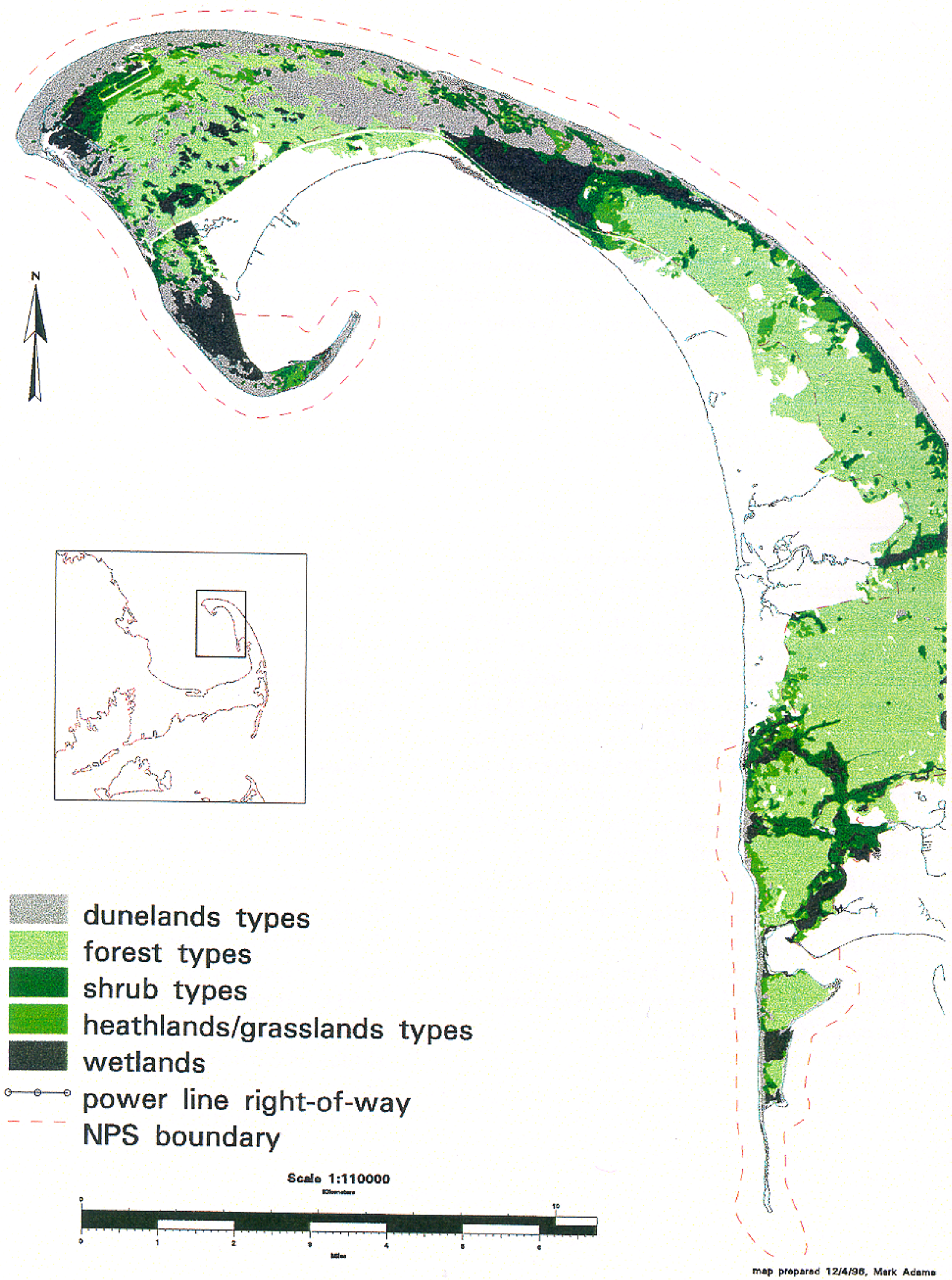
Heathlands

Multi-stemmed, woody plants that dominate open areas are classified as shrublands or thickets if the growth of the shrubs is fairly dense (Godfrey et al., 1978). Godfrey et al. describe heathlands, dominated by members of the heath family (Ericaceae), as one of the most distinctive shrub communities on the Cape (Table 3.1). Bearberry heath (*Arctostaphylos*), beach heather heath (*Hudsonia*), and huckleberry- blueberry heath (*Gaylussacia-Vaccinium*) are the dominant subtypes of heathlands on the Cape (Figure 3.1a-c). Due to increased natural succession of pine and oak, heath communities are decreasing in size. The Cape Cod National Seashore classifies the heathlands as a "Special Status Plant Community" (Carlson et al., 1991). Besides heathlands, mixed coastal shrubs (occurring on the dunes) and lowland shrubs (occurring on the border of wetlands) are also established shrub communities within the National Seashore (Godfrey et al., 1978).

Water Resources Management Plan

Figure 3.1a: Generalized Vegetation within Cape Cod National Seashore Boundary

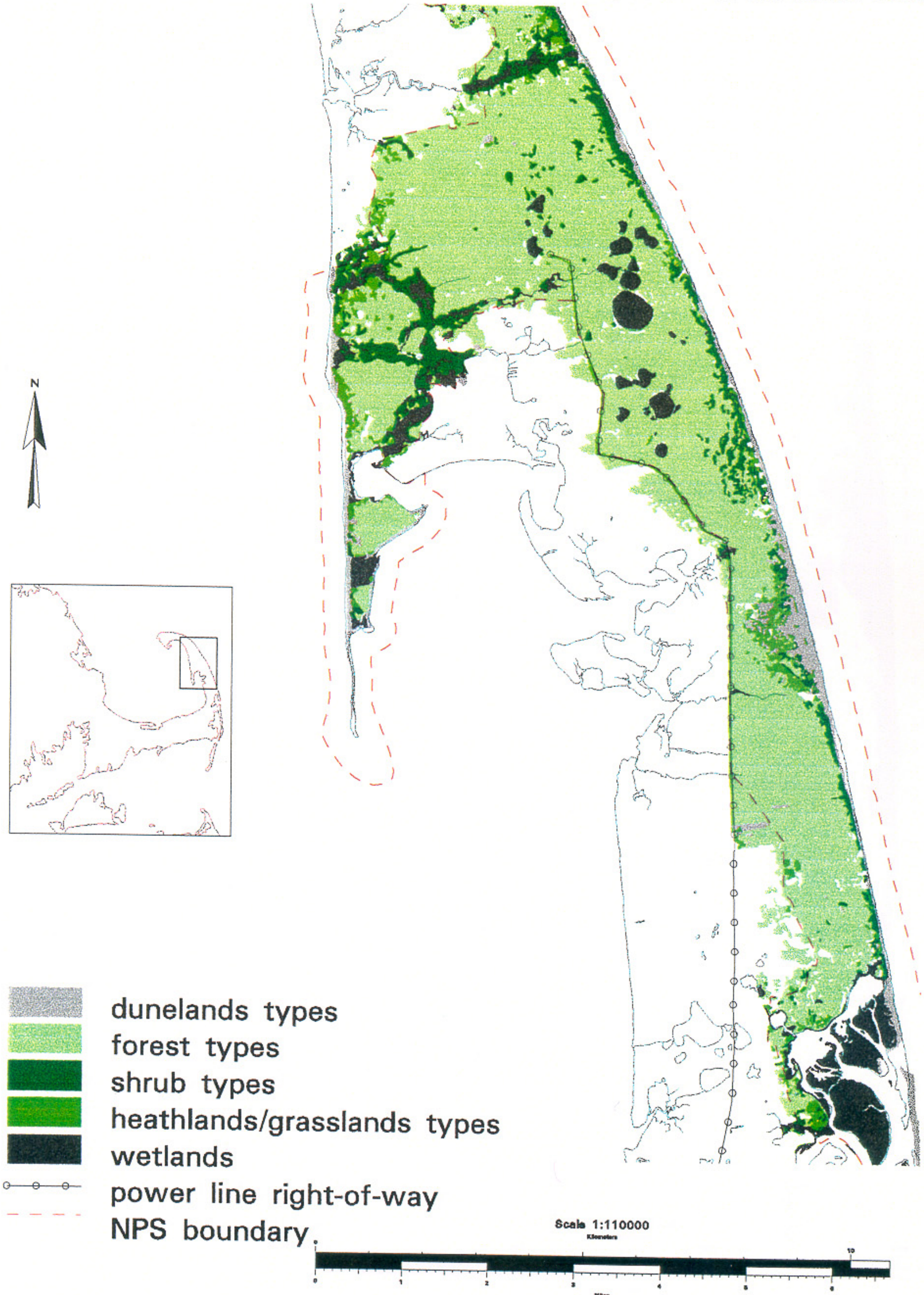
Sources: Vegetation interpreted from 1991 aerial photos by NPS staff.



Water Resources Management Plan

Figure 3.1b: Generalized Vegetation within Cape Cod National Seashore Boundary

Sources: Vegetation interpreted from 1991 aerial photos by NPS staff.



map prepared 12/4/98 Mark Adams wrvegw.aml

Figure 3.1c: Generalized Vegetation within Cape Cod National Seashore Boundary

Sources: Vegetation interpreted from 1991 aerial photos by NPS staff.

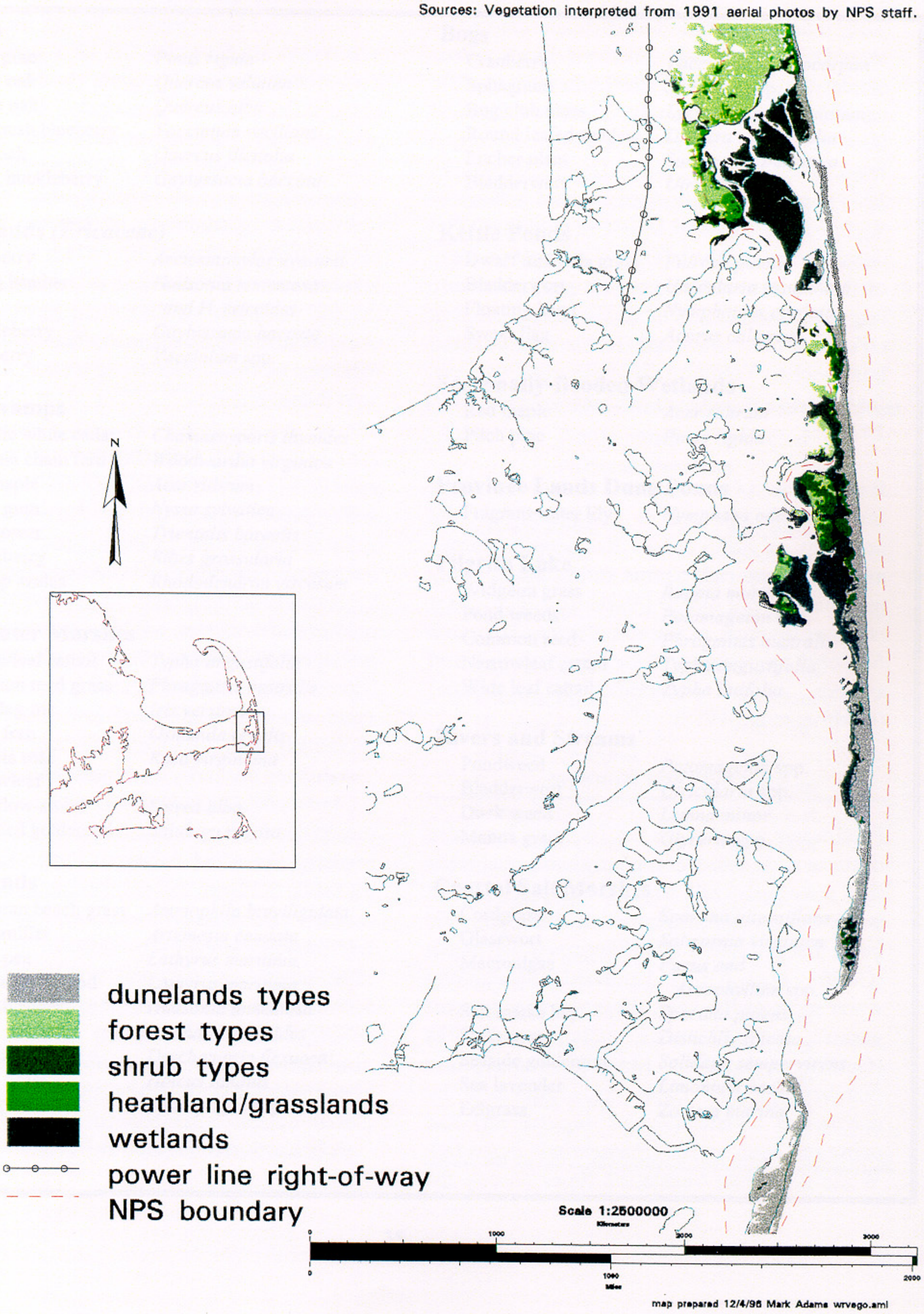


Table 3.1. Summary of characteristic plants by habitat.

Forests

Pitch pine	*Pinus rigida*
Black oak	*Quercus velutina*
White oak	*Quercus alba*
Low bush blueberry	*Vaccinium vacillans*
Bear oak	*Quercus ilicifolia*
Black huckleberry	*Gaylussacia baccata*

Heathlands *(Ericaceae)*

Bearberry	*Arctostaphylos uva-ursi*
Beach heather	*Hudsonia tomentosa and H. ericoides*
Huckleberry	*Gaylussacia baccata*
Blueberry	*Vaccinium* spp.

Tree Swamps

Atlantic white cedar	*Chamaecyparis thyoides*
Virginia chain fern	*Woodwardia virginica*
Red maple	*Acer rubrum*
Black gum	*Nyssa sylvatica*
Star flower	*Trientalis borealis*
Gooseberry	*Ribes grossularia*
Swamp azalea	*Rhododendron viscosum*

Freshwater Marshes

Narrowleaf cattail	*Typha angustifolia*
Common reed grass	*Phragmites australis*
Blue flag iris	*Iris versicolor*
Royal fern	*Osmunda regalis*
Virginia rose	*Rosa virginiana*
Narrowleaf meadow-sweet	*Spirea alba*
Wrinkled goldenrod	*Solidago rugosa*

Grasslands

American beach grass	*Ammophila breviligulata*
Dusty miller	*Artemesia caudata*
Beach pea	*Lathyrus maritima*
Seaside goldenrod	*Lathyrus maritima*
Beach heather	*Hudsonia tomentosa and H. ericoides*
Hairgrass	*Deschampsia flexuosa*
Velvet grass	*Holcus Ianatus*
Beardgrass	*Andropogon* spp.

Bogs

Cranberry	*Vaccinium macrocarpon*
Sphagnum	*Spagnum* spp.
Bog club moss	*Lycopodium inumdatum*
Round leafed sundew	*Drosera rotundifolia*
Pitcher plant	*Sarracenia purpurea*
Bladderwort	*Utricularia* spp.

Kettle Ponds

Dwarf umbrella grass	*Fuirena pumila*
Bladderwort	*Utricularia resupinata*
Floating heart	*Nymphoides cordata*
Sweet flag	*Acorus calamus*

Seasonally-flooded Wetlands

Red maple	*Acer rubrum*
Pitch pine	*Pinus rigida*

Province Lands Dune Ponds

Fragrant water lily	*Nymphaea odorata*

Pilgrim Lake

Widgeon grass	*Ruppia maritima*
Pond weeds	*Potamageton* spp.
Common reed	*Phragmites australis*
Narrowleaf cattail	*Typha angustifolia*
Wide leaf cattail	*Typha latifolia*

Rivers and Streams

Pondweed	*Potomageton* spp.
Bladderwort	*Utricularia* spp.
Duck weed	*Lemna minor*
Manna grass	*Glyceria* spp.

Coastal Salt Marshes

Cordgrass	*Spartina alterniflora*
Glasswort	*Salicornia virginica*
Macroalgae	*Fucus and Ascophyllum* spp.
Salt marsh hay	*Spartina patens*
Spike grass	*Distichlis spicata*
Seaside goldenrod	*Solidago sempervirens*
Sea lavender	*Limonium nashii*
Eelgrass	*Zostera marina*

Tree Swamps

The Atlantic white cedar (*Chamaecyparis thyoides*) community (Table 3.1) is a tree swamp that establishes itself under very specific conditions that are rare in New England (Godfrey et al., 1978; Motzkin, 1990). Only a few stands remain on the Cape (Brownlow, 1979); one of which is an 80-acre swamp in Wellfleet on National Seashore property. The dense canopy of the white cedar creates a dark, cool, humid microclimate that supports many bog plant species as well as Virginia chain fern (*Woodwardia virginica*) and moss covered hummocks. Traditionally these trees were cut for their decay-resistant properties (Brownlow, 1979).

Red maple (*Acer rubrum*) exists in moist lowland swamps and is often found in the company of white cedar. Red maple swamps and their deep rich humus soils support many members of the tupelo (*Nyssa sylvatica*) plant community such as the star flower (*Trientalis borealis*), gooseberry (*Ribes grossularia*), and swamp azalea (*Rhododendron viscosum*) (Godfrey et al., 1978).

Freshwater Marshes

Freshwater marshes on the National Seashore occur in river drainages, pond shores, and areas that were once salt water, but are now fresh water due to the placement of dikes and tide gates that prohibit tidal influences in the marsh (Godfrey et al., 1978). Saturated with standing water most of the year, these marshes support grasses, sedges, rushes, cattails, and forbs (Godfrey et al., 1978). Many of the freshwater marshes on the Cape are dominated by narrowleaf cattails (*Typha angustifolia*) and common reed grass (*Phragmites australis*). While these two vegetation types occupy the same habitat, they are usually found separately, growing in pure stands. Other plants (Table 3.1) found in the freshwater marshes are blue flag iris (*Iris versicolor*), royal fern (*Osmunda regalis*), and rose (*Rosa virginiana*) (Godfrey et al., 1978). Upslope of the cattails, marshes have wet to moist deep loam soil and are dominated by narrowleaf meadow-sweet (*Spiraea alba*) and wrinkled goldenrod (*Solidago rugosa*) (Godfrey et al., 1978). The freshwater marshes all support valuable habitat for a wide variety of wildlife such as waterfowl, raccoons (*Procyon lotor*), and great blue herons (*Ardea herodias*) as well as a variety of fish species.

Grasslands

The primary grasslands on the seashore are the beachgrass dunes located in the Province Lands, Great Island, Coast Guard Beach, and Nauset Beach (Figure 3.1a-c) (Godfrey et al., 1978). The dunes are dynamic, and their shape and direction of movement depend on prevailing winds, which are a constant force on dune formation (Brownlow, 1979). Godfrey et al. (1978) state that the dunes are stabilized primarily by American beach grass (*Ammophila breviligulata*) which can grow through 10 to 12 inches (.25 to .30m) of newly deposited sands. Other vegetation (Table 3.1) on the dunes includes dusty miller (*Artemesia caudata*), beach pea (*Lathyrus maritima*), seaside goldenrod (*Solidago sempervirens*), and beach heather (*Hudsonia tomentosa* and *H. ericoides*). Hairgrass (*Deschampsia*) dunes, mixed meadows, velvet-grass (*Holcus*) meadows, and beardgrass (*Andropogon*) grasslands are also upland communities located on the National Seashore (Godfrey et al., 1978).

SURFACE FRESHWATER RESOURCES

Bogs

Bogs are poorly drained wetlands that have a floating mat of vegetation on their surface made up of sphagnum moss, cranberries, insectivorous plants, or sedges to name a few (Godfrey et al., 1978). Bogs, typically acidic and low in nutrients, are often found in surface depressions that have accumulated thick layers of peat (Godfrey et al., 1978). There are several types of bogs that occur on the Cape (Figure 3.2a-c) as classified by the U.S. Fish & Wildlife Service Cowardin classification system (Cowardin et al., 1979). The predominant type is the cranberry bog which occurs in the interdune swales of the Province Lands (Brownlow, 1979). The cranberries (*Vaccinium macrocarpon*) thrive in saturated sandy loam soils that are acidic and nutrient poor (Brownlow, 1979). Once referred to as "red gold" by residents of Cape Cod, cranberry bogs are an integral part of the cultural landscape on Cape Cod. In the upper reaches of the Pamet River valley is an abandoned commercial cranberry bog that once served as a cranberry farm for a Cape Cod family from the 1800s through the 1950s.

Plants (Table 3.1) in the bogs include sphagnum (*Sphagnum spp.*), bog club moss (*Lycopodium inundatum*), round leafed sundew (*Drosera rotundifolia*), and insectivorous plants such as the pitcher plant (*Sarracenia purpurea*) and bladderwort (*Utricularia spp.*). Shankpainter Pond is a quaking bog located in the Province Lands, outside of the National Seashore (Figure3.1a-c). Quaking bogs are rare in southern New England and are vegetated mostly with sphagnum moss which floats a few feet above a loose bed of peat (Brownlow, 1979).

Kettle Ponds

Many of the surface freshwater resources on the Cape are kettle ponds, permanently flooded water bodies formed in ice-block depressions left in the landscape after the last glaciers melted about 12,000 years ago (Portnoy, 1995). There are 20 permanently flooded kettle ponds (Figure 3.2a-c) (Table 3.2) within the National Seashore that range from 3 to 90 acres and 60 feet (10 to 21 meters) deep (Portnoy, 1995); all of which occur in the towns of Wellfleet and Truro (Godfrey et al., 1978).

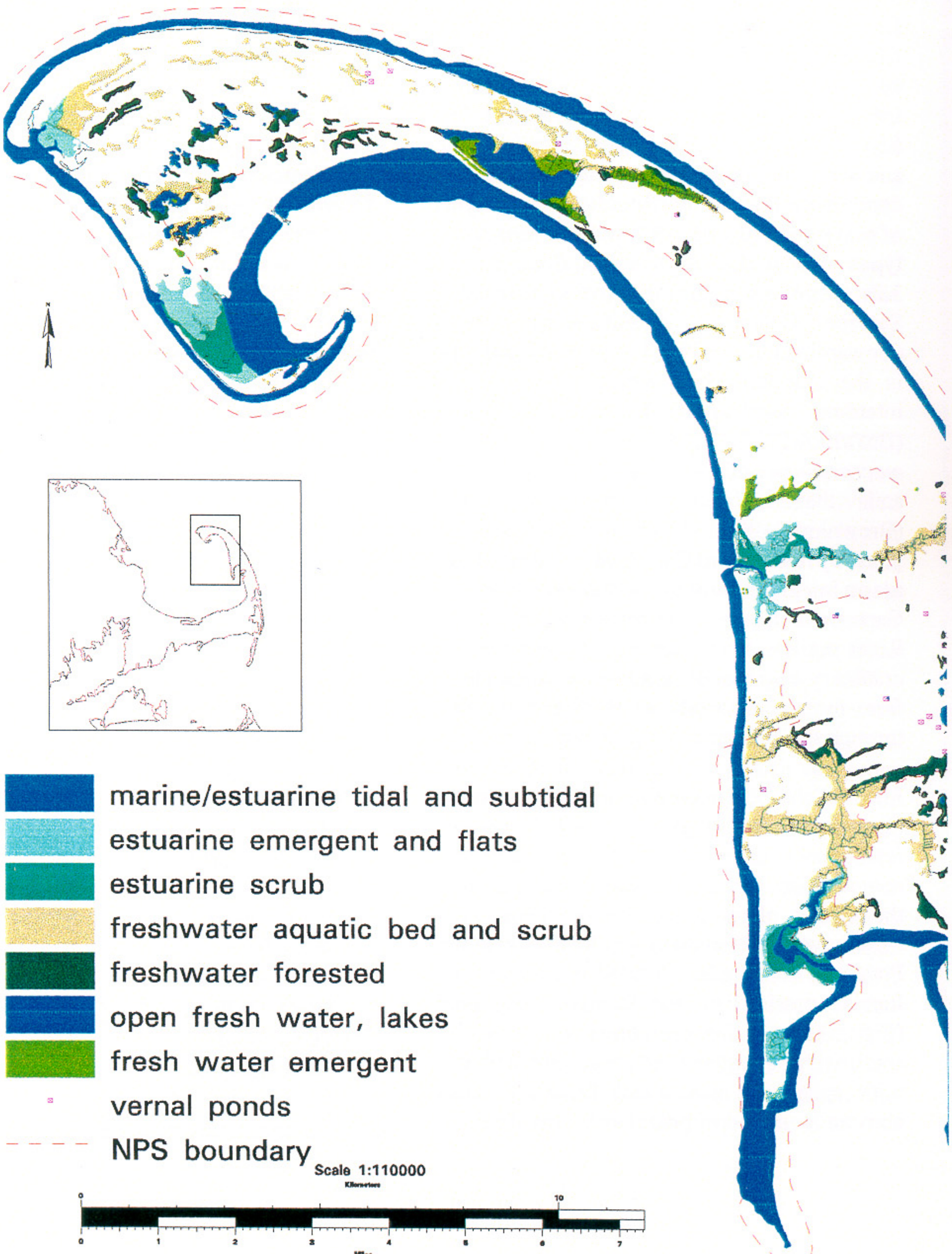
Table 3.2. Kettle ponds in Cape Cod National Seashore.

Kettle Pond	Location
Duck Pond	Wellfleet
Dyer Pond	Wellfleet
Great Pond	Truro
Great Pond	Wellfleet
Gull Pond	Wellfleet
Herring Pond	Wellfleet
Higgins Pond	Wellfleet
Horseleech Pond	Truro
Kinnacum Pond	Wellfleet
Long Pond	Wellfleet
Northeast Pond	Wellfleet
Round Pond-East	Truro
Round Pond-West	Truro
Ryder Pond	Truro
Slough Pond	Truro
Snow Pond	Truro
Southeast Pond	Wellfleet
Spectacle Pond	Wellfleet
Turtle Pond	Wellfleet
Williams Pond	Wellfleet

Water Resources Management Plan

Figure 3.2a: Wetlands
Provincetown/North Truro Quad

Sources: USFWS National Wetlands Inventory, digitized by NPS Denver Service Center.



map prepared 12/4/97, Mark Adams

Water Resources Management Plan

Figure 3.2b: Wetlands Wellfleet Quad

Sources: USFWS National Wetlands Inventory, digitized by NPS Denver Service Center.

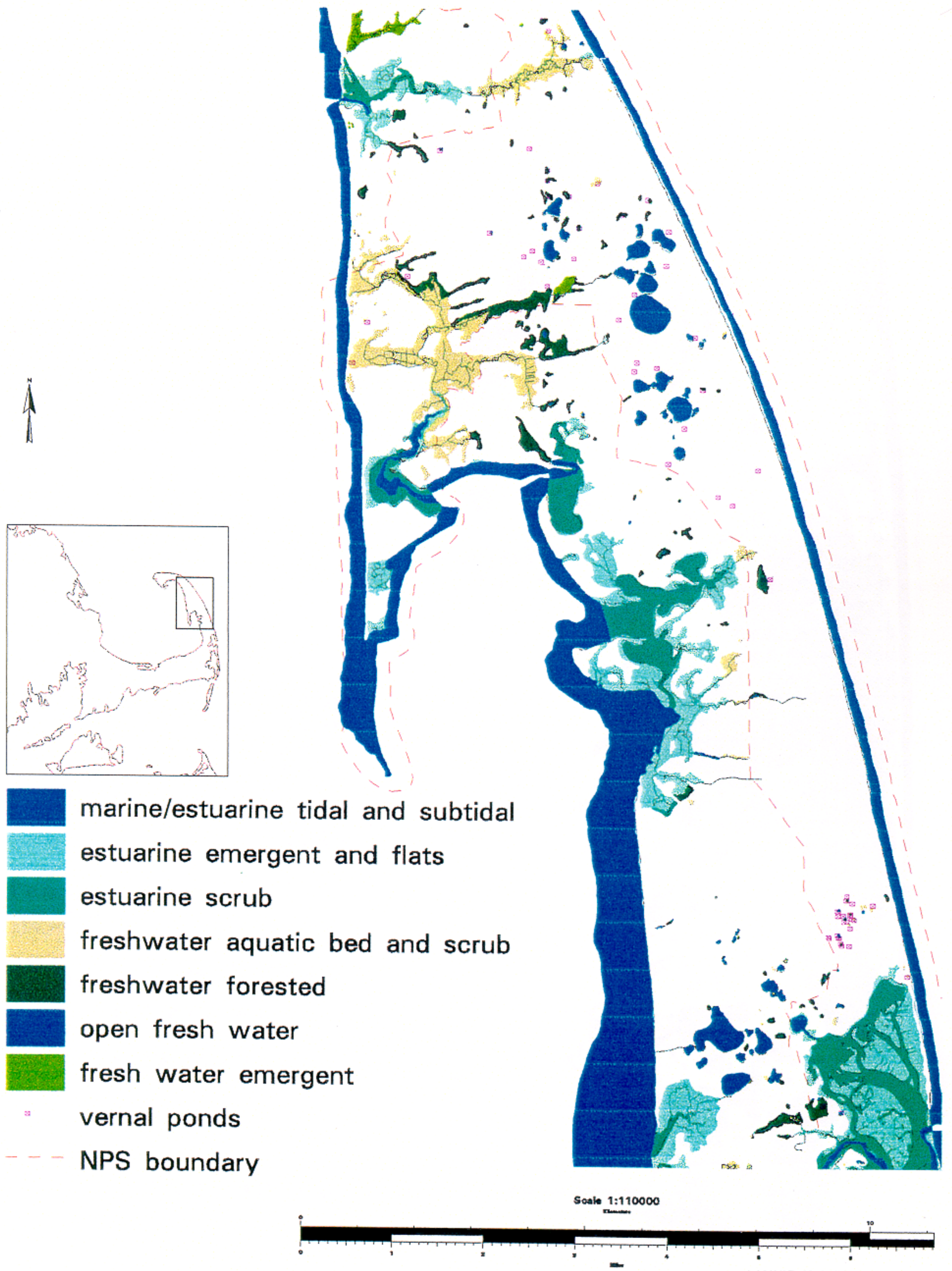
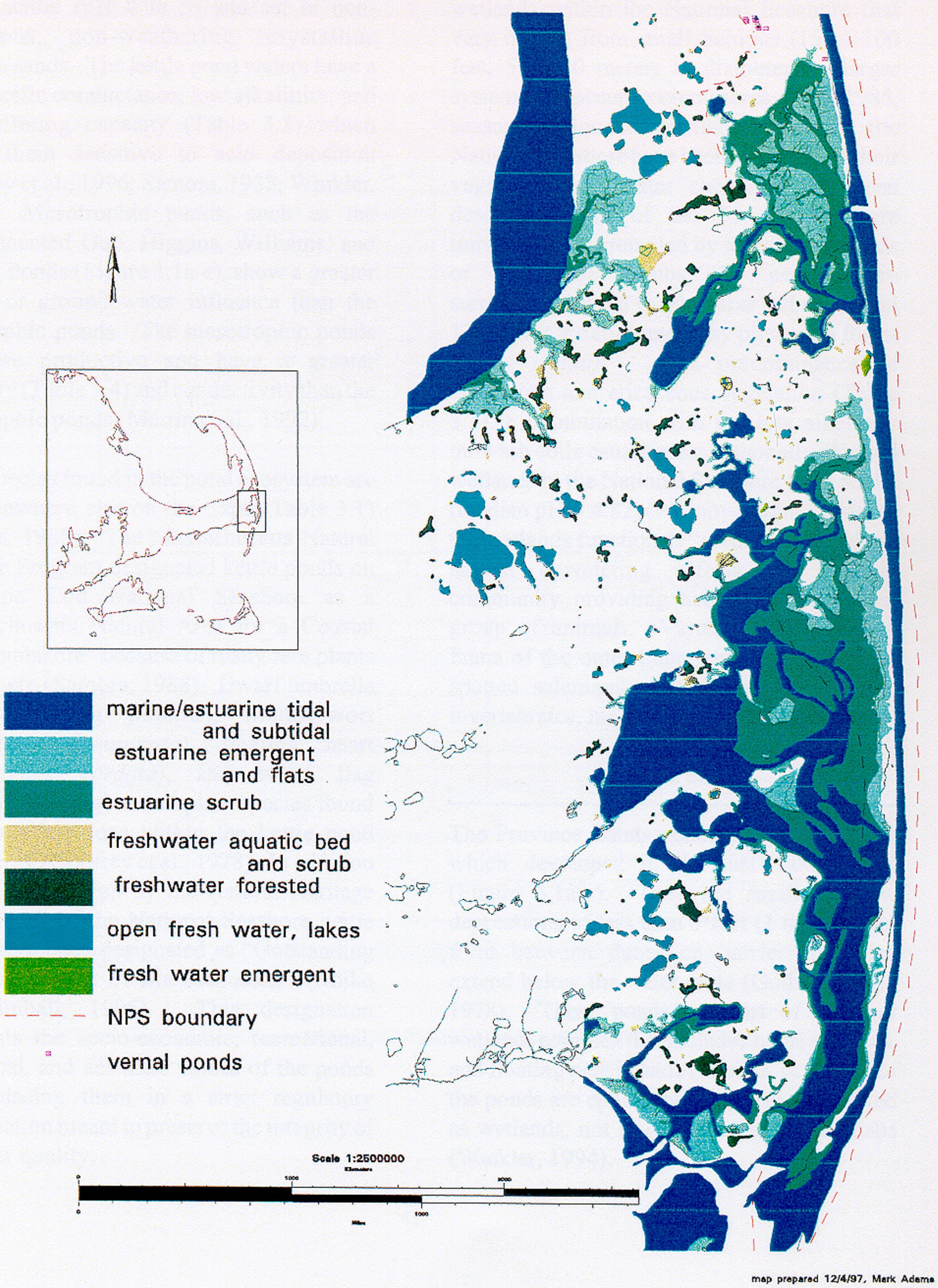


Figure 3.2c: Wetlands Orleans Quad

Sources: USFWS National Wetlands Inventory, digitized by NPS Denver Service Center.



map prepared 12/4/97, Mark Adams

The kettle ponds on the lower Cape are either oligotrophic or mesotrophic (Martin et al., 1992). The landlocked, oligotrophic ponds are highly acidic (pH 4 to 5) and set in non-calcareous, non-weathering, crystalline outwash sands. The kettle pond waters have a low specific conductance, low alkalinity, and low buffering capacity (Table 3.3) which makes them sensitive to acid deposition (Godfrey et al., 1996; Samora, 1988; Winkler, 1985). Mesotrophic ponds, such as the interconnected Gull, Higgins, Williams, and Herring Ponds (Figure 3.1a-c), show a greater marine or ground water influence than the oligotrophic ponds. The mesotrophic ponds are more productive and have a greater alkalinity (Table 3.4) and conductivity than the oligotrophic ponds (Martin et al., 1992).

Some species found in the pond ecosystem are found nowhere else on the Cape (Table 3.1) (Samora, 1988). The Massachusetts Natural Heritage Program designated kettle ponds on the Cape Cod National Seashore as a "Massachusetts Natural Area for a Coastal Plain Pondshore" because of many rare plants found there (Samora, 1988). Dwarf umbrella grass (*Fuirena pumila*), bladderwort (*Utricularia resupinata*), floating heart (*Nymphoides cordata*), and sweet flag (*Acornus calamus*) are all plant species found in various locations within the kettle pond community (Godfrey et al., 1978). In addition to their designation by the Natural Heritage Program, all of the National Seashore kettle ponds have been designated as "Outstanding Resource Waters of Massachusetts" (Rojko and Kimball, 1995). This designation highlights the socio-economic, recreational, ecological, and aesthetic values of the ponds while placing them in a strict regulatory classification meant to preserve the integrity of the water quality.

Seasonally-flooded Freshwater Wetlands

There are 55 documented seasonally-flooded wetlands within the National Seashore that vary in size from small habitats (15 to 100 feet; 5 to 30 meters in diameter) to larger systems that occupy several acres. Since 1985, seasonally-flooded wetlands within the National Seashore have been mapped and their vegetation and water chemistry has been described. Half of the 55 wetlands are immediately surrounded by mixed heathlands or ericaceous shrubs, 31 percent are surrounded by red maple (*Acer rubrum)*, and 13 percent are surrounded by pitch pine forest *(Pinus rigida)*. The predominance of coniferous and ericaceous vegetation (Table 3.1) in combination with the low alkalinity outwash soils causes most seasonally-flooded wetlands in the National Seashore to be acidic (median pH = 4.82) (Portnoy, 1986). Most of the wetlands function as "vernal pools" where annual dewatering affects the aquatic community providing habitat for a distinct group of animals. Vernal pool dependent fauna of the outer Cape include wood frogs, spotted salamanders, and many species of invertebrates, including state-listed species.

Dune Ponds

The Province Lands ponds are young ponds which developed in the last 1,000 years (Figure 3.1a-c). They are small, shallow depressions of less than 3 feet (1 meter), that form between dunes on barrier spits and extend below the water table (Godfrey et al., 1978). These ponds are part of a larger wetlands complex that includes bogs, marshes, and floating peat islands (Table 3.1). Some of the ponds are ephemeral and were designated as wetlands, not as open water, on old maps (Winkler, 1994).

Table 3.3. Acid rain monitoring project data for 16 Cape Cod National Seashore kettle ponds, averages from 1983 to 1993.

Abbreviations are as follows: ANC (acid neutrality capacity); TP (total phosphorus); SO_4 (sulfate); Cl (chloride); NO_3 (nitrate); Na (sodium); Ca (calcium); K (potassium); Mg (magnesium); Mn (manganese); Fe (iron); Al (alumium); Si (silica).

Lake	pH	ANC	TP	SO_4	Cl	NO_3	Color	Na	Ca	K	Mg	Mn	Fe	Al	Si
Duck Pond	4.70	-0.77	2.7	7.93	24.43	0.01	14.96	14.97	1.10	1.00	1.72	0.06	0.09	0.05	0.08
Dyer Pond	4.70	-0.83		8.41	26.10	0.00	3.00	14.93	1.12	0.84	1.90	0.11	0.06	0.04	0.19
Great Pond (T)	6.08	1.77		7.55	29.09	0.02	32.60	16.96	2.65	0.79	1.70	0.02	0.23	0.06	0.17
Great Pond (W)	4.81	-0.64	0.0	6.42	19.68	0.00	5.42	11.12	0.99	0.70	1.40	0.06	0.07	0.04	0.04
Gull Pond	6.63	3.18		8.43	30.49	0.01	4.47	18.41	1.81	1.03	2.48	0.01	0.05	0.01	0.06
Herring Pond	6.54	4.28	15.4	7.40	31.37	0.01	13.38	18.32	2.02	0.91	2.52	0.03	0.22	0.01	1.08
Higgins Pond	6.51	3.03	10.8	7.94	30.07	0.02	10.29	18.31	1.68	0.99	2.53	0.02	0.11	0.01	0.55
Horseleech Pond	5.79	0.67		10.56	38.31	0.04	9.20	22.60	1.56	1.11	3.33	0.17	0.27	0.01	0.67
Kinnacum Pond	4.47	-1.83		6.98	19.15	0.03	11.52	11.13	0.72	0.61	1.39	0.03	0.08	0.10	0.06
Long Pond	4.64	-0.98	3.9	7.54	20.67	0.01	4.00	11.71	1.20	0.78	1.41	0.05	0.05	0.08	0.04
Round Pond	4.81	-0.56	7.1	6.29	16.03	0.01	12.16	9.10	0.97	0.52	1.29	0.05	0.22	0.04	0.08
Ryder Pond	5.18	-0.39		9.17	31.85	0.03	5.80	19.94	1.52	0.84	1.91	0.05	0.10	0.10	0.17
Slough Pond	4.78	-0.66		10.29	27.91	0.02	9.64	16.57	1.35	0.84	2.25	0.04	0.06	0.06	0.08
Snow Pond	5.64	0.65		5.48	20.86	0.00	14.15	12.02	0.96	0.72	1.61	0.04	0.35	0.03	0.11
Spectacle Pond	5.01	-0.11	3.9	8.12	29.04	0.03	8.33	16.39	0.81	0.83	2.18	0.03	0.02	0.03	0.09
Williams Pond	5.92	1.69		8.71	31.54	0.02	51.08	19.43	1.78	1.08	2.52	0.06	0.61	0.04	0.25

Average consists of a minimum of 23 measurements and maximum of 45 measurements, except for Pilgrim Lake (1 measurement).
All units in mg/l except pH (pH units) and Color (PCUs).
Total Phosphorus (ug/l) only for April 1993.

Table 3.4. General characteristics of the kettle ponds of Cape Cod National Seashore. (J. Portnoy, 1998, personal communication, Cape Cod National Seashore). Conductivity data are from April 1998, showing general increases since 1982. pH and alkalinity data are from April 1998; chlorophyll *a* data are from August 1997.

Pond	Maximum Depth (m)	Area (ha)	Conductivity (uS/cm)	pH	Alkalinity (ppm)	Chl *a* mg/m^3	Shore Dwellings	Public Beach	Land-locked
Duck	18	5.1	112	4.76	-0.50	0.8	1	Yes	Yes
Dyer	10	4.8	92	4.85	-0.50	1.7	3	Yes	Yes
Great (W)	15	17.8	123	4.96	-0.25	1.1	8	Yes	Yes
Long	15	15.0	99	4.97	-0.25	2.1	22	Yes	Yes
Turtle	2	1.6	94	4.59	-1.00	3.1	2	No	Yes
Northeast	4	1.7	81	5.16	0.50	1.5	3	No	Yes
Southeast	4	1.1	107	5.03	0.00	1.1	1	No	Yes
Spectacle	7	0.5	145	5.22	0.00	2.2	0	Yes	Yes
Kinnacum	2	0.8	96	4.78	-0.50	1.2	1	No	Yes
Gull	19	44.0	145	6.81	3.25	0.4	21	Yes	No
Higgins	6	11.3	144	6.58	3.25	0.4	7	No	No
Herring	4	8.1	143	6.50	2.75	1.4	2	No	No
Williams	2	3.6	159	5.65	0.50	7.6	3	No	No
Slough	8	11.9	134	5.04	-0.25	1.0	9	No	Yes
Horseleech	5	10.0	171	5.66	0.50	0.3	4	No	Yes
Round (E)	8	2.6	111	5.02	0.00	1.0	1	No	Yes
Round (W)	9	0.8	76	4.89	-0.50	1.4	0	No	Yes
Ryder	10	8.3	143	4.72	-1.00	0.5	7	No	Yes
Snow	8	2.3	95	5.70	0.25	0.1	0	Yes	Yes
Great (T)	11	7.0	126	5.78	-0.25	0.2	6	No	Yes

Rivers and Streams

Despite the fact that Cape Cod has no major river system that serves as drainage for the entire area, it has been classified as a river basin under the Massachusetts River Basin Planning Program (Massachusetts Department of Environmental Management, 1994). The Herring and Pamet rivers represent the two major stream systems on the lower Cape (Figure 3.2a-c). The lack of a significant elevation gradient on the Cape coupled with highly permeable soils prevent extensive surface water runoff and stream development. However, both the Herring and Pamet rivers follow channels cut by catastrophic drainage of lakes by the melting of the glacier (Oldale, 1992; Mitchell and Soukup, 1981).

The Herring River estuary is greatly altered by diking and drainage that started during the early 1900s and, perhaps as early as the 1600s for the purpose of mosquito control, flood protection, and improved travel corridors. It has a discharge of 1.8 to 7.1 cubic feet/second (cfs) (50 to 200 liters/second) (J. Portnoy, 1997, pers. comm., National Park Service).

The Upper Pamet River, located in Truro, east of Route 6, was a salt marsh estuary until it was diked around 1860. It now is a freshwater wetland and stream system (Geise et al., 1993) that extends 1.6 miles (2.5 km) in length (Godfrey et al., 1978). Discharge varies from 1.4 to 3.9 cfs (40 to 110 liters/sec) (Marine Research Inc., 1986). Tide gates located at Castle Road prevent the estuarine Lower Pamet from influencing the freshwater environment of the Upper Pamet (Livingston, 1996). Plants (Table 3.1) found along the Upper Pamet River include pondweeds (*Potomageton*), bladderworts (*Utricularia*), floating duck weeds (*Lemna minor*) and many other species (Godfrey et al., 1978).

SURFACE BRACKISH RESOURCES

Brackish Lakes

Pilgrim Lake (Figure 3.2a), once a coastal
lagoon, is the only water body within the National Seashore large enough to warrant designation as a lake (Godfrey et al., 1978; Mitchell and Soukup, 1981). Natural processes accompanied by anthropogenic alterations have transformed this body of water from a salt water bay to the present 344 acre (139 ha) brackish, shallow, eutrophic lake (Mozgala, 1974; Applebaum and Brenninkmeyer, 1988). Subjected to diking, midge control, fish kills, eutrophication, and infilling from dune migration (Portnoy, 1991), this water body is subject to several management options discussed in Chapter 10.

SURFACE BRACKISH RESOURCES

Waterbodies	Location
Blackfish Creek	Wellfleet
Hatches Harbor	Provincetown
Herring River	Wellfleet
Little Pamet River	Truro
Pamet River	Truro
Nauset Marsh	Eastham
Salt Meadow/Pilgrim Lake	Truro

In addition to the prominent cyanobacteria and midges, common plant species (Table 3.1) found here are widgeon grass (*Ruppia maritima*), pond weeds (*Potamageton* spp.), common reed (*Phragmites australis*), and narrowleaf and wide leaf cattails (*Typha angustifolia and T. latifolia*) (Godfrey et al., 1978).

Estuaries

Estuaries are coastal waters influenced by a mixture of marine salt water and inland fresh water and are commonly located where fresh water rivers empty into salt water environments, primarily oceans and bays. Estuaries are one of the most valuable and productive ecosystems found anywhere, providing important nursery habitat to fish and shellfish (Mitchell and Soukup, 1981; Roman and Manski, 1993). Almost all of the estuarine systems on the National Seashore (Figure 3.2a-c) have been altered to some extent by dikes and tide gates, reducing their productivity and habitat values (Mitchell and Soukup, 1981). Cape Cod National Seashore has developed proposals for the restoration of the diked Hatches Harbor and Herring River estuary (Roman and Manski, 1993).

Coastal Salt Marshes

Salt marshes are productive systems, providing large amounts of nutrients and organic matter to marine food chains (Brownlow, 1979). The marsh system combines regular tidal submersion and wave protection for the vegetation to create a stable accreting marsh (Godfrey et al., 1978). Coastal salt marshes support a diverse variety of plants (Table 3.1) including mud flat pioneer species (Brownlow, 1979) such as cordgrass (*Spartina alterniflora*), glassworts (*Salicornia virginica*), and algae (*Fucus and Ascophyllum* spp.) as well as plants typically found in stable, interior salt marshes, including salt marsh hay (*Spartina patens*), spike grass (*Distichlis spicata*), seaside goldenrod (*Solidago sempervirens*), and sea lavender (*Limonium nashii*). Salt marshes on the lower Cape are located at Hatches Harbor (east of Race Point Light) (Figure 10.2), Pamet River (west of Route 6) (Figure 10.3), Nauset Marsh, Provincetown's West End (Figure 9.1a), and the lower Herring River (Wellfleet) (Figure 10.1) (Godfrey et al., 1978).

Eelgrass beds occur in the saline and brackish water environments on the Cape. Eelgrass (*Zostera marina*) is found below the level of low tide, in bays and estuaries, growing in dense stands as high as 4 feet (Brownlow, 1979). These beds provide food and shelter to a wide range of organisms such as shellfish (e.g., scallops), crustaceans (e.g., lobsters), and small fish. Benthic algae such as *Laminaria, Desmerestia, Chorda, Chondrus*, and *Codium* are associated with this environment (Brownlow, 1979), which occurs in several places on the Cape including Nauset Marsh (Roman et al., 1990).

WILDLIFE

Freshwater Fish

Water bodies such as Gull Pond and the Herring River support populations of largemouth bass (*Micropterus salmoides*), American eel (*Anguilla rostrata*), chain pickerel (*Esox niger*), sunfish (*Lepomis* spp.), white perch (*Morone americana*), yellow perch (*Perca flavescens*), brown bullheads (*Ameiurus nebulosus*), and shiners (*Notropis* spp.) (Table 3.5 and 3.6). The Pamet River also supports resident and migratory brook trout (Massachusetts Department of Environmental Management, 1994). According to Steve Hurley of the Massachusetts Division of Fisheries and Wildlife, brook, brown, and rainbow trout are stocked two to four times a year in Great Pond (Truro), four to eight times a year in Gull Pond (Wellfleet), and brook trout only once a year in the Pamet River. In 1995 the Massachusetts Division of Fisheries and

Wildlife stocked 450 fish in Great Pond, 3,351 fish in Gull Pond, and 400 in the Pamet River. All stocking occurs in the spring only (S. Hurley, 1996, pers. comm., Massachusetts Division of Fisheries and Wildlife). Historical stocking records are summarized in Table 3.7.

Reptiles and Amphibians

Freshwater wetlands, ponds, and estuaries of the National Seashore are habitat for a variety of reptiles and amphibians, though fewer species occur on the outer Cape peninsula than on the Massachusetts mainland (Lazell, 1972). The National Seashore was recently (ca 1993 to 1996) included in Massachusetts Audubon's "Herp Atlas," documenting presence/absence by topographic quadrangle.

Reptiles common to wetland habitats include the eastern ribbon snake (*Thamnophis sauritus*), eastern painted turtle (*Chrysemys picta*), and eastern box turtle (*Terrapene carolina*). Painted turtles occur in seasonally-flooded wetlands, kettle ponds and low-salinity zones of estuaries. Although generally considered terrestrial, box turtles spend long periods in freshwater ponds and bogs during the summer. Spotted turtles (*Clemmys guttata*), of State Special Concern, are apparently more rare but widely distributed in swamps and emergent wetlands. A disjunct population of *C. guttata* occurs in the Provincetown ponds. Diamondback terrapins (*Malaclemys terrapin*), of State Threatened Status, are restricted to Wellfleet Harbor with Great Island serving as the northernmost nesting site on the Atlantic coast. The northern water snake (*Nerodia sipedon*), though common elsewhere in the state, is rare on the outer Cape.

Common wetland-dependent amphibians include spotted salamander (*Ambystoma maculatum*), bullfrog (*Rana catesbeiana*), green frog (*Rana clamitans*), spring peeper (*Pseudacris crucifer*) and Fowler's toad (*Bufo woodhousii fowleri*). Although rarely seen except during spawning after heavy rain, spadefoot toads (*Scaphiopus holbrookii*) appear to be widely distributed from Eastham to the tip of the Cape. The spotted salamander is the only mole salamander within the National Seashore and breeds in some of the National Seashore's most acidic vernal ponds, along with wood frogs (*Rana sylvatica*) and spring peepers (Portnoy, 1990c). Wood frogs are a recent arrival from the south; breeding has been documented only as far north as Eastham. Bullfrogs have apparently extended their range to permanent waters throughout the National Seashore (J. Portnoy, 1997, personal observation, National Park Service), except for Pronvincetown, following their introduction in South Wellfleet in the early 1970s (Lazell, 1972). Green frogs are most common in seasonally-flooded ponds and emergent wetlands. Fowler's toads range throughout the National Seashore's upland, but breed only in the kettle ponds and interdunal ponds; these waters have higher alkalinity than the vernal ponds used by most other amphibian species for spawning.

There are insufficient data to evaluate whether National Seashore anurans (frogs and toads) are threatened with the kind of anuran decline observed in many other parts of the world, particularly the American northwest (Sarkar, 1996). Frequently cited possible causes include the effects of El Niño, increased solar ultraviolet radiation (UV-B) from diminished stratospheric ozone, and bacterial infections. The need is for long-term ecological studies.

Table 3.5. List of fish species that occur on the Cape Cod National Seashore. (Massachusetts Division of Fisheries & Wildlife).

Family	Common Name	Scientific Name	Occurrence
Anguillidae- freshwater eels	American eel	*Anguilla rostrata*	Ponds, streams Catadromous
Clupeidae- herrings	Blueback herring	*Alosa aestivalis*	Ponds, streams, Anadromous
	Alewife	*Alosa pseudoharengus*	Ponds, streams, Anadromous
Salmonidae- trouts	Rainbow trout	*Oncorhynchus mykiss*	Stocked
	Brown trout	*Salmo trutta*	Stocked
	Brook trout	*Salvelinus fontinalis*	Stocked
Esocidae- pikes	Redfin pickerel	*Esox americanus*	Streams
	Chain pickerel	*Esox niger*	Ponds
Cyprinidae- carps and minnows	Common carp	*Cyprinus carpio*	Pilgrim Lake
	Golden shiner	*Notemigonus crysoleucas*	Ponds, streams
	Bridled shiner	*Notropis bifrenatus*	Pamet River
Ictaluridae - bullhead catfishes	Brown bullhead	*Ameiurus nebulosus*	Ponds
Catostomidae- suckers	White Sucker	*Catostomus commersoni*	Ponds, streams
Cyprinodontidae- killifishes	Banded killfish	*Fundulus diaphanus*	Ponds
	Mummichog	*Fundulus heteroclitus*	Estuarine
	Striped killfish	*Fundulus majalis*	Estuarine
Gasterosteidae- sticklebacks	Fourspine stickleback	*Apeltes quadracus*	Estuarine
	Threespine stickleback	*Gasterosteus aculeatus*	Estuarine
Percichthyidae- temperate basses	White perch	*Morone americana*	Ponds, Anadromous
	Striped bass	*Morone saxatillis*	Estuarine
Centrarchidae- sunfishes	Banded sunfish	*Enneacanthus obesus*	Suspected
	Pumpkinseed	*Lepomis gibbosus*	Ponds
	Smallmouth bass	*Micropterus dolomieui*	Ponds
	Largemouth bass	*Micropterus salmoides*	Ponds

Table 3.6. Freshwater fish species in National Seashore ponds (S. Hurley, 1996, personal communication, Massachusetts Division of Fisheries & Wildlife, Southeast District).

	CLAPS	DUCK	DYER	GREAT (t)	GREAT (w)	TURTLE	GULL	HORSELEACH	LONG	PILGRIM	ROUND	RYDER	SLOUGH	Snow Pond
Last Survey Fish Species	**81**	**85**	**65**	**90**	**88**	**88**	**82**	**67**	**85**	**66**	**67**	**86**	**52**	**91**
American eel							C			E		O		
Blueback herring							R							
Alewife							C							
Rainbow trout							S							
Brown trout							S							
Brook trout				S			S							
Redfin pickerel									C					
Chain pickerel	C				C				C			C		
Golden shiner							C					C		
Common carp										O				
White sucker							C					C	C	
Brown bullhead	C			C					C			C	C	
Banded killifish				C			C				C	C	C	
White perch							C			C		C		
Pumpkinseed	C			C		O		C	C			C	C	R
Smallmouth bass				C			C					C		
Largemouth bass	C						C							R
Yellow perch		C	C	C	C		C	C	C		C	C	C	

Abbreviations are: O - observed R - reported E - expected C - Collected S - stocked

Table 3.7. Fish species and years stocked in National Seashore ponds (S. Hurley, 1997, personal communication, Massachusetts Division of Fisheries & Wildlife).

POND	AW	BK	BT	Chinook	CP	EST	GS	LMB	RT	SMB	WP	Walleye	YP	Smelt
Great (T)			1960-61 1985-89			1958-59 1961--64 1966-67 1970-72 1977 1979-1982 1985 1990-97			1958-62 1966-82 1987-89	1958 1980	1934			
Great (W)										1933 1940			1934	
Gull			1949 1964-82 1985-97			1949 1979-83 1984 1986 1990-96			1950 1964-97	1925 1935	1922		1935	1917-18
Horseleech											1927			
Kinnacum	1957-58							1956		1972-73				
Long	1954-57 1959 1967	1973		1914-17	1966		1967	1954-56	1902 1917		1938			1916-18
Pilgrim	1969													
Round (West)			1962			1961-64 1966-67			1960 1962					
Slough										1914	1939	1914		
Snow										1970				
RIVERS	**AW**	**BK**	**BT**	**Chinook**	**CP**	**EST**	**GS**	**LMB**	**RT**	**SMB**	**WP**	**Walleye**	**YP**	**Smelt**
Pamet			1964-65 1971-72 1974-75 1987-88			1986 1988-97			1976 1978-82 1989					

Abbreviations are as follows:

AW	Alewife	LMB	Largemouth Bass
BK	Banded Killifish	RT	Rainbow Trout
BT	Brown Trout	SMB	Smallmouth Bass
CP	Chain Pickerel	WP	White Perch
Chinook	Chinook Salmon	Smelt	Rainbow Smelt
EST	Eastern Brook Trout	YP	Yellow Perch
GS	Golden Shiner		

Table 3.8 Summary of state-listed species on Cape Cod National Seashore according to the Massachusetts Division of Fisheries & Wildlife. Plants.

PLANTS **Scientific Name**	**Common Name**	**State Rank**
Aristida purpurascens	**Purple needlegrass**	**Threatened**
Carex oligosperma	**Few-fruit sedge**	**Threatened**
Carex striata var brevis	**Walter's sedge**	**Endangered**
Corema conradii	**Broom crowberry**	**Special Concern**
Dichanthelium commonsianum	**Commons' panic-grass**	**Special Concern**
Drosera filiformis	**Thread-leaved sundew**	**Watch Listed**
Eleocharis obtusa var ovata	**Ovate spike-sedge**	**Endangered**
Fuirena pumila	**Umbrella-grass**	**Watch Listed**
Helianthemum dumosum	**Bushy rockrose**	**Special Concern**
Juncus debilis	**Weak rush**	**Endangered**
Mertensia maritima	**Oysterleaf**	**Endangered**
Opuntia humifusa	**Prickly pear**	**Threatened**
Orontium aquaticum	**Golden club**	**Threatened**
Rhynchospora scirpoides	**Long-beaked bald-sedge**	**Special Concern**
Sabatia kennedyana	**Plymouth Gentian**	**Special Concern**
Sagittaria teres	**Terete arrowhead**	**Special Concern**
Sphenopholis pensylvanica	**Swamp oats**	**Threatened**
Utricularia fibrosa	**Fibrous bladderwort**	**Threatened**
Utricularia subulata	**Subulate bladderwort**	**Special Concern**

Table 3.8 Summary of state-listed species on Cape Cod National Seashore according to the Massachusetts Division of Fisheries & Wildlife. Animals.

ANIMALS Scientific Name	Common Name	State Rank
Accipiter striatus	Sharp-shinned hawk	Special Concern
Asio flammeus	Short-eared owl	Endangered
Calidris canutus	Red knot	Watch Listed
Charadrius melodus	Piping plover	Threatened, Federal List
Circus cyaneus	Northern harrier	Threatened
Clemmys guttata	Spotted turtle	Special Concern
Hemidactylium scutatum	Four-toed salamander	Special Concern
Larus atricilla	Laughing gull	Watch Listed
Malaclemys terrapin	Diamondback terrapin	Threatened
Pandion haliaetus	Osprey	Watch Listed
Pooecetes gramineus	Vesper sparrow	Threatened
Rynchops niger	Black skimmer	Watch Listed
Scaphiopus holbrookii	Eastern spadefoot	Threatened
Sterna antillarum	Least tern	Special Concern
Sterna dougallii	Roseate tern	Endangered, Federal List
Sterna hirundo	Common tern	Special Concern
Sterna paradisaea	Arctic tern	Special Concern
Terrapene carolina	Eastern box turtle	Special Concern
Abagrotis crumbi benjamini	Coastal heathland cutworm	Special Concern
Apharetra purpurea	Blueberry sallow	Special Concern
Catocala herodias gerhardi	Gerhard's underwing moth	Threatened
Cingilia catenaria	Chain dot geometer	Special Concern
Enallagma laterale	New England bluet	Special Concern
Enallagma recurvatum	Barrens bluet	Threatened
Ferrissia walkeri	Walker's limpet	Special Concern
Fixsenia favonius ontario	Northern hairstreak	Special Concern

RARE, THREATENED AND ENDANGERED SPECIES

Currently no federally listed plant species have been identified in the National Seashore (S. Hurley, 1996, personal communication, Massachusetts Division of Fisheries and Wildlife). The Division does however identify 19 state listed plants and 28 state listed animals and insects, summarized in Table 3.8. There are two federally listed threatened and endangered animal species breeding on the National Seashore, the piping plover (*Charadrius melodus*) (threatened) and the roseate tern (*Steina dougallii*) (endangered).

Cape Cod National Seashore is home to several species of beach nesting seabirds and shorebirds. Barrier islands and spits, in particular, provide important nesting habitat for common and least terns, piping plovers, and a few roseate and Arctic terns. Roseate terns are a federal and state listed endangered species, piping plovers are federal and state listed as threatened, and all of the other terns are state listed as of special concern. Roseate terns nest on New Island in Nauset Marsh, and formerly nested on Plover Island, which is now attached to Coast Guard Beach. A colony of nearly 3,000 least and common terns, which nested on Plover Island in 1995, has moved to other lower Cape Cod nesting areas. Piping plovers show a marked preference for nesting areas with both ocean and estuarine foraging habitats, such as those found on barrier beaches. Although many plovers nest successfully on Cape Cod's ocean beaches without estuarine habitat, they are more concentrated on the barrier beaches, such as Coast Guard Beach, Nauset Heights Beach, Jeremy Point, and the Wood End.

The threatened northeastern beach tiger beetle (*Cincindela dorsalis dorsalis*) was formerly found on Cape Cod beaches as far north as Nauset Light. Coast Guard Beach has been identified as one of the best sites in the northeast for re-establishment of this species, which is currently found on only two other beaches north of the Chesapeake Bay (K. Jones, 1996, pers. comm., National Park Service).

At least two species of freshwater mussel, a group threatened throughout North America, occur in the more alkaline kettle ponds. These bivalves are important indicators of water quality.

Chapter Four: The Human Environment

Demographics

Population densities in coastal areas in America are growing at a faster rate than that of the general population (Valiela et al., 1992). Barnstable County, according to Valiela et al. (1992), is growing faster than all of the mainland Massachusetts counties. The population density for Barnstable County, which has an area of 396 square miles, is approximately 472 people per square mile. The outer Cape, consisting of 95.1 square miles, has a population density of 284 people per square mile (Figure 4.1). Orleans has the highest population density (414 people per square mile) while Provincetown has the most densely settled population center (residential areas in or near village centers without legally defined corporate limits) with a density of 1,874 people per square mile. The 1990 Federal Census population of the towns on the outer Cape (Chatham, Eastham, Orleans, Wellfleet, Truro, Provincetown) including the Cape Cod National Seashore is 24,506, approximately 13 percent of the county's total population. The estimated summer population of the same towns increases almost five fold to 113,600 people (National Park Service, 1998). The Massachusetts Institute for Social and Economic Research (MISER) and the Cape Cod Commission estimate that by the year 2020, the off-season or winter population of Cape Cod will increase by 23 percent and the summer population will increase by 16 percent. For the towns on the outer Cape, the Massachusetts Department of Environmental Management Office of Water Resources (1994) estimates an increase in winter population of 16.7 percent and an 11.4 percent increase in summer population.

Roads

Route 6 provides the north-south travel corridor on the lower Cape (Figure 4.1). These roads receive heavy amounts of traffic in the summer as they take the public from Provincetown to the upper Cape. These major routes represent the primary commercial corridor for the lower Cape, providing not only experiences for tourists but also the potential for non-point source contamination of surface and ground water. Other roads on the lower Cape that provide access to residential development are dirt roads and low use roads.

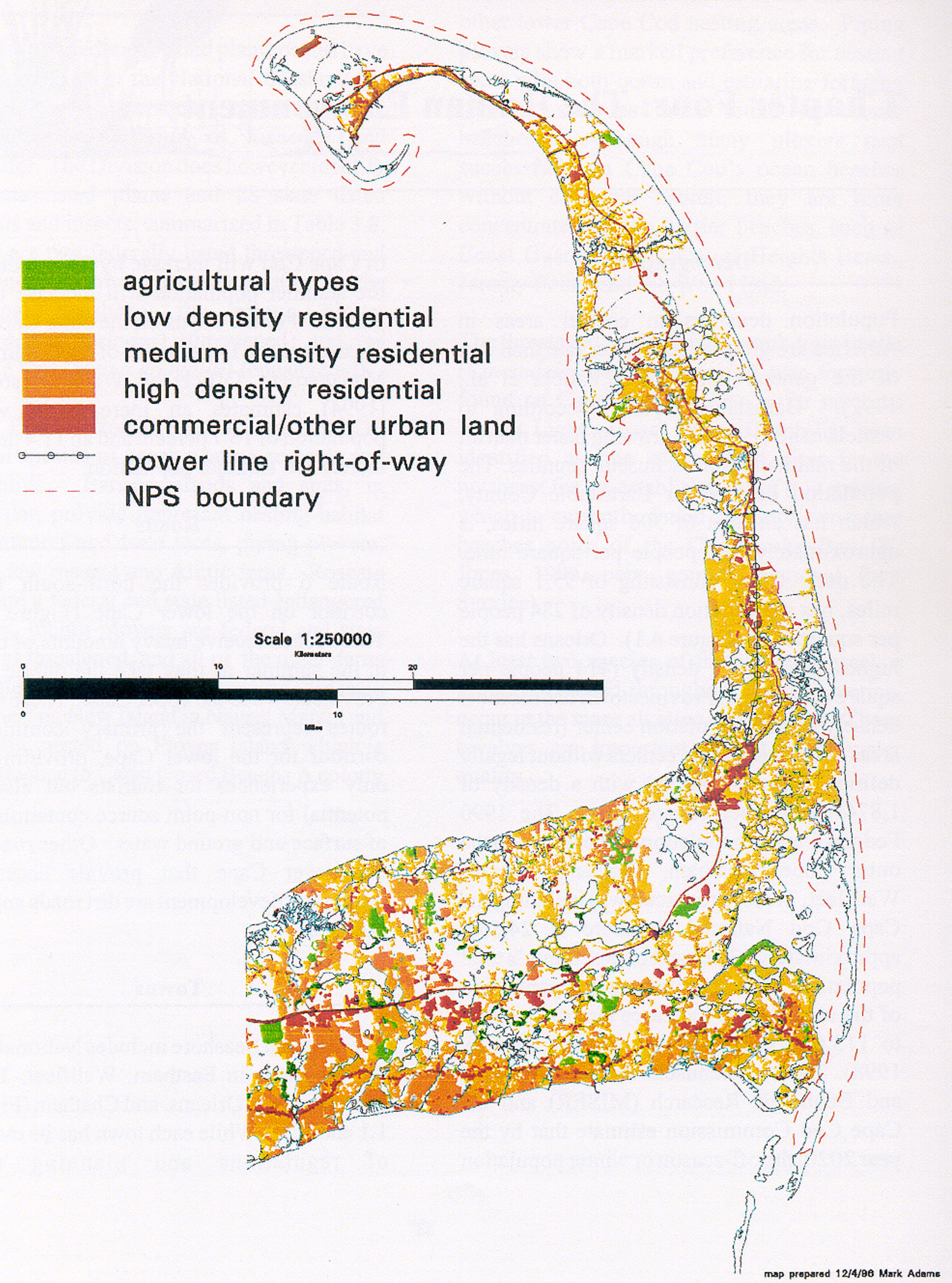
Towns

The National Seashore includes National Park Service lands in Eastham, Wellfleet, Truro, Provincetown, Orleans, and Chatham (Figures 1.1 and 1.2). While each town has its own set of regulations and planning tools

Water Resources Management Plan

Figure 4.1: Generalized Land Use Cape Cod National Seashore

Source: MassGIS, Commonwealth of Mass., 1990



for effective implementation of water resource management plans, the Lower Cape Water Management Task Force represents the water needs and concerns of the entire lower Cape, including the National Seashore. The task force, sponsored by the Cape Cod Commission's water resource program, provides the towns, state agencies, and the National Seashore with an opportunity for multi jurisdictional planning.

Land Use

Land use on the Cape is commercial, residential, agricultural, and public (Figures 4.1 and 4.2). Within the boundary of the National Seashore, each outer Cape town owns varying, but small amounts of land (Table 4.1). A larger amount is held by private "improved property" owners and the Commonwealth of Massachusetts. "Improved properties" are privately owned lands and dwellings within the park boundary not subject to condemnation. While 59 percent of the land is owned by the National Park Service, more than 30 percent within the National Seashore boundary is under the jurisdiction of other public entities, and nearly 4 percent is privately owned. The amount of upland (nontidal) acreage of each of the six communities contained in the National Seashore is shown in Table 4.1. Principal land uses within the National Seashore's boundary are conservation, recreation, rural residence, roads, a closed Air Force Base, and nine, pre-existing, private commercial uses such as gas stations and campgrounds. Each community on the outer Cape has developed zoning by-laws that comply with the Special Secretary of the Interior's zoning standards called for in PL87-126, the park's enabling legislation.

Areas adjacent to the National Seashore boundaries are generally zoned for residential development with a scattering of small-scale

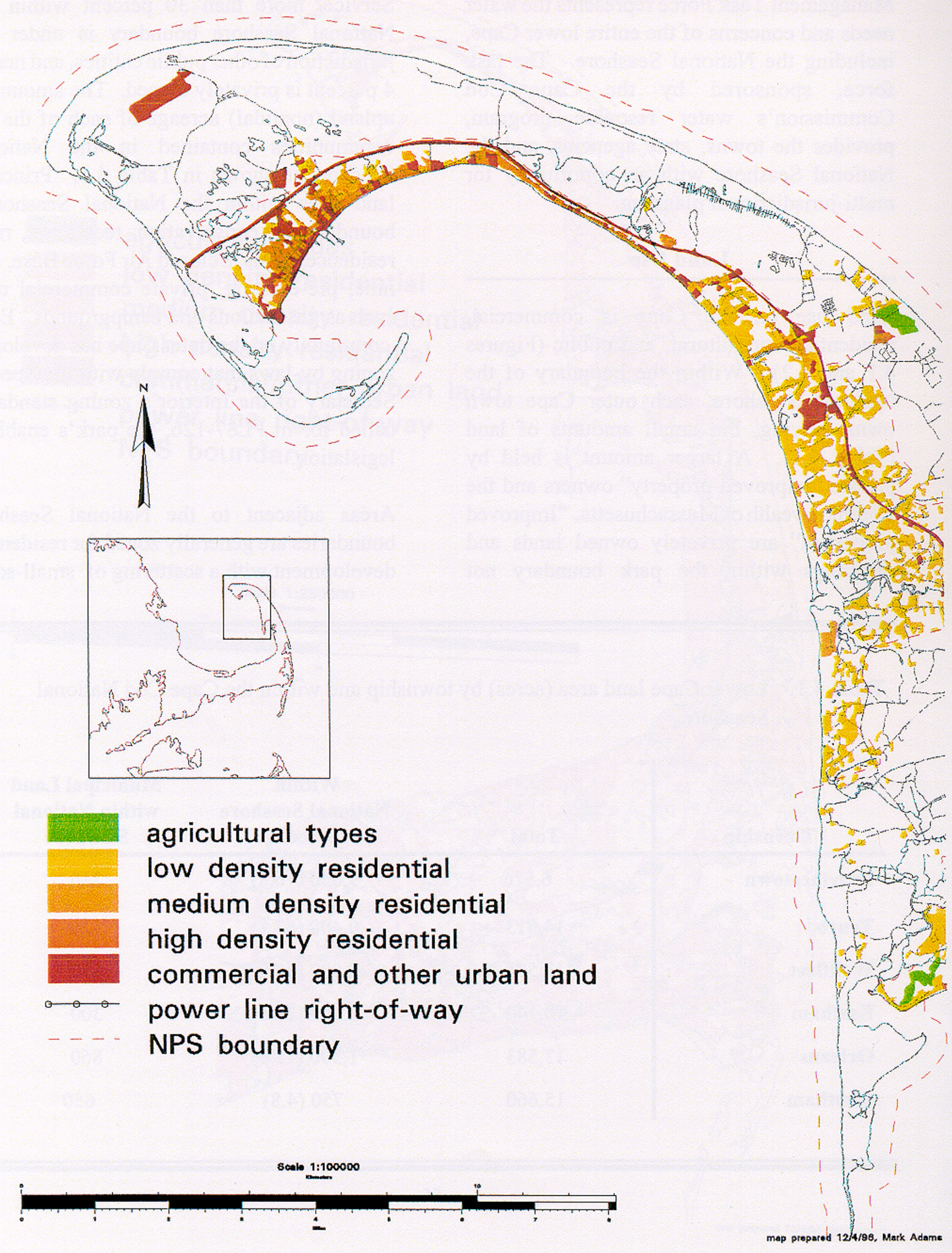
Table 4.1. Lower Cape land area (acres) by township and within the Cape Cod National Seashore.

Township	Total	Within National Seashore (percent)	Municipal Land within National Seashore
Provincetown	6,576	5,050 (76.8)	210
Truro	14,013	9,400 (67.1)	120
Wellfleet	13,584	8,000 (58.9)	670
Eastham	10,140	3,000 (29.6)	300
Orleans	13,583	1,500 (11.0)	860
Chatham	15,660	750(4.8)	650

Water Resources Management Plan

Figure 4.2a: Generalized Land Use (1990)
Provincetown/Truro - Cape Cod National Seashore

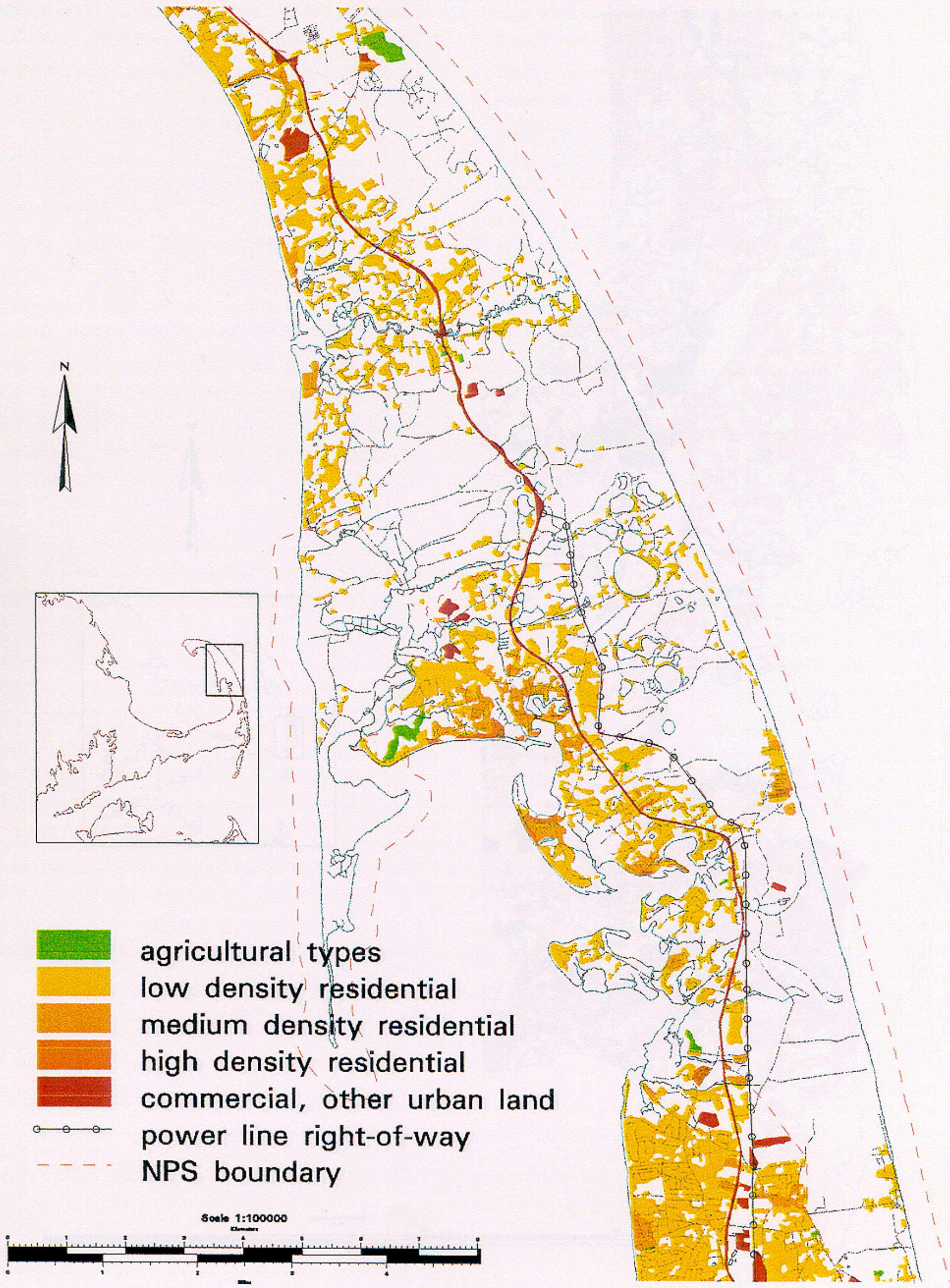
Source: MassGIS, Commonwealth of Massachusetts, 1990.



Water Resources Management Plan

Figure 4.2b: Generalized Land Use (1990)
Wellfleet - Cape Cod National Seashore

Source: MassGIS, Commonwealth of Massachusetts, 1990.

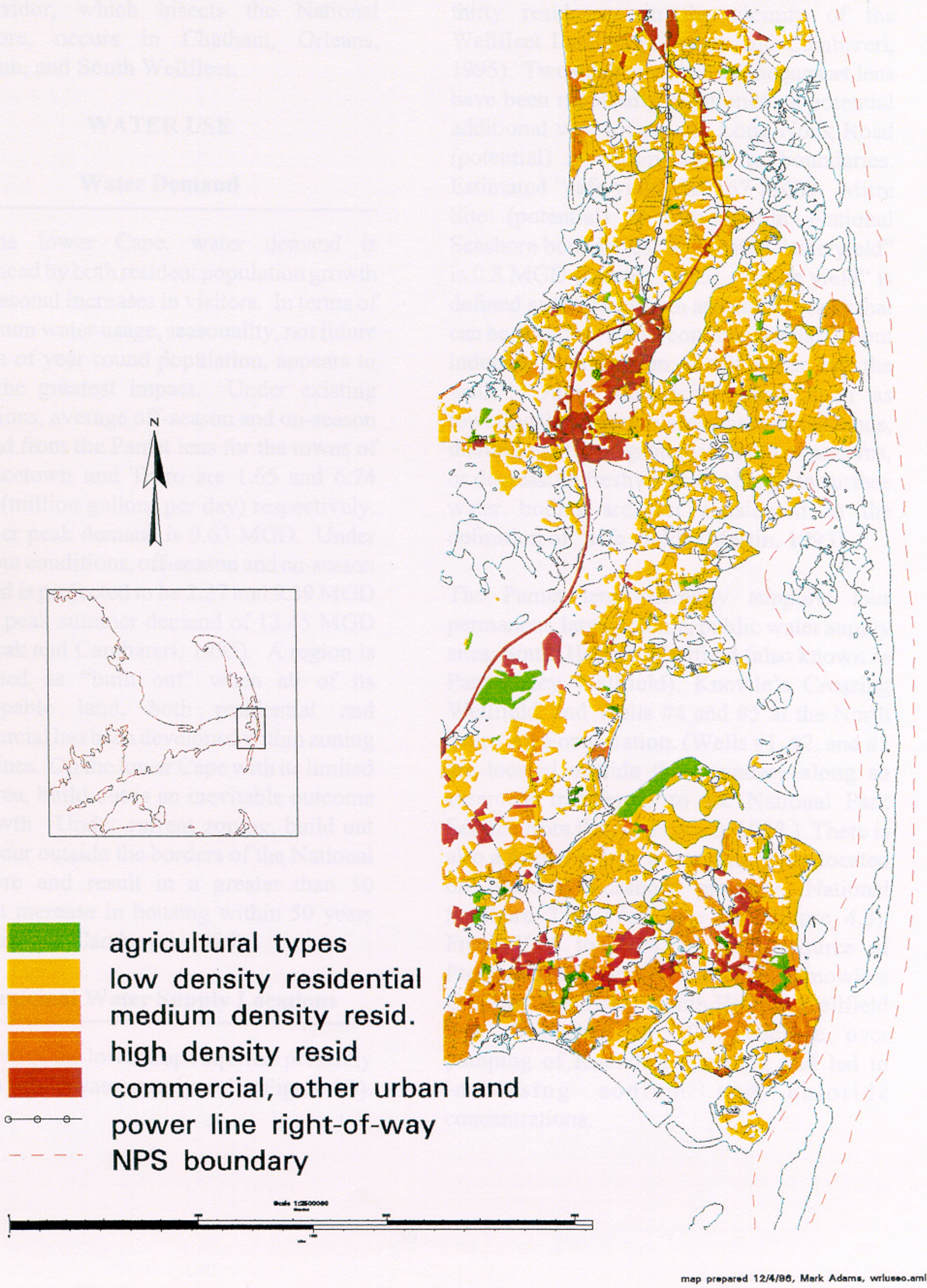


map prepared 12/4/96, Mark Adams, wriusew.aml

Water Resources Management Plan

Figure 4.2c: Generalized Land Use (1990) Orleans/Chatham - Cape Cod National Seashore

Source: MasGIS, Commonwealth of Massachusetts, 1990.



commercial uses. The heaviest commercial and residential development along the Route 6 corridor, which bisects the National Seashore, occurs in Chatham, Orleans, Eastham, and South Wellfleet.

WATER USE

Water Demand

On the lower Cape, water demand is influenced by both resident population growth and seasonal increases in visitors. In terms of maximum water usage, seasonality, not future growth of year round population, appears to have the greatest impact. Under existing conditions, average off-season and on-season demand from the Pamet lens for the towns of Provincetown and Truro are 1.65 and 6.74 MGD (million gallons per day) respectively. Summer peak demand is 9.63 MGD. Under build out conditions, off-season and on-season demand is projected to be 2.27 and 9.39 MGD with a peak summer demand of 13.45 MGD (Sobczak and Cambareri, 1995). A region is described as "built out" when all of its developable land, both residential and commercial has been developed within zoning guidelines. On the lower Cape with its limited land area, build out is an inevitable outcome of growth. Under current zoning, build out will occur outside the borders of the National Seashore and result in a greater than 50 percent increase in housing within 50 years (Sobczak and Cambareri, 1995).

Municipal Water Supply Locations

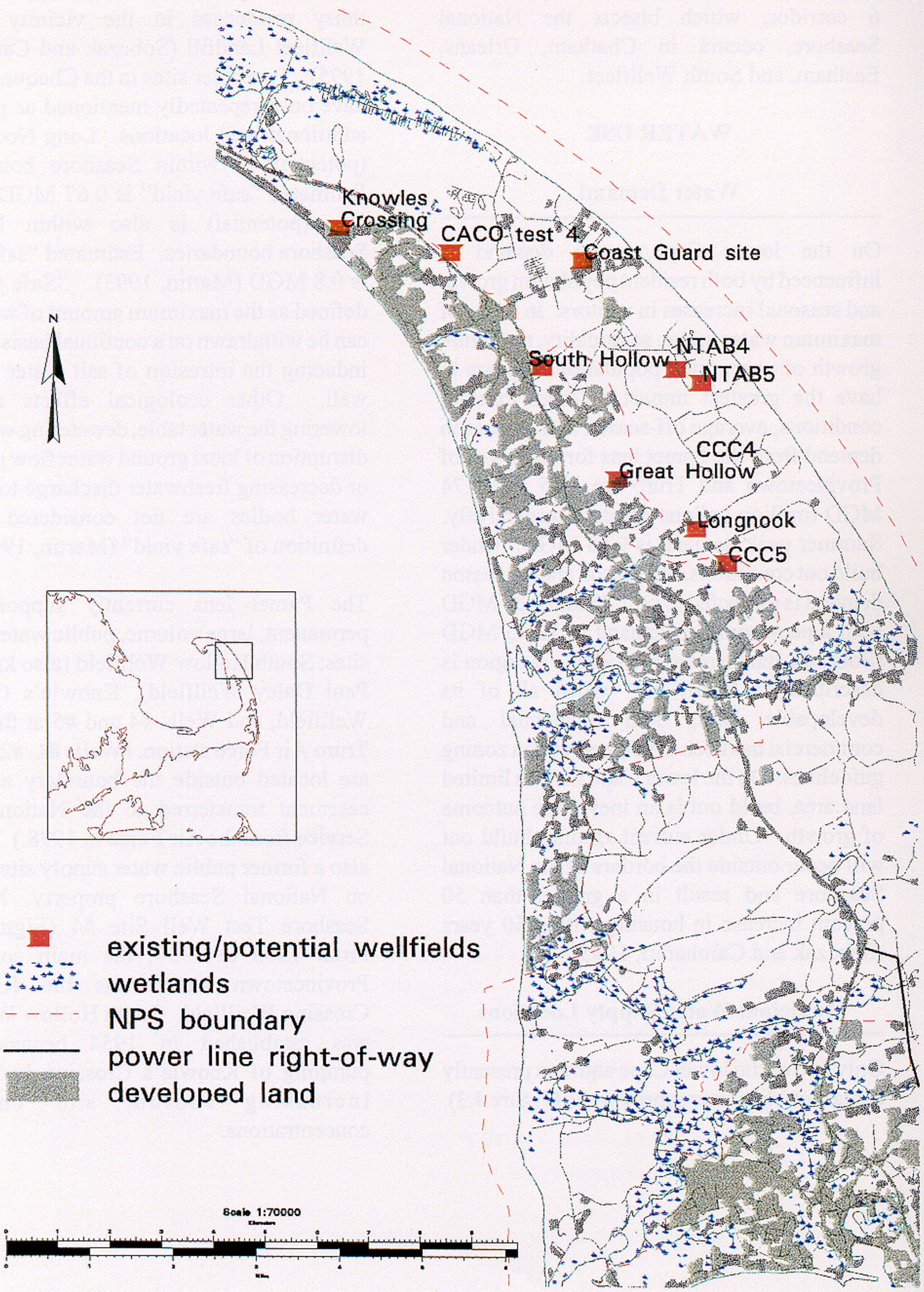
Only two of the lower Cape aquifers presently contain public water supply wells (Figure 4.3). The Coles Neck Well is a small volume well in the Chequesset lens that supplies about thirty residences in the vicinity of the Wellfleet Landfill (Sobczak and Cambareri, 1995). Two other sites in the Chequesset lens have been repeatedly mentioned as potential additional well locations. Long Nook Road (potential) is within Seashore boundaries. Estimated "safe yield" is 0.67 MGD. Mitre Site (potential) is also within National Seashore boundaries. Estimated "safe yield" is 0.8 MGD (Martin, 1993). "Safe yield" is defined as the maximum amount of water that can be withdrawn on a continual basis without inducing the intrusion of salt water into the well. Other ecological effects such as lowering the water table, dewatering wetlands, disruption of local ground water flow patterns, or decreasing freshwater discharge to surface water bodies are not considered in the definition of "safe yield" (Martin, 1993).

The Pamet lens currently supports four permanent, large volume, public water supply sites: South Hollow Wellfield (also known as Paul Daley Wellfield), Knowle's Crossing Wellfield, and Wells #4 and #5 at the North Truro Air Force station. (Wells #1, #2, and #3 are located outside the boundary along an easement transferred to the National Park Service from the Air Force in 1998.) There is also a former public water supply site located on National Seashore property, National Seashore Test Well Site #4 (Figure 4.3). From 1908 . to 1954, the main source of Provincetown water was the Knowle's Crossing Wellfield. South Hollow Wellfield was established in 1954 because over pumping of Knowle's Crossing had led to increasing sodium and chloride concentrations.

Water Resources Management Plan

Figure 4.3: Existing and Potential Wellfields Cape Cod National Seashore

Source: NPS Water Resources Division; USFWS, National Wetlands Inventory



map prepared 12/4/96, Mark Adams, wrwell.aml

In July of 1978, the South Hollow Wellfield was closed after an underground gasoline tank leaked 3,000 gallons about 600 feet from the well field. The National Park Service then allowed a temporary well site to be established at Test Site #4 to be used while South Hollow was off line. Pumping also began at a site located on the North Truro Air Force Base on a year by year emergency basis. (Brenninkmeyer et al., 1987; LeBlanc, 1982; Sobczak and Cambareri, 1995). Currently, the South Hollow and Knowle's Crossing wellfields are owned by the town of Provincetown and the Air Force Base wells and Test Site #4 are owned by the National Seashore (Cambareri et al., 1989). Since 1995, when the National Seashore took ownership of the Air Force Base wells, Provincetown has retained a year by year emergency use permit of the wells.

The South Hollow Wellfield is near the center of the Pamet aquifer about 1.5 miles from the Pamet River and Pilgrim Lake - Salt Meadow area. "Safe yield" is 0.8 MGD. Withdrawals averaged 0.6 MGD from 1987 to 1991 with a peak summer demand of 0.9 MGD (Martin, 1993). Currently, there are eight, eight-inch diameter gravel pack wells in the South Hollow Wellfield that normally pump greater than 1 MGD. Due to the gasoline spill, the well field was entirely shut down from 1978 to 1980, pumped at 0.25 MGD from 1981 to 1984, and went back up to 1 MGD in 1985 to 1986 after the contamination was remediated (Cambareri et al., 1989).

The Knowles Crossing Wellfield is less than a mile south of the Salt Meadow - Pilgrim Lake area. "Safe yield" has been estimated at 0.2 MGD. Withdrawals averaged 0.085 MGD from 1987 to 1991 with peak summer demand at 0.25 MGD (Martin, 1993). Knowles Crossing consists of three gravel packed wells located very near the shore of Cape Cod Bay. It has been in operation since 1908 and has experienced high sodium levels since its inception. Prolonged pumping at rates in excess of "safe yield" (0.2 MGD) have led to periodic salt water intrusions (Cambareri et al., 1989).

National Seashore Test Site #4 is located at the bottom of a kettle, east of Route 6 and midway between South Hollow and Knowles Crossing. "Safe yield" is about 0.3 MGD. The site was used from 1979 to 1985 due to gasoline contamination at South Hollow (Martin, 1993). Use of the well was discontinued in the fall of 1986 (Cambareri et al., 1989).

There are two wells at the North Truro Air Force Base that have been used for supplemental supply to Provincetown since 1978. Combined "safe yield" is 0.57 MGD. Withdrawals have averaged 0.12 MGD from 1987 to 1991 with peak summer demand at 0.3 MGD (Martin, 1993). In 1995, the North Truro Air Force Base was deactivated and the National Seashore took ownership of the land and the wells. To date, Provincetown has been operating these wells under an emergency special use permit. No long-term (i.e., non-emergency) use of these wells is allowed under National Park Service policy (see Appendix B, 78-2).

The majority of the water from the four public well sites is used to supply Provincetown. The Provincetown Water Department services 2,200 accounts (1988), 185 of them in Truro which use 11 to 15 percent of the total water pumped on an annual basis (275 million gallons). On a seasonal basis, the Truro accounts may use up to 25 percent of the water being pumped. The public water supply main runs along Route 6A. Truro residences and businesses, located north of the Route 6A and Highland Road intersection, that experience problems with their private water supply may connect to the main provided they are within a reasonable distance (Cambareri et al., 1989).

ENVIRONMENTAL RISK FACTORS

Non-point source pollution is a critical problem on the Cape. All of the National Seashore's water resources including ground water, ponds, marshes, and rivers are affected by various types of non-point source pollution (Portnoy, et al., 1998; Portnoy, 1994; Winkler, 1994; Noake, 1989). Most of the pollution is either organic or inorganic and caused by humans. Nutrient input to ground and surface waters from septic systems is a well documented problem on the Cape with far reaching effects to human populations and natural resources. Organic pollutants derived from landfills and leaking underground storage tanks as well as urban and septic leachate pose a serious threat to the integrity of clean drinking water supplies and natural resources. The atmospheric deposition of inorganic acids and metals to surface waters on the Cape further increases the extent of pollution impacts on all water resources. The intimate connection between ground water and surface water on the Cape compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the sand and gravel aquifer.

The lower Cape is also largely without a sewer system, relying on private septic systems that recycle wastewater back to the ground water creating problems of nutrient loading and nitrate contamination. Additionally, there are four inactive landfills on the lower Cape (Truro, Wellfleet, Eastham, Orleans), and one capped landfill in Provincetown. Both Provincetown and Truro landfills are located within the National Seashore boundaries and have contamination plumes emanating from their containment areas (Urish et al., 1991 and 1993; Cambareri et al., 1989; Frolich, 1991). The Wellfleet landfill abuts the National Seashore boundary and has a plume that travels southwest toward the Herring River. The effects of the five landfills are discussed in Chapter Five.

Underground storage tanks pose an additional threat to the quality of both ground and surface waters on the outer Cape. Barnstable County has a record of all active underground storage tanks in the towns surrounding the National Seashore. The majority of the tanks hold fuel oil and range in size from 200 to 2,000 gallons. Each town on the lower Cape has regulations for underground storage tanks that outlines an inspection and permitting program (Stiefel, 1996, pers. comm., Barnstable County Program Coordinator for Underground Storage Tanks). Additional details on the size and age of the underground storage tanks in Barnstable County are provided in Chapter Seven.

Chapter Five: Impacts of Ground Water Resources

Ground water is the principal source of fresh water for domestic, industrial, and agricultural use on the lower Cape. In addition, ground water supports freshwater ponds, wetlands, streams, and estuary environments, all of which represent specific and important habitats for native flora and fauna. Significant growth in the number of summer and permanent residents over the last 30 years has increased ground water use and placed stresses on ground water resources. In response to increasing water demand, several outer Cape communities have proposed placement of new public supply wells within or adjacent to the National Seashore boundaries. Potential impacts of these proposed well locations are, at present, poorly understood. In particular, there is concern over the extent of long-term declines in ground water and pond levels and in the quantity of stream flow, as well as about the possibility of saltwater intrusion from the surrounding ocean (Masterson and Barlow, 1994). The effects of increasing ground water withdrawals depend on the location of wells, local hydrogeologic conditions, the amount and rate of withdrawals and whether or not the water is returned to the aquifer after use (Martin, 1993).

Problem History

Most natural surface water resources on the lower Cape depend directly upon the current ground water configuration in the aquifer. Surface water resources are divided into two general categories, coastal and inland. Inland resources, such as kettle ponds, vernal pools and bogs, depend entirely on yearly and seasonal ground water levels to maintain their particular ecosystems. Fluctuations in the water table, due to either natural recharge variation or ground water withdrawals, are directly felt by these resources. Coastal resources, such as streams and estuaries depend on aquifer discharge to maintain yearly and seasonal flow rates and to regulate water chemistry (Sobczak and Cambareri, 1995). The particular ecological significance of the discharge depends on the rate at which freshwater mixes with saltwater. Rapid mixing zones such as high energy coasts and tidal marshes are less dependent on freshwater flows. Slow mixing zones such as streams and estuaries depend on the natural influx of freshwater for sustained health of the ecosystems (Sobczak and Cambareri, 1995).

The ground water lenses of the outer Cape are currently in a state of long-term, dynamic equilibrium where no regional, large-scale, trend of declining water levels has been observed (Massachusetts Department of Environmental Management, 1994). However, the equilibrium of any lens could be easily upset by a sustained stress on the system, such as excessive pumping or extended drought conditions (Sobczak & Cambareri, 1995;

(Massachusetts Department of Environmental Management, 1994). The Pamet lens, due to its small size and the public water supply demands placed upon it, is currently the most vulnerable of the outer Cape lenses (Cambareri et al., 1989a). Typically, a ground water flow system responds in the following manner to increases in ground water withdrawal rates unsupported by additional recharge inputs. Water pumped from wells is initially removed from aquifer storage. The water table is drawn down locally into a cone of depression. Any upland resources within the influence of the cone of depression will be depleted. As the volume of overlying fresh water in the aquifer is reduced, the fresh water-salt water interface is slowly pulled upwards, thinning the aquifer (Fetter, 1994). Eventually a new, steady state equilibrium is established with a lowered water table and raised interface. In the absence of any external recharge source to sustain pumping, water withdrawn under the new equilibrium conditions must come from a reduction in freshwater discharge, potentially depleting lowland resources (Sobczak and Cambareri, 1995; Wilson and Schreiber, 1981). Even under the present conditions of regional equilibrium, local effects of ground water withdrawal in the vicinity of pumping wells may be severe (LeBlanc, 1982).

In the Nauset lens, the only ground water withdrawals are those made by residences and small businesses with small volume, private wells and on-site septic systems. These small volume withdrawals do not appreciably stress the ground water system. Approximately 85 to 90 percent of the water removed in any location is quickly returned as wastewater. There is minimal net loss to the system on either a regional or local scale. However, the returned septic effluent is not of the same initial water quality. The Chequesset lens services private wells and on-site septic systems in Wellfleet, except for approximately 30 households in the Cole's Neck area (Sobczak and Cambareri, 1995).

In contrast, the balance of hydraulic inputs and outputs is somewhat altered for both the Pamet lens and the Pilgrim lens. Provincetown imports its entire water supply from wells located within the town of Truro in the Pamet aquifer. Water pumped from the Pamet aquifer to Provincetown is not returned as wastewater which constitutes a net loss from the system. Ground water withdrawals exceed 300 million gallons per year and peak demand during the summer is 1.45 MGD (million gallons per day, Table 5.1) (Martin, 1993). Average export to Provincetown is 0.9 MGD (1979) (Mass. Dept. of Environmental Management, 1994). Given an approximate

Table 5.1. Hydrologic inputs and outputs for the Pamet and Pilgrim lenses.

Average Export From Pamet to Pilgrim	Peak Export From Pamet to Pilgrim	Average Daily Pamet Recharge Removed	Artificial Recharge to Pilgrim Lens
0.9 MGD	1.45 MGD	10%	3.2 inches per year

surface area of 9.5 square miles and a natural recharge rate of 18 inches per year, the natural average daily recharge to the Pamet lens is approximately 8.2 MGD. Therefore, it is estimated that approximately 10 percent ofthe recharge to the Pamet lens is removed by the Provincetown water supply system (Cambareri et al., 1989a). Inversely, the importation of water to Provincetown constitutes a net ground water addition to the Pilgrim lens (Table 5.1).

The Challenge

To reconcile the growing needs for ground water supply with National Park Service requirements for protection of water dependent resources consistent with the requirements for legal compliance and national policy.

Local Water Table Declines

The initial impact of increased ground water withdrawals, observable on a scale from hours to days, will be a drawdown of the water table into a cone of depression surrounding the well (Fetter, 1994; Wilson and Schreiber, 1981). Upland resources in the vicinity of pumping wells may be depleted by the lowered water table (LeBlanc, 1982; Martin, 1993). Computer models of the lower Cape aquifers predict that the impacts of water table drawdown on a regional scale will be negligible. Simulated, large scale, regional changes in water table elevations caused by increased pumping are smaller than, and often indistinguishable from, those caused by natural seasonal variations in recharge (LeBlanc, 1982; Massachusetts Department of Environmental Management, 1994; Sobczak and Cambareri, 1995). Water levels at U.S. Geological Survey observation well TSW-89 in the Pamet lens fluctuates about 1.2 feet each year in response to seasonal changes in recharge. The maximum range measured over the last 17 years has been 2.6 feet, which is not significantly different from the other lower Cape lenses with no large volume public wells (LeBlanc, 1982).

Small scale, local impacts to freshwater resources in the immediate vicinity of the pumping wells are expected to be greater than the regional impacts (LeBlanc, 1982; Martin, 1993). None of the models, however, use a fine enough grid scale to accurately predict local water table declines. LeBlanc (1982) evaluates the modeled impacts of ground water withdrawals from National Seashore Test Site #4 (refer to Figure 4.4). He concludes that under the expected pumping regime (0.75 - 1.08 MGD), simulated, average, regional water tables declined by less than 0.6 feet as a result of the pumping. The model is incapable of accurately quantifying average water levels within 700 feet of the well, but LeBlanc expected them to fall by more than a foot. Ponds perched above the water table are not expected to be affected. Shallow screened wells will impart a greater degree of drawdown to the water table than deeper screened wells, but incur a lesser degree of saltwater intrusion (LeBlanc, 1982).

Saltwater Intrusion

On the lower Cape, where the freshwater lenses are underlain and surrounded by salt water, the threat of saltwater intrusion from over pumping is a significant concern (Ryan, 1980). The upper limit of quantity and rate of ground water withdrawals that will not induce saltwater intrusion is defined as "safe yield" (Martin, 1993). According to the Ghyben-Herzberg principle, the thickness of the freshwater lens below sea level at a point in the aquifer is generally 40 times the elevation of the water table above sea level at that point. For each 1 foot drop in the water table due to pumping, there is a 40 foot rise in the freshwater-saltwater interface (Fetter, 1994). Ground water withdrawals in excess of safe yield thin the aquifer from both the top and the bottom. The response time of the interface, however, can be long enough that, under the transient conditions prevalent in a stressed aquifer, the full response is not usually apparent unless the stress is maintained for many months. At the present time, despite localized incidences of saltwater intrusion at the Knowle's Crossing Wellfield and National Seashore Test Site #4 in the Pamet lens, no large scale movement of the regional freshwater-saltwater interface has been observed (LeBlanc, 1982; LeBlanc et al., 1986; Martin, 1993).

On the lower Cape, where the freshwater lenses are underlain and surrounded by salt water, the threat of saltwater intrusion from over pumping is a significant concern,

The degree of saltwater intrusion induced by a pumping well is dependent on the rate and duration of pumping and the local hydrogeologic conditions. When - a new pumping well comes on line, the position of the freshwater-saltwater interface slowly migrates up beneath the well until it eventually stabilizes at a new, higher equilibrium position. Subsequent increases in the pumping rate will produce progressively higher equilibrium positions of the interface. If the pumping rate exceeds the safe yield value, the interface will be disrupted, flow will occur in the underlying mass of salt water, and the well will rapidly become contaminated with saline water. The reason that the stable interface position for safe yield must be some distance below the bottom of the well is because the upward flow of fresh water immediately below the well intake is too fast to allow nearby underlying salt water to remain static. Therefore the freshwater-saltwater interface becomes disrupted in the turbulent zone immediately below the well screen (Reilly and LeBlanc, 1987). The calculated safe yield for National Seashore Test Site #4 is 0.30 MGD. The annual average pumping rate at National Seashore Test Site #4 in 1982 (LeBlanc, 1982) was 0.28 MGD, a value close to the calculated safe yield (Reilly and LeBlanc, 1987).

Reduction of Aquifer Discharge

Freshwater discharge from the aquifer may be reduced by two causes: 1) by interception of the water by well withdrawals, and 2) by lowering water table elevations (thereby reducing the head or driving force which moves water toward discharge areas). Prolonged reductions of aquifer discharge will reduce flow rates of streams and alter the salinity balance in estuarine environments (Martin, 1993). Reductions in discharge due to ground water withdrawals are generally felt most seriously by freshwater resources located closest to the wells.

If the volume of aquifer discharge is reduced enough, flow dynamics within the lower Cape ground water system may be altered. Streams and marshes which currently act as discharge boundaries, may become a source of aquifer recharge, inputting surface waters to the aquifer if the water table is low enough to reverse the hydraulic gradient. Under conditions of severe hydraulic stress, the streams that divide the Cape Cod aquifer into lenses may cease to act as discharge boundaries, and water may flow between the individual lenses (Guswa and LeBlanc, 1981). This same effect may be locally induced by excessive pumping (Fetter, 1994). An active supply well draws down the water table into a cone of depression surrounding it. The cone will grow until it has either reduced the aquifer discharge or intercepted a stream or similar water source capable of supplying enough recharge to balance the volume of water withdrawn by the well (Fetter, 1994).

The impacts of discharge reduction on high energy coastal areas has not been studied. The volume of fresh water discharging along the ocean shores is small relative to the salt water into which it mixes. Therefore, any reductions in freshwater discharge are unlikely to affect the ecological balance of surface waters along high energy shorelines (Martin, 1993). Nevertheless, a significant reduction in the volume of fresh water discharging to the edges of the aquifer could: 1) alter the shoreline pore water chemistry and impact interstitial fauna (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore), and 2) lower the hydraulic gradient and change the position of the saltwater-freshwater interface (Fetter, 1994). If coastal discharge has been only slightly diminished, the hydraulic gradient will remain pointed seaward, and the interface will only shift position landward very slowly. It may take hundreds of years for the boundary to move a significant distance. If, however, coastal discharge has been reduced enough to reverse the natural hydraulic gradient, fresh water will actively retreat upwards and landwards from the old interface. This situation generally occurs when concentrated well withdrawals in coastal areas have created a deep cone of depression. This type of rapid encroachment occurred below Brooklyn (New York City) in the 1930s when the water table was locally lowered 30 to 50 feet below sea level, and sea water entered the wells (Fetter, 1994).

Few sites are available on the lower Cape for locating large volume wells that do not risk causing saltwater intrusion or impacting surface water resources which are protected under the Massachusetts Water Management Act.

Specific Impacts of Current and Potential Public Wells

Few sites are available for locating large volume wells on the lower Cape that do not risk causing saltwater intrusion or impacting surface water resources which are protected under the Massachusetts Water Management Act. Some sites that would minimize these risks are located within the boundaries of Cape Cod National Seashore which is mandated to protect all resources within the park, including the ground water which feeds its surface water resources (Sobczak and Cambareri, 1995). The National Park Service mandate to "preserve and protect" may cause the National Seashore to have a different interpretation of what constitutes a significant environmental effect than other entities. For years, municipal discourse concerning ground water withdrawals revolved around the "safe yield" concept. The only concern regarding well yields was that they not be large enough to induce saltwater upconing and shut down the well. The National Seashore and the Massachusetts Department of Environmental Protection would also like to consider the impacts of ground water withdrawals on any ground water dependent ecosystems within National Seashore boundaries (Martin, 1993). The Lower Cape Water Management Task Force (1996) has addressed this by coining the term "upconing yield" to refer to that withdrawal rate which will not induce saltwater intrusion. They reserve the use of the term "safe yield" to include potential environmental impacts. The "safe yield" at any location will always be less than or equal to the "upconing yield", often significantly less.

Harris and Steeves (1994) used a geographic information system (GIS) to identify potential new public well locations on Cape Cod. A series of computerized data layers were overlapped to rule out unsuitable locations. In order of increasing importance, the criteria that comprised the data layers were: restricted use land (including the National Seashore), wetland areas, agricultural areas, residential areas, business/industrial areas, areas of known ground water contamination, and areas of high potential for salt water intrusion. The primary concern was finding a location with the best drinking water quality. No consideration was given to potential ecological impacts at the proposed locations. Primarily due to the high percentage of restricted National Seashore land, very few potential well sites were identified on the lower Cape (Harris and Steeves, 1994).

Provincetown Water Conservation Program

Recognizing the need to conserve water resources on the Iower Cape, the Provincetown Water Department has developed a water conservation program. This program is an effort on the part of Provincetown to reduce water demand and conserve clean water drinking supplies. The program's efforts change year to year as dictated by funding sources; however, over the last several years, the program has been more aggressive. In 1996 the Water Department implemented a system that alleviates drinking water demands by 10,000 gallons/day. This system consists of two wells that use brackish water (non-potable) for flushing purposes only. Low-flow showerheads, toilet dams, and low flow aerators have been installed. In 1999, a meter replacement program was implemented in an effort to better account for water use. By the end of 1999, $30,000 of new meters will have been installed. An additional $15,000 is budgeted for leak detection. A 102-year old, 10 inch cast iron transmission line will be decommissioned. Education in water conservation is a goal of the program. In 1999, 1,000 water conservation kits were distributed throughout the community. Additionally, several public information announcements were placed in newspapers, helping the public understand the value of water conservation. There have been several rules and regulations that have helped reduce water consumption within Provincetown, such as the Chapter 9 bylaw, which outlines restrictions on water use including water use for lawns, pools, and air-conditioners.

There are no well field locations, either existing or potential, where withdrawals will not have an effect on the water resources and dependent ecosystems of the area. Minimizing the impacts is the best that can be done. To this end, many computer ground water simulations have been created in an effort to understand ground water withdrawal impacts in a safe and inexpensive manner (refer to Appendix C). Some generalized findings have consistently emerged from the various studies. Recharge variability, and especially sustained drought conditions, has a much greater regional impact on aquifer discharge, water table elevation, and position of the freshwater-saltwater interface than do ground water withdrawals. Under stress conditions, the response of the interface on a regional scale is orders of magnitude slower than the response of the water table. This means that even when the water table drops and aquifer discharge diminishes, the volume of water in aquifer storage will not decrease substantially over short time periods. In contrast, aquifer discharge is directly affected by short and long term stresses of all types. Due to the scale of the model grids, none of the models were able to accurately predict small scale, local impacts of ground water withdrawals, but changes to both the water table and the interface in the immediate vicinity of large volume pumping wells were intimated. Environmental impacts to both upland and lowland surface water resources can therefore be minimized by placing supply wells away from sensitive surface waters (Sobczak and Cambareri, 1996; Martin, 1993).

In accordance with these findings, well fields (Knowle's Crossing) located closer than a mile from Salt Meadow and Pilgrim Lake at the northern boundary of the Pamet lens are expected to have a significant impact on the quantity of freshwater discharge from the Pamet aquifer to these drainages. Withdrawals from wells near the center of the aquifer, where the freshwater lens is thickest (North Truro Air Base), will likely have the least impact on discharge to these freshwater resources. Increased pumping at the Knowles Crossing Well field would, therefore, be expected to have the greatest impact on nearby lowland resources of any existing or proposed well location in the Pamet aquifer, and withdrawals from the North Truro Air Base Well field are predicted to incur the least (Martin, 1993; Sobczak and Cambareri, 1996).

Shifting withdrawals from the Knowles Crossing Well field to the North Truro Air Base Well field would reduce the impact on the Salt Meadow and Pilgrim Lake areas as well as eliminate the historic problem with saltwater upconing at the Knowles Crossing Well field. The proximity of the ocean to the North Truro Air Base, however, limits the amount of water that can be withdrawn before experiencing problems with saltwater intrusion (Martin, 1993).

South Hollow Well field is a major source of water because it is situated on the water table divide where the lens is thickest (Wilson and Schreiber, 1981). Withdrawals from the South Hollow Well field mostly affect discharge to the ocean with negligible ecological consequences. Impacts from South Hollow Well field on discharge to Salt Meadow or the Pamet River are minimal. The well field is, however, already running at maximum "safe yield" and further expansion is not feasible (Martin, 1993).

The use of National Seashore Test Site #4 is not recommended because proximity to Knowles Crossing and South Hollow Well fields would likely result in interference with no substantial net increase in aquifer yield (Wilson and Schreiber, 1981). Placing the proposed Long Nook Road Well field away from the Atlantic Ocean by .5 to .75 miles westward, thus moving it closer to the center of the lens, might significantly improve its "safe yield". Modeling studies predict that this well field substantially reduces discharge to the Little Pamet and Pamet River drainages, as well as interferes with the North Truro Air Base wells. The proposed Mitre Site was predicted to have significant impacts on discharge to the Bound Brook and Herring River drainages as well as the Featherbed Swamp area (Martin, 1993) (refer to Figure 4.3 for well locations). Existing well fields at Knowles Crossing, South Hollow, and North Truro Air Base meet current demands for Provincetown, but there is no backup in case one site is shut down, and there is no ability to increase overall supply. Further, in addition to the water demands of Provincetown, consideration must be given for future growth in Truro and Wellfleet. To meet future demand, several small well fields should be developed, which would probably have a lesser environmental impact than one large well field, and these additional sites would provide insurance in case one site was lost (Martin, 1993).

In response to the current perceived need for municipal water to supply the Wellfleet Center, the Wellfleet Landfill area, the Route 6 corridors in Wellfleet and Eastham, and the Eastham Landfill area (Sobczak and Cambareri, 1996), and in anticipation of future need, the Lower Cape Water Management Task Force has identified potential new public water supply locations both inside and outside the National Seashore boundaries. In the Chequesset lens, the Coles Neck Well currently supplying the Wellfleet Landfill area, could be used in conjunction with a well sited south of Dyer Pond to supply Wellfleet Center. Potential impacts to the Herring River on Seashore property are feared if the Coles Neck Well is used alone to expand supply (Sobczak and Cambareri, 1996). In the Nauset lens, Whitman and Howard test wells numbers 1 and 4, and Little Creek are inside the National Seashore boundaries but on land owned by the town. They could potentially impact vernal pools within National Seashore boundaries. In contrast, the Northeast Eastham, Marconi Beach, and Nauset Road sites inside National Seashore boundaries are predicted to have minimal impacts (Sobczak and Cambareri, 1996). In the Pamet lens, the North Truro Air Base wells and the proposed Coast Guard Site are predicted to have minimal impacts because most of the water withdrawal will only reduce direct discharge to the Atlantic Ocean (Sobczak and Cambareri, 1996).

Management Steps: Ground Water Withdrawal
400 Days to 5 Years

Committee
Work on locating sites for municipal water supply consistent with the legal restrictions of the National Park Service (Appendix A) while satisfying the needs of people living on the outer Cape and protecting the natural environment from excessive pumping.

Education
Use the model home for display of conservation devices. Solicit and employ the ideas of residents. Present conservation information in the newsletter, and develop an educational program that can be used in schools and for workshops, which comprehensively addresses water conservation.

Data Management
Record and collect conservation data derived from research. Monitor water use on the National Seashore, and develop a plan for conservation that targets specific high-use areas.

Research
Research possible alternative water use devices. Continue to study the best possible locations for large and small well placement. Study the impact differences between large and small well fields.

Current Research Projects

Potential Ground Water Withdrawal Effects on Plant Distributions, Fauna, Soils and Water Chemistry of Seasonally flooded Wetlands and Kettle Ponds of Cape Cod National Seashore (Roman et al., 1995; Colburn, 1996).

The objective of this study is to determine the ecological impact of ground water withdrawal on Cape Cod National Seashore's wetland habitats. Researchers plan to assess the ecological dependance of wetlands on current ground water regimes. By studying both the hydrology and ecology along a wetland to upland gradient, a relationship will be established between water table depth and elevation and response variables (vegetation and faunal composition and abundance as well as soil/pore water biogeochemistry). In this way ecological effects of altering the hydrologic regime may be predicted. It is particularly important to interpret seasonal effects of ground water withdrawal and ecological responses in view of the coincidence of large increases in water needs by both human and natural systems during the Cape Cod summer. Water supply is, in fact, a principal limiting factor for both economic and biological productivity during this critical season.

Kettle Pond Hydrogeology (Horsely and Witten, Inc., 1996).

The objective of this project, begun by Horsley & Witten, Inc. and continued by the National Park Service and Cape Cod Commission, is to describe and model the hydrogeologic system of the kettle ponds and the surrounding aquifer. Hydrogeologic information is needed to interpret pond limnology and sensitivity to disturbances, including nearby ground water contamination and municipal ground water withdrawal. The study employs well networks at both Duck and Gull ponds. These ponds were selected for study because they represent the two types ofNational Seashore kettle ponds; Duck Pond is oligotrophic (acidic and landlocked), and Gull Pond is mesotrophic (circumneutral and open, that is, connected to other water bodies). The study will map ground water flow directions and will identify important shorelines for inflow and outflow as affected by season and meteorology. The study will also estimate pondwater residence times. Numerical modeling will allow simulation of ground water withdrawal and its effects on surface water levels and ground water-surface water exchange.

Chapter Six: Water Resource Containment From non-point Source Point Pollution

Several reports that focus on Cape Cod have documented that pollutants derived from septic effluent degrade both ground and surface water resources located within and outside the National Seashore boundary (Persky, 1986; Sobczak and Cambareri, 1995; Valiela et al., 1992; Martin et al., 1992). Several other reports (Valiela et al., 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985) document the far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters. These findings are of great importance to the resource managers at the Cape Cod National Seashore as many of the ponds and estuaries within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic-contaminated ground water discharge (Portnoy, 1994; Portnoy et al., 1998; Martinet al., 1992).

Problem History

On the outer Cape, there is no sewer, and all homes and businesses rely on private septic systems for waste disposal. For almost two decades, various reports have documented increases in nitrate concentrations in the ground water on the outer Cape and have directly linked the elevated levels with increases in housing density and the number of actively used on-site septic systems (Frimpter and Gay, 1979; Persky, 1986; Noss 1989; Goetz et al., 1991; Sobczak and Cambareri, 1995). The Massachusetts Department of Environmental Protection has documented that faulty private septic systems are the largest contributor of pollutants to inland and coastal surface water bodies in the state (Eichner and Cambareri, 1991; Sit, 1995).

Residential and commercial development have been steadily increasing on the outer Cape since the early 1960s. From 1960 to 1975, year round population grew 82 percent, and that population triples during the summer (LeBlanc et al., 1986). Due to the proximity of private water supply wells and septic systems and the nature of the porous sand and gravel aquifer, there is great concern that as population growth on the outer Cape continues and the use of on-site wastewater disposal systems increases, occurrences in cross contamination of clean drinking water supplies will also increase (Sobczak and Cambareri, 1995). In light of increasing development and elevated levels of nitrates, land use planning has become an important issue on the lower Cape. Noss (1989) as well as Harper et al. (1992) examined various land uses that occur in aquifer recharge areas throughout Massachusetts, including Cape Cod. Both reports conclude that residential areas have the greatest impact on nitrate contributions to ground water through the use of on-site septic systems.

The far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters have been well documented (Valiela et al., 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985). However, Hatfield et al. (1994) concluded that in the case of land uses near ground water discharge areas, there is minimal impact on drinking water quality. These findings are of importance to resource managers at the Cape Cod National Seashore as many of the ponds and estuaries within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic contaminated ground water discharge (Portnoy, 1994; Martin et al., 1992). Eutrophication, the increased production of plants, phytoplankton, and macroalgae in surface waters, can result from nutrient loading. Eutrophication not only decreases the natural ecological value of the resource, but also decreases its recreational value to humans (Martin et al., 1992).

Natural background levels of nitrate on the lower Cape are generally less than 1 mg/L (Persky, 1986). The U.S. Environmental Protection Agency maximum contaminant level, safe drinking water guideline for nitrate is 10 mg/L (Table 6.1). Nitrate levels at or above the Massachusetts Department of Environmental Protection and U.S. Environmental Protection Agency safe drinking water guidelines have been linked to methemoglobinemia or blue baby syndrome, a potentially lethal condition which decreases the ability of the blood to transport oxygen in infants (Noake, 1989), and the formation of carcinogenic nitrosamines in adults (Cambareri, 1986). The Cape Cod

Table 6.1. Criteria for selected parameters important to monitoring water quality (adapted from Sobczak and Cambareri, 1995).

Parameter	Criterion	Source of the Criterion
Nitrate	10 mg/L	U.S. Environmental Protection Agency and Massachusetts Department of Environmental Protection Safe Drinking Water Act Guideline
	5mg/L	Cape Cod Commission Regional Policy Plan planning goal, CCPEDC (1991)
Total Dissolved Solids	500 mg/L	U.S. EPA Safe Drinking Water Act Guideline
Fecal Coliform	0 colonies /1 00ml	Massachusetts Guideline for Drinking Water
Lot Size	0.25 acres 0.50 acres	Legislated by local towns

Commission has set a regional policy planning goal for nitrate concentrations at 5 mg/L. By setting a standard for nitrate below the federal and state standard, Barnstable County is able to manage the problem of contaminated drinking water supplies before it reaches a potentially harmful level (Sobczak and Cambareri, 1995).

Organic, inorganic, and biological pollutants can enter the ground water through septic system leach fields. Biological pollutants are living organisms such as viruses, bacteria, and protozoans which are primarily derived from human fecal matter. Coliform bacteria are the indicator organisms used to detect biological pollutants because their presence may indicate the existence of other pathogenic organisms in ground and surface water resources (Janik, 1987). The state of Massachusetts requires that water samples be checked for the presence of coliform bacteria and that when the coliform bacteria levels exceed zero in the original sample and a check sample, the results must be reported to the Massachusetts Department of Environmental Protection within 48 hours (310 CMR Drinking Water, 1988).

Inorganic pollutants are introduced to the ground water on the outer Cape predominantly through septic system wastewater, landfill leachate, and urban runoff.

Inorganic pollutants are introduced to the ground water on the outer Cape predominantly through septic system wastewater, landfill leachate, and surface runoff (Janik, 1987). The polluted ground water then discharges into ponds and estuaries, which increases the potential for eutrophication of surface waters. The most common inorganic elements in the Cape Cod ground water, derived specifically from septic effluent, are nitrogen and phosphorus. Nitrate which is the form of nitrogen considered to pose the greatest threat to human health, is regulated and monitored in public and private drinking water supplies by the Massachusetts Department of Environmental Protection as outlined in the Massachusetts Drinking Water Regulations (310 CMR 22.00, Drinking Water, 1988).

The addition of phosphorus to pond surface waters via contaminated ground water discharge is a primary management concern ecologically, although it presents no major human health concern. According to Martin et al. (1992), phosphorus introduced to the ponds via septic system runoff has the potential to increase algal production and reduce the natural clarity of the pond waters. Martin et al. (1992) also stated that shoreline septic systems located at several residences, owned by both the National Park Service and private homeowners, are thought to be the primary source of additional phosphorus to some of the lower Cape ponds.

Organic pollutants have the potential to contaminate ground water via septic systems as well. Household cleaners, solvents and any petroleum-based products that are disposed of in sinks or toilets can enter the ground recharge water via the septic system. Household hazardous wastes containing contaminants such as benzene and toluene cannot be treated by on-site septic systems (Noake, 1989). Massachusetts Department of Environmental Protection, as outlined in the Massachusetts Drinking Water Regulations, monitors and regulates the level of organic pollutants in all public water supply systems (310 CMR 22.00, Drinking Water, 1988).

Title 5 (Mass. law 310 CMR 15, Requirements for the disposal of sanitary sewage) regulates the addition of new on-site below-ground septic systems to properties in Massachusetts. Title V also states that when any property is sold, expanded, or altered in its use, an inspection of the existing septic system be performed. The regulation requires that a septic system (i.e., leach field) be located at least 100 feet from surface drinking water supplies and 50 feet from wells, rivers, lakes, ponds, and wetlands. Additionally, a 4-foot unsaturated thickness of soil above high ground water level is also required. This distance is necessary to remove most pathogenic biological pollutants before they reach the ground water (Janik, 1987; Weiskell et al., 1996).

The Challenge

Ensure that a high level of water quality is maintained for both the natural and human environments on the outer Cape while development continues. Find cost efficient methods for alternative wastewater disposal and promote the use of these methods across the outer Cape. Work with surrounding agencies to develop cost effective methods for alternative wastewater disposal.

These distance requirements, however, are based on the distance over which coliform bacteria will be removed from the water. Nitrate and other chemical contaminants are often conserved in subsurface conditions characteristic of the outer Cape and may not be attenuated over distances that are adequate for removal of bacteria (Sobczak and Cambareri, 1995). Since ground water levels can fluctuate seasonally and annually, it is important to locate septic systems sufficiently above the highest possible ground water level (Janik, 1987). Frimpter and Belfit (1992) have created a widely used technique for the siting of septic systems (T. Cambareri, 1996, pers. comm., Cape Cod Commission). The technique allows the high ground water level to be estimated at any location on Cape Cod by comparing the water level taken at any time of the year with a series of index wells of known water level variability (Frimpter and Belfit, 1992).

Impacts of Nutrient Contamination of Ground Water

Nutrient loading, particularly nitrogen contamination, is the principal cause for concern regarding septic wastewaters on the outer Cape (Valiela et al., 1997). Nitrogen is present in the outer Cape ground water in a variety of forms: nitrate, nitrite, ammonium, and gaseous nitrogen. Ammonium is the dominant form in primary wastewaters, but organic nitrogen is more abundant in natural marsh deposits. Nitrate is the primary form in the ground water as well as the primary health issue (Janik, 1987). In the aerobic subsurface conditions of the lower Cape, ammonium in sewage and wastewater effluents quickly becomes oxidized to nitrate over short distances from its source. Nitrate is a negatively charged ion which is repelled by negatively charged soil particles. It is, therefore, conservative, unreactive, and persistent in the ground water (Frimpter and Gay, 1979; P. Veneman, 1996, pers. comm., University of Massachusetts).

All conventional septic systems, even when operating properly under ideal design conditions, will leach nitrogen to the ground water (P. Veneman, 1996, pers. comm., University of Massachusetts.) A minimum lot size of 40,000 square feet is needed to effectively dilute the nitrogen contribution of a single family septic system to concentrations below the Barnstable County planning guideline of 5 mg/L (P. Veneman, 1996, pers. comm., University of Massachusetts). In areas where this minimum lot size is unfeasible, alternative septic technologies, such as recirculating sand filters, peat filters, and the RUCK system have shown potential for increased nitrogen removal. Title V allows for the use of alternative systems in nitrate sensitive areas (P. Veneman, 1996, pers. comm., University of Massachusetts).

In a 1979 survey of ground water quality, Frimpter and Gay (1979) noted that in general the ground water of Cape Cod supplied the residents with good quality drinking water, characteristically low in dissolved solids, and virtually free of toxic heavy metals and organic compounds. Frimpter and Gay (1979) also found the natural pH of the water in general to be mildly acidic, between 6 and 7.

The average concentration of nitrate as nitrogen from 84 sites in 1979 was 0.5 mg/L with 90 percent less than 1.3 mg/L. The maximum was 6.3 mg/L from one well near Hyannis. According to Frimpter and Gay (1979), water containing concentrations of nitrate greater than 5 mg/L probably had been impacted by wastewater or fertilizer. While this report indicated that at the time nitrate levels were within safe limits for drinking water, it also stated that the ground water was susceptible to degradation from non-point pollution sources and must be carefully monitored and managed.

A computer generated map of nitrate concentrations was developed by Persky and the U.S. Geological Survey in 1986, seven years after the Frimpter and Gay report. The map Persky developed shows a positive relationship between nitrate concentrations and housing densities on Cape Cod. According to Persky (1986), in five out of nine sample areas, where housing density was greater than one home per acre, nitrate concentrations exceeded 5 mg/L in 25 percent of the wells. In comparison, at one of nine additional sample areas, where housing density was less than one home per acre,

Table 6.2. Aquifer lens water quality data (adapted from Janik, 1987).

Aquifer Lens	Number of Wells Sampled	Percent of Total Number of Wells	Percent > 10 mg/L Nitrate MCL[a]	Percent > 5 mg/L Nitrate[b]
Nauset	668	13%	2%	Not detected
Chequesset	371	12%	4%	10%
Pamet	158	12%	4%	10%

[a]MCL = Maximum Contaminant Level
'Cape Cod Commission Planning Goal

nitrate concentrations exceeded 5 mg/L in 25 percent of the wells. The Cape Cod Commission states that today, in many cases, housing lots are 3/4 of an acre or smaller (Sobczak and Cambareri, 1995). A study by Janik (Table 6.2), published in 1987, shows that 10 percent of the wells sampled in the Chequessett lens have nitrate concentrations greater than the regional planning goal of 5 percent.

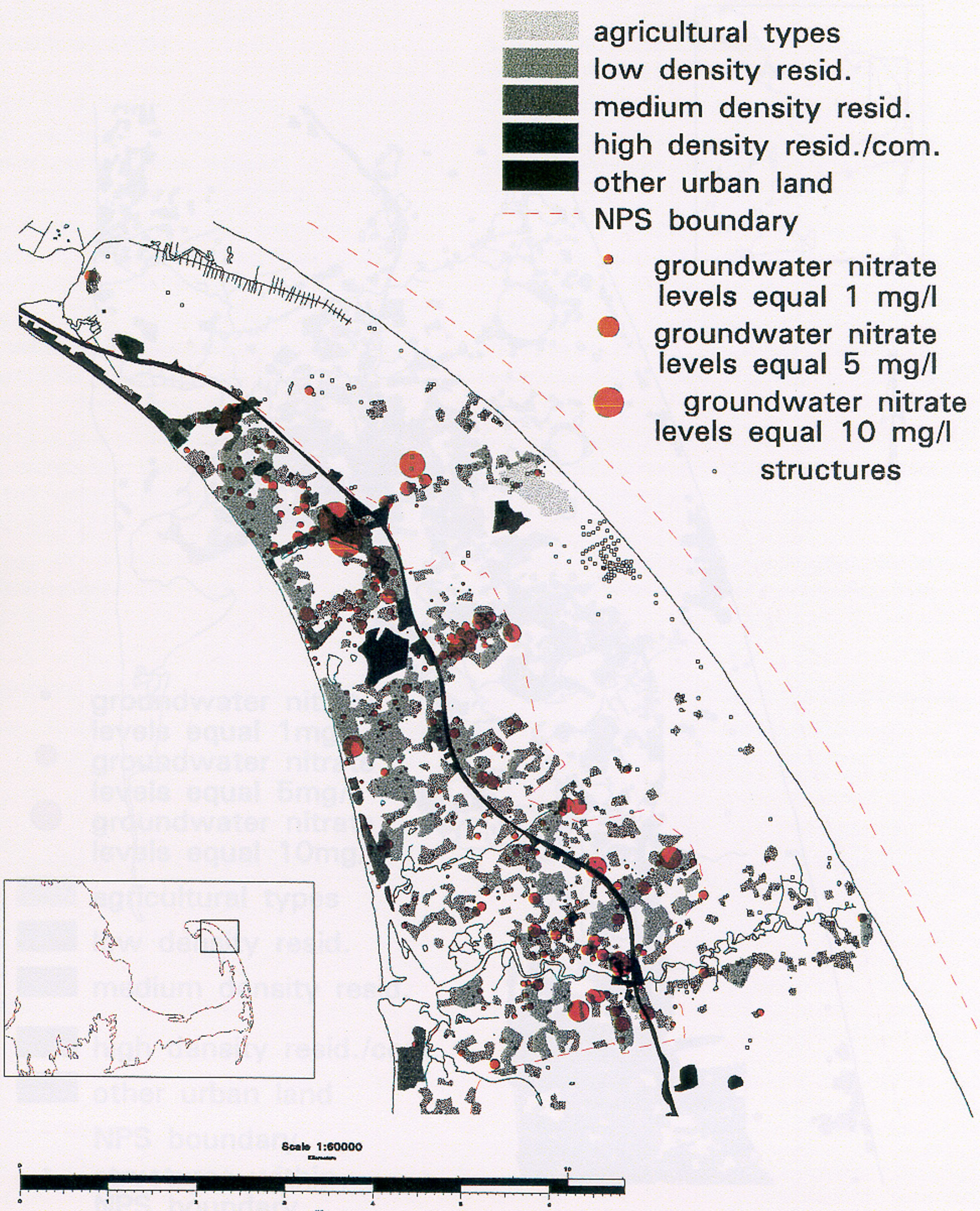
The seasonal nature of population densities on the lower Cape provides an additional complication to the problem of nutrient loading from septic systems. Postma et al. (1992) found that after 8 to 15 months, the continuous supply of wastewater to a conventional septic system produces a biological clogging mat of reduced permeability at the interface between soils and the leaching facility. The clogging mat then slows the rate at which effluent travels into the soil, promotes an even distribution of effluent throughout the treatment field, and enhances the septic system's ability to filter pollutants. The seasonal use of a septic system prevents the formation of a clogging mat and in turn limits the system's ability to filter pollutants efficiently. In the absence of a clogging mat, septic effluent is unevenly distributed and travels through sandy, porous soils in a concentrated, localized path with little treatment before reaching the ground water (Postma et al., 1992). In situations where the clogging mat may not develop due to coarse soils and/or seasonal use, a pressure dosing type septic system is recommended (P. Veneman, 1996, pers. comm., University of Massachusetts). Pressure dosing systems store effluent in a pumping chamber from which it is pumped at either preset time or volume intervals through a small diameter, slotted PVC pipe. This ensures even effluent distribution throughout the leaching facility, low loading rates, slow unsaturated flow, and enhanced treatment (P. Veneman, 1996, pers. comm., University of Massachusetts).

According to a report of the Lower Cape Water Management Task Force (Sobczak and Cambareri, 1996), "analysis of over 7,000 drinking water samples taken between 1980 and 1994 indicate that nitrate in water withdrawn from some private and small volume wells across the lower Cape is approaching or has exceeded public standards for safe drinking water." The report documented that densely populated areas such as Wellfleet Center and the Route 6 corridor in Eastham show the greatest degree of nitrate contamination (Figure 6.1 a-c). Additionally, more than 10 percent of the sampled wells in these areas exceeded the 10 mg/L maximum contaminant level, safe drinking water standard, and many other areas of Wellfleet, Eastham and Truro exceeded the 5 mg/L Barnstable County regional planning goal and approached the drinking water standard. The report also showed that nitrate exceedances have increased for many commercial and residential subregions over a 10 year period from 1984 to 1994. Factors influencing the increasing nitrate levels include: degree of build-out, well depth, well proximity to septic systems, sampling season, local hydrogeology, and local land and water uses (Sobczak and Cambareri, 1995). Densely populated areas, like Wellfleet Center, also using on-site private water wells may not be appropriate for alternative denitrifying septic systems. Although they will reduce nitrate loading to the ground water, other contaminants may continue to enter the ground water via household septics.

Water Resources Management Plan

Figure 6.1a: Nitrate Levels by Parcel - North Truro Quad
Cape Cod National Seashore

Sources: Cape Cod Commission and MassGIS



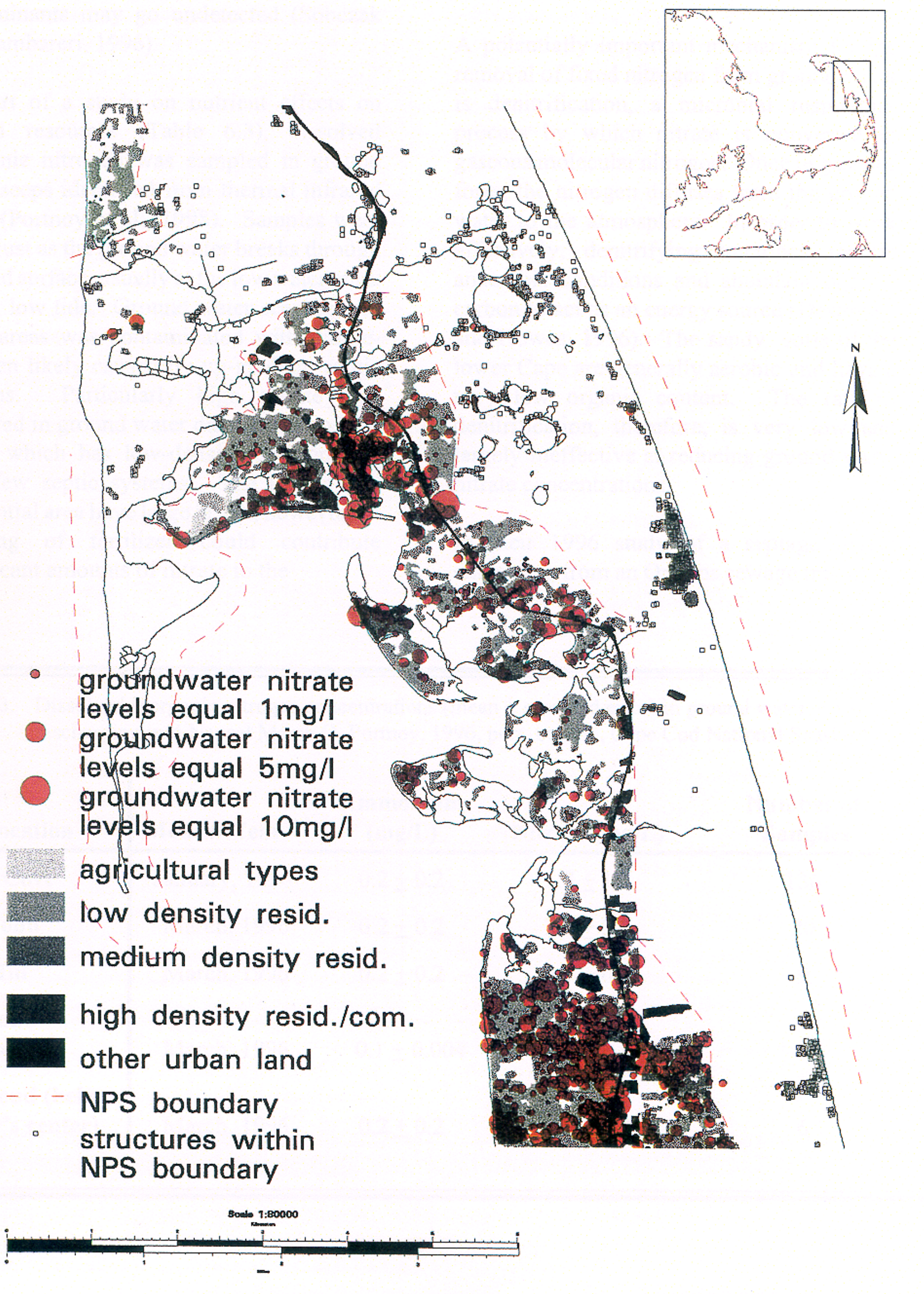
map prepared 12/4/96 by Mark Adams, wmltrt.aml

Water Resources Management Plan

Figure 6.1b: Nitrate Levels by Parcel - Wellfleet Quad

Cape Cod National Seashore

Sources: Cape Cod Commission and MassGIS



With the loss of nitrate as an indicator of septic contamination, these other contaminants may go undetected (Sobczak and Cambareri, 1996).

As part of a study on nutrient effects on natural resources (Table 6.3), dissolved inorganic nitrogen was sampled in ground water seeps identified from thermal infrared scans (Portnoy et al., 1998). Samples were taken just as the ground water breaks through the land surface, usually at the low water mark during low tide. Ground water seeping into these areas was contaminated with nitrate-nitrogen likely caused by up-gradient septic systems. Particularly high nitrate was observed in ground water discharge into Mill Pond, which has low-density development with few septic systems. The lots in this residential area have large lawns, however, so leaching of fertilizer could contribute significant amounts of nitrate to the ground water (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore).

A potentially important mechanism for the removal of fixed nitrogen from ground water is denitrification, a microbial respiratory process by which nitrate is converted to gaseous molecular nitrogen. Once in gaseous form, the nitrogen diffuses from the ground water to the atmosphere. In order to work effectively, denitrifying microbes require anaerobic conditions and abundant organic carbon to act as an energy source (Desimone and Howes, 1996). The sandy soils of the lower Cape are generally aerobic and have a very low organic content. The rate of denitrification, therefore, is very low and largely ineffective at reducing ground water nitrate concentrations.

In their 1996 study of a septage plume emanating from an Orleans sewage treatment

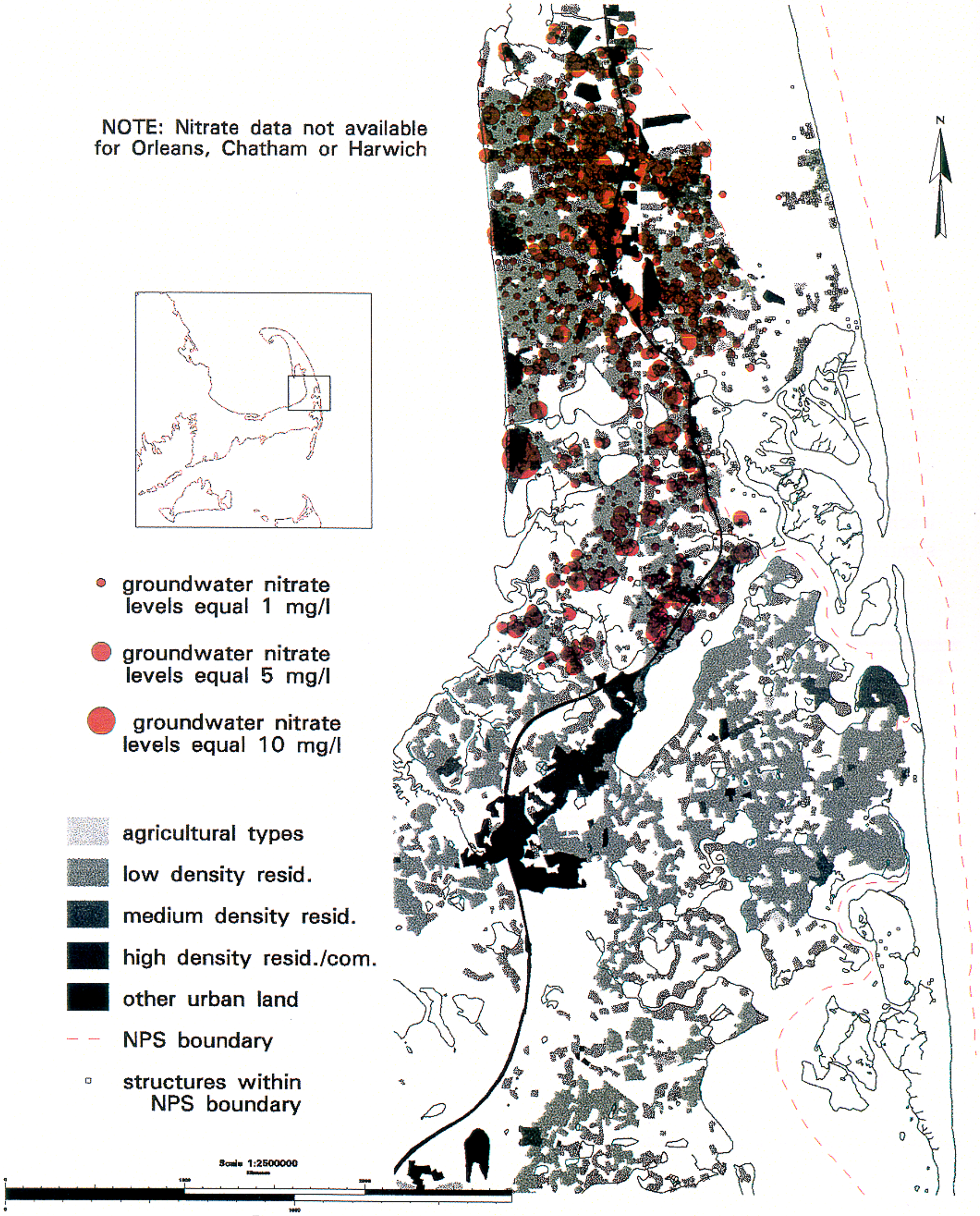
Table 6.3. Dissolved inorganic nitrogen concentrations (mean ± standard error) in ground water seeps discharging into Nauset Marsh (J. Portnoy, 1996, pers. comm., Cape Cod National Seashore).

Location	Month/ Year	Ammonium (mg/L)	Nitrate (mg/L)	Number of Samples
Town Cove	January, 1996	0.2 ± 0.2	1.7 ± 1.7	136
Mill Pond	March, 1996	0.2 ± 0.2	3.7 ± 3.2	20
Fort Hill	March, 1996	0.2 ± 0.2	0.7 ± 0.7	9
Salt Pond Channel	March, 1996	0.1 ± 0.004	0.2 ± 0.1	3
Salt Pond (below visitor's center)	March, 1996	0.2 ± 0.2	1.8 ± 0.8	6

Water Resources Management Plan

Figure 6.1c: Nitrate Levels by Parcel
Orleans/Chatham Quad - Cape Cod National Seashore

Sources: Cape Cod Commission and MassGIS



map prepared 12/4/96 by Mark Adams, wnitro.aml facility, Desimone and Howes found that an anoxic zone develops in the core of the plume; however, most of the organic content of the wastewater is stripped in the unsaturated zone before it enters the ground water. They suggest that denitrification could be improved if organic matter could be delivered to the anoxic zone in the plume (Desimone and Howes, 1996).

Impacts of Pond Shoreline Septic Systems

Many of the ponds within the National homes or that are Seashore boundaries have private inholdings on their shorelines accompanied by septic systems (Figure 6.2). Of the 20 kettle ponds located on National Seashore property, only three do not have shoreline residences. The highly permeable nature of the sand and gravel ground water aquifers on the Cape combined with septic system runoff of nutrients, particularly phosphorus, has the potential to cause eutrophication of the ponds. Seasonal residences are now becoming year round residences, increasing wastewater disposal and, potentially, phosphorus loading (Martin et al., 1992). The very low natural background levels of phosphorus in surrounding soils results in low primary production and a high water clarity in the ponds. The addition of human waste from the shoreline septic systems is assumed to be the primary source of phosphorus supporting increased primary production of plants and phytoplankton and cultural eutrophication

> **The addition of human waste from shoreline septic systems is assumed to be the primary source of phosphorus and likewise, increased primary production of plants and phytoplankton and cultural eutrophication.**

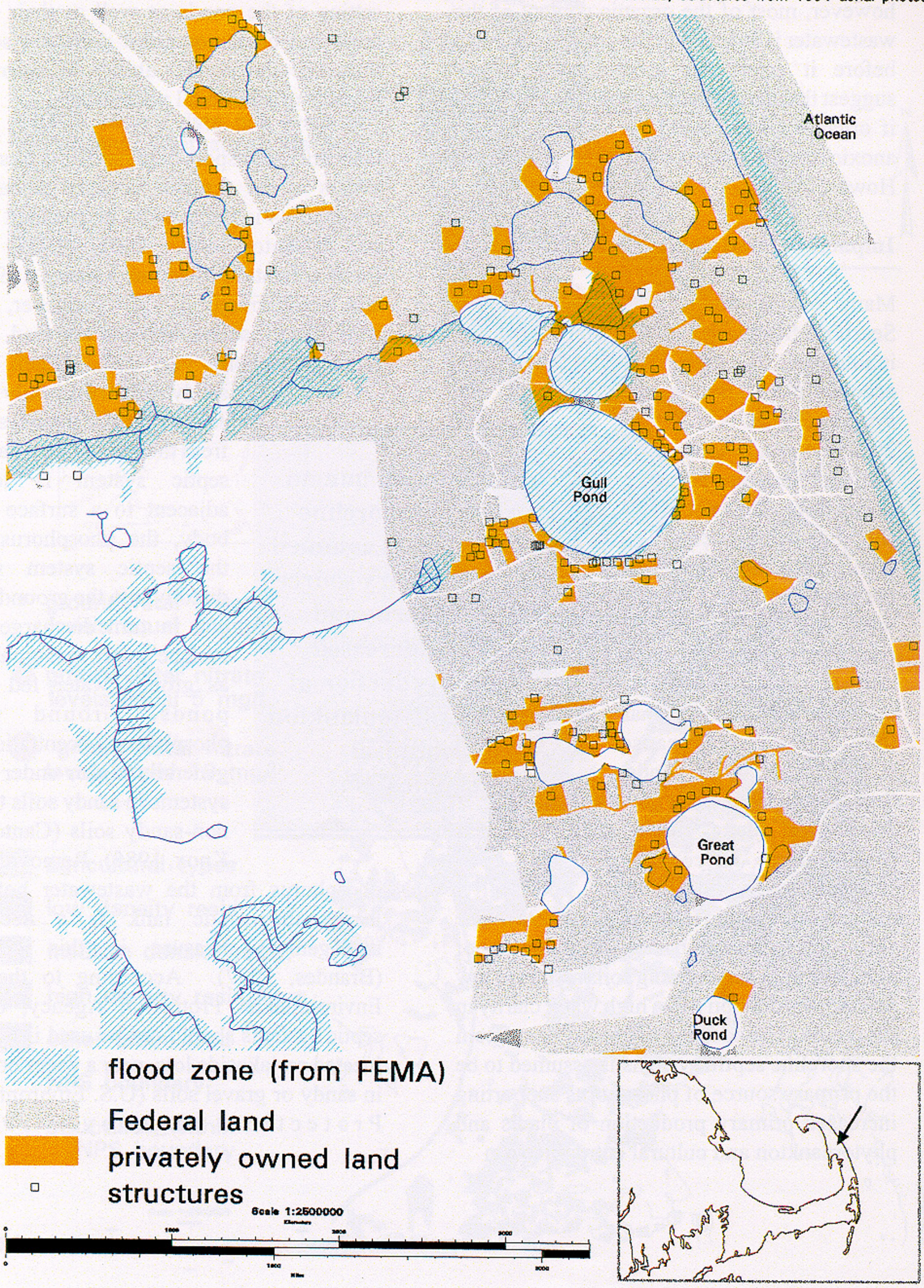
(Godfrey et al., 1978; Martin et al., 1992). As mentioned in Chapter 2, the geologic setting of the ponds as well as their depth, area, and other non-point pollution sources influence the ponds' ability to absorb the impacts of additional phosphorus.

Generally, transport of phosphorus to surface waters is not a major concern since most phosphorus is believed to be retained in the soil (Cantor and Knox, 1985; U.S. Environmental Protection Agency, 1990; Ho and Notodarmojo, 1995). However, sandy soils, like the soils found on Cape Cod, do not retain phosphorus very well. When coarse sandy soils are the only media separating the septic system from the ground water and the septic system is located adjacent to a surface water body, the phosphorus from the septic system moves directly into the ground water and in turn discharges into surface water resources such as ground water fed kettle ponds. Ground water phosphorus concentrations are generally higher under septic systems in sandy soils than in non-sandy soils (Cantor and Knox, 1985). Removal of the phosphorus from the wastewater before it leaves the septic tank is a necessary management measure in this situation (Brandes, 1977). According to the U.S. Environmental Protection Agency, on-site septic systems should not be used if they are located on lakeside lots, near a water body, or in sandy or gravel soils (U.S. Environmental Protection Agency, 1993).

Water Resources Management Plan

Figure 6.2: Shoreline Ownership and Building Density Near Wellfleet Kettle Ponds Cape Cod National Seashore

Sources: ownership from Federal Lands records; structures from 1991 aerial photos



map prepared 12/4/98, Mark Adams, wrpondbldg.aml

Once in the pond system, most phosphorus is immediately taken up by green plants and algae. During summer, a sharp temperature barrier prevents bottom waters from mixing with the surface waters where oxygen can be replaced by contact with the atmosphere. As a result of the oxygen depletion, a reducing environment is created for the iron in the sediments, and phosphorus is released. With subsequent mixing of the water column, the phosphorus can again become available for algal production. Thus, ponds with higher nutrient loads create an environment where some of past nutrient loads are returned internally from the sediments, exacerbating the effect of external nutrient loads. Hypolimnetic oxygen depletions are common in several National Seashore ponds (Martin et al., 1992).

The National Park Service, recognizing the need to monitor the effects of additional phosphorus on the 20 ponds located within the National Seashore, developed a kettle pond monitoring program in 1992, summarized in Table 6.4. Samples taken for this program have indicated a reduction in pond water clarity at some of the ponds within the National Seashore (C. Fan-is, 1996, pers. comm., Cape Cod National Seashore). Duck Pond, which has one shoreline residence and a Secchi disk transparency of 36 to 60 feet (11 to 18 meters), has suffered no impacts from additional nutrients (Table 6.5). Gull Pond has 21 shoreline residences. A Secchi disk transparency reading that is typically 13 feet (4 meters), suggests impacts from additional nutrients to the pond's system.

Besides phosphorus, leachate from shoreline septics or runoff from shoreline soils can add biological pollutants to the pond waters. For this reason, staff from the Town of Welifleet Health Department monitor fecal coliform and total coliform levels during June, July, and August when public use is greatest. Monitoring is done every two weeks in Gull, Long, Great, Duck, and Dyer ponds. Monitoring has occurred for the past 10 years and only twice in that time has a pond been closed for high levels of fecal or total coliform (J. Chatham, 1996, pers. comm., Wellfleet Health Department). According to John Chatham, Director of the Pond Sampling Program, Gull and Long ponds have each been closed once to swimmers, both occurrences over 5 years ago. Chatham noted that increased levels in fecal and total coliform occur predominantly after heavy rainfall events that produce significant runoff. Contrary to popular belief; high water temperature does not appear to be a factor in coliform levels at these five ponds (J. Chatham, pers. comm., Welifleet Health Department). Gull Pond has 21 shoreline dwellings and Long Pond has 22. Duck, Dyer, and Great ponds each have fewer than 10 shoreline dwellings.

Impacts of Nutrient Loading to Coastal Surface Waters From Septic Systems

Increases in the density of residential and commercial development on the Cape has increased the amount of nutrients that are delivered to rivers and estuaries by ground water discharge. In most cases, the sources of nutrients originate within the watershed rather than outside of it. The most common sources of nitrogen to surface waters are precipitation, fertilizers, and domestic wastewater; however, domestic wastewater delivers significantly more nitrogen to surface water than either precipitation or fertilizers (Valiela et al., 1997).

Table 6.4. Summary of Kettle Pond Monitoring Program at Cape Cod National Seashore.

I. Annual Spring (April) survey of all 20 ponds.

Depth Stations

Field variables | Lab. variables | Field variables

Lab. variables

Temperature

Conductivity | Total phosphorous | 1.6 ft. (0.5 m) from surface 1.6

Dissolved oxygen | ft (0.5 m) from surface

Redox potential | Nitrate | 3.3 ft (1 m) from bottom

pH | Phosphate | 3.3 ft (1 m) intervals Ammonium

Light | Sulfate

Secchi depth | Chloride

Calcium

Magnesium
Sodium
Potassium
Chlorophyll a

II. Quarterly (January, April, July, and October) 20 pond survey of pH, alkalinity (surface grab samples) and water level.

III. Summer (May-October) biweekly monitoring of Duck, Dyer, Great (Truro), Great (Wellfleet), Gull, Herring, Long (two basins), Snow, Spectacle and Ryder ponds.

Field variables
Temperature
Conductivity
Dissolved oxygen
Redox potential pH
Light
Secchi depth

Depth Stations
1.6 ft (0.5 m)
3.3 ft (1 m) from bottom
3.3 ft (1 m) intervals

IV. Annual August survey of all 20 ponds.

Depth Stations

Lab. variables | Field variables | Lab. variables

Total phosphorus | 1.6 ft (0.5 m) from surface 1.6

Field variables | ft (0.5 m) from surface

Temperature

Conductivity | Nitrate | 3.3 ft (1 m) from bottom

Dissolved oxygen | Phosphate | 3.3 ft (1 m) intervals Ammonium

Redox potential
pH
Chlorophyll a
Light
Secchi depth

Table 6.5. Depths and measures of typical summer (1996) productivity in five Cape Cod kettle ponds.

Pond	Depth (m)	Secchi (m)	Total Phosphorus	Chl a (mg m^{-3})
Duck	18	11	7-8	2-3
Gull	18	4	10-17	2-3
Ryder	11	8	16-21	3-5
Great (Truro)	10	6	9-18	6-7
Herring	4	3	60-70	14-17

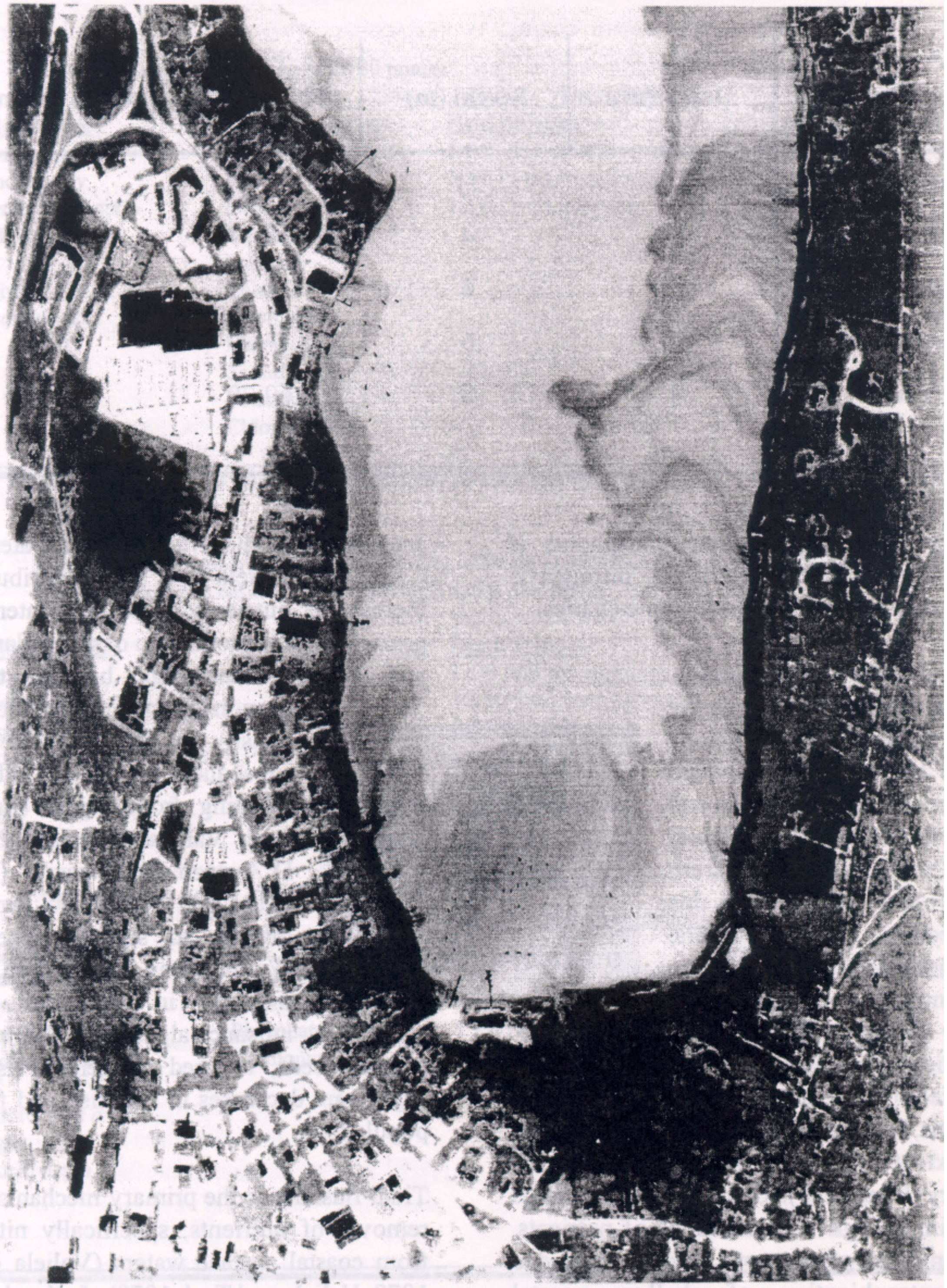
Unlike fresh water, where phosphorus is generally the limiting nutrient, nitrogen is generally the limiting nutrient in estuaries.

Ground water is the primary mechanism by which surface waters receive nutrients from septics (Valiela et al., 1992; 1997). Lowland resources, such as streams and estuaries, receive ground water flow (Sobczak and Cambareri, 1995) and because of this connection, estuaries, rivers, and ponds are susceptible to contamination from ground water discharge that contains organic, inorganic and biological pollutants. A preliminary analysis of Town Cove, Orleans, using aerial thermal sensing, displays the extent of ground water inflow into the estuary (Figure 6.3). Ground water discharge containing high concentrations of nutrients, predominantly from septic leachate, has led to the eutrophication of shallow coastal ecosystems in the Waquoit Bay watershed, Cape Cod. Valiela et al. (1992) attribute the increase of nutrients in surface waters, the greater primary production of phytoplankton, and increased macroalgal biomass to the growth in population and housing density on the Cape and the subsequent increase in nitrogen leaching from septic systems. Both Valiela et al. (1992) and D'Avanzo and Kramer (1994) note that increased nutrient loading to surface waters in Waquoit Bay has also led to an increase in red and green nuisance algae and a decrease in eelgrass beds, reduced oxygen levels, and significant decreases in shellfish and finfish populations.

Unlike fresh water, where phosphorus is generally the limiting nutrient, nitrogen is generally the limiting nutrient in estuaries.

Tidal flushing is the primary mechanism for removal of nutrients, specifically nitrogen from coastal surface waters (Valiela et al., 1978; Valiela and Teal, 1979). In the absence

Figure 6.3. Discharge of cold (dark) ground water into relatively warm estuarine waters of Town Cove, Orleans, August 1994 (Aero-Marine Surveys, Inc., Groton, CT).



of tidal flushing, nutrients introduced to coastal water bodies can remain in the system, increase algal production, and promote eutrophication.

An example of this is Pilgrim Lake, a shallow coastal lagoon located in North Truro. Pilgrim Lake has been closed off from tidal influences since about 1860 and is experiencing advanced stages of eutrophication due to the accumulation of nutrients, particularly phosphorus and nitrogen (Emery and Redfield, 1969; Mozgala, 1974; Applebaum and Brennickmeyer, 1988).

Recently, the National Park Service completed a three-year study of nitrogen loading from ground water to Nauset Marsh. There is concern about eutrophication of the surface waters (Portnoy, 1994; Portnoy et al., 1998; Nowicki et al., in press).

The purpose of this study is to:

1. describe patterns of ground water discharge and nitrogen contamination;
2. describe the extent of denitrification; and,
3. produce an estimate of nitrogen loading from estuaries to ground water.

The first year of study on the outer Cape surveyed ground water nutrient concentrations at 14 sites around Nauset Marsh. Ground water nitrogen levels were elevated above background levels at all shorelines surveyed except Salt Pond Bay; nitrate concentrations were directly related to the intensity of upgradient development. Along the developed shore in Orleans, nitrate concentrations averaged 2.8 mg/L, almost 40 times unpolluted background concentrations (Portnoy, 1994).

Management Steps: Non-point Contamination from Wastewater Disposal
400 Days to 5 Years

Committee
Examine current zoning as it relates to water resources. Evaluate the optimal size of cluster developments that minimize ecological impacts of wastewater treatment. Examine the current use of fertilizers

Education
Develop a segment in the newsletter that deals with septic and alternative systems. Incorporate information about proper wastewater disposal into school and public education programs.

Data Management
Collect information related to nutrient loading in ponds, estuaries, and ground water. Place information in a format that allows for easy comparative analysis.

Research
Continue to monitor nutrient loading into the ponds. Study the potential impacts of fertilizer use on drinking water supplies and ecological resources.

CONTRIBUTING ISSUES

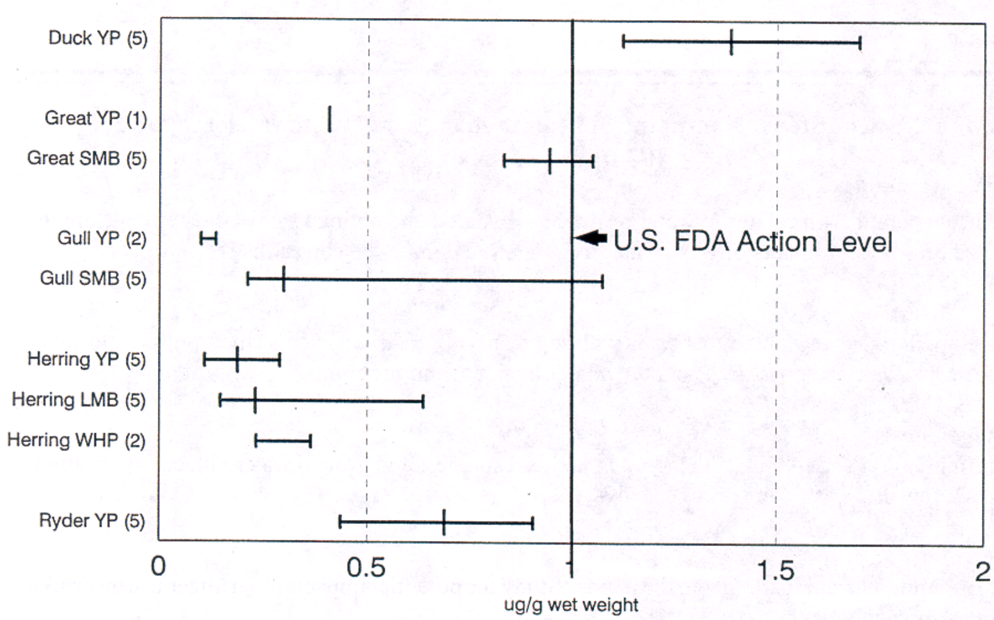
Atmospheric Deposition of Mercury

Atmospheric deposition is implicated as the major source of mercury in the kettle ponds of the National Seashore (Haines, 1996). Yellow perch, a favorite with fishermen, is known to accumulate mercury in its tissues. At the National Seashore's three most acidic ponds [Duck, Dyer and Great (Wellfleet)], yellow perch have exhibited necrotic lesions on the head and gill covers, a syndrome known as "hole in the head" disease (Winkler, 1994). The Biological Resources Division of the U.S. Geological Survey is currently engaged in a monitoring program that evaluates mercury contamination in five kettle ponds on the National Seashore as well as at Acadia National Park. A recent progress report shows that yellow perch in all five of the ponds studied have mercury accumulations (Haines, 1996; Figure 6.4). These preliminary findings suggest that atmospheric deposition of mercury is a threat to the National Seashore's surface waters.

A similar study in Massachusetts (Massachusetts Department of Environmental Protection, 1997b) found bioaccumulations of mercury in largemouth bass and yellow perch but less so in brown bullhead. The study did not include any lakes on Cape Cod. However, there was a strong correlation between

Figure 6.4. Median and Range of Mercury Concentrations in Fish Fillets from Five Kettle Ponds on Cape Cod National Seashore (from Haines, 1996; Standards from NESCAUM, 1998). Great = Great Pond (Truro).

Figure 6.4. Median and Range of Mercury Concentrations in Fish Fillets from Five Kettle Ponds on Cape Cod National Seashore (from Haines, 1996; Standards from NESCAUM, 1998). Great = Great Pond (Truro).



SMB = Smallmouth Bass; YP = Yellow Perch; LMB = Largemouth Bass; WHP = White Perch.
Sample size in ( )

conditions indicative of acid deposition impacts, such as low pH and calcium and higher mercury concentrations in predaceous fish tissue. Low pH and calcium are typical chemical characteristics of nearly all Cape ponds (Godfrey et al., 1996).

Lakes, ponds, and rivers with high acidity easily transform the inorganic mercury from the atmosphere's pollution to more toxic organic forms of mercury. Additionally, bioaccumulation of mercury in the food chain is increased with high levels of acidity. Since many of the incinerators in Massachusetts are not properly equipped to remove mercury from air emissions, mercury is a prevalent air pollution problem in the state. Incinerators burn over 11,000 tons of trash every day and emit 19 tons of mercury per year in Massachusetts.

Acid Rain

Acid deposition is relatively high on Cape Cod. Acid deposition is produced when the atmosphere is contaminated with nitrates and sulfates. Sulfate in precipitation on the Cape declined by about 16 percent from the late 1980s to the mid-1990s; however, the volume-weighted average pH of the precipitation did not change significantly (Table 6.6). Some ponds and streams on the lower Cape have been monitored quarterly from 1983 to 1994 by the Acid Rain Monitoring Project (ARM Project) of the University of Massachusetts, Amherst (Godfrey et al., 1996) and Long Pond was monitored by the Eastern Lakes Survey (U.S. Environmental Protection Agency, 1986). A comparison of these two surveys for Long Pond is shown in Table 6.7. Generally the ponds on the Cape are very low in both pH and alkalinity (Godfrey et al., 1996; Mattson et al., 1992) and would be expected to be very sensitive to changes in acidic inputs. Although there appears to be a general trend toward increasing pH and alkalinity in Massachusetts (Godfrey et al., 1996), this trend is not apparent on Cape Cod.

Table 6.6.
National Atmospheric Deposition Program data (NADP/NIN Coordinating Office, 1981 to 1996), for sulfate and lab pH for precipitation at Truro, Mass. Data from *nadp.nrel.colostate.edu/NADP.* Variability not reported.

Year	Lab pH	Sulfate (mg/1)
1981	4.49	2.00
1982	4.41	2.14
1983	4.65	1.62
1984	4.63	1.47
1985	4.41	2.15
1986	4.42	1.88
1987	4.51	1.67
1988	4.39	2.18
1989	4.49	1.85
1990	4.54	1.62
1991	4.41	1.98
1992	4.54	1.54
1993	4.63	1.50
1994	4.53	1.44
1995	4.49	1.51
1996	4.61	1.37

Eleven of the ponds and two streams have sufficient data to analyze for trends in acid/base chemistry from 1983 to 1994 (Table 6.8). All of the ponds and both streams have very low, or even negative alkalinities and low pH. The results show that Northeast Pond is increasing in alkalinity, Kinnacum Pond is decreasing in alkalinity and the remaining nine ponds are not significantly changing in alkalinity. Both of the streams with available data have significant trends in adjusted alkalinity; Herring River is increasing in alkalinity while Silver Spring Brook is decreasing in alkalinity (Mattson et al., 1997; Godfrey et al., 1996). Thus, while the ponds are fairly acidic there appears to be little change in the acidity status over the past 10 years.

According to several reports, temporary ponds in the United States are not only critical habitats for amphibians but also freshwater bodies extremely sensitive to atmospheric deposition of acids (Portnoy, 1990; Jackson and Griffin, 1991).

In light of these characteristics, many studies have attempted to find a correlation between the breeding success of amphibians and acidification of breeding ponds. Focusing on the relationship between water chemistry and the breeding success of spotted salamanders in temporary woodland ponds on the lower Cape, Portnoy (1990) observed that successful embryonic development and hatching occurred at pHs as low as 4.5. He concluded that Cape mole salamanders have been reproducing successfully at low pH levels for hundreds, perhaps thousands of years given the lower Cape soils, vegetation, and long history of acidic environments. Jackson and Griffin (1991) explored differences in acid tolerance within mole salamanders. Realizing a highly variable intra-species sensitivity to acidity, Jackson and Griffin concluded that locally, "habitat loss is probably a more immediate threat to salamander populations than acid precipitation."

Current Monitoring

National Atmospheric Deposition Program: Data Collection and Monitoring (NADP)

NADP consists of weekly precipitation samples collected to monitor precipitation chemistry. A monitoring site located within the Cape Cod National Seashore in Truro provides data on pH, calcium, magnesium, potassium, sodium, nitrate, chlorine, ammonium, sulfate, and hydrogen.

Table 6.7. Comparison of data for Long Pond, Wellfleet (PALSARIS Code #96179) resulting from the U.S. Environmental Protection Agency Eastern Lakes Survey (STORET) and the Acid Rain Monitoring Project.

Parameter	STORET from U.S. EPA Eastern Lake Survey (11/6/84, one sample only)	Acid Rain Monitoring Project Average from 1983-1993 (Number of samples)	Parameter	STORET from U.S. EPA Eastern Lake Survey (11/6/84, one sample only)	Acid Rain Monitoring Project Average from 1983-1993 (Number of samples)
Temperature °c	13.2		Mg (mg/1)	1.4	1.41 (29)
Transparency (m)	7.9		Na (mg/1)	11.83	11.71 (29)
Color (PCU)	5	4.00(27)	K (mg/1)	0.84	0.78 (30)
Conductance (umhos/cm)	97		Si (mg/I as SiO_2)	0.04	0.04 (28)
SO4-S (mg/1)	7.32	7.54(30)	CI (mg/I)	22.0	20.67 (30)
pH	4.7	4.64(43)	Fl (mg/I)	0.01	
ANC (ueq/l)	-18.1	-19.6(43)	Mn (ug/I)	55.5	50 (29)
Total P (ug/l)	5.7	3.9(1)	Al (ug/l)	51	80 (30)
DIC (mg/1)	0.6		NO3-N (mg/1)	0.07	0.01 (30)
DOC (mg/I)	0.3		Fe (ug/l)	31	50 (29)
Ca (mg/l)	1.1	1.20(30)	Turbidity (NTUs)	0.4	

Sampling depth = 1 meter for U.S. EPA samples and 2/3 meter for ARM samples.

Table 6.8. Surface Water acid/base trends, 1983-1994, on Lower Cape Cod. Average pH, average alkalinity, trend in alkalinity (adjusted to remove the effect of yearly variation in precipitation and runoff), and significance level of trend from (Godfrey et al., 1997). Alkalinity and trends in units of calcium carbonate mg/l and mg/1/yr., respectively.

Name	Town	Ave. pH	Ave. Alk.	Signif icanc	
Ponds					
Northeast	Wellfleet	4.86	- 0.44	+0.13	<0.05
Kinnacum	Wellfleet	4.47	- 1.83	- 0.14	<0.05
Dyer	Wellfleet	4.81	- 0.64	- 0.06	NS
Great	Wellfleet	4.70	- 0.83	+0.04	NS
Gull	Wellfleet	6.63	+3.18	+0.06	NS
Higgins	Wellfleet	6.51	+3.30	+0.13	NS
Horseleech	Truro	5.79	+0.67	- 0.04	NS
Round	Truro	4.81	- 0.56	+0.02	NS
Slough	Truro	4.78	- 0.66	+0.02	NS
Spectacle	Wellfleet	5.01	- 0.11	+0.01	NS
Williams	Wellfleet	5.92	+1.69	+0.02	NS
Streams					
Herring River	Wellfleet	6.08	+6.49	+0.25	<0.05
Silver Spring Brook	Wellfleet	6.54	+9.14	- 0.25	<0.05

NS = not significant at **the** 0.05 **leve**

Chapter Seven: Confirmed and Potential Contannaᵖton Sites

Organic, inorganic, or biological pollutants derived from landfills and leaking underground storage tanks pose a serious threat to the integrity of clean water drinking supplies as well as rivers and estuaries. The intimate connection between ground water and surface water on the Cape compounds the difficulty of managing these point sources of pollution, as does the permeability and generally poor contaminant adsorption characteristics of the sand and gravel aquifer.

PROBLEM HISTORY
Waste Disposal Facilities

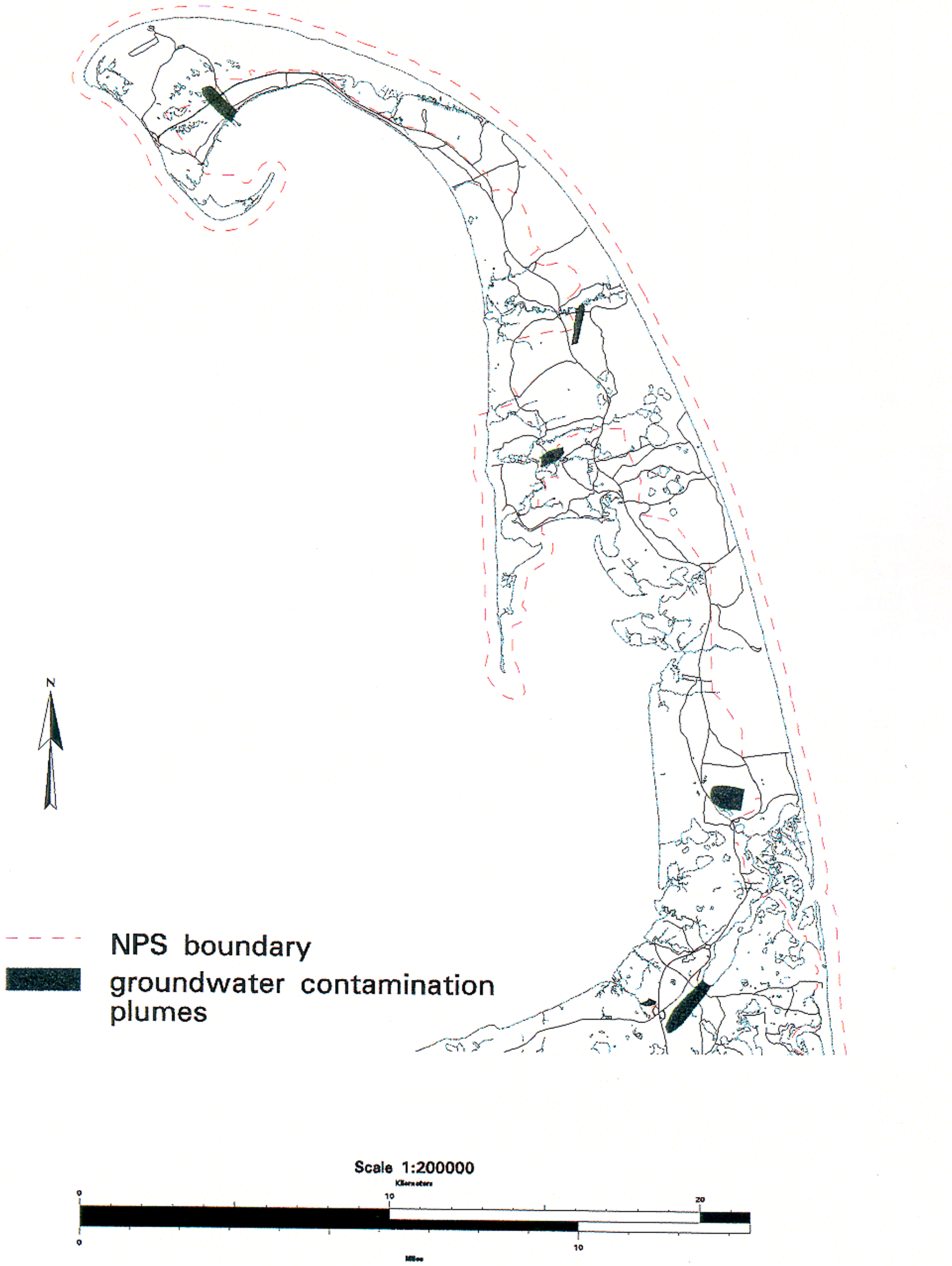
Landfills are among the five most serious threats to ground water quality in the United States (Noake, 1989). In Massachusetts, leachate contamination of ground water from landfills has been responsible for private well contamination in at least nine communities (Massachusetts Department of Environmental Quality Engineering, 1988). On the Cape, pollutants related to landfill leachate are also considered a threat to ground water supplies (Janik, 1987). A 1996 report (ATP Environmental, 1995) documents that the Eastham Municipal Landfill is directly responsible for contaminated private drinking water supplies within its vicinity.

Water that enters a landfill, usually in the form of rain and snow, comes into contact with buried wastes and forms leachate or dissolved waste. This leachate can contain toxic chemicals from commercial and household wastes. Often, the leachate leaves the landfill and follows the ground water flow, potentially entering recharge zones for water wells (Noake, 1989). Poorly contained landfills, such as unlined landfills in the sandy soils of the Cape, are especially vulnerable because water can infiltrate them from all sides, including underneath the waste (Massachusetts Department of Environmental Quality Engineering, 1988).

There are five landfills (now closed) located on the outer Cape (Figure 7.1), all of which have the potential to impact the surface water resources within the National Seashore (Table 7.1). The Provincetown and Truro landfills are located inside the National Seashore boundary. Wellfleet's landfill abuts the National Seashore boundary, and the two in Orleans and Eastham are in close proximity to the National Seashore. All landfills have been monitored by wells and the contaminant plume (Figures 7.2a-d), at each site mapped and discussed in various reports (Cambareri et al., 1989 a and b; Frolich, 1991; Urish et al., 1991; Urish et al., 1993; Winkler, 1994). According to these reports, some

Figure 7.1: General Location of Major Groundwater Contamination Plumes, Cape Cod National Seashore

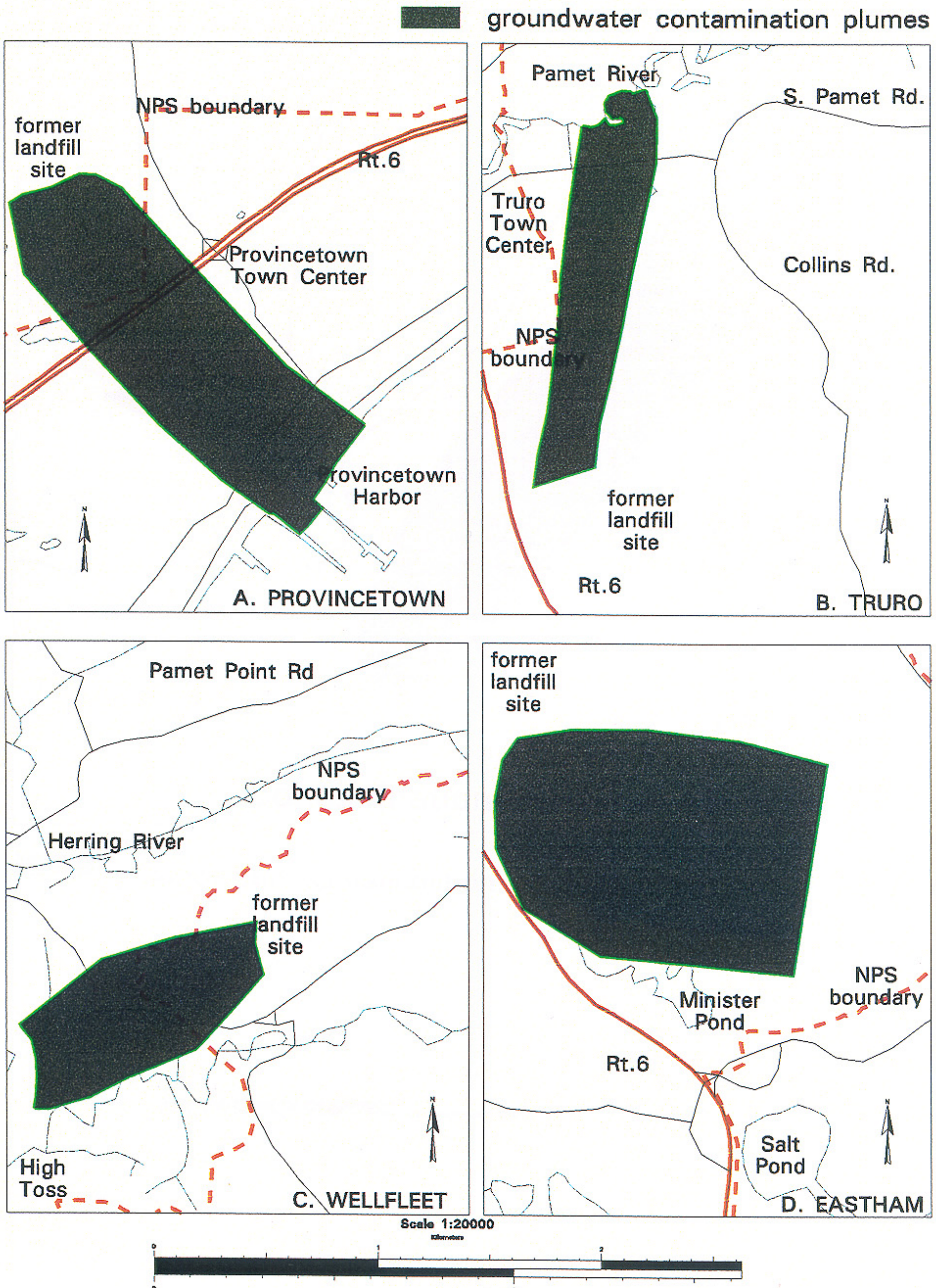
Source: Cape Cod Commission GIS program.



Water Resources Management Plan

Figure 7.2a-d: Major Groundwater Contamination Plumes Cape Cod National Seashore

Source: Cape Cod Commission GIS data.



Water Resources Management Plan

Figure 7.2e: Major Groundwater Contamination Plumes Orleans - Cape Cod National Seashore

Source: Cape Cod Commission GIS program.

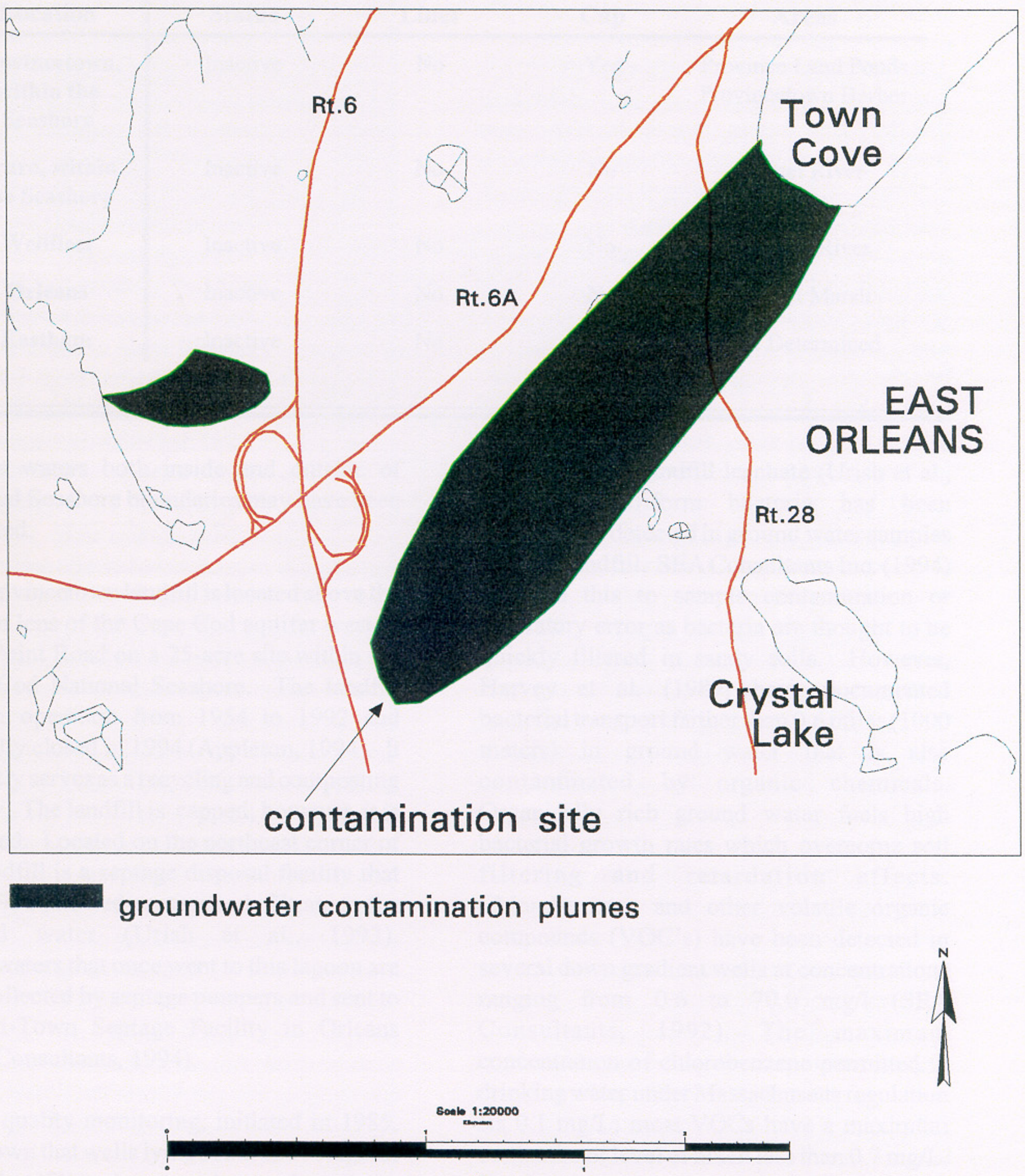


Table 7.1. Status summary of landfills on outer Cape Cod.

Location	Status	Liner	Cap	Potential Impact Areas
Provincetown, within the Seashore	Inactive	No	Yes	Province Land Ponds Provincetown Harbor
Truro, within the Seashore	Inactive	No	No	Pamet River
Welifleet	Inactive	No	No	Herring River
Orleans	Inactive	No	No	Nauset Marsh
Eastham	Inactive	No	No	Not Determined

surface waters both inside and outside of National Seashore boundaries may have been impacted.

The Provincetown landfill is located above the Pilgrim lens of the Cape Cod aquifer west of Race Point Road on a 25-acre site within the Cape Cod National Seashore. The landfill was in operation from 1954 to 1992 and officially closed in 1994 (Appleton, 1994). It currently serves as a recycling and composting facility. The landfill is capped; however, it is not lined. Located on the northeast corner of the landfill is a septage disposal facility that until 1991 allowed septage to infiltrate to the ground water (Urish et al., 1993). Wastewaters that once went to this lagoon are now collected by septage pumpers and sent to the Tri-Town Septage Facility in Orleans (SEA Consultants, 1994).

Water quality monitoring, initiated in 1985, has shown that wells lying south and southeast of the landfill and septage lagoon have been impacted with landfill leachate (Urish et al., 1993). Coliform bacteria has been consistently detected in ground water samples near the landfill. SEA Consultants Inc. (1994) attribute this to sample contamination or laboratory error as bacteria are thought to be quickly filtered in sandy soils. However, Harvey et al. (1989) have documented bacterial transport farther than 0.6 miles (1000 meters) in ground water that is also contaminated by organic chemicals. Organically rich ground water fuels high bacterial growth rates which overcome soil filtering and retardation effects. Chlorobenzene and other volatile organic compounds (VOC's) have been detected in several down gradient wells at concentrations ranging from 0.6 to 70.0 mg/l (SEA Consultants, 1992). The maximum concentration of chlorobenzene permitted in drinking water under Massachusetts regulation sis 0.1 mg/L; most VOCs have a maximum contaminant level of much less than 0.7 mg/L. Total xylenes have a limit of 10 mg/1 (310

CMR Drinking Water, 1997). Levels of combustible gas exceeding explosive limits have also been detected in soil gas along the northwest edge of the landfill (SEA Consultants, 1992).

The flow path of the contamination plume has been mapped (Figure 7.2a). It is estimated that the plume moves from the landfill across Route 6 and continues southeasterly under a cemetery and residential area terminating in Provincetown Harbor (Urish et al., 1993). Ground water contaminated by this landfill's leachate exhibits high electrical conductivity, alkalinity, bicarbonate, ammonia, nitrate, orthophosphate, calcium, chemical oxygen demand, sulfate, chloride, metals, and volatile organic carbon compounds. Additional contaminants, including automotive contaminants, road salt, and on-site sewage disposal effluents, enter the water table and the landfill plume as it travels towards Provincetown Harbor (Urish et al., 1993). Travel time of contaminants from the Provincetown landfill to the harbor is estimated to be 10 to 30 years (Urish et al., 1993). Winkler (1994) concluded that the landfill and septic lagoon leachates are impacting surface waters to the west of the landfill as well. Two ponds that are adjacent to the landfill in the Province Lands, Duck and Bennett, showed increased nutrient levels and indications of eutrophication in recent sediments. However, it should be noted that SEA Consultants (1992), hired by Provincetown to monitor the landfill, has found no evidence that surface waters in either Bennett or Duck ponds are incurring impacts from landfill leachate.

Travel time of contaminants from the Provincetown landfill to the harbor is estimated to be 10 to 30 years.

The Truro landfill, also within the National Seashore, is located on the east side of Route 6, in southern Truro. The landfill sits over the Chequesset lens of the Cape Cod aquifer and was in operation for over 35 years. The landfill was closed in 1990, and all refuse has since been shipped off Cape to be incinerated at the SEMASS facility in Rochester, Mass. (East Cape Engineering, 1996). Although inactive, the landfill has not yet been capped. The latest proposal for capping this landfill was submitted to the Massachusetts Department of Environmental Protection on July 5, 1996 by East Cape Engineering. The septage lagoons at the landfill were closed in the early 1990s and the closure was approved by the Massachusetts Department of Environmental Protection (East Cape Engineering, 1996). Currently, septage from Truro is sent to Orleans for treatment. A landfill leachate plume, identified by increased specific conductance, alkalinity, pH, nitrate, sodium, iron, and VOC's, follows the ground water flow path north towards the Pamet River (Cambareri et al., 1989; Figure 7.2b). High nitrate levels at two monitoring wells indicate that there is a separate, shallower plume emanating from the septage lagoons. It is estimated that ground water migration from the Truro landfill to the Pamet River takes about 9 years and that contaminants from the landfill have been discharging into the Pamet River for at least the last two decades (Cambareri et al., 1989).

The Challenge

To formalize communication links with the Massachusetts Department of Environmental Protection and Cape towns regarding landfill plumes and hazardous releases from underground storage tanks. Monitor the effects of nearby landfills on natural resources of Cape Cod National Seashore.

The Wellfleet sanitary landfill, located above the Chequesset lens of the Cape Cod aquifer and off of Coles Neck Road, occupies 8.22 acres, 5.3 of which are used for the landfill itself. The landfill and associated septage lagoons were in operation from 1938 to 1992. All refuse has since been shipped off Cape to be incinerated at the SEMASS facility in Rochester, MA (Coastal Engineering Co., 1993). The site is not lined and is currently not capped (Coastal Engineering Co., Inc., 1993). Down gradient water samples exhibit elevated conductivity, temperature, ammonium, calcium, iron, magnesium, sodium, vinyl chloride in concentrations of 66.0 to 87.0 ppb, dichloroethane at 76.0 ppb, and other VOC's (Coastal Engineering Co., 1993). The maximum contaminant level (MCL) allowed for drinking water is 2 ppb for vinyl chloride and 5 ppb for dichloroethane (310 CMR Drinking Water, 1997). The contamination plume flows in a southwesterly path toward the Herring River (Figure 7.2c). The Herring River flows into Cape Cod Bay two miles from the landfill. According to Coastal Engineering Co. (1993), who monitors the landfill, existing information on the ground water flow path is insufficiently detailed for any environmental impact assessments to be made.

The Eastham landfill is also currently inactive and unlined, (M. Dakers, 1996, pers. comm., Massachusetts Department of Environmental Protection) but is currently being capped (J. Portnoy, 1997, pers. comm., Cape Cod National Seashore). Down gradient wells to the south and east of the landfill contain landfill leachate parameters with high specific conductance and chemical oxygen demand, as well as petroleum-based VOC's (ATP Environmental, 1995). Ground water flow direction and the extent of contamination was poorly defined in the 1995 ATP Environmental study due to insufficient data; however, regional flow is thought to be generally to the south and southeast, toward National Seashore lands (Figure 7.2d).

The Orleans landfill was in operation from 1949 to 1992 and the septage lagoons were in use from 1949 to 1989. All refuse has since been shipped off Cape to be incinerated at the SEMASS facility in Rochester, Mass. (Coastal Engineering Co., Inc. 1992). The landfill is unlined and has not been capped to date (Coastal Engineering Co., Inc. 1992). The landfill overlies the Monomoy lens of the Cape Cod aquifer which is not associated with National Seashore lands. Ground water at the site, however, has been mapped to flow north towards Town Cove and Nauset Marsh (Coastal Engineering Co., Inc., 1992), surface water bodies partially within the National Seashore.

It is important to note that little research to determine the impacts from these landfills is being conducted. The National Park Service does not actively engage in formalized dialogue with the towns, contracted consultants, or the Massachusetts Department of Environmental Protection regarding impacts from landfills (M. Reynolds, 1996, pers. comm., Cape Cod National Seashore). Similarly, there are no requirements for the Massachusetts Department of Environmental Protection to discuss the problem with the National Park Service, nor have they voluntarily done so. The Massachusetts Department of Environmental Protection is required to notify the National Seashore if contaminants exceed the state limit in National Seashore drinking water supply wells. (M. Dakers, 1996, pers. comm., Massachusetts Department of Environmental Protection).

In Massachusetts, it is estimated that there are 50,000 underground storage tanks, 20 percent of them leaking each year.

Underground Storage Tanks

In Massachusetts, it is estimated that there are 50,000 underground storage tanks, 20 percent of them leaking each year (Massachusetts Department of Environmental Quality Engineering, 1988). Underground storage tanks are used by many homeowners and commercial businesses on the lower Cape. Each underground tank poses a threat to ground water quality depending on the age and the type of tank (Noake, 1989). The majority of the tanks documented by Barnstable County hold fuel oil and range in size from 250 to 4000 gallons and range in age from 60 years to new (C. Stiefel, 1996, pers. comm., Barnstable County Coordinator for Underground Program Storage Tanks). The towns in Barnstable County each have their own set of regulations for the tanks; Barnstable County keeps a record of their location and inspection

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Management steps: Contamination Sites
400 Days to 5 Years

Committee
Cooperate with towns and the state to determine potential impacts from the landfill plumes. Review the existing contaminant studies specific to the landfills and evaluate the adequacy of testing all relevant contaminants.

Education
Educate residents within the Cape Cod National Seashore boundary that their participation in underground storage tank programs is essential. Develop a survey that is sent to all National Seashore residents asking them the age, type, and purpose of their tanks.

Data Management
Complete a scenario for the next 50 years based on fine resolution ground water models that predicts the locations and impacts of the plumes.

Research
Work to improve descriptions of landfill plumes by using finer resolution ground water models.

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documentation. According to Charlotte Stiefel, Program Coordinator for Underground Storage Tanks in Barnstable County, the location of each tank in Barnstable County is currently being entered into a geographic information system database that the Commonwealth of Massachusetts will develop into a data layer.

The Bureau of Waste Site Cleanup in the Massachusetts Department of Environmental Protection maintains a current list of all confirmed and transitional oil and hazardous material disposal sites. The latest standard release report lists spills (releases of two hours) and sites (releases of 120 days) reported since October 1, 1993. In addition to this list, the Department of Environmental Protection maintains a transition list of every "site" in Massachusetts that the agency investigated.

Of the 32 listings for the lower Cape, eight were for underground storage tanks and 15 were for above ground storage tanks; all of these listings were two-hour spills (releases of two hours). Twenty-eight sites are listed on the transition list for the lower Cape. While the source of the contamination is not listed, six of them are confirmed priority sites.

National Park Service Owned Underground Storage Tanks

The latest inventory of underground storage tanks is dated May 3, 1993 and is summarized in Table 7.2. Any changes in status since this date are not reflected in this summary. Actively used underground storage tanks on the National Seashore, with the exception of the four listed in Table 7.2, are constructed with double walled fiberglass and hold gasoline, heating fuel, fuel oil, and diesel. These new tanks range in size from 1,000 to 4,000 gallons.

Table 7.2. Summary of recorded underground storage tanks owned by the National Seashore.

Status	Number	Remarks
Removed	19	Removed in past 10 years
Installed	11	Double walled fiberglass tanks; Less than 10 years old
Unknown	3	NEED building, Ahearn house, and N K Motel
Steel	1	Airport/Camp Wellfleet, Aviation gas

Chapter Eight: Cultural Impacts on Pond Water Quality

Heavy public use of many kettle pond shorelines has caused soil erosion and sediment deposition. This has added to the current decline in pond water quality caused by the addition of phosphorus from wastewater. Disturbed soils which erode into pond waters may increase the nutrient loading problem by carrying nutrients from non-point pollution sources. Every pond used for recreation, such as swimming and fishing, is experiencing sediment deposition due to erosion of roads, trails, and shorelines. Many of the ponds are accessible by car, making them a target for heavy use. In addition to problems of erosion, stream channelization to improve anadromous fish access is another pond management issue that has come into controversy in past years. The effects of the anadromous herring run on Gull Pond are unknown, as are the effects of allowing the Gull-Higgins ponds sluiceway to naturally close by deposition of sand.

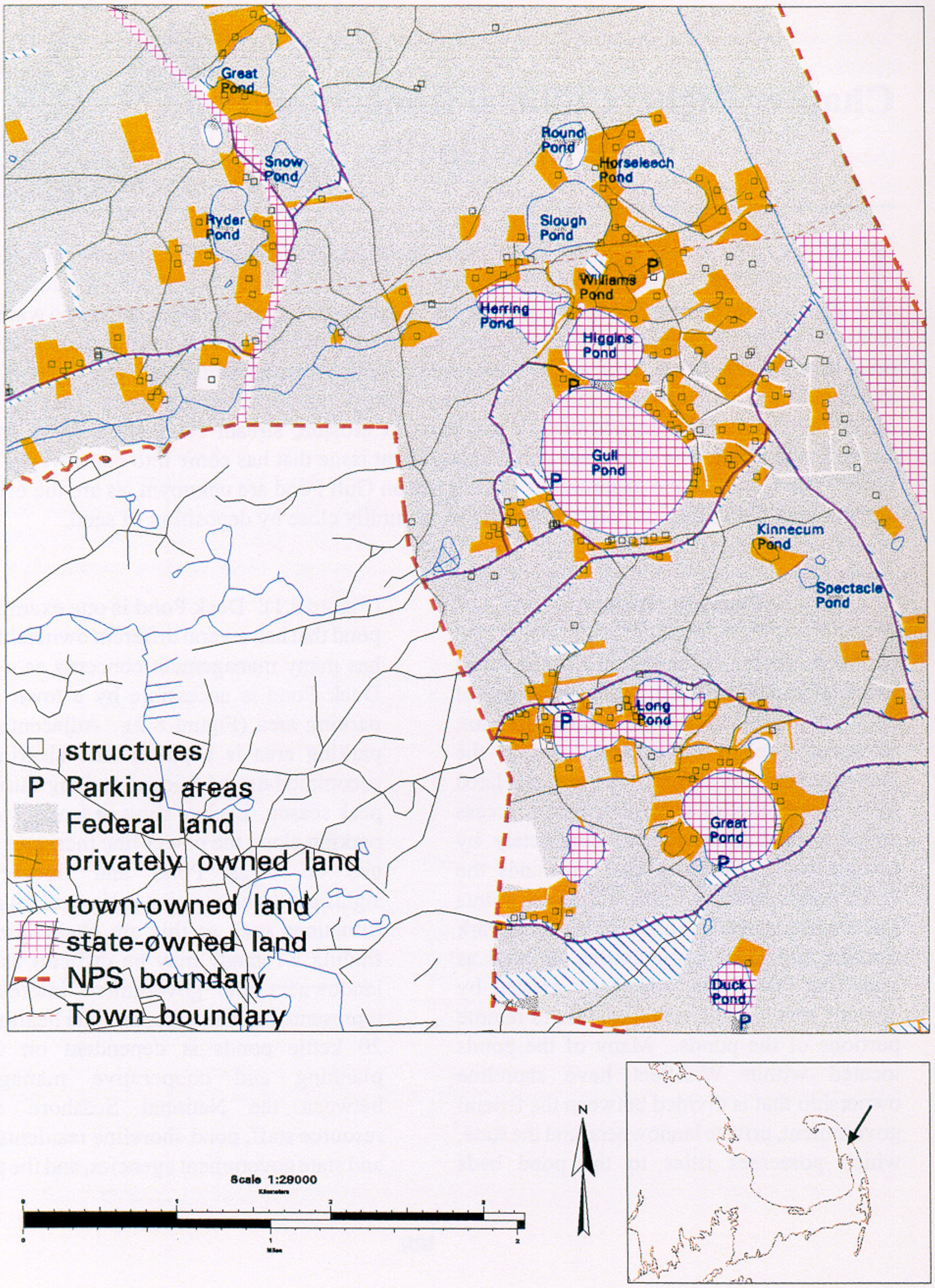
Problem History

In most cases, revegetation is the most practical method of mitigating problems of heavy soil erosion around pond shorelines. However, the 20 kettle ponds within the National Seashore suffer from impacts related to multi jurisdictional ownership and access which cannot be mitigated completely by revegetation. The area that surrounds the kettle ponds contains roads and access points that are maintained by both the National Park Service and local communities, as well as ones that have been informally created by persons seeking alternative access to remote portions of the ponds. Many of the ponds located within Wellfleet have shoreline ownership that is divided between the federal government, private landowners, and the state, which possesses titles to the pond beds (Figure 8.1). Duck Pond is one example of a pond that has several different ownerships and has many management concerns as a result. Duck Pond is accessible by a town owned parking area (Figure 8.2). Adjacent to this parking area is a power line clearing that accommodates additional parking during the peak season. Lack of signs or fencing to deter parking along the power line increases public use on Duck Pond and threatens to significantly change its ecological character. Situations such as this are challenging and finding a remedy may be difficult as many landowners and government interests are represented in a small area. The health of the 20 kettle ponds is dependent on careful planning and cooperative management between the National Seashore natural resource staff, pond shoreline residents, local and state government agencies, and the public.

Water Resources Management Plan

Figure 8.1: Shoreline Ownership Patterns Wellfleet/Truro Kettle Ponds

Source: ownership from Federal lands records.

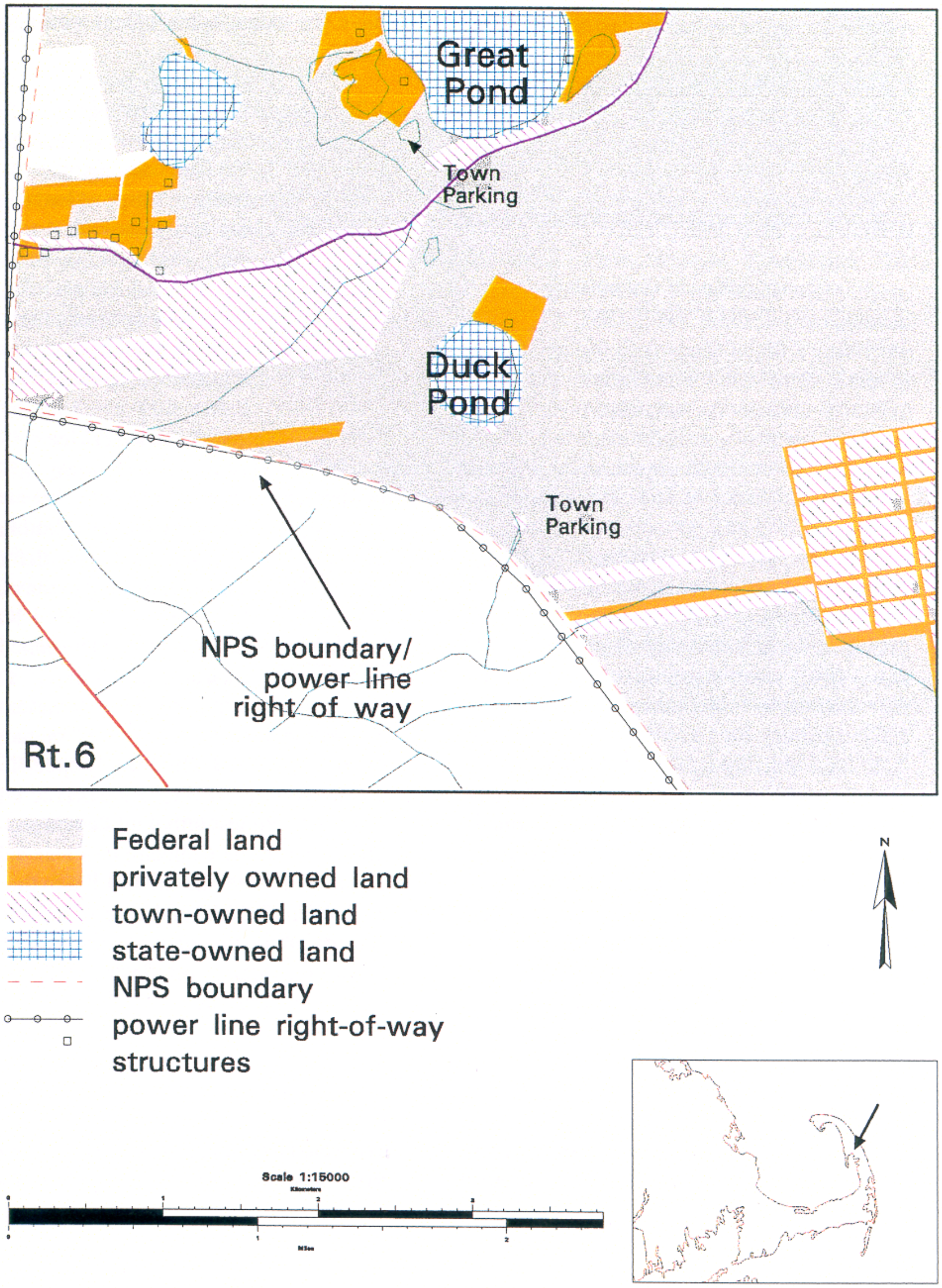


map prepared 12/4/96, Mark Adams, wrpondareo.aml

Water Resources Management Plan

Figure 8.2: Multi-Jurisdictional Land Ownership Near Duck Pond Cape Cod National Seashore

Sources: Ownership from Federal lands records.



map prepared 12/4/96, Mark Adams, wrduck.aml

The Challenge

Design and implement a cooperative management program for the 20 kettle ponds that sustains the resource. Consider access issues and relate recreational use to water quality. Mitigate recreational impacts.

Complexities of Ownership

Jurisdiction and management of the 20 kettle ponds is dependent on two factors: who owns rights to the pond, and who owns access points to the pond. All ponds greater than 10 acres are *great ponds* as established by the Colonial Ordinance of 1641 and amended in 1647. This law, as it remains today, grants the title to the bed (i.e., submerged land) of a great pond to the Commonwealth of Massachusetts. The state has the right to control and regulate the use of great ponds and can limit their use under certain circumstances. Additionally, the state has the right to convey the title of a great pond to the National Park Service. Title to bed, but not the water, has been transferred to the National Park Service for National Seashore ponds in Truro and Provincetown. The State of Massachusetts continues to hold the titles to ponds in Wellfleet. The state can also delegate regulatory authority to local towns by Mass. G.L. Chapter II, Section 45. This agreement has made it possible for Truro and Wellfleet to enact rules and regulations concerning pond activities that are enforceable by local police. The public has the right to access any great pond, and where no access exists, the public may cross, by foot, private property which is not "improved, enclosed or cultivated." Ownership of the shoreline on a great pond conveys no special authority over or ownership of the pond itself; landowners have the same rights of use as the general public.

When a pond is less than 10 acres and private residences occupy the shoreline, the title to the pond bed is divided among the shoreline owners. Ownership of the pond bed runs from the property lines on the shore to the center of the pond, creating a wedge-shaped piece of property for private landowners. Shoreline owners have the authority to regulate public access to their land or to close their section of the shore to the public completely.

National Park Service Management Zoning

The General Management Plan (National Park Service, 1998) places ponds in the natural management zone. According to the plan, the natural zone "includes most of the National Seashore where the primary experience is one of being in natural surroundings, such as woods or along the beach." The natural zone is broken down into four management subzones, three of which apply specifically to ponds: Concentrated Use, Dispersed Use, and Low Use. Ponds with well developed public access are in the Concentrated Use subzone. These areas are easily accessible to the public by hardened trails or boardwalks and have parking areas provided. Examples are Snow Pond and Duck Pond. Dispersed Use refers to more remote areas which have no public facilities or improvements. Vehicles are permitted only in designated corridors and along ungated sand roads. Low Use refers to remote natural areas where a person can expect to be completely immersed in a natural landscape and where tranquility and freedom from settlements or people is highly likely. These management subzones allow the National Park Service to modify or enhance existing access to any of the ponds.

Natural resource problems created by multi jurisdictional management of the 20 kettle ponds are complex and difficult to resolve using pond by pond solutions because access restriction to one pond may cause increased use, and subsequent overuse, of another. By managing the ponds as a single recreational and natural resource, all those with vested interests would have the ability to manage the pond system in a way that is best for the system as a whole. Currently, no comprehensive plan for the ponds exists. Several plans for individual ponds have been started and never completed (Martin et al., 1992). A plan that covers soil erosion on pond shorelines as well as shoreline septic systems (see Chapter Six) and addresses the various interests of each management partner would serve all interests in the future.

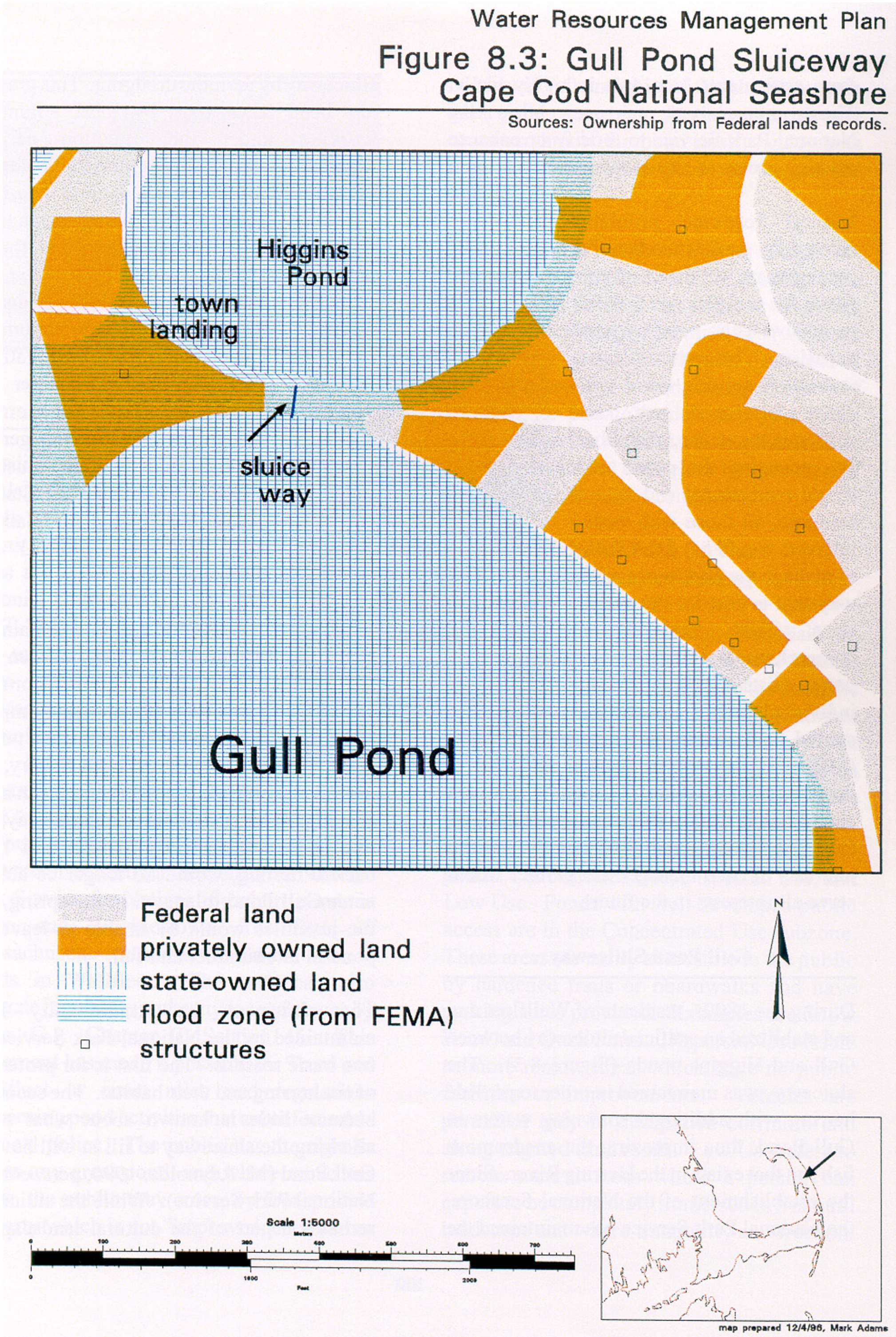
Natural resource problems created by multi jurisdictional management of the 20 kettle ponds are complex and difficult to resolve using pond by pond solutions because access restriction to one pond may cause increased use, and subsequent overuse, of another.

Gull Pond Sluiceway

During the 1800s, residents of Wellfleet dug and stabilized an artificial sluiceway between Gull and Higgins ponds (Figure 8.3). The sluiceway was maintained in order to provide herring with additional spawning waters in Gull Pond, thus improving the anadromous fish run that exists in the Herring River. Since the establishment of the National Seashore, the National Park Service has maintained the sluiceway by periodic dredging. This practice has been taken over by local volunteers working under the direction of the Massachusetts Herring Run Protection Program. Gull Pond is also used as a trout fishery. The fishery is managed by the Commonwealth of Massachusetts, Division of Fisheries and Wildlife under the terms of a Memorandum of Understanding with the National Park Service (December 20, 1968). This agreement recognizes that the management of fish and wildlife must be cooperative between the State of Massachusetts and the National Park Service (Mitchell and Soukup, 1981).

Whether or not to maintain the historical sluiceway between Gull and Higgins ponds is a complex question with potential impacts on the natural biota of the ponds, the introduced trout fishery, and the anadromous herring run in the Herring River. Without the sluiceway, the two species of herring, alewife and blue-backed herring, would no longer be able to enter Gull Pond to spawn in the spring, and the juveniles would be unable to leave the pond in late summer and fall.

The sluiceway has traditionally been maintained by the National Park Service for two basic reasons. The first is for protection of the herring and their habitat. The second is because little is known about what effect allowing the sluiceway to fill in will have on Gull Pond (M. Reynolds, 1996, pers. comm., National Park Service). While the sluiceway remains a part of the cultural landscape of


Water Resources Management Plan
Figure 8.3: Gull Pond Sluiceway
Cape Cod National Seashore
Sources: Ownership from Federal lands records.
Higgins Pond
town landing
sluice way
Gull Pond
Federal land
privately owned land
state-owned land
flood zone (from FEMA)
structures
N
Scale 1:5000
map prepared 12/4/96, Mark Adams

Cape Cod, a National Seashore natural resource management objective (National Park Service, 1996a) contradicts the current preservation efforts. The objective states, " (management should) allow natural processes to continue unimpeded in natural zones, including the action of wind and water, and neutralize the effects of human intervention where it has adversely affected natural systems."

Whether or not to maintain the historical sluiceway between Gull and Higgins ponds is a complex question with potential impacts on the natural biota of the ponds, the introduced trout fishery, and the anadromous herring run in the Herring River

The influx of herring into relatively small freshwater systems may have a considerable impact upon pre-established food chains and nutrient cycles. Adult fish may remain from a few days to many weeks on the spawning grounds; mortality of adult fish on the spawning grounds is high, 39 to 57 percent (Durbin et al., 1979). Young alewives spend part or all of their first summer in the nursery area and then migrate to sea. Since most of their growth and nutrient uptake occurs at sea, these fish may represent a nutrient source to ponds (through shedding eggs and sperm, excretions, and the carcasses of the dead spawners). In ground water fed lakes, which do not have large amounts of water flowing in and out, such nutrient additions may be significant (Mitchell and Soukup, 1981).

The introduction of alewives can also change the aquatic community of plants and animals. Alewives eat zooplankton. Zooplankton, such as *Daphnia* spp., are herbivores and feed on algae in lakes and ponds and thus reduce algal concentrations. When planktivores, such as the alewife, are introduced to a pond, the populations of zooplankton may decrease significantly and the populations of algae increase with the reduced grazing pressure (Shapiro, 1990). Based on this occurrence, which has been observed in several locations including Lake Michigan (Shapiro, 1990), Gull Pond would hypothetically see a decrease in algal growth after the sluiceway is closed and alewives are prevented from entering. This algal density may be one factor in the relatively low clarity observed in Gull Pond. Reduced clarity may, in turn, contribute to the dissolved oxygen deficit observed at the bottom of Gull Pond by reducing the level of light penetration at these depths. Additionally, the subsequent increase in deposition of organic matter reduces dissolved oxygen. This change may eventually affect the trout fishery in Gull Pond (Mitchell and Soukup, 1981).

Current Monitoring and Mitigation

Annual Pond Monitoring Program

The National Park Service recognizes the need for a comprehensive, systematic, and intensive pond monitoring protocol that will enable the park staff to detect important limnological changes associated with human activities. A program of pond monitoring was established (Martin et al., 1992). Monitoring objectives include: 1) characterize the trophic status of the ponds; 2) recommend and implement methods of monitoring trophic status and limnological processes to detect important changes; 3) describe pond-specific and seasonal in-lake and hydrological processes affecting water quality; and, 4) identify and design management actions to mitigate anthropogenic effects.

Management Steps: Recreational Impacts to Pond Water Quality
400 Days to 5 Years

Committee

Address the current problems and obstacles related to managing the 20 kettle ponds. Consider cooperative management solutions that benefit the natural environment as well as parties involved.

Education

Place signs near ponds that have a significant sensitivity to recreational use. Explain the importance of hiking on designated trails and remaining in designated recreation areas.

Data Management.

Gather a detailed information base-that comprehensively illustrates ownership complexities in and around each cluster of ponds: Place this information on maps and use them as a tool in the management process.

Research

Examine the solutions that other parks have utilized in resolving multi-jurisdictional ownership problems related to the use of a natural resource for recreation. Examine the 20 ponds as a single unit, concentrating on access points and alternatives to access that would ease impacts to the ponds themselves. Conduct a survey of current and old on-site wastewater treatment systems within 25 feet (100 m) of pond shorelines. Identify the location and depth relative to the water table. Identify problems specific to any systems.

Chapter Nine: Cape Cod, National Seashore Infrastructure

The Cape Cod National Seashore has three types of properties within its boundaries. One is National Park Service facilities, houses, waste disposal systems, and storage tanks. Contracted homes also exist within the National Seashore which are federally owned, but privately occupied. Many of these homes are located adjacent to surface water bodies such as ponds and marshes. They will be turned over to the National Park Service for occupancy within the next two years; however, the National Park Service will also inherit the underground storage tanks, septic systems and all other components of the property. At this time, no criteria has been established to determine the fate of these homes. And finally, there are grandfathered private properties or "inholdings" that will always exist within the National Seashore, but will never fall under ownership of the National Park Service unless donated or sold to Cape Cod National Seashore. What all of these properties have in common is that they exist and function within the National Seashore and have the potential to impact public water resources. For this reason, it is important to examine the inventory of all properties, regardless of ownership status, within the park.

FACILITIES CURRENTLY OWNED AND OCCUPIED BY NATIONAL PARK SERVICE

Problem History

There are approximately 80 National Park Service owned housing units within the National Seashore that are suitable for year-round or seasonal residence (Figure 9.1a-c). All of these units predate the establishment of Cape Cod National Seashore. The National Seashore has the capacity to house approximately 24 year-round employees and 138 seasonal employees. Some of these housing units are located near or adjacent to ponds and estuaries. Unfortunately, there exists a shortage of housing for both seasonal and year-round employees, so it is difficult to close units. However, as the park acquires former use and occupancy units, it will aggressively seek to use them as alternatives to housing located in sensitive resource areas. Two such houses were vacated in 1999.

Septic systems, both within and outside the National Seashore boundaries, carry the same potential for ground and surface water contamination. The National Seashore is subject to Massachusetts Title 5 regulations. As funds become available or as failures occur, septic systems are replaced.

The town of Eastham requires that all septic systems within the town and owned by the National Park Service, undergo regular

Water Resources Management Plan

Figure 9.1a: Facilities - Provincetown/Truro Quads
Cape Cod National Seashore

Sources: USGS quadrangles; 1991 aerial photos.

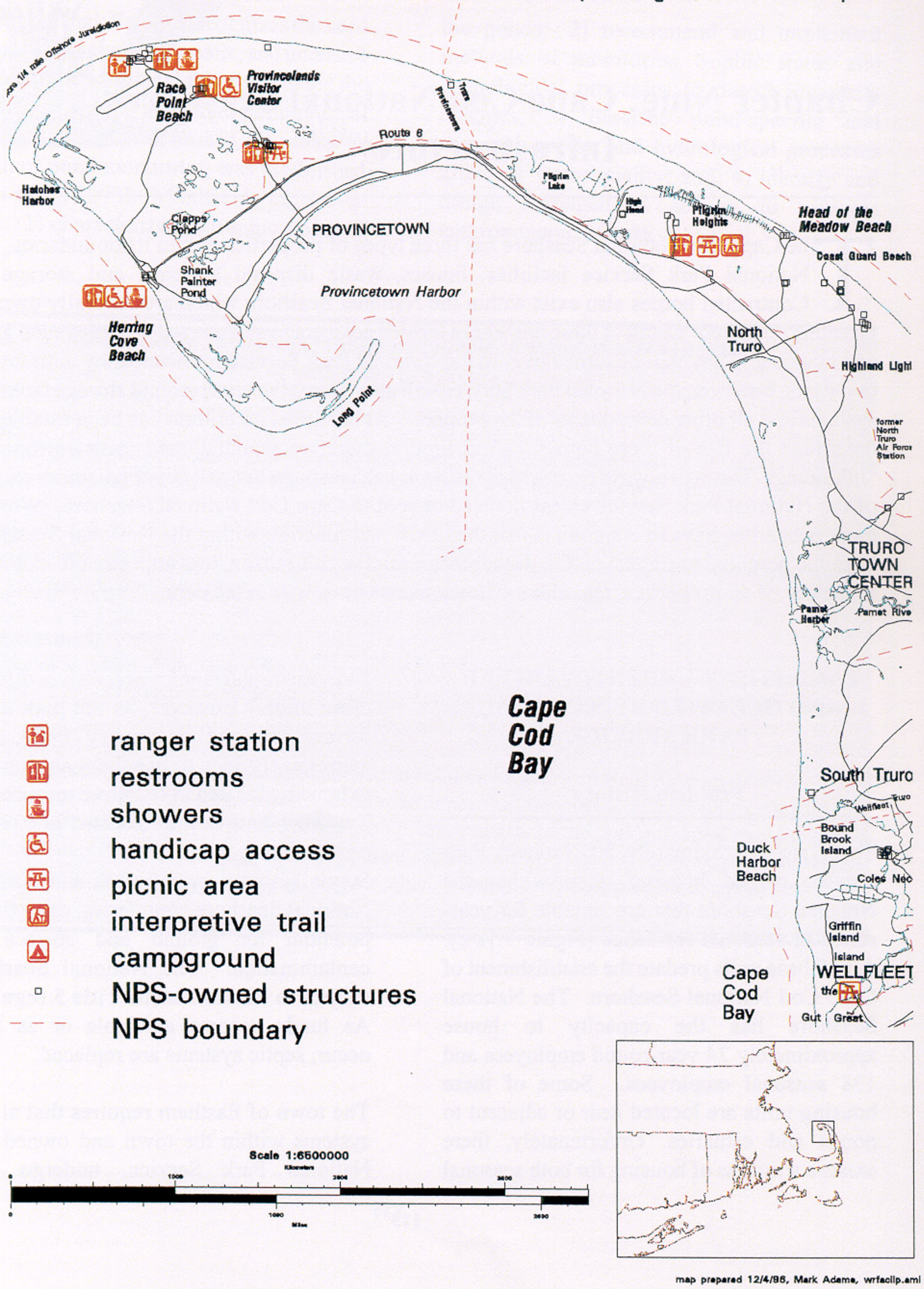


Figure 9.1b: Facilities - Wellfleet Quad Cape Cod National Seashore

Sources: USGS quadrangle maps; 1991 aerial photos

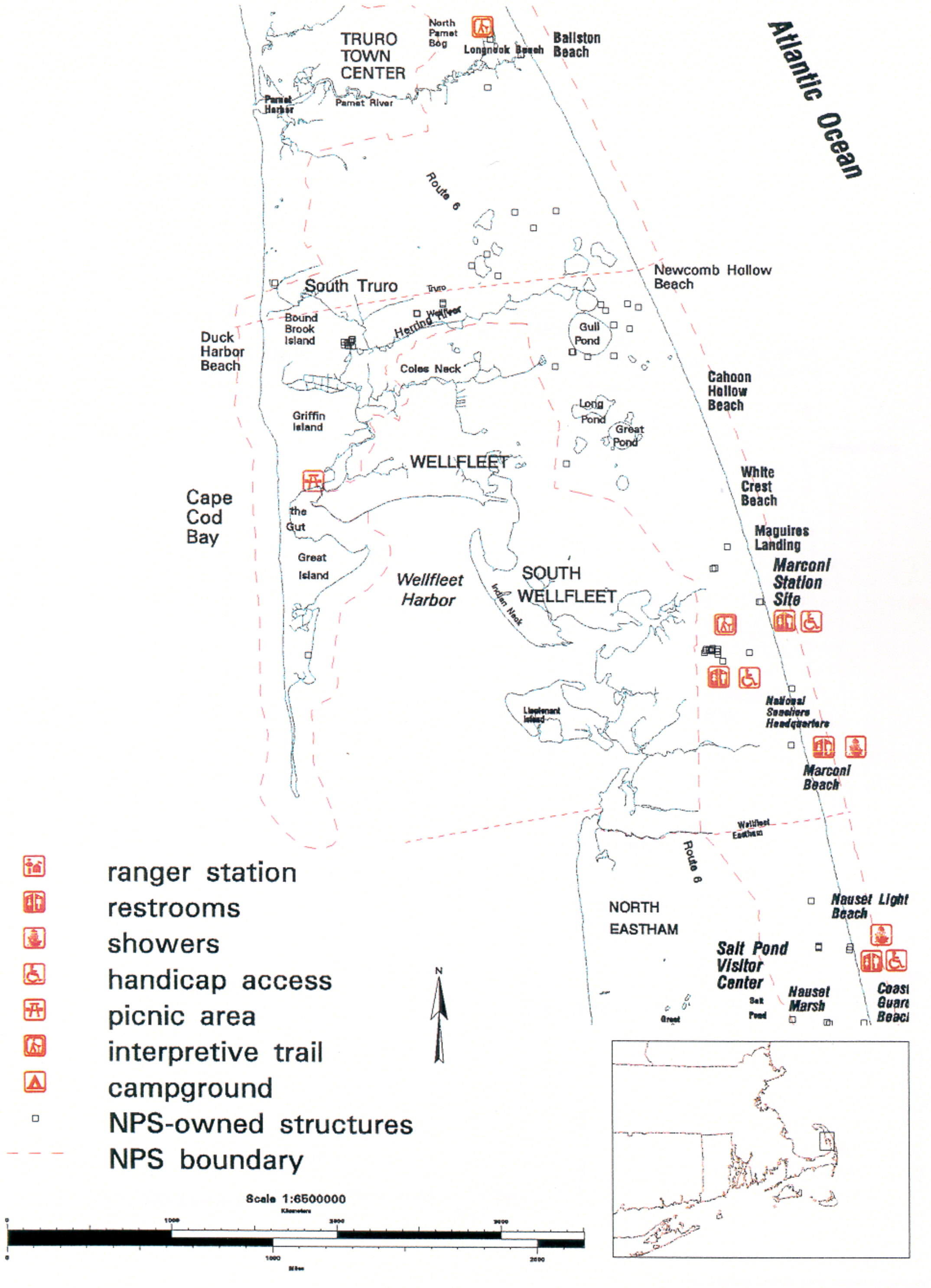
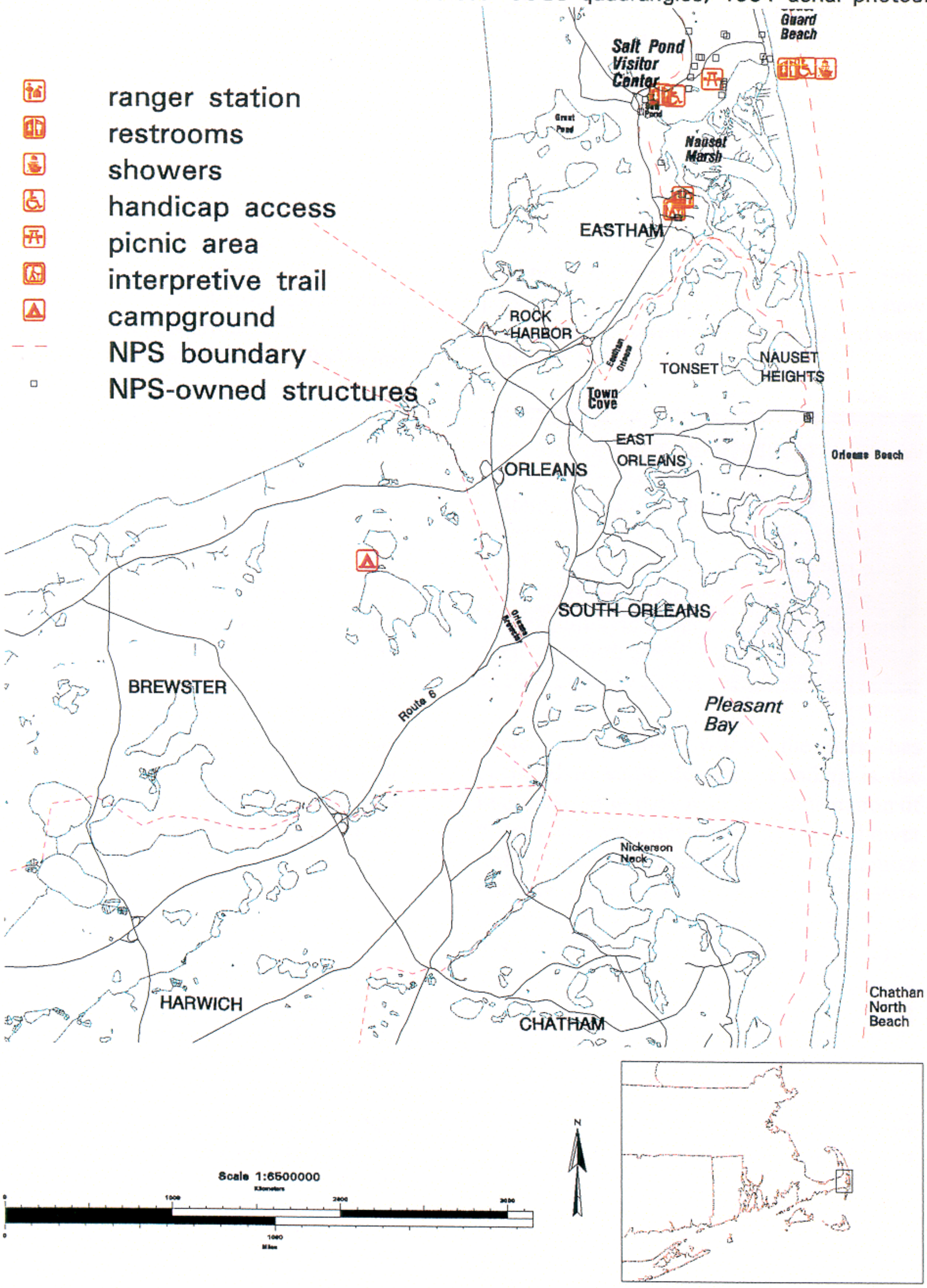


Figure 9.1c: Facilities - Orleans/Chatham Quads
Cape Cod National Seashore

Sources: USGS quadrangles; 1991 aerial photos.



map prepared 12/4/96, Mark Adams, wrfacilo.aml inspections. Eastham is the only town to enforce such an aggressive inspection program.

Conventional leaching systems such as cesspools, drain pits, septic systems and leaching galleries complete the inventory of on-site wastewater disposal systems located in seasonal and permanent housing, as well as all buildings on the National Seashore, not including utilities. There are also a peat leaching system and a waterloo filter, which are nutrient reduction systems, located on two National Seashore properties. The majority of the systems were installed prior to 1960 (some date back to 1920) and range in size from 500 to 15,000 gallons.

Drinking Water Supply

The National Park Service tests for contaminants in the water by following testing standards for Massachusetts' Department of Environmental Protection drinking water guidelines (310 CMR 22.00, Drinking Water, 1997) and National Park Service Special Directive 83 (the water standards for the National Park Service, equivalent to the state standards). Results are reported to both agencies. This helps the National Park Service monitor any elevated levels of contaminants closely.

Water Use

Limited supplies of fresh water on the Cape make water conservation an important part of water resource management for the park as well as for towns on the lower Cape. Provincetown has taken the lead on conservation by working collaboratively with the National Park Service on educating the public about water conservation. The National Park Service needs to continue to fill a critical role as educator by modeling water conservation strategies at the National Seashore. Table 9.1 reflects annual water use at each of the main visitor centers for 1993 to 1995 (Phipps, 1996, pers. comm., National Park Service). These numbers are reported to the state every year and placed in a yearly water report for Massachusetts. In 1996, the septic system at the Salt Pond Visitor's Center had been declared "failed" (Phipps, 1996, pers. comm., National Park Service). A new Title 5 septic system was designed and went online in 1998.

The Challenge

Manage. the infrastructure of the National Seashore in a way that is sustainable for both natural resources and human use. Promote education through the use of innovations in water conservation and wastewater disposal.

Water conservation within the park has occurred to some degree. Funding is the major barrier to park wide implementation of water conserving devices. Low flow shower heads have been installed in all of the houses that are owned and occupied by the Park Service and low flush toilets have been placed in some of the seasonal homes (Table 9.2).

Table 9.1. Water use statistics (in gallons/year) for the Cape Cod National Seashore (see Figure 9.1 a-b for locations)

Location	1993	1994	1995
Marconi Bathhouse, Headquarters	**4,981,680**	**2,101,860**	**2,302,840**
Coastguard Bathhouse	**1,800,750**	**669,300**	**1,200,400**
NEED Building	**172,200**	**295,500**	**233,800**
Salt Pond Visitor's Center	525,700	**714,200**	**636,400**
Doane Rock	**51,700**	**51,900**	**63,100**
Hemenway Landing	**148,800**	**90,400**	**186,000**
Herring Cove	**424,900**	**405,300**	**closed**
Head of the Meadows	**127,700**	**200,500**	**203,500**
Nauset Light	**619,000**	**668,800**	**583,700**
Highland Light	**50,600**	**64,200**	**132,000**
Pilgrim Heights	**40,400**	**163,000**	**143,400**
TOTAL	**8,943,430**	**5,424,960**	**5,685,140**

National Park Service Owned Underground Storage Tanks

The latest inventory of underground storage tanks is dated May 3, 1993 and is summarized in Table 9.3. Any changes in status since this date are not reflected in this summary. Actively used underground storage tanks on the National Seashore, with the exception of the four listed in Table 9.3, are constructed with double walled fiberglass and hold gasoline, heating fuel, fuel oil, and diesel. These new tanks range in size from 1,000 to 4,000 gallons.

Table 9.2. Number of improved properties by town within the National Seashore.

Chatham	9	Wellfleet	28
Eastham	5	Truro	14
Orleans	0	Provincetown	12

Table 9.3. Summary of recorded underground storage tanks owned by the National Seashore.

Status	Number	Remarks
Removed	19	Removed in past 10 years
Installed	11	Double walled fiberglass tanks; Less than 10 years old
Unknown	3	NEED building, Ahearn house, and N K Motel
Steel	1	Airport/Camp Wellfleet, Aviation gas

CONTRIBUTING ISSUES

Use and Occupancy Houses

In 1997, there were 68 homes that were part of the use and occupancy reservations in the park. About one-half of those reservations expired in 1998 and 1999. The owners entered into contracts with the National Park Service when their houses were purchased (mainly 1962 to 1975). They agreed to turn over possession of their homes to the National Park Service after a specified number of years. The fate of these homes once they come into federal hands is particularly important now as 45 of the permits run out between 1998 and 1999.

Many of these homes are on pond shorelines or close to other surface waters, which could be receiving negative impacts from their use. The planners at the National Seashore are currently putting together criteria for management of these properties based on financial constraints and demographic needs within the park. Water quality is the primary consideration in deciding on maintenance or removal. As discussed earlier in this section, when use of such a house can allow closure of a current employee housing unit in a sensitive resource area, the exchange will be made.

Private Inholdings

Currently, there are over 600 homes within the National Seashore that represent private improved properties. The National Seashore's enabling legislation defines an improved property as "a detached, one-family dwelling the construction of which was begun before September 1, 1959...together with so much of the land on which the dwelling is situated, the said land being the same ownership as the dwelling, as the Secretary shall designate to be reasonably necessary for the enjoyment of the dwelling for the sole purpose of noncommercial residential use, together with any structures accessory to the dwelling which are situated on the land so designated."

These private properties, within the boundary of the National Seashore, cannot be acquired by the National Park Service through eminent domain, and owners are allowed to sell their properties to others.

There is no formal coordination of management or collaboration between these residents and the National Park Service other then that mandated by town zoning bylaw concerning redevelopment or expansion of improvements. While the infrastructure represented by these inholdings does not belong to the National Seashore, it, nevertheless, is an important consideration in managing National Seashore water resources.

These homes must conform to the regulations of the town in which they are located. During the year following the establishment of the National Seashore, the towns, which had lands falling partially within the boundary of the National Seashore, established zoning laws that were in accord with the zoning standards prescribed by the Secretary of the Interior. The enabling legislation stated that once a town had adopted a zoning bylaw that complied with the federal zoning standards, the National Park Service could not acquire properties in that town through condemnation as long as they conformed to the bylaw. The zoning standards were to: 1) support the prohibition of commercial and industrial uses, other than those permitted by the Secretary, of all property within the boundaries of the National Seashore, and 2) promote the preservation and development of the area comprising the National Seashore in accordance with the purpose of the legislation.

However, the Secretary can acquire property through a certificate of condemnation when a property fails to conform to the bylaws or a town grants a variance which the Secretary believes is inconsistent with the purposes of the park and when such acquisition supports the purposes of the National Seashore.

In addition to the enabling legislation, the National Seashore also has a Land Protection Plan (Killian, 1985) and a set of guidelines which provide examples of compatible and non-compatible development activities on lands within the National Seashore. By following the zoning bylaw for their town, property owners are able to continue their occupation of the area and avoid the issuance of a certificate of condemnation. The guidelines provide additional information and suggestions on ways to keep redevelopment appropriate. Since the National Park Service has little authority to enforce these guidelines, the National Park Service has encouraged the towns to adopt the guidelines into their zoning bylaws. The town of Eastham is the first and only town to include the guidelines in their zoning bylaws (National Park Service, 1998). Adjustments to the guidelines and zoning are warranted and will be discussed with relevant towns.

Management Steps : National Seashore Infrastructure
400 Days to 5 Years

Committee
Communicate on ways to improve local zoning and discuss the consistent management of the town lands that are located inside the National Seashore boundary. Work with towns to model an inspection ordinance for septic systems as Eastham has done. Redefine "infrastructure" as all homes and structures located within the National Seashore.

Education
Develop informational flyers and newsletters for residents within the National Seashore boundary informing them of their special role in natural resource management and preservation on the Cape. Encourage these residents and others to become knowledgeable about the model home development and the newsletter as tools for education and water conservation.

Data Management
Survey residents within National Seashore boundaries in order to assess the type and efficiency of wastewater treatment systems. Evaluate the current. infrastructure of the National Seashore and compile all inventories on a single database. Evaluate contracted homes with criteria that relate to their potential impact to surface and ground water quality.

Research
Evaluate the current water and wastewater infrastructure of the National Seashore. Audit the existing inventory and recommend replacement based on assessed risk to water quality.... Review alternative wastewater management techniques and implement one on a trial basis. Meter water use at National Seashore facilities and evaluate alternative hardware and behavioral approaches to water conservation.

Chapter Ten: Ecological Impacts of Tidal Restriction

Salt marshes are very productive ecosystems, providing a rich food base and habitat for resident and migratory shellfish as well as finfish and birds (Portnoy and Soukup, 1988). Fifty percent of the nation's coastal wetlands have been lost and even more have been significantly impacted (Roman et al., 1995a). Most of the marshes within the Cape Cod National Seashore have been altered with dikes and/or tide gates and subsequently drained. This practice of "marsh reclamation", started in the late 1600s, was meant to reduce mosquito populations, increase productive agricultural acreage, and improve roadways (Portnoy and Soukup, 1988). Mosquito abatement, due to diking and drainage, is reported but undocumented; agricultural development never materialized. Meanwhile, native habitat has been lost and freshwater wetland and upland plant species have invaded the diked areas.

Problem History

Research by the National Park Service since 1980 has documented that restricted seawater flow into salt marshes dramatically changes plant and wildlife habitat (Soukup and Portnoy, 1986). Salt marshes depend on sediment from the ocean in order to stay above sea level rise. Dike structures prevent this process from occurring, in turn causing the marshes to be vulnerable to flooding when dikes are breached. Additionally, decomposing salt marsh peat, left after the marsh is drained, periodically releases toxic levels of acids and aluminum, resulting in massive fish kills (Soukup and Portnoy, 1986). Constant summertime oxygen stress (Portnoy, 1991), from lack of tidal flushing, reduces both fish and invertebrate numbers as well as diversity in both diked and drained wetlands. Even temporary tidal restriction reduces the vigor of the salt marsh community (Portnoy and Valiela, 1997). In drained salt marsh soils, acidification and metal mobilization increase and nutrients become less available. In waterlogged salt marsh soils, sulfide toxicity reduces plant production.

Restoration of salt marshes provides resource managers with a valuable tool for maintaining and enhancing coastal zone habitat diversity (Roman et al., 1995a). Numerous studies in other regions have shown that degraded coastal wetlands and small estuaries can be successfully restored. Hydrologic modeling is one method used to predict tide height levels and tidal flooding elevations that can occur as a result of salt marsh restoration. Roman et al. (1995a) used this method to predict the effects of dike and tide gate removal at Herring River in Wellfleet and Hatches Harbor in Provincetown. Hydrologic modeling combined with research and interagency planning since 1986 has resulted in an ongoing project to restore up to 90 acres of salt marsh at Hatches Harbor and to provide flood protection for the town's airport built in the floodplain.

The Challenge

Restore wetlands and satisfy the needs of existing development in those floodplains where building has occurred since historic diking.

Herring River Restoration

The history of anthropogenic alterations to the Herring River system has been well documented by the Cape Cod National Seashore scientific staff who have completed extensive research on past and proposed management of the Herring River system (Portnoy and Reynolds, 1997). The Herring River (Figure 10.1) was diked completely at its mouth by 1910 primarily to reduce the breeding ground for salt marsh mosquitoes *(Aedes sollicitans; A. cantator).* While salt hay production and fisheries productivity decreased, the mosquitos remained a nuisance. As a further attempt to eradicate the mosquitos, drainage ditches were dug in the marsh behind the dike structure. By the mid-1930s, the Herring River's mainstream, now flowing with fresh water, was channelized and straightened. A golf course and two residential dwellings were constructed in the floodplain. The wetland became dominated by freshwater vegetation and upland shrubs and trees. In 1982, the National Park Service began research that examined salt marsh restoration alternatives. In 1984, the Massachusetts Department of Environmental Protection gained control of the flood gates from the town of Wellfleet in order to enforce an Order of Conditions set by the local Conservation Commission on the dike's reconstruction during the mid-1970s. Ownership and maintenance of the dike and flood gates are retained by the town.

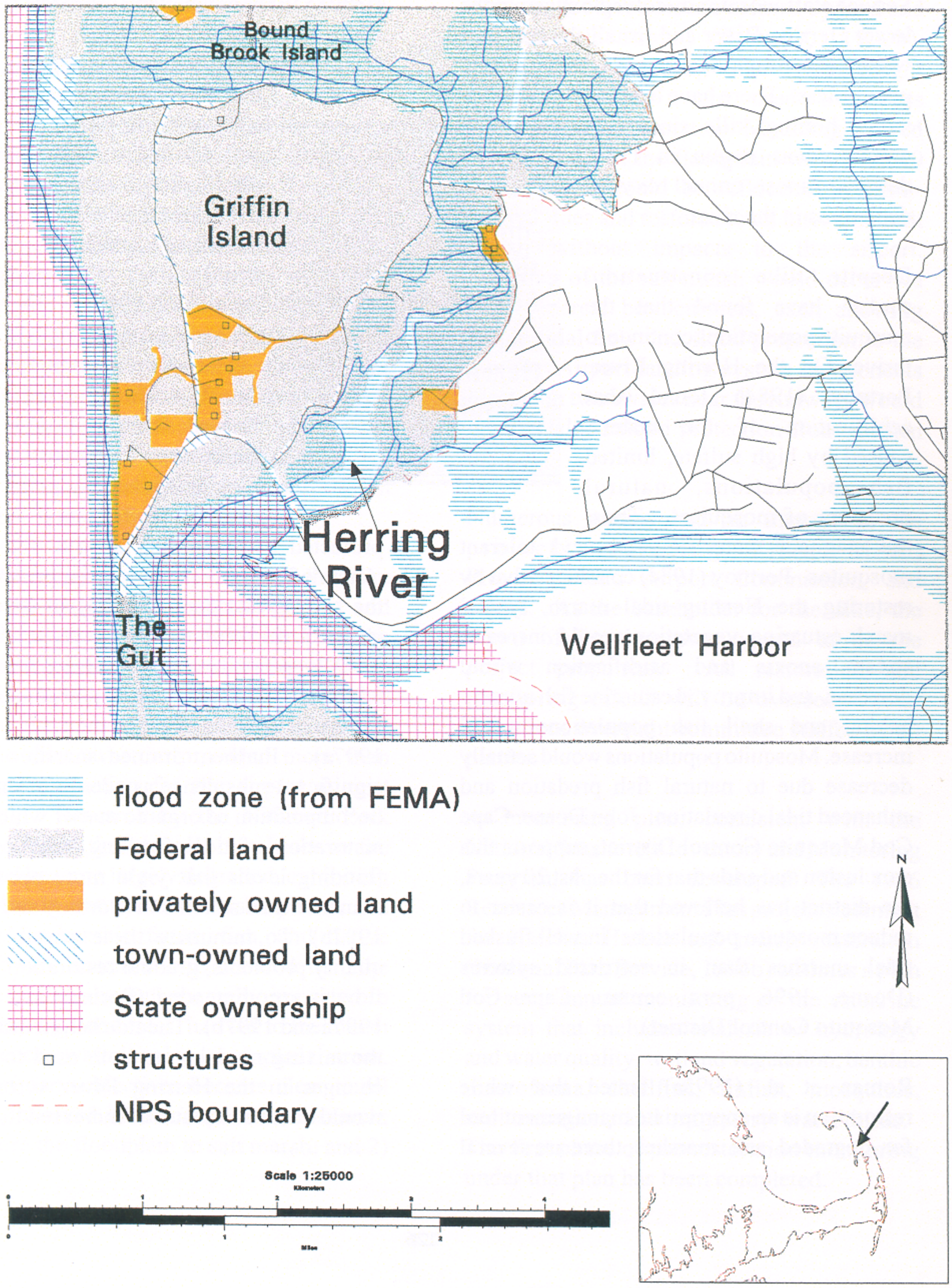
The National Park Service showed that serious water quality problems existed due to diking and reduced tidal flushing of the salt marshes. Problems included surface water acidification (Soukup and Portnoy, 1986) and oxygen depletion (Portnoy, 1991 a) that led to massive fish kills and the persistence of abundant mosquito populations (Portnoy, 1984). In 1980, the dissolution of sulfurous compounds from the old salt marsh deposits and consequent acidification of the Herring River and tributaries by oxidized sulfur (sulfuric acid) caused a massive eel kill (Soukup and Portnoy, 1986). Aluminum leached from native clay was elevated to lethal levels.

Reduced flushing of the Herring River has also caused oxygen stress and summertime oxygen depletions (Portnoy, 1991a). Starting in mid-May to early June, increased water temperature causes mid-day dissolved oxygen concentrations to decrease from 100 percent to 50 percent saturation levels. Total anoxia occurs during times of heavy precipitation, and resulting high flow contains proportionately more organic matter from the wetlands (Portnoy, 1991). These periods of high stream flow also stimulate juvenile herring to leave upstream natal ponds. If the stream is anoxic at the time of migration, massive fish kills ensue.

In July and August of both 1984 and 1985, the entire juvenile herring run was killed in the Herring River as a result of anoxic stream conditions (Portnoy and Soukup, 1988). A

Figure 10.1: Herring River, Wellfleet
Cape Cod National Seashore

Sources: FEMA Flood Insurance Rate Maps, Federal land ownership records; 1991 aerials.



map prepared 12/4/96, Mark Adams, wrherring.aml

Fish grate is now in place to prevent juvenile herring from entering the river during anoxic episodes (Portnoy et al., 1987). National Park Service staff monitor dissolved oxygen in the lower Herring River and install the fish gate when concentrations at midday are decline to 3 ppm or less. There have been no major Herring kills since this program was begun in1986, despite almost annual oxygen depletions in the river.

In both 1984 and 1985 it was documented that the entire juvenile herring runs were killed in the Herring River as a result **of. anoxic stream conditions.**

Despite dike construction, studies have found that the mosquito populations continue to thrive. On the Herring River, Portnoy (1984) found that acidification of the waters, caused by high sulfate, limited fish populations, natural predators of mosquitos. Thus, the stagnant water favored acid tolerant mosquitos. Portnoy (1984) concluded that by restoring the Herring tidal marsh, typical marsh-estuarine vegetation would increase, stream anoxia and acidification would decrease, and improved estuarine fish nursery habitat and shell fish populations would increase. Mosquito populations would actually decrease due to natural fish predation and enhanced tidal circulation. John Doane, Cape Cod Mosquito Control District, supports this conclusion and adds that for the past 20 years, the district has believed that it is easier to reduce mosquito populations in well flushed tidal marshes than in restricted systems (Doane, 1996, pers. comm., Cape Cod Mosquito Control District).

Roman et al. (1995a) stated that while restoration is an appropriate management tool for degraded salt marshes, there are several concerns that must be addressed before restoration can take place. One concern surrounding restored tidal flushing of the Herring River is salt water intrusion of private wells in the diked salt marsh. However, a U.S. Geological Survey investigation found that the freshwater lens at the very edge of the upland is 6.6 feet (20 m) thick and, therefore, projected tide height increases of 1.5 feet (0.5 m) after restoration would not impact wells outside of the floodplain (Fitterman and Dennehy, 1992). A second concern is flooding of a golf course and private homes within the floodplain. Nuttle (1992) showed that the golf course, which occupies a portion of the Herring River floodplain along a Mill Creek tributary, could be protected by rebuilding an old dike at the mouth of Mill Creek. However, protection of the two private homes is still an unresolved issue. A third concern is that restoration will initially generate a large pulse of nutrients, which may increase primary production and lower oxygen levels (Portnoy and Giblin, 1997a). Further, drained marshes exhibit significant subsidence as a result of increased decomposition of organic matter which, after restoration of tidal flushing, may result in flooding levels that yield more open water than intertidal salt marsh (Portnoy and Giblin, 1997b). To minimize these possible water quality problems, gradual restoration of tidal flow is recommended (Portnoy and Giblin, 1997a and 1997b). The tide height model and the mixing model were both used to predict changes in the Herring River system that would occur as a result of increased tidal flow

(Roman, 1987). The results of these two models allow all parties involved to evaluate and consider ecological and socioeconomic impacts (Roman, 1987; Roman et al., 1995a).

Hatches Harbor Restoration

Prior to 1930, Hatches Harbor was a productive 200 acre salt marsh and open water embayment. During the 1930s, the natural tidal regime of this embayment was altered by a newly constructed dike that isolated half of the estuary from the sea in an attempt to reduce salt marsh mosquito habitat (Figure 10.2). Subsequent to diking, a small airfield, now Provincetown Municipal Airport, was constructed on the floodplain above the dike. Flood protection for the airport became the primary role of the dike structure, and the dike was repaired three times for this purpose, in 1946, 1978 and 1984 (Portnoy, 1990a).

The 1987 major reconstruction of the dike prompted dialog between both airport and natural resource interests, who explored the possibility of salt marsh restoration. These discussions, facilitated by Massachussetts Coastal Zone Management, led to agreement that the dike structure provided more than adequate protection for the airport against flooding. Research by the National Park Service found that the salt marsh above the dike had become largely degraded, exhibiting a decline in natural salt marsh species and habitat for benthic fauna, fish, and native waterfowl. Research also showed that the reduction in sediment, normally imported to the marsh by flood tides, had led to the marsh subsidence, waterlogging, and plant stress. Two primary objectives became clear to all parties involved in the cooperative research: 1) restore the floodplain to salt marsh, and 2) protect the airport from flooding (Portnoy, 1990a).

Since both objectives are defined by land and surface elevations (Portnoy, 1990b), bathymetric mapping and tide height modeling studies were used to assess alternatives for restoration. Modeling showed that 90 acres of the floodplain within the 10 foot contour could be reflooded by semi-diurnal tides and restored to an inter-tidal salt marsh without impacts to the airport. Flooding of the salt marsh would occur via four concrete box culverts, each allowing ample tidal flow and flood protection to the airport. Airport landing system components located in two swales near the runways would receive added flood protection from earthen berms.

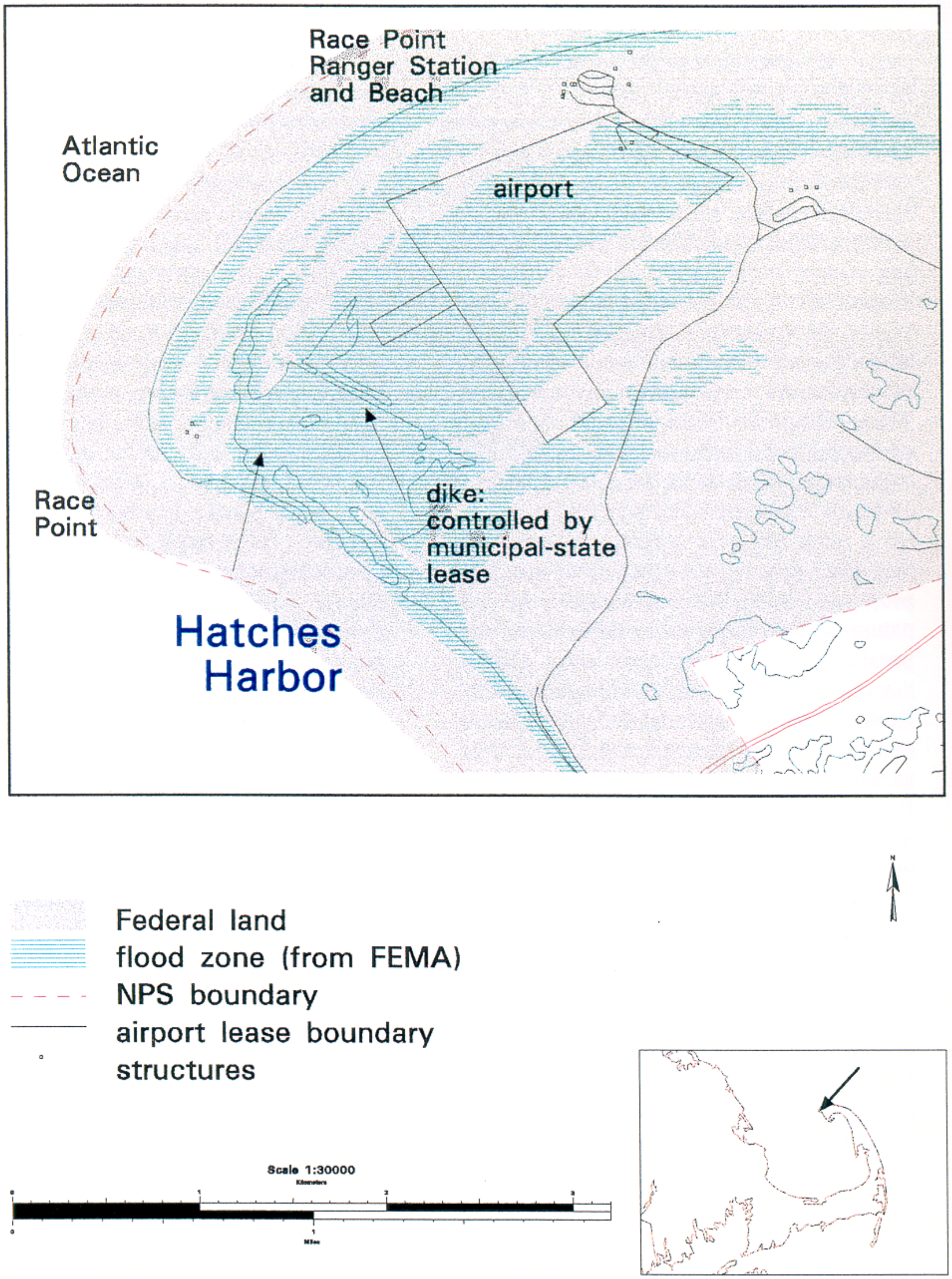
Numerous parties had an interest in the project, including FAA, MAC, Provincetown's Airport Commission, and others. As the baseholder for the dike, the Town of Provincetown agreed to be the project proponent. All restoration and monitoring efforts will be overseen by an operations oversight committee staffed by all parties.

A monitoring plan, consistent with the National Seashore's Inventory and Monitoring Program, has been developed. The 1996 Resources Management Plan project statement for Hatches Harbor salt marsh restoration (National Park Service, 1996b) outlines a plan for semi-annual monitoring of the estuarine system that includes analysis of hydrology and water quality, wetland vegetation, benthic macrofauna, shellfish, finfish, mosquitos, sedimentation, and migratory water birds.
The first phase of pre-restoration monitoring under that plan has been completed.

Water Resources Management Plan

Figure 10.2: Hatches Harbor Cape Cod National Seashore

Source: Provincetown airport lease documents; Federal land ownership records.



map prepared 12/4/96, Mark Adams, wrhatches.aml

A description of this restoration project is not complete without a summary of the project's significance to the Town of Provincetown, National Seashore and the State of Massachusetts. Portnoy (1990a) describes the restoration of Hatches Harbor as "the largest single wetland restoration project in the history of Massachusetts."

The 10 year planning process behind the restoration proposal for Hatches Harbor is a significant multi jurisdictional achievement among 11 different local, state, and federal agencies (Portnoy, 1990a). The Cape Cod National Seashore has placed this restoration project first on the park's priority list of resource management projects (National Park Service, 1996a).

Pamet River Restoration

Pamet Harbor (Figure 10.3), located on Cape Cod Bay, was once a viable commercial port that served a large fleet of local fishing vessels operating in the cod and mackerel industry (Giese and Mello, 1985). During the mid-1800s, commercial fishing fleets were competing for space to anchor in Pamet Harbor, which could not accommodate all the vessels. As a result, the fishing industry declined and human population decreased. Remaining residents began to alter the Pamet in hopes of restoring and increasing the capacity of the harbor (Giese et al., 1985). From 1850 to 1930, significant alterations were made to the estuary system including diking and dredging.

Wilder's Dike was built in 1869 to replace a rotting bridge across the mid-section of the Great Pamet and in 1950, a clapper valve and dike structure were built to accommodate the consturuction of Route 6 (Giese et al., 1993).

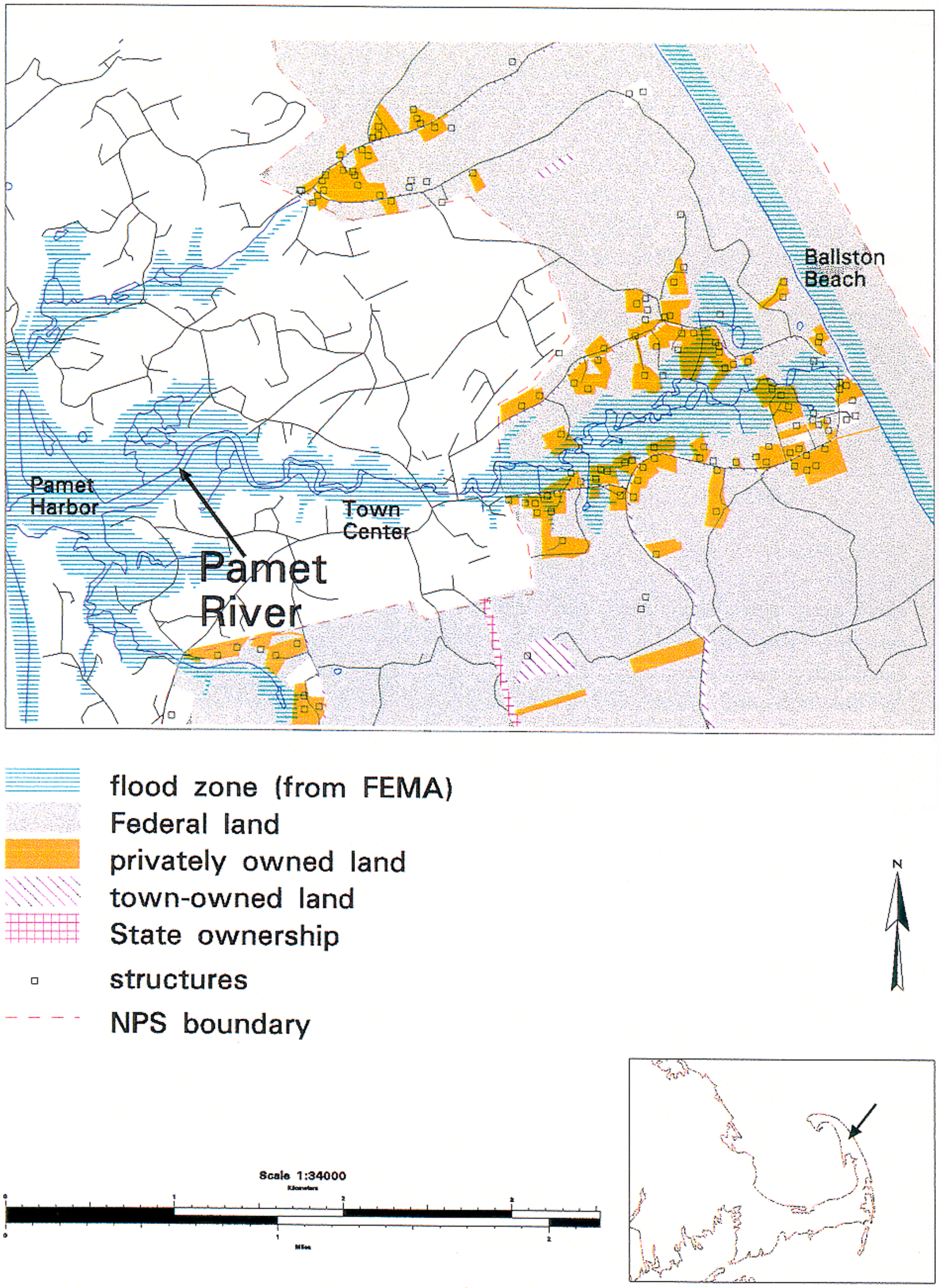
The alterations of the Pamet have divided the river into two distinct hydrological sections, the upper Pamet and the lower Pamet (Livingston, 1996). East of the tide gate located just west of Route 6, the upper Pamet is freshwater (Figure 10.3) with a watershed encompassing approximately 192 acres. Many upland species of salt-intolerant plants have invaded the area. Ground water discharge from the Pamet and Chequesset lenses, as well as precipitation are continuously recharging this section of the Pamet. The upper Pamet flows slowly west and enters into the lower Pamet, a saltmarsh estuary (National Park Service, 1986).

The lower Pamet is an intertidal estuary, greatly stressed by past alterations that have reduced natural tidal circulation and in turn increased shoaling and sedimentation (Giese et al., 1993). Tidal channel beds, except for the outermost section of the inlet channel, are higher than the mean low tide in Cape Cod Bay (Livingston, 1996)

Restoring tidal flow to the upper Pamet River would provide many benefits including increased natural flushing in the estuary which would in turn improve water quality, maintain habitat diversity, and balance sediment loads in the Pamet River

Figure 10.3: Pamet River, Truro
Cape Cod National Seashore

Sources: Federal land ownership records; 1991 aerial photos



map prepared 12/4/96, Mark Adams, wrpamet.aml

Valley (National Park Service, 1986). Additionally, restoration of natural flows would allow the salt marsh to regain a state of equilibrium between sea level and wetlands elevations in the upper Pamet at Ballston Beach.

Currently, the upper Pamet River is vulnerable to storm overwashes at Ballston Beach, on the Atlantic Ocean side of the Cape and at the upstream end of the freshwater section of the Pamet River. Such an overwash could fill the upper, freshwater portion of the Pamet River with undiluted seawater, an extremely unusual situation for most river/estuarine systems. Further, because of the restriction of discharge imposed by Route 6 and Castle Road, saltwater cannot readily discharge to Cape Cod Bay. If an overwash were to occur in summer, present salt-intolerant vegetation would die. The U.S. Army Corps of Engineers and Cape Cod Commission are studying alternatives that address this concern, as well as the possibility of tidal restoration in the upper Pamet River.

Since the construction of the dike, the waters of Pilgrim Lake have become brackish and eutrophic.

Pilgrim Lake

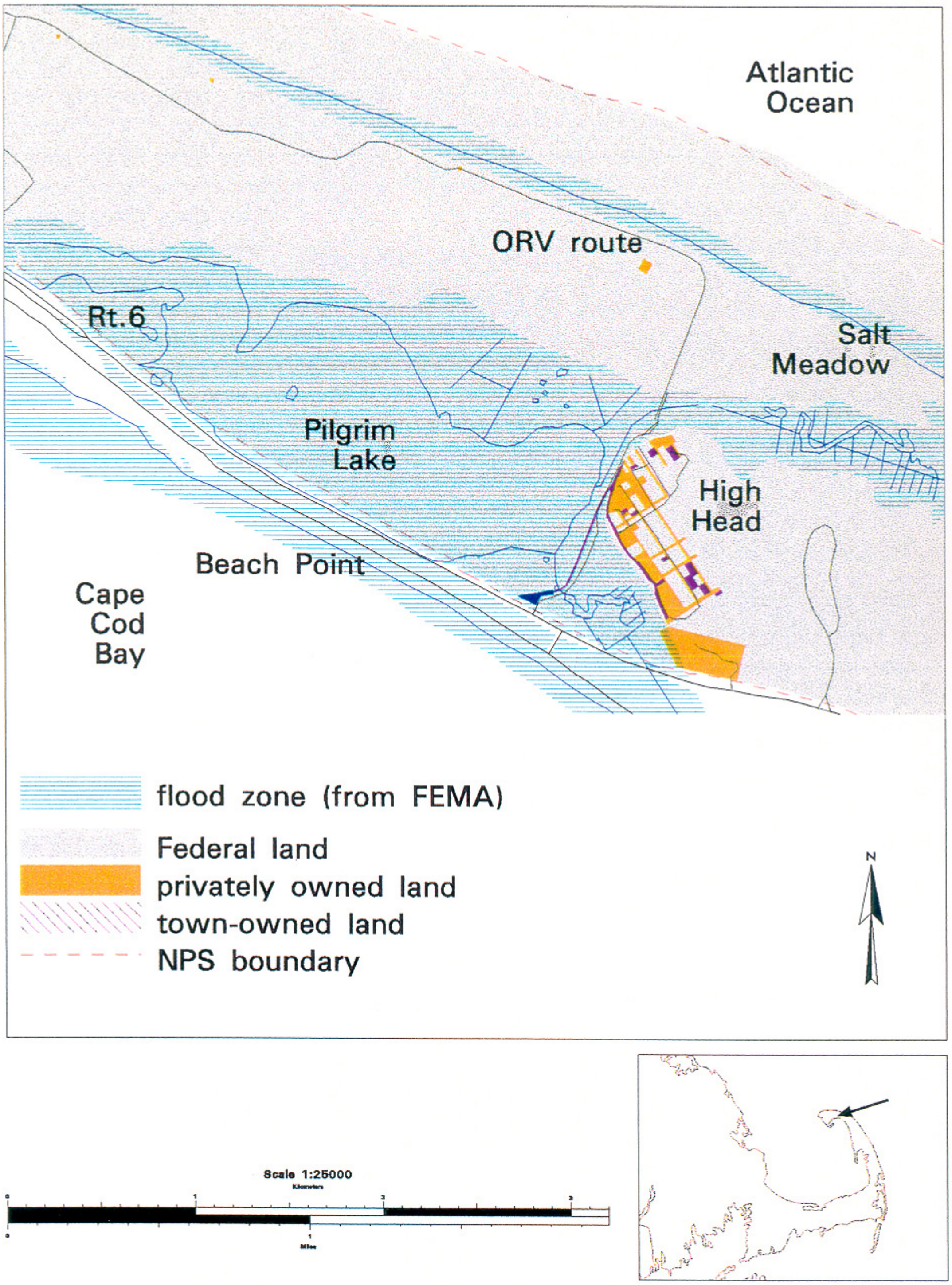
Pilgrim Lake is a 344 acre coastal lagoon that once functioned as a tidal back barrier estuary and salt marsh system connected to Cape Cod Bay by an inlet at its western end (National Park Service, 1996c) (Figure 10.4). East Harbor, as it was once called, was closed off from Cape Cod Bay completely in 1868 with the construction of a dike meant to provide a travel corridor for cars and the railroad. Since the construction of the dike, the waters of Pilgrim Lake have become brackish and eutrophic (Applebaum and Brinnekmeyer, 1988). The eutrophic condition of the lake is believed to be the result of natural and human factors such as the shallow depth (2.5 ft in 1987), stirring of lake sediments by coastal winds, nutrient input from septic system effluent and animal feces, and saltwater intrusion from malfunctioning weir boards (Mitchell and Soukup, 1981). There are fairly consistent blue-green algal blooms and periodic outbreaks of midges (Chironomidae). The algae blooms occur in all seasons except winter and give the lake its blue-green color. High values of total phosphorus, and ammonia-nitrogen have been recorded (Mozgala, 1974). The source of these high values has not been determined but may be from organic bottom sediments, septic systems, and leaching from old salt marsh sediment. The nutrient supply from these sources nourishes a large algal population. The lake's surface elevation is believed to be a major factor in its functioning.

Lake level is determined by 1) the height of the water level control structure, located on the bay side of the lake and operated by the Cape Cod Mosquito Control Project, and 2) the opening of tide gates in the dike operated by the Massachusetts Division of Waterways (National Park Service, 1996c). The significance of the lake's water level to the ecological community was highlighted in 1968 when weir boards were removed from the water level control structure. After the boards were removed, there was a fish kill and massive outbreaks of midges, whose larvae live in lake bottom sediments (Portnoy, 1991b). After the 1968 episode, water depth, salinity levels, midge larval counts, dissolved oxygen, and nutrients were examined. Emery

Water Resources Management Plan

Figure 10.4: Pilgrim Lake, Truro
Cape Cod National Seashore

Sources: FEMA Flood Ins. Rate Maps, Federal land ownership records



map prepared 12/4/96, Mark Adams, wrpilgr.aml and Redfield (1969) compiled a thorough set of data at this time; however, their study was not continued. The 1969 midge outbreaks were controlled with pesticides, a practice that is not acceptable to the National Park Service today.

The three major management concerns for Pilgrim Lake are sand deposition, eutrophication, and nuisance insects (National Park Service, 1996c). Sand deposition continues to decrease the depth of this already shallow lake. The extensive migrating dune system upwind of Pilgrim Lake may be partly responsible for the 1.5 foot (0.5 m) decrease in depth from 1948 to 1987. While past and present infilling rates have been poorly recorded, a 1987 assessment determined that the lake may fill in completely in 25 years (Applebaum and Brinnekmeyer, 1988).

Current Research

Research and Resource Management Projects-Fiscal Year 1996:

Salt Marsh Restoration Research/Planning: Herring River, Hatches Harbor, Pilgrim Lake

- Extend hydrodynamic modeling of expected tidal heights and salinities into the Herring River floodplain.
- Begin salt marsh restoration at Hatches Harbor and continue to monitor affected resources.
- Develop data compendium and research plan for Pilgrim Lake hydrology and aquatic ecology.

Pamet River Restoration/Hydrologic Cooperative Study

- Develop Pamet River restoration plan in cooperation with Town of Truro, Cape Cod Commission and U.S. Army Corps of Engineers.

Management Steps: Impacts of Diked Water Bodies
400 Days to 5 Years

Committee

Continue conversations regarding Herring River restoration. Develop a collective statement of management objectives for the wetland areas connected with the Herring River.

Education

Inform communities and private landowners of options regarding land trust donations and conservation restrictions on property that includes wetlands.

Data Management

Place all information, including monitoring data, related *to* the restoration projects in a central, easily retrievable database.

Research

Determine the relative importance of freshwater discharge from ground water and fresh surface waters versus tidal flushing from the ocean in maintaining the natural habitat and biota of estuaries.

Chapter Eleven: Summary of Recommended Water Resources Management Plan

Introduction

Cape Cod National Seashore represents a nearly unique departure from the rest of the National Park System in that it was established after the area had been settled for more than 300 years. The manner and timing of the National Seashore's creation has resulted in the greater challenges for this park. The opportunity to set aside wilderness or to assume responsibility for a large private holding was not an option for the National Seashore. Consequently, there is an ongoing difficulty with sorting out historical jurisdictions in ways that preserve the mandate of the National Seashore. A thorough review of those jurisdictional interests and historical precedents combined with improved communication is inherent in many of this plan's tasks.

The history of environmental research and management at the National Seashore has provided an exemplary resource, but the National Seashore is both fragile and complex. Increased understanding of the complexity and sensitivity of the ecosystem are critical to wise management of the seashore environment. Therefore, a second and major thrust is to maintain and expand the knowledge of National Seashore water resources.

Since the National Seashore is neither wilderness nor exclusively recreational, the park must be a responsible combination of the two that optimizes both needs. Therefore, another important piece of the plan is to improve access to the information on the National Seashore's natural environment; to formalize communication channels among the many stewards of Cape Cod; and, to create innovative ways for people to understand more about the National Seashore environment.

Ground water is the lifeblood of many living things on the Cape, but water withdrawals and water quality impacts threaten the natural and human environment. While much is known, more study is needed to assess the consequences of current or future development, particularly for maintaining adequate water quality for human consumption or adequate water quantity and quality for surface water resources. Many of the tasks identified in this report propose ways to improve our understanding of the interaction between the water resources of Cape Cod and their continued, even increased, human use.

The National Seashore has a responsibility in common with other Cape water users to conserve water to the best of its ability. Further, the National Seashore, in its role as an environmental protector and educator, has a responsibility to lead the way in development, use and demonstration of water conservation techniques. Recommended actions to improve existing practices are detailed in this report.

Connected with ground water issues, non-point source pollution from individual systems, largely septic systems, and atmospheric deposition threaten ground and surface water quality. Some of the proposed management is concerned with enhancing and refining monitoring, particularly for atmospheric deposition problems. The majority of the effort concerns improving ways to manage nutrients from individual septic systems and understanding the impacts on National Seashore kettle ponds. Some issues relate to the proximity of septic systems to water resources. Also, many of the systems are older and not in compliance with current technology. Some systems are used seasonally by temporary residents and so are unable to function as cleanly or efficiently. Other issues relate to the response of the ponds to varied nutrient inputs.

The plan identifies two areas with regard to potential major contamination. The first involves historic landfills in the vicinity of the National Seashore. Proposed action focuses on understanding the continuing pollution from those landfills and their impact on surface and ground waters. The second concerns heightened preparation for and awareness of potential toxic contamination from National Seashore or private facilities and operations.

Recreational impacts continue to threaten the water quality of the 20 kettle ponds in the National Seashore. The preservation of water quality is complicated by the sometimes conflicting management aims of towns, state agencies and the National Park Service, along with differing needs of permanent and temporary residents. Proposed measures include improving communication between agencies; improving the flow of information to both permanent and seasonal residents along with creating a process for feedback; and, developing a feasible plan that, coupled with water quality monitoring, will reduce or eliminate deleterious human impacts from recreation.

The National Seashore is a leader in the effort to restore the natural tidal environment of estuaries, reversing many decades of well-intentioned but environmentally damaging efforts to drain and alter these systems. In the process of restoration, there are many issues regarding how these systems originally functioned;, how best to arrive at restored systems that resemble the original systems as closely as possible; and, how to make the transition in an environmentally safe and culturally sensitive manner. A number of specific tasks are outlined that continue the restoration process already begun at the National Seashore.

In sum, this Water Resources Management Plan updates the previous effort of 1981, identifies priority areas for continued research, management and outreach for the next 10 years, and suggests a number of specific projects and activities that either will help complete the knowledge base, respond to critical issues or enhance the role of the National Seashore in preservation, recreation, and research. The following table briefly lists those projects that are recommended. More detailed descriptions of proposed projects follow these summary tables and are referenced to the chapter where background information is presented.

Current Projects

Issues Addressed	Problem Summary	Project Statements
Water Resource Characteristics	Baseline surveys of many basic characteristics of the biotic and abiotic water resource environment are incomplete or outdated.	• Inventory freshwater and anadromous fish • Northern diamondback terrapin study • Synthesize existing wetland plant inventory data • Map the interdunal wetlands • Monitor the water quality of the interdunal wetlands
Human Environment	Water resources education is a critical part of maintaining the quality of water resources in the National Seashore.	
Ground Water Withdrawal	Ground water is the principal source of fresh water for Cape Cod, but it is threatened by increased water withdrawal, septic effluent, and contamination.	• Assess ecological effects of ground water withdrawal at vernal pond and kettle pond littoral zones.
Water Resource Contamination Non-Point Sources	The relatively permeable nature of Cape Cod soils to nutrients and the almost total reliance on private septic systems combine to pose a serious threat to the water quality of ground water, fresh water and estuarine resources. Other contaminant sources are atmospheric deposition, road runoff, and surface runoff.	• Monitor kettle pond water quality • Evaluate mercury contamination in aquatic environments • Study the paleo-limnology of kettle ponds • Continue National Atmospheric Deposition Plan monitoring
Confirmed and Potential Source Point Contamination Sites	Landfills, mostly uncapped, and associated septage lagoons threaten expanded contamination of the ground water.	
Cultural Impacts on Pond Water Quality and Biota	There is no integrated approach to recreational management of the 20 kettle ponds within the National Seashore boundary.	

Cape Cod National Seashore Infrastructure	An updated, formalized inventory of all park facilities and their associated water efficiency does not exist.	
Ecological Impacts of Tidal Restriction	Several major estuaries in the National Seashore have historically been diked to control mosquitos. A host of unanticipated impacts have occurred. Restoration of tidal flow seems desirable, but the consequences need to be fully explored.	• Monitor Herring River dissolved oxygen • Develop Memorandum of Understanding with Cape Cod Mosquito Control Project • Monitor ecological changes resulting from tidal restoration in Herring River, Hatches Harbor, and the Pamet River • Coordinate planning and construction of enlarged culverts • Coordinate planning and construction of the Mill Creek dike • Monitor Nauset marsh

Recommended Projects and Activities

The following projects are intended to address the major water resource management issues at Cape Cod National Seashore. They derive from a number of working meetings of Seashore scientific and management staff with university cooperators and local and state technical experts. They are intentionally listed in no particular priority order, reflecting the understanding that the relative importance of each project is likely to change over the expected 10-year life of this plan. In short, management should be adaptive, and more specifically, the full range of projects should be reviewed annually and selected to advance water resource management based upon the best and most current information.

The First 400 Days of the Water Management Program
Project Statement for Chapter One

The federal mandate of the National Seashore encompasses two conflicting goals of resource protection and public access. Cape Cod National Seashore must exist with the apparent contradiction between serving as a major attraction to people and protecting the National Seashore lands in as natural a condition as possible. These conflicting goals pervade a wide range of issues from beach access to ground water use. This conflict has become increasingly pertinent as Cape Cod has come under enormous development pressure in the past two decades. Most of that pressure has occurred on the upper Cape towns located west of Chatham in Barnstable County, but demographic trends suggest that the pressure will increase on the outer Cape (see Figure 1.2), in part because of the existence of Cape Cod National Seashore.

In recognition of these circumstances, the Cape Cod National Seashore Water Resources Management Plan must reconcile these opposing pressures by identifying alternatives and recommending actions that protect the water resources' characteristics.

Jurisdictional Analysis

Issues Addressed	**Problem Summary**	**Project Statement**
Resolution of jurisdictional conflicts	Management of the National Seashore generates conflicts within the National Park Service over the preservation and maintenance of the natural resources, and externally due to growth pressure from Cape towns and the region. There is local and state ownership and/or jurisdiction within the boundary, and their policies and regulations can differ from those of the National Seashore.	**1.1 Description of Policy Statement Regarding the Desired "Natural State" for Water Resources** Review of founding legislation and experiences of other national parks with similar potential conflicts; Review of all policy and practice by the National Park Service and other agencies with jurisdiction of park resources; Develop an overarching policy statement that reconciles internal and external conflicts or proposes a means to achieve that goal.
Integration of the efforts and interests of multiple agencies and consolidation of information	Many agencies, municipalities and non-profit organizations are active in various water resource activities, but coordinated effort is hampered by the lack of a structured forum in information exchange.	**1.2 Establish a Cooperative Program Committee** **1.3 Begin community extension work to involve residents and visitors in water resource protection** **1.4 Begin development of a comprehensive water resources database**

Resource Characteristics
Project Statements for Chapter Three

Much is known about the characteristics of the water resources of Cape Cod National Seashore, but its many habitats require continued inventory, monitoring, and research efforts that the past effort continue for those areas that have yet to receive sufficient attention. Also, both improvements in assessment techniques and a greater appreciation of the need for a holistic watershed view including assessment of external watershed influences require an ongoing base program to monitor and inventory watershed characterics.

Water Resources Characterization

Issue Addressed	Problem Summary	Project Statements
Baseline survey and monitoring of chemical, physical and biological characteristics	Baseline surveys of many basic characteristics of the biotic and abiotic water resource environment are incomplete or outdated.	**3.1 Inventory Aquatic Macrophytes** **3.2 Inventory Amphibian and Reptile Populations** **3.3 Study the Causes and Effects of Bullfrog Expansion** **3.4 Monitor Spotted Salamander Reproduction** **3.5 Wetland Plant Species Monitoring** **3.6 Inventory Kettle Pond Benthic Invertebrates**

Swamps, Bogs, Freshwater Marshes, and Seasonally-flooded Wetlands

Issues Addressed	Problem Summary	Project Statements
Location, characteristics and potential impacts to these habitats	Very little is known about the interdunal bogs and vernal ponds. Wetland mapping and classification is outdated. The impacts of water level change have not been evaluated.	**3.7 Update GIS Map of Wetlands** **3.8 Develop a Monitoring Program for Seasonally-flooded Dune Wetlands** **3.9 Develop Informational Display on the Interdunal Wetlands** **3.10 Historic Cranberry Bog Restoration** **3.11 Development of an Informational Display on the Role of Cranberry Bogs and their Use of Water** **3.12 Monitor Water Level Changes in Atlantic Cedar Swamps, Interdunal Ponds and Vernal Pools**

The Human Environment
Project Statements for Chapter Four

Communication is a critical and necessary component of the Cape Cod National Seashore Water Resources Management Plan. To enhance the ability of all interested parties to communicate effectively, a comprehensive, objective database needs to be created and maintained. This database will not only provide important resource information useful for those entities (National Park Service, local communities and governments, the public) already interested and involved, but will provide a method to reach a broader audience. Open communication about water resources issues, supported by a comprehensive information database, will allow good decisions to be made in the process of guiding the National Seashore through the next decade.

Water Resources Information Database

Issues Addressed	**Problem Summary**	**Project Statement**
	There is no formalized database that provides updated, readily available monitoring information on water quality for the National Seashore.	**4.1 Develop a Water Resources Information Database** Identify a database that is easy to use and is compatible with NPS information formats; Through the use of interns, enter the existing information into the database; Designate one person to update the database as information changes.
Non-point source contamination	Adjacent development increases the potential degradation of park water resources.	**4.2 Periodically Map and Assess Adjacent Land Use**

There is a good history of cooperation between the National Seashore, the public agencies and interest groups, but it is not perfect; cooperation usually develops as a reaction to perceived problems and focuses on conflict resolution rather than as a joint effort to anticipate and resolve problems before they become conflicts. Some conflicts do not get resolved and simply fester. The record of scientific inquiry concerning the resources of the National Seashore is quite good but not always intimately connected with the political conflict resolution process because various participants' opinions are formed and positions taken prior to the full dissemination of good science.

Technical Interagency Committee

Issues Addressed	Problem Summary	Project Statement
	There are no formalized links of communication between water resource stakeholder groups on the outer Cape and the National Park Service by which management is determined collaboratively and information is transferred regularly.	**4.3 Develop Technical Interagency Committee** Include representatives from the six towns, state agencies such as Coastal Zone Management, Department of Environmental Protection, Department of Environmental Management, Fisheries & Wildlife, regional agencies such as the Cape Cod Commission and local interest groups such as the Friends of the Seashore and Massachusetts Audubon; Develop a Memorandum of Understanding between all agencies that acknowledges the need for cooperative management efforts that complement each other; Create a technical committee as a subset of this group to focus on more technical issues including: • an evaluation of zoning and healthy bylaws on the outer Cape as they relate to water resources; • water quality issues relating to septic systems; • landfills and their management • land use planning; • fertilizer use and landscaping alternatives; and, • cluster developments.

From its inception, Cape residents have been incorporated in the land management process through what is referred to as the "Cape Cod Formula." Despite the farsightedness of the Cape Cod Formula, conflicts still arise, many over water resources issues, and some of these have the potential to become precedent setting for future national park management. Full information exchange provides an opportunity to facilitate solutions to specific National Seashore problems and explore solutions to more general park issues.

Information Exchange with the Public

Issues Addressed	Problem Summary	Project Statements
	Currently, there are no formalized tools for communication between the public and National Park Service staff.	**4.4 Publish a Newsletter** Information on recent National Seashore research, information from the pond management committee, model home updates, articles from residents, articles from stakeholder organizations, and other information useful to both visitors and residents can be included in a newsletter. **4.5 Develop an Interactive Web Page** **4.6 Create a Cape Cod Institute** Patterned after the successful Yellowstone Institute.

Impacts to Ground Water Resources
Project Statements from Chapter Five

Ground water is the principal source of fresh water for domestic, industrial and agricultural use on the lower Cape. In addition, the ground water resource supports freshwater ponds, wetlands, streams, and estuary environments, all of which represent a specific and important habitat for rare flora, fauna and fish spawning. The ground water quantity and quality are threatened by a variety of impacts such as increased water withdrawal, septic effluent, and contamination from landfills, leaking underground storage tanks, and urban runoff.

Ground Water Models

Issues Addressed	Problem Summary	Project Statements
Ground water withdrawal Contamination sites Septic systems	Ground water models are of insufficient resolution to adequately estimate the local impacts of increased withdrawal. Prior work on water quality modeling has addressed only salt intrusion. Finer resolution models and a more comprehensive sampling network are needed for determining and predicting contamination flows and withdrawal impacts.	**5.1 Conduct Comprehensive Fine Resolution Ground Water Modeling** Analyze existing modeling efforts to determine: 1) areas of increased water quantity and quality data needs; and 2) the feasibility of using models for investigating local impacts and for evaluating the entire outer Cape ground water system. Design a cost-effective well network for finer resolution analysis; Implement refined well network system and collect additional information on outer Cape lithology, hydrology and ground water quality; Develop comprehensive outer Cape ground water model and sub-models targeted at specific local issues such as: • locations for potential new well fields; • Pilgrim Lake impacts; • threat of contamination to Duck and Bennett ponds; • landfill contamination flows and impacts; and, • nitrate impacts on ground water quality. **5.2 Establish a Network of Water Table Monitoring Wells**

Non-Point Source Pollution
Project Statements for Chapter Six

Septic Systems

Issues Addressed	Problem Summary	Project Statements
Septic systems	The relatively permeable nature of Cape Cod soils to nutrients and the almost total reliance on private septic systems combine to pose a serious threat to the water quality of ground water, freshwater and estuarine resources. Given the seasonal use of many Cape Cod septic systems, alternative waste treatment technologies need to be researched and tested on a case study basis.	**6.1 Review Alternative Methods of Wastewater Disposal** • alternative technologies for private septic systems; • cluster or package treatment plants for selected areas; and, • increased on-line sewerage. **6.2 Develop Case Studies of Improved or Alternative Systems** **6.3 Determine Nutrient Inputs from Shoreline Septic Systems** **6.4 Determine the Rate of Nutrient Attenuation with Distance** **6.5 Prioritize the Future of In-holdings Reverting to the National Seashore**

Kettle Pond Nutrient Management

Issues Addressed	Problem Summary	Project Statements
Impacts of eutrophication on pond water quality	A variety of eutrophication pressures threaten the 20 kettle ponds in the National Seashore; some are general to all the ponds and some are specific to individual ponds. Some basic monitoring has been conducted, but there has been no comprehensive effort to quantify the nutrient sources or likely impacts, and to develop cost-effective strategies for management.	**6.6 Develop Nutrient Budgets for the Kettle Ponds** **6.7 Review and Evaluate Existing Water Quality Monitoring Data** **6.8 Complete Specific Kettle Pond Management Plans and Develop a Comprehensive Kettle Pond Management Plan** **6.9 Develop a Nutrient Loading Risk Assessment for Changes in National Seashore Practice or Aquifer Water Quality** **6.10 Investigate the Cause of pH Changes in Ryder Pond** **6.11 Survey the Kettle Ponds for Invasive Species, Develop an Informational Program and Prepare a Response Plan** **6.12 Evaluate Feasibility of Remote Multi-parameter Data Logging** **6.13 Evaluate the Role of Aquatic Macrophytes in Permanently Sequestering Nutrients**

Heavy Metal Impacts

Issues Addressed	Problem Summary	Project Statements
Deposition and bioaccumulation of heavy metals, particularly mercury	Southeastern Massachusetts is highly impacted by atmospheric deposition that results in bioaccumulation of toxic metals, threatening human and environmental health. The high acidity of National Seashore ponds suggests this problem will be equally severe in the 20 kettle ponds with potential effects on the freshwater and estuarine biota.	**6.14 Monitor Mercury Deposition at Cape Cod NADP Site** **6.15 Evaluate Mercury Levels in Sediments of Freshwater Ponds** **6.16 Conduct Top Predator Fish Tissue Monitoring in Fresh and Estuarine Environments** **6.17 Evaluate Mercury Pathways and Management Alternatives**

Confirmed and Potential Point-Source Contamination Sites
Project Statements from Chapter Seven

Organic, inorganic, or biologic pollutants derived from landfills pose a serious threat to the integrity of clean drinking water supplies as well as rivers and estuaries. The intimate connection between ground water and surface water on the Cape compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the sand and gravel aquifer.

Landfills are among the five most serious threats to ground water quality in the U.S. (Noake, 1989). In Massachusetts, leachate contamination of ground water from landfills has been responsible for private well contamination in at least nine communities (Massachusetts Department of Environmental Quality Engineering, 1988). On the Cape, pollutants related to landfill leachate are also considered a threat to ground water supplies (Janik, 1987). A 1996 report (ATP Environmental, 1995) documents that the Eastham Municipal Landfill is directly responsible for contaminating private drinking water supplies within its vicinity.

There are five landfills (now closed) located on the outer Cape (Figure 7.1), all of which have the potential to impact the surface water resources within the National Seashore (Table 7.1). The Provincetown and Truro landfills are located inside the National Seashore boundary. Wellfleet's landfill abuts the National Seashore boundary, and the two others in Orleans and Eastham are in close proximity to the National Seashore. All landfills have monitoring wells, and the contaminant plume for each site has been mapped and discussed in various reports (Cambareri et al., 1989 a, b; Frolich, 1991; Urish et al., 1991; Urish et al., 1993; Winkler, 1994). According to these reports, some surface waters both inside and outside of the National Seashore boundaries may have been impacted.

Landfill Impact Evaluation

Issues Addressed	Problem Summary	Project Statements
Movement and impact of landfill contaminant plumes on surface and ground water resources	Five landfills, mostly uncapped, and associated septage lagoons threaten expanded contamination of the ground water and may provide excess nutrients or toxic substances to nearby ponds, streams and estuaries.	**7.1 Continue Landfill Plume Monitoring** **7.2 Review and Evaluate the Study Design of Past Plume Monitoring** **7.3 Review the Literature on Landfill Capping and Recommend the Best Technique** **7.4 Assess Contaminant Discharge into Surface Waters** **7.5 Create a Forum for Dialogue on Contamination Issues**

Hazardous Waste

Issues Addressed	Problem Summary	Project Statements
Potential impact on water resources from hazardous waste spills	Hazardous waste spillage may occur from large sources or small but significant sources that will impact both surface and ground water resources.	**7.6 Hazardous Waste Spill Preparation** Add information on private homes as well as septic systems within the National Seashore, and conduct an inventory of the park infrastructure. Conduct an inventory (i.e., gather existing information from towns and/or owners) of septic systems and storage tanks on homes located on or near surface water resources. Place storage tanks into a GIS data layer -- code by their age and the risk they present to water resources; Develop an outreach program primarily for homes that are NPS-owned and privately occupied to help homeowners understand water resource issues. Evaluate each property using criteria that relates to its potential impacts to surface and ground water quality. Use this evaluation in the decision making process for management of these homes if they are NPS-owned and occupied; Prepare an emergency response plan for spills or leakages of contaminants specific to the National Seashore.

Cultural Impacts on Pond Water Quality
Project Statements for Chapter Eight

Perhaps more than any other park in the National Park System, the Cape Cod National Seashore has an inherent conflict between natural preservation, historical preservation, recreational use and the long-standing and presently burgeoning needs and desires of visitors and residents. In addition, much of the resource to be managed is not solely under the jurisdiction of the National Park Service. While this affects all water resource management activities in the National Seashore, it is an especially difficult issue for the management of the kettle ponds.

Kettle Pond Recreational Management Plan

Issues Addressed	Problem Summary	Project Statement
Recreational impacts to pond water quality	No plan currently exists that provides an integrated approach to the recreational management of all 20 kettle ponds within the National Seashore boundary.	**8.1 Develop a Kettle Pond Recreational Management Plan** Assemble a Pond Management committee consisting of all involved organizations; Review existing knowledge base and develop a plan for larger citizen involvement and problem identification, prioritization and solution implementation; Characterize problems and issues by surveying current recreational patterns, categorizing constraints to management, identify cause of impacts, and perform a rapid environmental impact analysis for each pond that highlights critical sites; Develop an appropriate outreach program for recreational plans: • Prepare public outreach document that summarizes the plan and its intentions. • Organize a public meeting and lake management committees to work on volunteer activities such as monitoring, re-vegetation, etc.; Research the feasibility of remediation, rationalization, and implementation of best management practices. Follow up with public meetings. Implement the plan and pursue monitoring after remediation. Readjust accordingly, and continue public participation.

Managing the Gull Pond Sluiceway

Issues Addressed	Problem Summary	Project Statement
Whether or not to continue the maintenance of the historical sluiceway between Gull and Higgins ponds due to concerns about water quality and alterations to Gull Pond's trophic structure	The National Park Service, and now a volunteer group, has historically maintained the Gull Pond sluiceway (established in the 1800s) to protect herring and their habitat and because the impacts from removal of the sluiceway are unknown. Whether to maintain the sluiceway between Gull and Higgins ponds is a complex question with potential impacts on the natural biota of the ponds, the introduced trout fishery in Gull Pond, and the anadromous herring run in the Herring River.	**8.2 Managing the Gull Pond Sluiceway** Gain an understanding of the ecological impact of the sluiceway by: • determining a detailed nutrient budget for Gull Pond and the freshwater reach of the Herring River system; • determining the trophic structure of Gull Pond and the chain of ponds, river and estuary downstream; and, • completing a study which models the trophic structure and nutrient status of Gull Pond with and without river herring.

Cape Cod National Seashore Infrastructure
Project Statements for Chapter Nine

The Cape Cod National Seashore has three types of properties within its boundaries. One encompasses facilities owned by the National Park Service including houses, waste disposal systems, and storage tanks. Another is permitted homes within the National Seashore that are federally owned, but privately occupied. These homes have septic systems; some also have underground storage tanks. A number of these homes are located adjacent to ponds and marshes and will be turned over to the National Park Service for occupancy within a specified period of time. Finally, there are private improved properties or "in-holdings" that will always exist within the National Seashore, but will never fall under the ownership of the National Park Service unless donated or sold to the National Seashore. What the three types of properties have in common is that they exist and function within the National Seashore and have a potential impact on water resources. For this reason, it is important to inventory all properties within the park, regardless of ownership status.

Evaluate Current Infrastructure at the National Seashore

Issues Addressed	Problem Summary	Project Statements
Park infrastructure	An updated, formalized inventory of all park facilities and their efficiency does not exist.	**9.1 Update All Water-Related Facilities within the National Seashore and Monitor their Efficiency** Meter all National Seashore facilities and use as a tool to evaluate different approaches to water conservation and wastewater minimization.

Model Home Case Study

<table>
<tr><th>Issues Addressed</th><th>Problem Summary</th><th>Project Statements</th></tr>
<tr><td>Ground water withdrawal

Septic systems

Park infrastructure</td><td>The National Seashore currently does not have a forum to combine park research with public education.</td><td>9.2 Use a National Seashore-owned Home(s) to Showcase a Living Laboratory for the Public

The home(s) (possibly the Highlands Center, a former Air Force station that will become a center for exploring the arts and environmental understanding) may include:
• alternative septic system;
• modern water conservation devices;
• xeriscaping;
• pervious outdoor surfaces; and,
• rooftop rainfall collection;

Develop workshops for visiting schools and public groups. Cover:
• the importance of water on the outer Cape;
• threats to the water resources on the Cape;
• what the National Seashore is doing to prevent resource degradation; and,
• what individuals can do to protect the resource;

Include model home activities in the newsletter;

Monitor the results of various technologies and management practices, and place results in water research database.</td></tr>
</table>

Impacts of Estuary Tidal Restriction
Project Statements for Chapter Ten

Most of the marshes within the Cape Cod National Seashore have been altered with dikes and/or tide gates and subsequently drained. This practice of "marsh reclamation," started in the late 1600s, was meant to reduce mosquito populations, increase productive agricultural acreage, and improve roadways (Portnoy and Soukup, 1988). As a result, native habitat has been lost and freshwater wetland and upland plant species have invaded the diked areas. Salt marshes depend on sediment from the ocean in order to stay above sea level rise. Dike structures prevent this process from occurring, in turn causing the marshes to be vulnerable to flooding when dikes are breached. Decomposing salt marsh peat, left after a marsh is drained, periodically releases toxic levels of acids and aluminum, resulting in massive fish kills. Lack of tidal flushing also results in constant summertime oxygen stress, which reduces both fish and invertebrate numbers and diversity in both diked and drained wetlands.

Estuarine Habitat Restoration

Issues Addressed	Problem Summary	Project Statements
Restoration of natural tidal flushing to the Herring River General improvement and restoration of estuarine habitat	Considerable effort has already been expended to demonstrate the importance and feasibility of tidal restoration to diked estuaries in the National Seashore. Three areas are under consideration for tidal restoration. Each presents specific problems to be solved but together they present an ideal opportunity to improve the predictability of tidal restoration.	**10.1 Topographic Survey and Hydrodynamic Modeling for Estuarine Habitat Restoration at Herring River, Wellfleet** Design a restoration plan by: • improving modeling of the dike removal effect by adding topographic and hydrologic evaluation and expanding the portion of the floodplain evaluated; • designing a tidal control structure that allows incremental restoration of tidal flow in the Herring River; and, • evaluating the flood storage capacity of the Mill Creek floodplain below the golf course fairway to size a pump-out system capable of preventing flooding of the golf course after a historic dike is rebuilt. **10.2 Monitoring of Planned Estuary Restorations** Evaluate tidal restoration by comparing a restored system with both a natural system and a tidally restricted system using indices of biological integrity, hydrology, and chemistry; Through monitoring, determine the costs and benefits of restoration of tidal flushing.

Pilgrim Lake, formerly East Harbor, was closed off from Cape Cod Bay completely in 1868 with the construction of a dike structure meant to provide a travel corridor for cars and railroad. Since the construction of the dike, the waters of Pilgrim Lake have become brackish and eutrophic (Applebaum and Brinnekmeyer, 1988). The eutrophic condition of the lake is believed to be the result of natural and human factors such as the shallow depth (2.5 ft in 1987), stirring of lake sediments by coastal winds, nutrient input from septic system effluent and animal feces, and saltwater intrusion from malfunctioning weir boards (Mitchell and Soukup, 1981). There are fairly consistent blue-green algal blooms and periodic outbreaks of midges (Chironomidae).

Pilgrim Lake Management

Issues Addressed	Problem Summary	Project Statements
Eutrophication, sedimentation and midge control	Pilgrim Lake, originally a coastal embayment and now a landlocked, brackish, shallow basin experiences high levels of noxious algae, frequent outbreaks of midges under changed hydrologic regimes, and is rapidly filling in.	**10.3 Determine Bathymetry and Sedimentation Patterns in Pilgrim Lake** **10.4 Study Controls of Midge Production** **10.5 Evaluate the Cause of the Eutrophication Problem in Pilgrim Lake**

Project Statements

The First 400 Days of Water Management Plan

Jurisdictional Analysis

Project Statement 1.1
Development of Policy Statement Regarding the Desired "Natural State" for Water Resources in the National Seashore

Problem Statement

Unlike most national parks that were created from wilderness or focus on an historical event, the Cape Cod National Seashore attempts to encompass the natural environment, history and current recreation needs. There is an inherent conflict between the National Park Service authorizing mandate to maintain the park as "permanently preserved in its present state" as of its creation in 1961 while also carrying forward on the goals of "restoring cultural landscapes or natural conditions where disturbed or precluding natural changes in the environment," as expressed in the General Management Plan (National Park Service, 1998). The conflict arises not only because 1961 was not a particularly notable time for demonstration of the ideal balance of cultural and natural influences, but because the choice between restoration or preservation of the natural, historic and recent multiple use environment are often at serious conflict between environment and culture and between multiple jurisdictions with differing goals. Some examples of conflict areas include housing inholdings, fish stocking, the Gull Pond sluiceway, tidal restoration, Pilgrim Lake, and historical cranberry operations. Choices cannot be simply based on earliest chronology because some early practices have had major environmental repercussions while others are clearly resident in our deepest sense of Cape Cod and have little or no impact on the natural environment. Other customary activities or uses may be deeply held by one jurisdiction but felt to be deleterious to the primary goals of another. It is clear that the original legislative mandate to preserve the National Seashore as it was in 1961 has been altered to selectively preserve critical resources in culturally and environmentally meaningful ways.

Description of Recommended Project

Development of a consistent policy to guide these complex choices is the purpose of this project. The initial step would be a review of founding legislation and existing policy in other parks with comparable challenges. Some notable examples are Acadia National Park because of inholdings and state management of lakes and the Great Smoky Mountains National Park with its Cades Cove area where nature and unique culture must coexist. The second step would be a review of current policy and practice by the National Seashore and other agencies involved in management of Cape Cod resources. Finally, a statement of preservation targets for identifiable resources would be created with an overarching target for less well-defined resources. The targets would be based on a process that permitted rational decision between options based on overall benefit for cultural and environmental purposes with procedures for resolving jurisdictional conflict.

Budget

Year 1	$10,000

Integration of Effort and Consolidation of Information

Project Statement 1.2
Establishment of a Cooperative Program Committee

Problem Statement

Many of the conflicts and problems that arise for the National Seashore are the result of conflicting interests, mandates and goals of other agencies and organizations and incomplete or untimely communication. A formal process of establishing early communication between the interested parties is not in place or functions only when specific issues arise, often after positions are well established.

Description of Recommended Project

Establish a Cooperative Program Committee that includes the Cape Cod National Seashore, Cape Cod Commission, Massachusetts Coastal Zone Management, six towns in the National Seashore, Massachusetts Department of Environmental Protection, Massachusetts Divisions of Marine Fisheries, and Fisheries & Wildlife, Massachusetts Audubon, and Friends of the Cape Cod National Seashore. This committee represents all parties with government jurisdiction and others with a strong record of past involvement that have a stake in future water resource management on the outer Cape. The first goal is to develop between all the agencies a memorandum of understanding that acknowledges the need for management efforts that complement each other. The agreement should be focused on developing a consensus for sustainable management and development of the water resources, holistically considering short- and long-term impacts. Guidelines should be set for meetings, protocols, and technology and for information transfer between agencies and the National Seashore. An initial task of the committee should be an examination of current zoning as it relates to water quality and quantity. Additionally, the staff at the Cape Cod National Seashore should review conflict resolution methods, determine which ones are most appropriate for implementation at the National Seashore, and complete a comparison of responses to multi-jurisdictional issues that have been successful in other parks. This information can then be used in initial talks concerning water withdrawal from within the National Seashore, salt marsh restoration at Herring River and Pamet River, and water quality protection.

Budget

Ongoing	$1,000

Project Statement 1.3
Development of Community Extension

Problem Statement

Most of the interpretive effort of the National Seashore is aimed at the natural history and cultural history of the outer Cape. Yet many of the pressing issues for the National Seashore require a more comprehensive effort to involve the surrounding community and the National Seashore visitors in the process of planning and management for the park and its surrounding communities because the actions, intended or unintended, by an one group will have consequences on the others.

Description of Recommended Project

Develop a comprehensive water resource database that is manageable, consistent, and compatible with other National Park Service databases. This database should consolidate data into a format that is easily retrievable and easily updated. The plan for the database should include GIS data layers, U.S. Geological Survey water sampling data, National Park Service research and monitoring data sets, and park facilities monitoring data. The databases should be organized relationally, with common identifiers that will allow them to be linked and Internet linkages to other online databases be created including a metdatabase describing the information resources available in each, data quality limits to use and data structure. Consideration should be given to creating an intranet database for efficient input of data and easy output of information integration from a variety of related databases.

Budget

Year 1	$50,000
Year 2	$50,000
Ongoing	$15,000/year

Watershed Characteristics
Project Statements 3.1 through 3.6

Much is known about the characteristics of the water resources of Cape Cod National Seashore, but its many unique habitats require that past efforts continue for those areas that have yet to receive sufficient attention. Also, an ongoing base program to monitor and inventory watershed characteristics is required, especially in light of both improvements in techniques for assessment and a greater appreciation for the integration of individual components into a holistic watershed view. Many of the suggested studies were identified in a 1993 description of a prototype monitoring program for the National Seashore (Roman and Manski, 1993).

Project Statement 3.1
Inventory Aquatic Macrophytes

Problem Statement

The 20 kettle ponds within Cape Cod National Seashore are a unique and sensitive natural resource with significant ecological, aesthetic and recreational value. The ponds are essentially oligotrophic, naturally acidic, and extremely clear; attributes that are highly valued by the public. In addition, the kettle pond environment is the pre-eminent rare plant habitat at the National Seashore with state-listed species occurring within 18 ponds. Many of the ponds are heavily used, both by day visitors and by the seasonal residents located on private land around them. All of the dwellings adjacent to the pond shorelines rely on septic systems, which, given the unconsolidated nature of the ground water aquifer, can contribute to pond eutrophication. Some seasonal cottages are being converted to year-round residences with a resulting year-round impact. Given the inherently low nutrient levels at these ponds, impacts from septic effluents on pond water quality and associated fauna and flora are of real concern. Increased nutrient loading from septic systems can greatly increase pond aquatic macrophyte production. While the National Park Service has collected water quality data at the kettle ponds for over a decade, limited quantitative information is available on pond margin and wetland transition macrophytes (Soukup, 1977; Hinds and Hathaway, 1968). Having baseline data on pond aquatic macrophytes is essential to understanding the trophic status of the ponds, for monitoring trends of rare species, and in helping to detect future changes to the pond environment. Initiation of this project has been identified as an important need in the National Seashore's Water Quality Monitoring Plan for Kettle Ponds.

Description of Recommended Project

Objectives for all 20 kettle ponds are to: 1) develop baseline area maps of the current distribution of macrophytes along pond shorelines, and 2) inventory the species composition and abundance of mapped emergent pond vegetation.

Each pond would be surveyed for submerged aquatic macrophytes (objective 1) employing techniques currently in use by the Massachusetts Department of Environmental Protection (R. McVoy, 1996, pers. comm., Massachusetts Department of Environmental Protection) and by the Massachusetts Water Watch Partnership (M. F. Walk, 1996, pers. comm., Massachusetts Water Resources Research Center) and adapted from the U.S. Environmental Protection Agency (Simpson, 1991). In brief, this survey is conducted throughout the littoral area of the lake in mid to late summer. The areal extent of macrophytes is semi-quantitatively determined by viewing the bottom with a viewscope and estimating density in quartiles. The extent of macrophyte coverage is estimated and mapped. Species are determined at several sampling sites by four casts, one to each quadrant, of a specially modified rake. The recovered plants are identified wherever possible. All data are transferred to GIS base maps of the lake. The use of GIS permits easy comparison of change between surveys.

More extensive vegetation monitoring will focus on the five ponds that represent a range of bathymetric, hydrologic, and chemical characteristics. Listed in order of enrichment status (oligotrophic toward eutrophic), the ponds are Duck, Ryder, Great (Truro), Gull, and Herring. Complementary, ongoing studies by park staff and the U.S. Geological Survey, Biological Resources Division cooperators at these ponds include water quality monitoring, hydrogeologic investigations, and investigations of ground water withdrawal effects on pond chemistry and biota. In addition to the two objectives for all ponds, study of these five ponds will: investigate relationships between pond trophic status and macrophyte species composition, production and growth form; study the local factors (e.g., bathymetry, slope, aspect, insolation) controlling the distribution of aquatic plants; and, develop long term monitoring protocols to assess and detect changes in distribution, species composition and cover in response to potential nutrient loading at the ponds.

Budget

Year 1	$23,000
Year 2	$ 5,200

Project Statement 3.2
Inventory Amphibian and Reptile Populations

Problem Statement

The insular nature of the outer Cape, and its glaciated past, have resulted in a unique assemblage of amphibians and reptiles. A comprehensive survey of reptile and amphibian populations within the National Seashore has never been accomplished, despite these animals' sensitivity to natural and anthropogenic changes to their aquatic and terrestrial habitats and their important roles as both bioindicators and members of temperate ecosystems. Our current knowledge of local populations is based upon Lazell's (1972) surveys of the entire Cape and Islands (Martha's Vineyard and Nantucket) region, Jones (1992) surveys of National Seashore reptiles and amphibians, Seipt’s (1987) surveys of state-listed rare species, Portnoy's (1986) inventory of amphibians associated with temporary ponds, the Massachusetts Audubon Society's terrapin studies (Shipley and Prescott, 1989), and casual observations. Amphibian populations, in particular, have exhibited dramatic local declines throughout the world, variously attributed to development impacts, global climate change and attendant shifts in habitat, predation and/or competition, and acid rain. Insular reptile populations are especially vulnerable to development on the outer Cape peninsula with associated isolation of habitat and direct mortality (e.g., road kills, wanton killing) inevitable with increased human activity. Without comprehensive surveys, National Seashore managers will be unable to identify and protect critical habitat or to monitor this resource.

Description of Recommended Project

National Seashore-wide surveys are initially proposed to provide qualitative information on species occurrence and relative abundance; search will be keyed to specific habitats and seasons, especially for amphibians, to identify important breeding groups. Identified centers of activity (e.g., breeding ponds, denning sites) will be intensively studied to provide more quantitative data on populations, habitat use and breeding phenology and other aspects of their natural history.

Budget

Year 1	$ 7,200
Year 2	$12,000

Project Statement 3.3
Study the Causes and Effects of Bullfrog Expansion

Problem Statement

When J. Lazell published his 1960s observations on the distributions of reptiles and amphibians on the outer Cape, bullfrogs were restricted to the upper Cape (Orleans and westward), and one introduced group was in South Wellfleet, outside the National Seashore. Today bullfrogs are widely distributed throughout kettle ponds, temporary ponds, and streams at least as far north as Truro. Although well known for displacing other amphibian species, particularly green frogs, nothing is known about their impact within the National Seashore. Current wisdom (see Freda, 1986) holds that the bullfrog is excluded from highly acidic habitats (pH < 5). However, this species occurs and breeds abundantly and successfully in National Seashore ponds with pH ca. 4.5. The absence of generally acid-tolerant green frogs from these sites suggests they, and perhaps other native fauna, have been eliminated by the larger predatory bullfrogs. The recent observation that bullfrogs inhabit a number of vernal pools may be of special concern because these pool-dependent communities have evolved over the last 10,000 years without large anuran predation (E. Colburn, 1998, pers. comm., Massachusetts Audubon Society) .

Description of Recommended Project or Activity

Proposed research includes: 1) a survey of the distribution of the bullfrog on the entire outer Cape peninsula from Eastham through Provincetown, and 2) an examination of the ecological role of bullfrogs on lake and temporary pond faunal communities. Establishing the present distribution is particularly important to the second phase because it creates a baseline for future comparison and permits selection of appropriate sites for further study. Using GIS and biological and chemical water quality data derived from other projects, the pattern of occurrence can be analyzed, particularly identifying those water bodies that are within the present range but do not have bullfrog populations or are on the margins of the present range. In the second phase, emphasis will be placed on interspecific relations, but the influences of aquatic chemistry and vegetative cover will also be assessed using GIS and other techniques to help explain the mechanism and possible limits to the apparent range expansion. A detailed ecological analysis should clarify important factors controlling the species' success and identify impacted native aquatic species. Field observation and analysis may be supplemented by experimental study in the lab to confirm hypotheses and further resolve critical circumstances or life cycle periods that might lead to management strategies for the preservation of the original diversity of aquatic life.

Budget

Year 1	$15,000
Year 2	$10,000

Project Statement 3.4
Monitor Spotted Salamander Reproduction

Problem Statement

Mole salamanders (*Ambystomidae*) have long been considered vulnerable to acidification impacts due to their near exclusive use of temporary isolated wetlands (vernal ponds) for breeding. On Cape Cod these habitats are poorly buffered due to their isolation from mineral soils; the presence of sphagnum and pine, oak and maple litter which results in highly acidic water of pH 4.5 to 5.5, no reserve alkalinity, and high color. Recent work by Portnoy (1990) has demonstrated a high level of acid tolerance among Cape spotted salamanders, but also a clear sensitivity of embryos to the combination of low pH and high concentrations of polyphenolic compounds. It is hypothesized that further reductions in pH (e.g., due to acid rain: pH 4.3), in highly colored sites will substantially reduce embryonic survival and recruitment within isolated demes. Since the common and widely distributed spotted salamander is the only amphibian whose breeding abundance and embryonic survival have been systematically inventoried throughout the National Seashore, a clear opportunity exists to use the existing baseline and methods to evaluate the biological effects of potential acidification.

Description of Recommended Project or Activity

The basic tool for monitoring spotted salamander populations is by egg mass counts conducted annually at traditional breeding ponds and pond complexes. Although adult salamanders are fossorial and difficult to find, it is possible to determine their reproductive output on an annual basis because they assemble to mate and oviposit within a fairly predictable time period in early April. Work elsewhere indicates that egg mass counts are a good index of breeding female abundance (S. Jackson, 1999, pers. comm., University of Massachusetts). These counts, coupled with coincident water chemistry (at least pH, alkalinity/acidity, color and tannin-lignin), should over the long-term, predict biologically important changes in water chemistry. If declines are suspected as a result of water chemistry changes, results should be confirmed with egg mortality studies to help identify whether the cause is due to changes in embryonic mortality rates. Additional research may be necessary to assess survival and recruitment in the adult population.

Budget

Year 1	$1,000
Year 2	$1,000
Year 3	$1,000

Project Statement 3.5
Wetland Plant Species Monitoring

Problem Statement

Anthropogenic pressures on both freshwater and saltwater wetlands potentially impact wetland plant species occurring in, on or adjacent to wetland shores. Nutrient runoff from household septic systems and the resulting accelerated growth of aquatic plants is a critical concern. Municipal ground water withdrawal plans, the subsequent lowering of the water table and changes in nutrient availability could alter plant species composition of some National Seashore wetlands allowing for increased encroachment of upland plants (Cortell, 1983). In addition, recreational use (e.g., foot traffic, flora and fauna collecting, littering and shellfishing) impact wetland plant communities. While inventories that identify wetland plant species within the National Seashore have been completed (Cortell, 1983; LeBlond, 1990; Patterson, 1988), little quantitative monitoring has been implemented to document changes in species communities from human impacts. Without field monitoring that documents changes in wetland plant species communities, National Seashore managers will lack quantitative data to support potential wetland protection measures.

Description of Recommended Project

Project 1: Synthesize Existing Wetland Plant Inventory Data

Existing inventory and monitoring plots will be identified, located, and mapped on the National Seashore's geographic information system.

Project 2: Define Monitoring Methodology

Existing wetland inventory and monitoring plots use different classification and sampling systems. A resampling and monitoring scheme will be developed after reviewing inital data and determining applicability to future management needs. Wetland areas without established monitoring plots and in need of quantitative sampling of data will be identified in priority order. Standards for classification and sampling wetland plant species and communities will be identified. The time interval between monitoring efforts will be identified.

Budget

	Project 1	Project 2
Year 1	$8,000	$8,000
Year 2	$5,000	$5,000
Year 3	$5,000	

Project Statement 3.6
Inventory Kettle Pond Benthic Invertebrates

Problem Statement

Baseline data on benthic invertebrate taxa are critically needed in order to understand the impacts of any water quality changes associated with public use and adjacent residential development. A complete survey of each pond for benthic invertebrates is also necessary for evaluation of the state's active fish stocking program. At present little information exists on kettle pond benthic invertebrates (Shortelle and Colburn, 1986).

Description of Recommended Project or Activity

Select ponds and habitats to represent the full range of water chemistries, depths, sediment types and vegetational communities within which to characterize benthic macroinvertebrates. Develop functional models of faunal/habitat relationships and verify models in newly sampled ponds and habitats. Produce detailed protocols for characterizing benthic invertebrate abundance and diversity along with important environmental attributes. The variety of habitats available for macroinvertebrates requires the use of semiquantitative techniques such as sweep nets, dredges and hand-picking to develop as complete a species list as possible. Select groups may be quantitatively sampled with a dredge or multi-plate sampler. However, pond changes are probably first observed by the loss of the least frequently occurring species, the same ones that will probably not be sampled by standard quantitative methods.

Budget

Year 1	$50,000
Year 2	$50,000

Swamps, Bogs, Freshwater Marshes, and Seasonally-flooded Wetlands
Project Statements 3.7 through 3.12

Problem Statement

The National Seashore has a wide variety of swamps, bogs, freshwater marshes and seasonally-flooded wetlands. The Atlantic white cedar (*Chamaecyparis thyoides*) community (Table 3.1) is a tree swamp that establishes itself under very specific conditions that are rare in New England (Godfrey and Soukup, 1978; Motzkin, 1990). Only a few stands remain on the Cape (Brownlow, 1979); one of which is an 80-acre swamp in Wellfleet on National Seashore property.

Cranberry bogs are relatively common in the interdunal swales of the Province Lands. For example, an abandoned commercial cranberry bog is located in the upper reaches of the Pamet River valley. From the 1800s through the 1950s, it served as a cranberry farm for a Cape Cod family. Now it provides an opportunity to educate the public about some of the early history of the Cape as well as to demonstrate early water management practices.

There are 55 documented seasonally-flooded wetlands within the National Seashore that vary in size from small habitats to larger systems (15 to 60 feet; 5 to 20 meters in diameter) that occupy several hectares. Since 1985, seasonally-flooded wetlands within the National Seashore have been mapped; their vegetation has been described; and, the water chemistry has been surveyed. The predominance of coniferous and ericaceous vegetation (Table .3.1) in combination with the low-alkality native outwash soils causes most seasonally-flooded wetlands in the National Seashore to be acidic (median pH = 4.82).

The Province Lands ponds are young ponds formed in the last 1,000 years (Winkler, 1994) by the development of dunes on barrier spits (Figure 3.1a-c). They are small, shallow depressions less than 3 feet (1 meter) deep, that form between dunes and extend below the water table (Godfrey and Soukup, 1978). These ponds are part of a larger wetlands complex that includes bogs, marshes, and floating peat islands (Table 3.1). Some of the ponds are ephemeral and were designated as wetlands, not as open water, on old maps (Winkler, 1994).

Project Statement 3.7
Update GIS Map of Wetlands

Description of Recommended Project

The Province Lands interdunal wetlands represent different geological origins, with their development following a reverse sequence from wetland to bog to shallow pond. Paleoclimatic research (Winkler, 1994) suggests that different periods of natural or cultural land use caused the development and change in the interdunal ponds. Changes may also have resulted from contaminant inputs from landfills and other sources and from changes in ground water level. These dynamic systems should be accurately mapped from orthogonally corrected aerial photography and incorporated into the National Seashore geographic information system so that physical changes in extent may be temporally analyzed.

Budget $5,000

Project Statement 3.8
Develop a Monitoring Program for Seasonally-flooded Dune Wetlands

Description of Recommended Project

The interdunal wetlands, bogs and ponds represent an opportunity for the study and demonstration of some "island biogeography" principles and improving the understanding of the interaction between biotic and abiotic components in the reverse of the normal development from lake to wet meadow of these wetlands. A plan for conducting an inventory and monitoring of seasonally-flooded wetlands, analogous to the plans for estuarine resources and kettle ponds, should be developed so that the current composition of the flora and fauna can be documented and future trends can be detected. All data should be incorporated in the National Seashore geographic information system database.

Budget	Year 1	$5,000
	Year 2	$5,000

Project Statement 3.9
Development of an Informational Display on the Interdunal Wetlands

Description of Recommended Project

A park display should be developed, which explains the unusual characteristics of interdunal wetlands and the synchrony of development associated with the large-scale climatic change experienced on the Cape. This project will be developed through cooperation with the National Seashore's Interpretive Division.

Budget $5,000

Project Statement 3.10
Historic Cranberry Bog Restoration

Description of Recommended Project

An abandoned cranberry bog with surviving related agricultural buildings in the upper Pamet River valley presents a rich historical resource for the National Seashore. However, the hydrological regime of the area has been altered by road construction. Restoring this bog as a working example of the cranberry industry on the Cape will require restoration of the earlier hydrology, but this will also re-expose heavy metals used as pesticides in the past. The hydrology of the bog should be analyzed to determine the extent of hydrologic restoration necessary and the degree of potential release of toxic metals. Plans should be developed for the sequestration of these metals.

Budget	Year 1	$20,000
	Year 2	$15,000

Project Statement 3.11
Development of an Informational Display on the Role of Cranberry Bogs and their Use of Water

Description of Recommended Project

Upon the completion of the restoration of the historic cranberry operation in the upper Pamet River valley, a National Seashore informational display should be developed, which illustrates the history of the cranberry operation and its relation to the unique aquatic environment provided by the Cape.

Budget $10,000

Project Statement 3.12
Monitor Water Level Changes in Atlantic White Cedar Swamps, Interdunal Ponds and Vernal Ponds

Description of Recommended Project

Atlantic white cedar swamps are very rare in New England and depend on a unique set of hydrologic conditions. Interdunal ponds and vernal ponds are likely to be similarly very sensitive to water level changes. A network of wells should be established where ground water levels are monitored and, in conjunction with other ground water level analyses, impacts of short- and long-term ground water level change should be evaluated. The well network installation, evaluation and optimization for a larger area proposed by Weiskel and Cambareri (1998) should be expanded or focused to include Atlantic white cedar swamps, interdunal ponds, and vernal ponds.

Budget $15,000

The Human Environment
Project Statements 4.1 through 4.5

Project Statement 4.1
Develop a Water Resources Information Database

Problem Statement

The literature on the water resources of Cape Cod National Seashore is extensive: some in peer-reviewed journals, some in "gray" literature (principally National Park Service publications), and some in file copies of reports or data. The task of assembling the data for new purposes can be formidable and heavily reliant on the memory of long-term staff. The task of combining data from different National Seashore programs and offices can be daunting such that the program manager would have great difficulty in developing a holistic view of National Seashore water resources.

Description of Recommended Project

Cape Cod National Seashore managers should develop a water resources information database that permits easy input, flexible structure, and easy output in a variety of forms. The database should be created with both input and output in mind, guaranteeing its long-term value and eliminating the possibility that it will fall into disuse. The data collector should find the process of data input simple; and, the data user should find the manipulation of data into common formats more convenient and easier than attempting the same thing in other ways. Output, even that which is rarely requested, should be relatively simple to generate and should include tabular, graphical and geographic information system (where applicable) viewing of the data. Import and export to commonly used software should be possible and simple. The ultimate goal is for the data collector and user to prefer this system over other alternatives because it is easier and more comprehensive.

The first step is to identify the information to be included in the database. Examples of desirable data resources include: pond water quality, water resources infrastructure, well monitoring, and landfill monitoring. A committee of data collectors/users should identify the types and characteristics of the data they commonly collect and use and identify future needs. The database designer should incorporate these needs with a database management program consistent with National Seashore computer capability. The final design should be extensively tested by the users. Interns might be used to enter historical information. One National Seashore staff person should serve as quality control officer for the database, reviewing all data entries with assistance from software that provides historical context for comparison.

While all data should be available to National Seashore staff, most data should also be available through the Internet. Access to reports in a format which is easy to download (i.e., pdf format), would expand availability to National Seashore research for the scientific community. Access to this web site might be further enhanced by some real time data collection, e.g., tide tables, weather, number of visitors, an almanac of natural history events, etc.

Budget	$15,000	for design
	$40,000	for initial data entry ($20,000/yr for 2 years)
	$ 2,000	for testing

Project Statement 4.2
Periodically Map and Assess Adjacent Land Use

Problem Statement

Residential and commercial development is increasing rapidly adjacent to Cape Cod National Seashore water resources both within and outside park boundaries. Forest clearance, new subdivision roads, extended pavement, additional on-site wastewater disposal, and increased use of pesticides and fertilizers all threaten water resources. If these stressors and their likely implications to natural resources are not monitored and evaluated, park management cannot effectively and proactively collaborate with local communities in mitigating development impacts.

Description of Recommended Project

To monitor and assess these rapid changes, the park needs regular mapping of land use and GIS analysis of potential consequences. Land use mapping will quantify areas of lawns, impermeable surfaces, and point and non-point sources of pollution in relation to down-gradient resources. The GIS analysis will include hydrologic (ground water and surface water flow direction and velocities) and geologic (soils and surficial geology) information to predict development effects on down-gradient wetlands, ponds and estuaries. For example, existing particle tracking methods have been developed by U.S. Geological Survey, Water Resources Division, and can be integrated into the Cape Cod National Seashore GIS to model the flow paths of pollutants from existing and potential land use changes. Instead of attempting to assess each development project individually, the GIS approach will provide a much more systematic, comprehensive and scientifically credible way to assess cumulative development impacts.

Budget

Year 1 — $20,000 to upgrade the Cape Cod National Seashore GIS to include particle tracking and other new methods.

Year 1 and every five years thereafter
$10,000 to map adjacent land use or incorporate data from cooperating agencies (e.g., Cape Cod Commission)

Project Statement 4.3
Develop a Technical Interagency Committee

Problem Statement

Cape Cod National Seashore was established in 1961 from public and private land, within six Massachusetts' towns, creating a unique park situation where over 30 percent of the land within its boundaries is under the jurisdiction of state and municipal entities. Cape Cod National Seashore management is faced with administering an integrated program of natural and historical preservation that must be consistent with federal law and National Park Service policy, state laws and regulations, and local community bylaws. It must also be sensitive to the desires and needs of the residents of the communities located within its boundaries and the thousands of annual visitors. And it must be caretaker of a fragile and rare ecosystem.

There is a good history of cooperation between the National Seashore, the public agencies and interest groups, but it is not perfect; cooperation usually develops as a reaction to perceived problems and focuses on conflict resolution rather than as a joint effort to anticipate and resolve problems before they become conflicts. Some conflicts do not get resolved and simply fester. The record of scientific inquiry concerning the resources of the National Seashore is quite good but not always intimately connected with the political conflict resolution process because opinions are often formed and positions taken prior to the full dissemination of good science.

Description of Recommended Project

Creation of formalized links to interested groups and jurisdictional authorities for the purpose of planning management strategies collaboratively and improving the regular flow of scientifically-based information would provide a routine mechanism for dialogue. Development of a working relationship with the multiplicity of agencies and interest groups will take time, care, and multiple steps.

The first step will be to invite agencies, municipalities, planning commissions, and interest groups to participate in a standing committee; the teams created by the Massachusetts Watershed Initiative make an excellent starting point. The committee should include representatives from the six towns; state agencies such as Coastal Zone Management, Department of Environmental Protection, Department of Environmental Management, Fisheries & Wildlife; regional agencies such as the Cape Cod Commission; and, local interest groups such as the Friends of the National Seashore and Massachusetts Audubon. The first meeting of this group should be professionally facilitated with the purpose of exposing present and anticipated issues and to seek a common ground of understanding. One objective would be to agree on areas where memoranda of understanding are needed and on the protocol for improving information transfer and communication. Areas of possible complementary activity should also be identified. Finally, a subset of the committee should be selected to focus on technical issues with additional advisors as needed. The full committee should meet at least once a year and publish a summary of its conclusions. The technical committee should meet at least once more per year, preferably before the larger meeting so that technical issues might be appropriately developed and based on recent research results.

Initial topics should include:

- Zoning and health bylaws as water resources management tools
- Water quality issues relating to septic systems
- Landfills and their management
- Land use planning
- Fertilizer use and landscaping alternatives
- Cluster development as an alternative to individual lots

Budget

$2,000	for professional facilitator (first year only)
$1,000/year	for meeting costs and publication of meeting summary
$1,000/year	for outside technical advisors

Information Exchange with the Public
Project Statements 4.4 through 4.6

Problem Statement

Cape Cod National Seashore established in 1961 from public and private land under different ownership, coexists intimately with six longstanding towns and with interspersed "in-holdings" of private, public and leased land. From its inception, residents have been incorporated in the land management process through what is referred to as the "Cape Cod Formula." Despite the farsightedness of the Cape Cod Formula, conflicts still arise, many over water resources issues, and many of these are precedent setting for future national park management. Full information exchange provides an opportunity to facilitate and explore solutions to specific National Seashore problems and to more general park issues. Insufficient or poorly timed communication often complicates attempts to develop acceptable compromises.

Project Statement 4.4
Publish a Newsletter

Description of Recommended Activity

Develop a newsletter to be published four times annually and distributed to residents, tourist havens, town halls, citizen clubs, libraries, and newspapers. A National Seashore staff person, trained in journalism and public relations should be the editor. An editorial board should be formed of National Seashore staff and interested public, who will participate in editorial decisions and the review of articles. While the newsletter might contain some general information for the casual visitor, it should principally focus on topical matters. These might include:

- Information on recent National Seashore research
- Information from the Pond Management Committees
- Model home updates
- Articles from residents living within the National Seashore boundaries and on the lower Cape
- Articles from various organizations concerned with water resource issues relevant to the lower Cape
- Other information to be included should be exciting natural history events such as whale sightings, migratory bird arrivals, etc.

Budget		
	Staff	$5,000/year
	Printing	$3,000/year

Project Statement 4.5
Develop an Interactive Web Page

Description of Recommended Project

The Internet is quickly becoming an important resource for many people to gain information. Some of the National Parks (e.g.,Yellowstone, Crater Lake, Great Smokies, Isle Royale) have developed *Virtual Visitor Centers* that can be accessed from the National Park Service home page. These web sites provide links to information similar to that presented in a newsletter but at less cost. Information may be general, graphic (maps and photographs), technical, and may include policy statements. The current Cape Cod National Seashore web page is a fact sheet with one picture. A staff person or intern trained in journalism, but also experienced with web page design, should work with an editorial board to develop both permanent pages of information as well as those that need to be updated regularly. Links to other key Cape Cod organizations should be included (e.g., Cape Cod Commission, Massachusetts Audubon Society, etc.)

Budget $5,000

Project Statement 4.6
Create a Cape Cod Institute

Description of Recommended Project

Investigate the possibility of starting a "Cape Cod Institute" patterned after the successful Yellowstone Institute. This would be a non-profit field school operated in partnership with the National Park Service featuring short courses on the Cape Cod ecosystem and taught by park service employees, college professors, and local experts. Many courses might be offered for college credit through a university continuing education program. Courses are two to five days in length, and participants would gain knowledge about the National Seashore's ecology. Lodging could be provided in National Seashore owned housing. There might be a modest startup cost, but in the long-term, the institute should be self-supporting.

Budget Self-supporting

Impacts of Ground Water Withdrawals
Project Statements 5.1 and 5.2

Problem Statement

Ground water is the principal source of fresh water for domestic, industrial, and agricultural use on the lower Cape. In addition, the ground water resource supports freshwater ponds, wetlands, streams, and estuary environments, all of which represent a specific and important habitat for rare plants, fauna, and fish spawning. The ground water quantity and quality are threatened by a variety of impacts such as increased water withdrawal, septic effluent, and contamination from landfills, leaking underground storage tanks, and urban runoff.

Significant growth in the number of summer and permanent residents over the last 30 years has increased ground water use and placed stresses on the ground water resources. In response to increasing water demand, several outer Cape communities have proposed placement of new public supply wells within or adjacent to the National Seashore boundaries. Potential impacts of these proposed well locations are, at present, poorly understood. In particular there is concern over the extent of long term declines in ground water and pond levels and in the quantity of stream flow, as well as in the possibility of saltwater intrusion from the surrounding ocean (Masterson and Barlow, 1994). The effects of increasing ground water withdrawals depend on the location of wells, local hydrogeologic conditions, the amount and rate of withdrawals, and whether or not the water is returned to the aquifer after use (Martin, 1993).

Several reports that focus on Cape Cod have documented that pollutants derived from septic effluent negatively impact both ground and surface water resources located within and outside the National Seashore boundary (Persky, 1986; Sobczak and Cambareri, 1995; Valiela et al., 1992; Martin et al., 1992). Several other reports (Valiela et al. 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985) document the far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters. These findings are of great importance to the resource managers at Cape Cod National Seashore as many of the ponds, estuaries, and marshes within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic contaminated ground water discharge (Portnoy et al., 1998; Martin et al., 1992).

Organic, inorganic, or biologic pollutants derived from landfills, leaking underground storage tanks, and urban runoff pose a serious threat to the integrity of clean water drinking supplies as well as rivers and estuaries. The intimate connection between ground water and surface water on the Cape compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the sand and gravel aquifer.

Understanding the risk and developing cost-effective management plans for ground water protection will depend on an improved understanding of ground water flow, recharge, and the impacts of withdrawal. The ground water models currently used to evaluate threats to the lower Cape do not have sufficient resolution to assess alternative strategies for increased water withdrawal and interrelationships between ground and surface water resources. Specifically, higher resolution models should: 1) determine locations for potential new well fields; 2) determine the effect of the Knowle's Crossing well field on Pilgrim Lake; 3) determine the threat of ground water contamination on Duck and Bennett ponds; 4) evaluate landfill contamination flows and impacts; 5) evaluate nitrate impacts on ground water quality; and, 6) contrast the use of many small volume well fields against fewer large volume well fields.

Project Statement 5.1
Conduct Comprehensive Fine Resolution Ground Water Modeling

Description of Recommended Project

This project reflects logical stages in the development of a more comprehensive view of the outer Cape ground water systems critical to National Seashore management of its water resources. This three-part project would: 1) provide comprehensive analysis of existing modeling efforts and sampling networks; 2) implement refined data gathering that will improve knowledge of the lithology, hydrology, and water quality; and, 3) development of an improved model describing the outer Cape ground water system and fine resolution sub-models of specific impact zones. The three parts lead to a system that can be represented in a geographic information system and queried on the impact of specific water use or contamination issues that can be used to make management recommendations.

Part 1: A number of ground water models have been developed for the lower Cape (Guswa and LeBlanc, 1981; Wilson and Schreiber, 1981; Cambareri et al., 1989a; Martin, 1993; Barlow, 1994a, b; Masterson and Barlow, 1994; Massachusetts Department of Environmental Management, 1994; Sobczak and Cambareri, 1995). All of these models have used simplifying assumptions, two-dimensional analysis, or relatively coarse resolution scales and appear inadequate to investigate interconnections between aquifers, localized impacts, discharge to surface waters, and water quality other than salt intrusion. Although they have been appropriate for the specific question that was addressed, they do not provide sufficient integration to address other questions. An initial detailed analysis of the strengths and weaknesses of these models and the sampling network that supports them will permit structuring of an improved model or set of models. Envisioned is a nested system of models built from high resolution data at selected local potential impact areas and expanding with some loss of resolution for computational reasons to a model of the entire outer Cape ground water system (Weiskel and Cambareri, 1998). The detailed analysis would also permit assessment of those elements and data from prior studies that are still useful in the final model and reveal areas where insufficient well data are available.

For example, previous reports of all landfill monitoring will be rigorously evaluated. The placement of existing monitoring wells will be examined to ascertain if an adequate network exists for future contaminant monitoring and fine-scale ground water monitoring. The depths of these wells must be noted to determine if an adequate mechanism for monitoring at various levels in the leachate plumes exists. Results of previous chemical analyses will be inspected to see if the lists of analytes is appropriate for the suspected contamination from the leachate.

The results of this analysis would provide the scope necessary for the final model development and identify areas where greater focus should exist. Areas of special focus will include freshwater ponds, ground water discharge to surface waters, landfill plumes, and water quality in addition to salt intrusion.

The final stage in this first part will be to develop the conceptual design of the complete final model such that individual parts can be accomplished as funds become available, yet all of these parts, or sub-models, will be consistent with the overall model needs. Consideration will be given to allowing the model to be updated as model elements are improved. Data needs will be prioritized to maximize results cost-effectively.

Part 2: Based on the recognized data collection needs from step one, additional wells would be added and additional parameters measured. New observation wells will be installed in locations deemed critical for management and protection of key resources. It is likely that this part could be expensive, but it is of value to all agencies and communities with concern for outer Cape water issues. Partners should be sought to share in this stage.

Part 3: Based on the conceptual framework developed in part one, the final phase will be the development of all model elements, development of means to connect sub-models to the comprehensive model, and quality testing. All elements of the model should be closely coupled to geographic information system. After the model is verified, a number of specific questions will be probed. These questions will be developed from issues in the Water Resources Management Plan and through discussions with the National Park Service. These will probably include:

- Documenting the detailed effects of increased levels of pumping from the Knowle's Crossing wellfield on Salt Meadow and Pilgrim Lake.
- Determining the relative merits of different positions for the proposed Long Nook well.
- Evaluating the balance between increased use of the Coles Neck well and an additional well in the Chequesset lens.
- Assessing the merits of several smaller wells vs. one large well to increase water supply.
- Assessing the impact of existing and proposed housing development in proximity to National Seashore surface waters.
- Determining the future impact of existing uncapped landfills on National Seashore water resources.

Based on these and other modeling studies, recommendations for future management will be assembled in a report suggesting the most effective management and mitigation strategies.

Budget

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Phase 1	$50,000	$50,000					
Phase 2			$30,000*	$30,000*			
Phase 3					$100,000	$100,000	$100,000

* Assuming that other partners provide something more than $100,000 for well construction and water quality analysis.

Project Statement 5.2
Establish a Network of Water Table Monitoring Wells

Description of Recommended Project

The surface fresh water and estuarine resources of the National Seashore are dependent upon a lens of fresh ground water floating atop the generally saline ground water under the Cape peninsula. A substantial local withdrawal, e.g., a municipal well field, results in a lateral zone of depression of the water table. This effect is greatest upgradient of the withdrawal site. Any wetlands within this affected zone will experience an artificially lowered water table. Such a chronic lowering of surface waters in emergent wetlands can produce major shifts in floral dominance and/or can limit flooded habitat for dependent aquatic fauna.

The resolution of various land management concerns at the National Seashore is dependent on a clear and detailed understanding of ground water relationships. These relations, including site-specific data on direction of flow, high discharge locations, thickness of the fresh water lens and depth to seawater, are crucial to maintaining the quality and quantity of National Seashore surface water resources. The effects of adjacent human developments, e.g., wastewater and solid waste disposal, surface runoff and nutrient-laden ground water discharge, will never be understood without this information. Given the unconfined nature of the Cape Cod aquifer, a simple (albeit detailed) water table map is the single most important piece of information for interpreting development impacts. Only coarse vertical resolution ground water contour maps (5-ft contours, U.S. Geological Survey) presently exist, except for a few special project sites of less than 1 km in diameter.

Beginning with existing bench marks and permanent piezometric measuring points (e.g., U.S. Geological Survey observation wells), this project will develop a high density system of horizontally controlled water table observation points using the National Park Service's geographic information system. This is conceived as multi-phase process of gathering existing data, correlating extant measuring points and establishing new ones as necessary to achieve the desired degree of spatial resolution. A stratified design is likely with special attention to adjacent development impacts. Particular emphasis will be given to regions near kettle ponds, wetlands and discharge areas into estuaries. Actual water height observations should be synoptic and at least quarterly until the hydrology is well described. Data generated from this effort will have important and diverse applications for both land management and long-term research, including global change issues. This will provide the basic information to interpret in a site-specific fashion the depth of fresh water and the likelihood for surface water impacts from proposed municipal pumping. Second, the National Seashore, through cooperating or contracted hydrologists, will conduct specific analyses and evaluations of the extent and degree of water table depression and salt water upconing expected from specific withdrawal proposals.

Budget

Year 1 (installation of network)	$80,000
Successive years (quarterly monitoring of water table height)	$ 5,000
Approximately Year 5 (analysis of compiled data)	$25,000

Non-Point Source Pollution

Septic Systems

Project Statements 6.1 through 6.5

Problem Statement

On the outer Cape, many homes and businesses are unsewered and rely on private septic systems for waste disposal. For almost two decades, various reports have documented increases in nitrate (NO_3) concentrations in the ground water on the outer Cape and directly linked the elevated levels with increases in housing density and the number of actively used on-site septic systems (Frimpter and Gay, 1979; Persky, 1986; Noss, 1989; Goetz et al., 1991; Cambareri and Sobczak, 1995). The Massachusetts Department of Environmental Protection has documented that private septic systems statewide in Massachusetts are the largest contributor of pollutants to inland and coastal surface water bodies in the state (Sit, 1995).

While Hatfield et al. (1994) conclude that land uses near ground water discharge areas have a minimum impact on drinking water quality, several other reports (Valiela et al., 1992; D'Avanzo and Kremer, 1994; Cantor and Knox, 1985) document the far reaching ecological impacts derived from the discharge of contaminated ground water to surface waters. These findings are of great importance to the resource managers at Cape Cod National Seashore as many of the ponds, estuaries, and marshes within the National Seashore's boundary are at risk of becoming polluted by increased nutrient loading derived from septic system-contaminated ground water discharge (Portnoy, 1994; Portnoy et al., 1998; Martin et al., 1992). Eutrophication, the increased production of plants and phytoplankton in surface waters, can result from increased nutrient loading. Eutrophication not only decreases the natural ecological value of the resource, but decreases its recreational value to humans as well (Martin et al., 1992).

Inorganic pollutants are introduced to the ground water on the outer Cape predominantly through septic system wastewater, landfill leachate, and urban runoff (Janik, 1987). The polluted ground water then discharges into ponds and estuaries, in turn increasing the potential for eutrophication of surface waters. The most common inorganic elements in the Cape Cod ground water, derived specifically from septic effluent, are nitrogen (N) and phosphorus (P). Nitrate (NO_3) which is the form of nitrogen considered to pose the greatest threat to human health, is regulated and monitored in public and private drinking water supplies by the Massachusetts Department of Environmental Protection as outlined in the Massachusetts Drinking Water Regulations (310 CMR 22.00, Drinking Water, 1988). However, nitrate can adversely affect surface water quality at concentrations much lower than drinking water standards.

The addition of phosphorus to pond surface waters via contaminated ground water discharge is a primary management concern ecologically, although it presents no major human health concern. Extra watershed phosphorus that is introduced to fresh water ponds by humans via septic system runoff has the potential to increase algal production and reduce the native clarity of the pond waters (Martin et al., 1992). Martin et al. (1992) state that shoreline septic systems located at several residences, owned by both the National Park Service and private homeowners, are thought to be the primary source of additional phosphorus to the ponds.

Title 5 (Massachusetts law 310 CMR 15, Requirements for the Disposal of Sanitary Sewage) regulates the siting, design and construction of on-site below ground septic systems in Massachusetts. Title 5 also requires that when any property is sold, expanded, or altered in its use that an inspection of the existing septic system be performed. The regulation also requires that a soil absorption system maintains a 400-foot distance from surface drinking water supplies, 100-foot separation from wells, and a 50-foot distance from rivers, lakes, ponds, and wetlands. Additionally, a 4-foot unsaturated zone of soil (5 feet in sandy soils) above the high ground water level is required. This distance is necessary to remove most pathogenic biological pollutants before they reach the ground water (Janik, 1987; Weiskell et al., 1996).

Nutrient loading, particularly nitrogen contamination, is the principal cause for concern regarding septic waste waters on the outer Cape (Valiela et al., 1997). All conventional septic systems, even when operating properly under ideal design conditions, will leach nitrogen to the ground water (Veneman, unpublished). A minimum lot size of 40,000 square feet is needed to effectively dilute the nitrogen contribution of a single-family septic system to concentrations below the Barnstable County planning guideline of 5 mg/L (Veneman, unpublished). In areas where this minimum lot size is unfeasible, alternative septic technologies, such as recirculating sand filters, peat filters, and the RUCK system have shown potential for increased nitrogen removal. Title 5 allows for the use of alternative systems in nitrate sensitive areas (Veneman, 1996).

The seasonal nature of population densities on the lower Cape provides an additional complication to the problem of nutrient loading from septic systems. Postma et al. (1992) reported that after a septic system operates for 8 to 15 months, the continuous supply of wastewater to a conventional system produces a biological clogging mat that slows the rate at which effluent travels into the soil, promotes an even distribution of effluent throughout the treatment field, and enhances the septic system's ability to filter pollutants. The seasonal use of a septic system prevents the formation of a clogging mat and reduces the system's ability to remove pollutants efficiently. In the absence of a clogging mat, septic effluent is unevenly distributed and travels through sandy porous soils in a concentrated, localized path with little treatment before reaching the ground water (Postma et al., 1992). In situations where the clogging mat doesn't properly develop, a pressure dosing type septic system is recommended (Veneman, 1996). Pressure dosing systems store effluent in a pumping chamber from which it is pumped at either preset time or volume intervals through a small diameter, perforated PVC pipe. This ensures even effluent distribution throughout the leaching facility, low loading rates, slow unsaturated flow, and enhanced treatment (Veneman, 1996).

Many of the ponds within the National Seashore boundaries have private homes or in-holdings on their shorelines that are accompanied by septic systems. Of the 20 kettle ponds located within National Seashore property, only three do not have shoreline residences. The highly permeable nature of the sand and gravel ground water aquifers on the Cape combined with septic system runoff of nutrients, particularly phosphorus, has the potential to cause eutrophication of the ponds. Part year residences are now becoming year-round residences, exacerbating the nutrient deposition with increased waste disposal (Martin et al., 1992). The very low natural background levels of phosphorus in surrounding soils results in very limited primary production and a high water clarity in the ponds. The addition of human waste from septic systems is assumed to be the primary source of phosphorus and likewise, increased primary production of plants and phytoplankton and cultural eutrophication (Godfrey and Soukup, 1978; Martin et al., 1992).

Generally, transport of phosphorus to surface waters is not a major concern since most phosphorus is believed to be retained in the unsaturated soil (Cantor and Knox, 1985; U.S. Environmental Protection Agency, 1990). However, sandy soils, like the soils found on Cape Cod, do not bind phosphorus very well. When coarse sandy soils are the only media separating the septic system from the ground water and the septic system is located adjacent to a surface water body, the phosphorus from the septic system moves directly into the ground water, and in turn discharges into surface water resources such as ground water fed kettle ponds. Ground water phosphorus concentrations are generally higher under septic systems in sandy soils than in non-sandy soils (Cantor and Knox, 1985). Removal of the phosphorus from the wastewater before it leaves the septic tank is a necessary management measure in this situation (Brandes, 1977). According to the U.S. Environmental Protection Agency, when septic systems are located on lakeside lots near a water body or in sandy or gravelly soils, on site septic systems should not be used (U.S. Environmental Protection Agency, 1993).

Project Statement 6.1
Review Alternative Methods of Wastewater Disposal

Description of Recommended Project

Conduct a literature review of alternative methods of wastewater disposal including:

- alternative technologies for private septic systems;
- cluster or package treatment plants for selected areas; and,
- increased on-line sewerage.

The review should include available information on cost, maintenance requirements, effectiveness, conditions for use (seasonal vs. year round), and user reaction. The alternative use information should be matched against facility requirements in the National Seashore to develop alternative technology options for the National Seashore.

Budget $10,000

Project Statement 6.2
Develop Case Studies of Improved or Alternative Systems

Description of Recommended Project

Develop one or two model case studies to evaluate and demonstrate appropriate systems for wastewater disposal within Cape Cod National Seashore. Ideally, one of these would be seasonally occupied, the other year-round, and both in close proximity to a kettle pond. Information would be collected on installation cost, maintenance requirements, efficacy of treatment, and user reaction. To test treatment efficacy, several shallow wells with a 1 to 5-foot screened interval would be installed between the system and the pond. Several ground water samples would be taken to determine background chemistry prior to installation of the new system. After installation, measurements would be taken monthly for one year to determine changes in nutrient transport.

Budget $25,000 including installation costs

Project Statement 6.3
Determine Nutrient Inputs from Shoreline Septic Systems

Description of Recommended Project

Establish shallow wells with 1 to 5- foot screened intervals near the shore line between existing septic systems on National Seashore owned properties and kettle ponds to determine the seasonal rate of phosphorus and nitrate input for systems operating under different conditions, e.g., seasonal vs. year round, family vs. dormitory style, etc. Sufficient sites should be selected to permit analysis of variance for each "treatment." The number of wells installed should be sufficient to determine the direction and gradient of ground water flow.

Budget $30,000

Project Statement 6.4
Determine the Rate of Nutrient Attenuation with Distance

Description of Recommended Project

Determine the rate of nitrate and phosphorus attenuation relative to the distance of the septic system from a pond shoreline and the level of the water table by creating a transect of shallow wells with 1 to 5-foot screened intervals. Replicate residences should be selected for both year-round and seasonal with systems sufficiently far from the pond to permit evaluation. Sampling should be conducted monthly for 1 year to evaluate seasonal effects.

Budget $15,000

Project Statement 6.5
Prioritize the Future of In-holdings Reverting to the National Seashore

Description of Recommended Project

When the National Seashore was established, there were 68 homes within its boundaries whose owners entered into contracts to turn over ownership of their home to the National Park Service. The contract allowed the previous owner to remain in the home for a specified number of years. The fate of these homes is particularly important now as 45 of the use and occupancy permits have run out (between 1998 and 1999), and these homes have reverted to federal ownership. Many of the dwellings are located on pond shorelines or close to other surface waters which could be receiving negative impacts from their use. The planners at the National Seashore are currently putting together criteria for management based on financial constraints and demographic needs within the park. Water quality is not part of these criteria but proximity to water resources is being strongly considered. Specifically, the risk to water quality should be included in the management criteria. Risk might be defined as the type, age and distance of the septic system from a pond and planned use of the structure as it relates to waste output. Plans for year round or seasonal use of the home should also be considered since seasonal wastewater systems may not function as effectively as year round systems. The nature and location of many older septic systems may be inadequately known and may require some on-site inspection.

Budget $5,000

Kettle Pond Eutrophication Management
Project Statements 6.6 through 6.13

Problem Statement

Within the boundary of the National Seashore, 20 permanent ponds provide excellent examples of the kettle pond habitat type in the North Atlantic region. The earliest water quality monitoring of the ponds was done in the early 1950s; the National Park Service began monitoring in 1975 (Soukup, 1977) and regular monitoring has been conducted since (Roman and Manski, 1993). In 1992, a panel of experts was convened to develop a comprehensive protocol for monitoring the kettle ponds. The panel also identified three key issues with strong potential for altering or degrading the ponds:

1. phosphorus loading from development and recreational activities adjacent to the ponds;
2. acid rain effects on pH, alkalinity and sulfur and phosphorus cycling; and,
3. liming ponds to increase pH for enhanced recreational fishing.

Since that time, there has been no liming of public lakes conducted in Massachusetts, but the other two issues, both non-point pollution problems, continue to be of even greater concern.

The kettle ponds of the National Seashore have a 20-year record of baseline monitoring. The protocol for pond monitoring has been peer reviewed (Martin et al., 1993), and detailed plans for additional development have been prepared (National Park Service, 1993). Less is known about cause and effect relationships. The record has shown that the 20 ponds are quite different, even though they lie within a 5 km diameter and, in principle, have the same ground water and atmospheric sources, the same geology and similar terrestrial components of their watersheds. However, some are more acidic, others are much more productive. The productive ponds may have 100 times the algal production of the least productive (Martin et al., 1993). In one case, Gull Pond, a major cause of increased productivity may be nutrient contributions by gulls (as much as 42 percent) with the major input of nutrients estimated to be septic system leachate (Portnoy, 1990d), but it is not the most productive pond. Other ponds apparently do not have a similar gull problem.

The 20-year record has also shown that some of the ponds are experiencing symptoms of increasing eutrophication. Both Gull and Duck ponds have experienced reduced transparency since 1975; Williams Pond is much more productive than any other pond in the vicinity. To the contrary, Ryder Pond has shown a 2-pH unit decline since the mid-1980s. The causes of these changes are not well known. Key components necessary for understanding the functioning of these ecosystems and their interrelationship through ground water hydrology are recognized but have not been studied.

Project Statement 6.6
Develop Nutrient Budgets for the Kettle Ponds

Description of Recommended Project

Understanding the causes of eutrophication involves understanding the dynamics of nutrient supply, lake response, and lake loss of nutrients. Partitioning the sources, particularly during critical periods of biological activity, will enable managers to make good decisions about how to most effectively and cost-efficiently maintain or restore desired water quality. Nutrient budgets were the mainstay of the Massachusetts Clean Lakes program (Massachusetts Department of Environmental Quality Engineering, 1989). No nutrient budgets have been developed for National Seashore kettle ponds.

Nutrient budgets are traditionally developed in two ways, which are complimentary and equally effective. The first method uses “land use factors” which relate percentages of land use coupled with published factors that suggest the amount of nutrient reaching a lake. These factors are derived from systems with minimal ground water input and most input from streamflow and surface runoff. The second method measures nutrient inputs and outputs from the lake. Again, most of these studies have been done on systems which primarily have stream inputs and outputs. These conditions do not apply to National Seashore kettle ponds since ground water is the primary source for inputs and outputs. However, major elements have been studied and may be used to reduce the cost of further study by combining known factors with direct measurements.

National Seashore kettle ponds, consequently, present a special problem for developing nutrient budgets. Since the inputs and outputs may be primarily ground water with potentially significant inputs from the atmosphere (including temporary avian visitors), the task of developing a nutrient budget requires close coupling of hydrogeological and limnological techniques.

The first step in this process is to develop priorities for the ponds to be studied. These priorities should be based on the existing knowledge of the ponds’ current state and recent changes; the value of the pond for recreational use and for uniqueness in the National Seashore chain of ponds; and, the existence of cultural pressures that suggest the likelihood for future change. These priorities have been established for the 20 National Seashore ponds (Martin et al., 1993). Based on this, nutrient budgets should be developed for all 20 kettle ponds. The research approach should change as information is developed. At first, direct measurement of inputs and outputs will be needed because of the ground water nature of the pond systems. As this database develops, correlational models between land use and hydrogeological characteristics should be developed with the hope that later nutrient budgets can be related to the hydrogeological and land use characteristics rather than require the more expensive direct measurement technique. These so-called “empirical nutrient loading models” of eutrophication have been well developed for surface water input and output systems but have not been sufficiently developed for ground water dominated systems. These models that relate land use practices with nutrient loads permit managers to partition nutrient loading among sources, evaluate the most cost-effective strategies, and estimate the outcome of implementation.

Direct measurement of ground water inputs will require a shoreline ring of multilevel piezometers to intercept ground water from the watershed. Since this same well network can be used for studies of the septic system impacts, this types of research should be coupled with nutrient budget measurements. The National Atmospheric Deposition Program site may be used for additional nutrient measurements. Work done by Portnoy on avian contributions (Portnoy, 1990d) along with waterfowl counts may be used to estimate transient contributions. Based on Martin et al. (1992) Duck, Gull, Spectacle, Great (Truro) and Ryder ponds provide the widest array of morphology, anthropogenic use, and surface hydrology. Gull Pond has an existing network of multilevel piezometers. Inlets or outlets will be sampled with grab sample methods at monthly intervals and after significant precipitation events. In-lake monitoring will follow the protocols described in Martin et al. (1992).

Budget

Year 1	Development of monitoring for nutrient budgets first two ponds	$20,000
Year 2	Development of monitoring for nutrient budgets next two ponds	$20,000
Year 3	Initial effort to develop land use factor models and monitoring of two more lakes	$25,000
Year 4	Development of monitoring for third two ponds to be used for verifying model	$20,000

At two or more ponds per year, all ponds should have nutrient budgets developed.

Project Statement 6.7
Review and Evaluate Existing Water Quality Monitoring Data

Description of Recommended Project

Since the earliest days of the National Seashore, water quality has been monitored (e.g., Soukup, 1977). In recent years, the water quality monitoring program has expanded as a result of the advice of a technical committee (National Park Service, 1995). The committee's efforts were focused on developing appropriate field and lab operating principles for the future. Despite the extensive research effort, there has not been an effort to assemble existing water quality data, particularly routine monitoring data, into a consistent, quality-defined synthesis describing past and present conditions, trends, and projections for the future. During the development of the Water Resources Management Plan, it became clear that water quality issues have been the focus of considerable high quality research. This makes an effort to synthesize past research especially rewarding. Part of the synthesis should include recommendations for future study. Following a synthesis of existing data, it would be appropriate to revisit the protocols developed in 1995 (National Park Service, 1995).

Budget	Year 1	$40,000
	Year 2	$ 5,000

Project Statement 6.8
Complete Specific Kettle Pond Management Plans and Develop a Comprehensive Kettle Pond Management Plan

Description of Recommended Project

Each of the 20 kettle ponds within the National Seashore has different physical and ecological characteristics, public recreation uses, and land ownership patterns. In order to meet the specific needs of these diverse resources, efforts are underway to develop management plans for each of these ponds. These plans will establish the purpose and needs, program direction, responsibilities and scheduled activities to be carried out to accomplish stated recreation and conservation objectives. Management plans for three kettle ponds within National Park Service jurisdiction (Snow, Round West and Spectacle) have been completed. Development of plans for two other ponds with multiple ownership (Duck and Gull) was started but not completed by a committee composed of National Seashore officials, pond residents, and town officials. There is particular interest from landowners and the Friends of the Cape Cod National Seashore group to complete the plan for Duck Pond. These plans should be completed with the assistance of an *ad hoc* public advisory group with park staff taking the lead and coordination role.

Development should also begin on a comprehensive management plan that consolidates common elements in the specific kettle pond plans and provides flexibility for unique differences. This effort should include input from a technical interagency committee and representatives from the individual pond committees, with the lead and coordination role taken by park staff.

Development of individual pond plans can probably be done at the rate of three per year with the comprehensive plan development starting when half of the ponds have completed plans.

Budget	Year 1	$10,000
	Year 2	$10,000
	Year 3	$15,000
	Year 4	$15,000

Project Statement 6.9
Develop a Nutrient Loading Risk Assessment for Changes in National Seashore Practices or Aquifer Water Quality

Description of Recommended Project

Upon the completion of nutrient budgets for each kettle pond, the impact of individual septic systems, their location, type and use should be determined. An estimation of aquifer water quality resulting from ground water pollution by area-wide sources and a sensitivity analysis should be conducted to determine the impact of potential changes in National Seashore practices or changes in aquifer water quality or depth to ground water. For nutrients, this analysis would use existing empirical models of trophic state change (e.g., Dillon and Rigler, 1974). For other pollutants, analysis would be based on established risk assessment procedures. Based on the results of the risk assessment, National Seashore and regional policy regarding kettle pond source water pollution should be revised.

Budget $25,000

Project Statement 6.10
Investigate the Cause of pH Changes in Ryder Pond

Description of Recommended Project

Ryder Pond, a 8.3-ha, 11-m-deep kettle pond located in the Wellfleet outwash plain, has shown a dramatic decline in pH since 1986 (Godfrey et al., 1996). Annual maxima and minima have declined from pH 6.1 and 5.5 to the present pH 4.6 and 4.2, respectively, making Ryder the most acidic kettle pond in the National Seashore. The cause of this large decrease in pH is unknown. Ionic analyses of surface samples from 1985 through 1995 show no major shifts in dominant anions and cations, except for an apparent increase in sulfate since 1988. Although sulfate is the dominant anion in local precipitation (Truro NADP site), precipitation inputs seem insufficient to effect so rapid a change in pond chemistry. There are no reports of chemical contamination over the period of pH decline. Besides, the observed increase in sulfate would have required the addition of about 700 gallons of concentrated sulfuric acid, e.g., from septic system cleaners, an unlikely scenario.

Cumulative increases in sulfate concentration in pond water were calculated by assuming the conservative retention of sulfate from precipitation (Portnoy, unpublished data). Sulfate deposition was measured at the Truro NADP site. Loadings over the pond surface were converted to concentrations by dividing by the total volume of Ryder Pond. Successive annual loadings were added to the initial concentration (7.18 mg/L) measured by the Acid Rain Monitoring (ARM) project in 1986. All other actual pond water sulfate concentrations are from ARM (and post-ARM) samples collected during spring mixing.

Even treating sulfate as a conservative substance, i.e. discounting dissimulatory sulfate reduction and microbial assimilation, sulfate deposition is still much too small to account for the sulfate doubling, and consequent pH decrease, between 1986 and 1993. By normalizing sulfate concentrations to chloride, it was found that most of the increase on pond water sulfate could not be attributed to salt spray.

The source of non-seasalt sulfate to Ryder Pond remains unknown. A reserve of reduced sulphur in pond shoreline sediments (marine or freshwater wetland peat), which undergo alternate periods of aeration and waterlogging, could be the source. (Sulfate reduction in waterlogged, anoxic sediments releases alkalinity; aeration of the sediment oxidizes sulphur and releases acidity.) Although pH does not clearly vary with pond elevation, total annual precipitation does appear to vary directly with pH, and indirectly with sulfate. M.G. Winkler (1996) has found a significant relationship between pH and precipitation when the latter was lagged by two years, and attributed recent pH decline to drought. Thus acidity generation seems related to low precipitation, but not necessarily to low lake levels. Perhaps a wetter year causes higher soil/sediment moisture conditions above the water table, promoting low redox, while drier years promote better aerated soils in the unsaturated zone, in turn promoting the oxidation of sulfur.

There is a basic problem with the notion that the acidification of Ryder Pond by sulfate is drought-induced: Why do other similar land-locked kettle ponds show no change over the same period of low precipitation? One possible explanation is that sulfur cycling is different and/or sulfur reserves are much greater in Ryder Pond's watershed.

To begin to understand the unusual situation in Ryder Pond, sediment cores should be collected, and total sulfur analyzed from wetland sediments surrounding the pond and compared with sediments from other National Seashore landlocked ponds. This will test the hypothesis that Ryder's watershed contains greater reserves of sulphur, which, depending on climate and water budget, has a correspondingly greater influence on acid-base chemistry.

To identify the principal source(s) of sulfur in the watershed, conduct stable S isotope analysis. Sulfur in atmospheric and marine sulfate have very different isotopic signatures. Stable isotope analysis should help identify whether the sulphur, which cycles from sedimentary reserves to the water column during drought and is from the atmosphere or from pyritic marine sediments.

Budget

Year 1	$30,000
Year 2	$20,000

Project Statement 6.11
Survey the Kettle Ponds for Invasive Species,
Develop an Information Program, and Prepare a Response Plan

Description of Recommended Project

Throughout Massachusetts, severe lake and pond problems are resulting from the introduction of invasive, introduced species of aquatic macrophytes. Within a few years, an accidental introduction can spread throughout the entire lake, ruining it for its prior uses. Mattson et al. (1997) list the following species found in Massachusetts that cause serious lake problems.

Submersed plants	milfoil	*Myriophyllum spicatum*
	parrot feather*	*Myriophyllum aquaticum*
	pondweed	*Potamogeton crispus*
	bushy pondweed	*Najas minor*
	Brazilian elodea	*Egeria densa*
	fanwort	*Cabomba caroliniana*
	water clover	*Marsilea quadrifolia*
	hydrilla*	*Hydrilla verticillata*
	frogbit*	*Hydrocharis morsus-ranae*
	alligator weed*	*Alternanthera philoxeroides*
	watercress	*Nasturtium officinale*
	European starwort	*Callitriche stagnalis*
Floating plants	American lotus	*Nelumbo lutea*
	lotus	*Nelumbo nucifera*
	water chestnut	*Trapa natans*
	floating heart	*Nymphoides peltatum*
	water hyacinth	*Eichornia crassipes*
Emergent plants	reed grass	*Phragmites australis*
	purple loosestrife	*Lythrum salicaria*
	flowering rush*	*Butomus umbellatus*
	yellow iris	*Iris pseudacorus*
*in nearby states but not officially known in Massachusetts		

While many of these species prefer nutrient rich, relatively hard water, and higher pH than what is typically found at National Seashore kettle ponds; others are broadly tolerant.

To avoid accidental introductions, pond users need to diligently check that no weeds are attached to their boats or other items that will be put into the pond. A small snippet is usually enough to begin an infestation. In the case of purple loosestrife, it is often sold as a decorative garden plant. All nurseries in the area should be warned of the danger posed by purple loosestrife.

Each pond should be qualitatively surveyed each year for any initial colonization by these species. Eradication is far easier initially than in later years when whole pond chemical treatment may be the only alternative; periodic retreatment may also be necessary. There are few less drastic treatments that are effective after a foothold has been gained. National Seashore staff should prepare an emergency response if an invasion is discovered. Since use of chemicals and consequent effects on both native and invasive species is inconsistent with National Seashore policy, short-term response should be carefully weighed against the long-term consequences.

Budget Included in annual kettle pond monitoring program.

Project Statement 6.12
Evaluate Feasibility of Remote Multi-parameter Data Logging

Description of Recommended Project

Routine monitoring of the National Seashore kettle ponds began in the mid-1980s and two major studies, in 1956-1957 and 1975-1976, were conducted prior. Frequency and parameters measured changed from year to year; critical measurements of nutrients and algal biomass have been included sporadically. Until 1993, there was not a standard sampling protocol followed by these studies.

Remote sensing of aquatic environments has become a reality for many key water quality parameters. Data loggers attached to multi-parameter probes can lessen the need for staff to monitor frequently for several easily measured parameters. Coupling multi-probe devices with cellular phone uplinks can provide real-time information. Such information could be used in two ways. The first would be to alert the water resources manager to unusual events in the ecosystem. A good example for the National Seashore would be impending anoxia in the upper Herring River. Another would be continuous monitoring of shoreline wells to record relatively short-term changes in water table height and chemistry. The second use would be to increase public awareness of pond conditions. An example would be pond temperature and turbidity at the surface and at several depths in stratified lakes; both would be useful to fishermen and swimmers. Combining these with displays of other information about the ponds might improve the public's awareness of pond issues.

The project would review available multi-parameter probes and logging or real-time systems; prioritize the data needs and information dissemination possibilities; and, implement an evaluation of cost-effectiveness.

Budget $10,000

Project Statement 6.13
Evaluate the Role of Aquatic Macrophytes in Permanently Sequestering Nutrients

Description of Recommended Project

New research suggests that the aquatic macrophytes, which occupy the shorelines and shallow waters of National Seashore kettle ponds, may be performing an important function in maintaining water clarity. These plants grow in strategic positions for the interception of pollutants carried by ground water as it flows from the underground aquifer into pond surface waters. If these early research findings are correct, the common practice of removing "weeds" from beaches may be counter-productive for water quality preservation and for the long-term enjoyment of clear-water swimming and fishing.

The growth of algae, as well as aquatic plants, in Cape kettle ponds largely depends on the supply of phosphorus which is scarce in native Cape Cod soils. Therefore, the addition of phosphorus to most freshwater systems results in increased plant growth, algal blooms, or both. Where phosphorus is scarce, plants and algae compete for the nutrient. In deep ponds like the National Seashore kettle ponds where rooted plants are limited to the shorelines, excess phosphorus mostly benefits planktonic algae, which can cloud the water, die and sink to the bottom where the dead organic matter consumes dissolved oxygen and kills fish.

Aquatic plants may reduce eutrophication by producing conditions in the sediments that lead to permanent sequestration of phosphorus. Not only do they compete with algae for phosphorus in the water column, but they also intercept phosphorus before it leaks from the ground water system into the pond. Plants do this by bringing oxygen into their root zones. The oxygen changes the chemistry of the sediment. Specifically, in the presence of oxygen, soluble ferrous iron is oxidized to form nonsoluble ferric oxyhydroxide which adsorbs phosphate. The phosphorus is thereby removed from the water before the water reaches the open pond water environment. In the same way, phosphorus which leaks from decomposing organic matter along the pond's shorelines may be "captured" in the plant's aerated root zones and kept out of the pond water.

Preliminary analysis of sediments in vegetated versus non-vegetated areas indicates that phosphorus is more abundant in the sediments of vegetated areas (Portnoy, unpublished date, 1997). Many questions remain. Do the macrophytes scavenge the phosphorus from the water column and sequester it in the aerobic zone? Do they provide the chemically appropriate environment that converts potential ground water inputs to a nonsoluble form before it can become part of the plant or algal biomass? Is the phosphorus permanently sequestered or temporarily sequestered for later release?

Evaluation of the process of phosphorus sequestration by macrophytes will require analysis of the phosphorus partitions and redox potential in the sediments of vegetated and non-vegetated areas. Samples should be collected at various seasons to determine if the effect is permanent or temporary.

Budget $15,000

Heavy Metal Impacts
Project Statements 6.14 through 6.17

Problem Statement

Atmospheric deposition is implicated as a major source of mercury in the kettle ponds of the National Seashore (Haines, 1996). Yellow perch, a favorite with fishermen, is known to accumulate mercury in its tissues. At the National Seashore's three most acidic ponds [Duck (Wellfleet), Dyer and Great (Wellfleet)], the perch over time have exhibited necrotic lesions on their heads and gill covers, a syndrome known as "hole in the head" disease (Winkler, 1994). The U.S. Geological Survey Biological Resources Division is currently engaged in a monitoring program that evaluates mercury contamination in five kettle ponds on the National Seashore as well as at Acadia National Park. A recent progress report shows that yellow perch in all five of the study ponds have mercury accumulations. This monitoring program is not yet complete, however, preliminary findings suggest that atmospheric deposition is a threat to the National Seashore's surface waters.

A similar study in Massachusetts (Massachusetts Department of Environmental Protection, 1997b) found bioaccumulations of mercury in largemouth bass and yellow perch but less so in brown bullhead. The study did not include any lakes on Cape Cod. However, there was a strong correlation between conditions indicative of acid deposition impacts, such as low pH and calcium and higher mercury concentrations in predaceous fish tissue. Low pH and calcium are typical chemical characteristics of nearly all Cape ponds (Table 6.7).

Lakes, ponds and rivers with high acidity easily transform inorganic mercury from atmospheric pollution to more toxic organic forms of mercury. Additionally, bioaccumulation of mercury in the food chain is increased with high levels of acidity. Since many of the incinerators in Massachusetts are not properly equipped to filter mercury from air emissions, mercury is a prevalent air pollution problem in the state. Incinerators, which burn over 11,000 tons of trash every day, emit 19 tons of mercury per year in Massachusetts.

Project Statement 6.14
Monitor Mercury Deposition at Cape Cod NADP Site

Description of Recommended Project

A National Atmospheric Deposition (NADP) site is located in Truro. The equipment at this site monitors precipitation, and samples are collected weekly. A variety of cations and anions are analyzed routinely from these samples. An additional collector, dedicated to monitoring mercury deposition, should be erected at the site. This collector would be emptied weekly, and the samples would be analyzed at a certified environmental laboratory for total mercury. The collection process would be carried out for one year to assess seasonal and meteorologically controlled changes in mercury deposition rates. Cumulative data can be used to calculate atmospheric mercury loading rates on the ponds of the National Seashore. At the conclusion of a year, the data would be evaluated to determine if sampling should continue indefinitely.

Budget		
	Year 1	$20,000
	Year 2	$15,000 potentially recurring

Project Statement 6.15

Evaluate Mercury Levels in Sediments of Freshwater Ponds

Description of Recommended Project

Samples of surface sediments will be collected from all 20 freshwater ponds in Cape Cod National Seashore. Three samples will be collected from different locations and depths in each pond to assess distribution. General sediment characteristics (grain size, organic content and bulk mineralogy) will be analyzed for each sediment sample, and mercury, other toxic metals, sulfate, and sulfide concentrations will be determined by a certified environmental laboratory. Patterns in the distribution will be documented on maps and contoured where appropriate. Once surficial distribution is determined, two ponds will be selected for sediment coring using a Livingstone corer or similar apparatus. These cores will be analyzed for vertical changes in sediment characteristics and toxic metal content to evaluate historical changes in mercury and other metal accumulation in the ponds. Chronology of the cores will be established by a suitable dating technique, such as ^{210}Pb.

Budget	Year 1	$25,000
	Year 2	$30,000
	Year 3	$25,000

Project Statement 6.16
Conduct Top Predator Fish Tissue Monitoring in Fresh and Estuarine Environments

Description of Recommended Project

Expand the program currently being conducted by the U.S.Geological Survey, Biological Resources Division to include the remaining freshwater ponds and estuaries and to monitor for additional toxic metals. As part of this expansion, all 20 ponds would have completed fish surveys, since most have not been surveyed for more than a decade but a subset are currently being surveyed (Mather, 1998). Results would be compared with historical data when available and of appropriate quality to determine trends. Five to ten fish would be selected from common predators, yellow perch or white perch for fish tissue analysis. Fish tissue analysis would complement the analysis of sediments. The combined fish survey and tissue analysis would serve as the basis for a risk assessment to consumers of predator fish, including humans, other mammals and birds. The fish tissue monitoring would be repeated every 5 years.

Budget Year 1 $35,000 (recurring every 5 years)

Project Statement 6.17
Evaluate Mercury Pathways and Management Alternatives

Description of Recommended Project

From the data on sediment and fish tissue concentrations of toxic metals, including mercury, one pond will be selected for intensive study of food chain pathways of metal bioaccumulation. Samples of lake water, surficial sediments, benthic invertebrates, zooplankton, and macrophytes will be analyzed for methyl mercury and total mercury. Forage fish and predator fish will be analyzed for total mercury content. Organisms will be stratified by habitat: pelagic, littoral, benthic (soft and hard bottom), and macrovegetation. Relatively high body burdens will be compared with habitat type to reveal possible pathways and will be confirmed by gut content analysis in larger species.

Budget

Year 1 $35,000
Year 2 $35,000
Year 3 $25,000

Project Statements 6.14 through 6.17 compliment each other to a high degree. Combining them into a single project would yield one 4 to 5 year project.

	Year 1	Year 2	Year 3	Year 4	Year 5
Deposition monitoring	x	x	x	x	x
Sediment analysis		x	x	x	
Fish tissue analysis		x			
Pathway analysis			x	x	x

Budget

Year 1 $ 20,000
Year 2 $ 75,000
Year 3 $ 70,000
Year 4 $ 75,000
Year 5 $ 40,000
Total $290,000

Confirmed and Potential Point-Source Contamination Sites

Landfills

Project Statements 7.1 through 7.5

Problem Statement

Organic, inorganic, or biologic pollutants derived from landfills and leaking underground storage tanks pose a serious threat to the integrity of clean water drinking supplies as well as rivers and estuaries. The intimate connection between ground water and surface water on the Cape compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant adsorption characteristics of the sand and gravel aquifer.

Landfills are among the five most serious threats to ground water quality in the United States (Noake, 1989). In Massachusetts, leachate contamination of ground water from landfills has been responsible for private well contamination in at least nine communities (Massachusetts Department of Environmental Quality Engineering, 1988). On the Cape, pollutants related to landfill leachate are also considered a threat to ground water supplies (Janik, 1987). A 1996 report (ATP Environmental, 1995) documents that the Eastham Municipal Landfill is directly responsible for contaminated private drinking water supplies within its vicinity.

Water that enters a landfill, usually in the form of rain and snow, comes into contact with buried wastes and forms leachate or dissolved waste. This leachate can contain toxic chemicals from commercial and household wastes. Often, the leachate leaves the landfill and follows the ground water flow, potentially entering recharge zones for water wells (Noake, 1989). Poorly contained landfills, such as unlined landfills in the sandy soils of the Cape, are especially vulnerable because water can infiltrate them from all sides, including underneath the waste (Massachusetts Department of Environmental Quality Engineering, 1988).

There are five closed landfills located on the outer Cape (Figure 7.1), all of which have the potential to impact the surface water resources within the National Seashore (Table 7.1). The Provincetown and Truro landfills are located inside the National Seashore boundary. Wellfleet's landfill abuts the National Seashore boundary, and the two others in Orleans and Eastham are in close proximity to the National Seashore. All landfills have monitoring wells and the contaminant plume for each site has been mapped and discussed in various reports (Cambareri et al., 1989 a, b; Frolich, 1991; Urish et al., 1991; Urish et al., 1993; Winkler, 1994). According to these reports, some surface waters both inside and outside of National Seashore boundaries may have been impacted.

The first two recommended projects overlap with the recommended comprehensive ground water study plan.

Project Statement 7.1
Continue Landfill Plume Monitoring

Description of Recommended Project

The five landfills at Provincetown, Truro, Wellfleet, Eastham and Orleans have all been investigated at various times for the impacts of the leachate upon the ground water. The investigations have been done by different contractors during different time periods. In order to fully evaluate the effects of the landfill leachate on the ground water, a synchronized survey of the leachate plumes is necessary. In consultation with the Massachusetts Department of Environmental Protection, the existing monitoring and observation wells around the landfills will be revisited. Measurements of specific conductance and pH will be done in the field, along with hydrostatic head determinations. Samples will be collected from each well and analyzed for a few major indicators of contamination: chloride, alkalinity, sodium, nitrate, and dissolved organic carbon. These data can then be plotted on layers using geographic information system and contour maps generated to provide a synoptic picture of the landfill plumes impacting Cape Cod National Seashore. This survey is to be done annually for three years to gauge the changes in the landfill plumes.

Budget	Year 1	$25,000
	Year 2	$25,000
	Year 3	$25,000

Project Statement 7.2
Review and Evaluate the Study Design of Past Plume Monitoring

Description of Recommended Project

The previous reports of all landfill monitoring in the vicinity of the National Seashore will be rigorously evaluated, and a protocol for future action developed. The placement of existing monitoring wells will be examined to ascertain if an adequate network exists for future contaminant monitoring and fine-scale ground water monitoring. The depths of these wells must be noted to determine if an adequate mechanism for monitoring at various levels in the leachate plumes exists. Previous chemical analyses will be inspected to see if the lists of analytes are appropriate for the suspected contamination from the leachate. Based on these results, a program for improving the network and monitoring tasks will be recommended.

Budget	Year 1	$30,000
	Year 2	$15,000

Project Statement 7.3
Review the Literature on Landfill Capping and Recommend the Best Technique

Description of Recommended Project

It is clear that the existing landfills will need to be capped to minimize future leachate generation and migration. Different methods of capping may lead to different impacts upon the existing leachate plume. Surveys will be made of available techniques for closing a landfill, and estimates will be made for the influence of these various methods on leachate generation and the migration of the existing contaminant plumes. Based on hydrological assumptions about the effects of the capping techniques, numerical modeling of the plume (see Impacts to Ground Water Resources) will be completed and likely scenarios predicted. The most effective techniques will be recommended as will other possible mitigation strategies, such as relief wells to influence the direction or rate of leachate migration.

Budget	Year 1	$20,000
	Year 2	$15,000

Project Statement 7.4
Assess Contaminant Discharge into Surface Waters

Description of Recommended Project

Plumes of contaminated ground water flow from landfills in Truro and Wellfleet toward National Seashore surface waters at Herring and Pamet Rivers. Both of these landfills originated with the dumping of household waste, building materials, and probably some hazardous chemicals into seasonally flooded freshwater wetlands. This ensures that wastes are in intimate contact with the ground water flow system with little or no separation by unsaturated soil. Given the periods of landfill use and estimated ground water flow rates, contamination has probably been leaking into downgradient wetlands and streams for decades. Despite the high probability of surface water contamination, site assessments have been limited to the ground water system. Study should be extended into wetland sediments and surface waters by:

1) Employing well installation and monitoring, and surface geophysical soundings to map effluent plumes and discharge locations into surface waters.

2) Monitoring sediment and water quality at identified leachate discharge zones with analyses of volatile organic carbon compounds, metals, and nutrients.

3) Devising and implementing remediation of identified toxic or nutrient-rich leachate.

Budget	1)	$50,000
	2)	$40,000
	3)	$40,000

Project Statement 7.5
Create a Forum for Dialogue on Contamination Issues

Description of Recommended Project

Using the interagency technical advisory committee, establish compatible procedures for prevention of and response to contamination incidents.

Budget $1,000 per year.

Hazardous Waste

Project Statement 7.6
Hazardous Waste Spill Preparation

Problem Statement

In Massachusetts, it is estimated that there are 50,000 underground storage tanks, 20 percent of them leaking each year (Massachusetts Department of Environmental Quality Engineering, 1988). Underground storage tanks are used by many homeowners and commercial businesses on the lower Cape. Each underground tank poses a threat to ground water quality depending on the age and type of the tank (Noake, 1989). The majority of the tanks documented by Barnstable County hold fuel oil and range in size from 250 to 4000 gallons and in age from new to 60 years old (C. Stiefel,1996, pers. comm., Barnstable County Program Coordinator for Underground Storage Tanks). The towns in Barnstable County each have their own set of regulations for the tanks; Barnstable County keeps a record of their location and inspection documentation. According to Charlotte Stiefel, Program Coordinator for Underground Storage Tanks in Barnstable County, the location of each tank in the county is currently being entered into a geographic information system database that the Commonwealth of Massachusetts will develop into a data layer.

The Bureau of Waste Site Cleanup in the Massachusetts Department of Environmental Protection maintains a current list of all confirmed and transitional oil and hazardous material disposal sites. The latest standard release report lists spills (releases of two hours) and sites (releases of 120 days) reported since October 1, 1993. In addition to this list, the Department of Environmental Protection maintains a transition list of every "site" in Massachusetts that the agency has investigated. Of the 32 listings for the lower Cape, eight were for underground storage tanks and 15 were for above ground storage tanks; all of these listings were two-hour spills (releases of two hours). Twenty-eight sites are listed on the transition list for the lower Cape. While the source of the contamination is not listed, six of them are confirmed priority sites.

The latest inventory of National Park Service-owned underground storage tanks is dated May 3, 1993. All but four actively used underground storage tanks on the National Seashore have been replaced with double walled fiberglass tanks. These tanks hold gasoline, heating fuel, fuel oil, and diesel. The new tanks range in size from 1,000 to 4,000 gallons.

All facilities within the National Seashore, indeed all facilities on the outer Cape, are dependent on ground water from a limited number of aquifers. A small spill or misuse of contaminants can have drastic effects on water supply and water resource management issues for large numbers of people and over long time periods. For example, leakage of 3,000 gallons of gasoline from an underground storage tank near the South Hollow Wellfield, the main source of Provincetown water at the time, closed that well in 1978. Use of the well was discontinued and emergency supplies were taken from Test Site#4 within the National Seashore. For 2 years, the South Hollow Wellfield was completely unavailable; for 5 more years, it provided one fourth of its previous capacity. The wellfield went back to full capacity 9 years after the contamination incident.

Contamination incidents on the outer Cape are unlikely to approach the massive problem that exists around the closed Edwards Air Force Base on the upper Cape, where a plume of various contaminants is inexorably moving toward major population areas that have no alternative water sources. However, the example of a relatively small leak and its decades long consequence requires that the National Seashore conduct an assessment of similar and even smaller risks from individual home owner use of contaminants throughout its infrastructure. The consequences and range of options should be assessed by the National Seashore in response to potential incidents outside its boundaries.

The responsibility for minimizing ground water contamination and for managing the decontamination process lies with state and local agencies, but the responsibility for being prepared to respond in a rapid and ethical way lies with the National Seashore. Prior analysis of the risk and the response, including publicizing the plan, are essential to the general understanding that the National Seashore is both a responsible and active community member, but has pre-established limits on its emergency resources and is able to respond only in a manner consistent with the National Seashore's founding requirements.

The risks from contamination events, from leaking storage tanks to the misuse of degreasers, can have consequences ranging from providing emergency community water supplies to replacing individual wells for contract homes or in-holdings with small distribution systems or bottled water.

Description of Recommended Project

The risk of contamination events from leaking storage tanks to misuse of degreasers can have consequences to the operation of the National Seashore ranging from providing emergency community water supplies to replacing individual wells for contract homes or in-holdings with small distribution systems or bottled water.

The first step in developing a contamination plan will be to create an outreach program that educates people on the risks of certain practices and responsibilities under existing state programs. Efforts will be primarily targeted toward the contract houses and in-holdings within the park, but the information for general distribution on the outer Cape. Considerable information has been developed by other agencies and should be used; the National Seashore can most efficiently target the audience and provide follow-up.

Budget $1,000/year ongoing

The second step will be to evaluate the potential sources of contamination within the National Seashore and a reasonable distance from its boundary. Much of this information already exists, but needs to be installed in a geographic information system (GIS). Coupling the GIS with hydrogeological modeling will provide a means for risk assessment based on quantity and proximity. Potential contaminant sources should be prioritized and future efforts to develop educational programs and remediation planning aimed at the highest priority potential sources.

Budget $15,000 for 1 year

The third step will be the preparation of an emergency response. This is not intended to duplicate plans that may be in place with state agencies or towns, but specifically to plan for the National Seashore response in providing emergency resources or in reacting to impacts on National Seashore infrastructure. Specific policy decisions should be detailed for various scenarios. The prior two steps are primarily concerned with known potential contaminant sources, but accidental spills represent a similar hazard and are less predictable. Given the number of visitors to the National Seashore and the lower Cape, a response plan should be developed for known contaminant sources and accidental spills.

Budget $10,000 for 1 year

Cultural Impacts on Pond Water Quality

Project Statement 8.1
Develop a Kettle Pond Recreational Management Plan

Problem Statement

Perhaps more than any other park in the National Park System, Cape Cod National Seashore has an inherent conflict between natural and historical preservation, recreational use and the customary and presently burgeoning needs and desires of the public and surrounding residents. In addition, much of the management of the resource is not solely under the jurisdiction of the National Park Service. While this affects all water resource management activities in the National Seashore, it is an especially difficult issue for the management of the kettle ponds.

The General Management Plan (National Park Service, 1998) places ponds in the natural management zone. According to the plan, the natural zone "includes most of the National Seashore where the primary experience is one of being in natural surroundings, such as woods or along the beach." The natural zone is broken down into four management subzones, three of which apply specifically to ponds: Concentrated Use, Dispersed Use, and Low Use. Those ponds with well developed public access are considered the concentrated use subzone. These areas are easily accessible to the public by hardened trails or boardwalks and have parking areas provided. Examples are Snow and Duck ponds. Dispersed Use refers to more remote areas which have no visitor facilities or improvements. Vehicles are permitted only in designated corridors and along ungated sand roads. Low Use refers to remote natural areas where a person can expect to be completely immersed in a natural landscape and where tranquility and freedom from settlements or people is highly likely. These management subzones provide an initial framework for the National Park Service to determine how to modify or enhance existing access to any of the ponds. However, this framework does not address the multi-jurisdiction issue that potentially alters the intent of the National Park Service nor does it develop a comprehensive plan for integration of pond management goals with conflicting interests and practices.

Jurisdiction and management of the 20 kettle ponds is dependent on two factors: who owns rights to the pond, and who owns the access points to the pond. All ponds greater than 10 acres are Great Ponds as established by Colonial Ordinance of 1641 and amended in 1647. This law, as it remains today, grants the title to the bed of a great pond to the Commonwealth of Massachusetts. The state has the right to control and regulate the use of Great Ponds and can limit their use under certain circumstances. Additionally, the state has the right to convey the title of a Great Pond to the National Park Service, a right currently exercised in Truro and Provincetown. The State of Massachusetts continues to hold the titles to ponds in Wellfleet. The state can also delegate regulatory authority to local towns by Massachusetts General Law Chapter II, Section 45. This agreement has made it possible for Truro and Wellfleet to enact rules and regulations concerning pond activities that are enforceable by local police. The public has the right to access any Great Pond and where no access exists, the public may cross, by foot, private property which is not "improved, enclosed or cultivated." Members of the public who own portions of the shoreline on a Great Pond have the same rights to use as the public and do not have any special authority or ownership of the pond itself.

The title to a pond bed, where the pond is less than 10 acres and private residences occupy the shoreline, is divided among the shoreline owners. Ownership of the pond bed runs from the property lines on the shore to the center of the pond, creating a wedge-shaped piece of property for private land owners. Shoreline owners have the authority to regulate public use on their land or to close their section to the public completely. With so many active "players" in pond use, the planning and management process must be both comprehensive and consensus building.

Duck Pond is an example of a pond that has several different owners and has many management concerns as a result. Duck Pond is accessible by a town-owned parking area. Adjacent to this parking area is a power line clearing that has accommodated additional parking during the peak season. Lack of signs or fencing to deter parking along the power line allows heavier public use on Duck Pond, with a sufficient number of visitors to significantly change its ecological character. Situations such as this are challenging to remedy as many land owners and government interests are represented in a concentrated area. The health of the 20 kettle ponds is therefore dependent on carefully planned, cooperative management that comes from the Cape Cod National Seashore natural resource staff as well as the pond shoreline residents, local governments, state government agencies, and visitors.

Description of Recommended Project

The principal goals would be to develop an integrated watershed management plan encompassing all 20 ponds to minimize impact, mitigate problems, preserve sensitive ecosystems, maintain water quality and landscape aesthetics, and provide sustainable recreational opportunity for local landowners and day visitors alike. Since the solution of the many issues requires the sustained participation of pond users, they should become active partners in the earliest stages. Several stages in the process are envisioned. First, a Technical Committee should be assembled consisting of local, park, academic and state members knowledgeable about the National Seashore ponds, the local environment and watershed monitoring and management. The committee's task would be to review the existing knowledge base and recommend a common process for involving the larger community, identifying and prioritizing problems, designing monitoring and management programs, implementing recommendations, and sustaining stewardship. Second, the committee would prepare a brief overview of the existing conditions in the ponds and the potential impacts and barriers to their resolution for distribution to pond users. One or more public meetings would be held to encourage wider participation in solutions. At the meetings, attendees would be advised of the issues facing National Seashore ponds and encouraged to participate in a variety of activities to resolve those issues through membership in Pond Management Committees. For the purposes of maintaining reasonable group numbers, ponds would be grouped by proximity. Each Pond Management Committee would select a liaison to attend general planning meetings that would link the activities of the different Pond Management Committees. Pond Management Committees would develop pond specific lists of issues and prioritize them. They would propose and evaluate plans for resolving those issues that might include education, remediation and monitoring.

Implementation plans would be referred to the initial Technical Committee for the development of standardized, credible procedures and for development of training workshops when appropriate. The Pond Management Committees would recommend appropriate ways to accomplish the established goals; some might be volunteer programs, high school projects, and projects conducted by National Seashore or town staff or by outside contractors. An intermediate step might be collection of more information through various monitoring projects.

Monitoring activities might include:

- landscape characterization and land ownership patterns;
- mapping of unique vegetation and wildlife habitat presence or potential;
- recreational activity and seasonal patterns of use;
- sediment sampling and analysis;
- pond chemical and biological monitoring; and,
- shallow ground water monitoring.

Depending on the nature of the project, National Seashore staff and the Technical Committee would either provide oversight or arrange for analysis of the data, preparation of annual and final reports, and distribution to the interested community.

When sufficient information was available, plans for protection or remediation would be developed by the Pond Management Committee with input from the Technical Committee and National Seashore. Such plans would have to be consistent with National Park policy and the laws of Massachusetts and the local towns. The goal of all plans would be to minimize impact, mitigate problems, preserve sensitive ecosystems, provide sustainable recreational opportunity, monitor for success of plan implementation, and identify other problems.

A public meeting would be held to present these plans to the larger community.

Budget	Year 1	$15,000
	Subsequent years	$ 5,000

Project Statement 8.2
Managing the Gull Pond Sluiceway

Problem Statement

During the 1800s, residents of Wellfleet dug and stabilized an artificial sluiceway between Gull and Higgins Ponds (Figure 8.3). The sluiceway was maintained in order to provide herring with additional spawning waters in Gull Pond, thus improving the anadromous fish run that exists in the Herring River. The National Park Service has been maintaining the sluiceway by periodic dredging since the establishment of the National Seashore. This practice has been taken over by local volunteers working under the direction of the Massachusetts Herring Run Protection Program. Whether to maintain the historical sluiceway between Gull and Higgins ponds is a complex question with potential impacts on the natural biota of the ponds, the introduced trout fishery in Gull Pond, and the anadromous herring run in the Herring River. Without this surface flow of water, the two species of herring, alewife (*Alosa pseudoharengus*) and blue-backed herring (*A. aestivalis*), would no longer be able to enter Gull Pond to spawn in the spring and the juveniles would be unable to leave the pond in late summer and fall.

The sluiceway has traditionally been maintained by the National Park Service for two basic reasons. The first is for protection of the herring and their habitat. The second is because little is known about what effect allowing the sluiceway to fill in would have on Gull Pond (M. Reynolds, 1996, pers. comm., Cape Cod National Seashore). While the sluiceway remains a part of the cultural landscape of Cape Cod, a National Seashore natural resource management objective, stated in the General Management Plan (National Park Service, 1996), contradicts the current preservation efforts. The objective states, "(management should) allow natural processes to continue unimpeded in natural zones, including the action of wind and water, and neutralize the effects of human intervention where it has adversely affected natural systems."

The influx of these fish into relatively small freshwater systems may have a considerable impact upon pre-established food chains and nutrient cycles. Adult fish may remain from a few days to many weeks on the spawning grounds; mortality of adult fish on the spawning grounds is high, 39 to 57 percent (Durbin et al., 1979). Young alewives spend part or all of their first summer in the nursery area and then migrate to sea. Since most of their growth and nutrient uptake occurs at sea, these fish may represent a nutrient source to ponds (through shedding eggs and sperm, excretions and the carcasses of the dead spawners). In ground water fed lakes, which do not have large amounts of water flowing in and out, such nutrient additions may be significant (Mitchell and Soukup, 1981).

The introduction of alewives can also change the aquatic community of plants and animals. Alewives are planktivores, fish that eat zooplankton. Zooplankton, such as *Daphnia*, are herbivores and feed on algae in lakes and ponds and in turn reduce the amount of algae that grows. When planktivores such as the alewife are introduced to a pond, the populations of zooplankton are decreased significantly, and the populations of algae increase with the reduced grazing pressure (Shapiro, 1990). Based on this occurrence, which according to Shapiro (1990) has been observed in several locations including Lake Michigan, Gull Pond would hypothetically see a decrease in algal growth after the sluiceway is closed and herring are prevented from entering. Algal density may be one factor in the relatively low clarity observed in Gull Pond. Reduced clarity may, in turn, contribute to the dissolved oxygen deficit observed at the bottom of the pond by reducing the level of light penetration at these depths and increasing the deposition of organic matter to the bottom. This change may eventually affect the trout fishery in Gull Pond (Mitchell and Soukup, 1981). The fishery is managed by the Commonwealth of Massachusetts, Division of Fisheries and Wildlife under the terms of a Memorandum of Understanding with the National Park Service (December 20, 1968). This agreement recognizes that the management of fish and wildlife must be cooperative between the State of Massachusetts and the National Park Service (Mitchell and Soukup, 1981).

Description of Recommended Project

History and ecology are highly interconnected on the issue of maintaining the sluiceway to Gull Pond. From an historical perspective, the nearly 200-year existence of the sluiceway (Winkler, 1994b) is a strong argument that it should be maintained, just as other historical structures in the park are maintained. From an ecological perspective, the sluiceway is neither natural nor self-maintaining; natural processes would cause it to fill in. An alternative approach is to determine whether the sluiceway creates an overall ecological benefit to the entire Herring River ecosystem.

Understanding the ecological impact of the sluiceway may be divided into three steps: 1) determination of a detailed nutrient budget for Gull Pond and the freshwater reach of the Herring River system; 2) determination of the trophic structure of Gull Pond and the chain of ponds, river and estuary downstream; and, 3) completion of a study which models the effect of removing the herring run from Gull Pond. The latter, which provides the means to ask "What if?" may only be necessary if the first two steps show that the contribution of the anadromous run is large and if the trophic structure does appear to be skewed in ways typical of herring grazing on zooplankton. An assessment of the anadromous fish use of the Gull Pond chain and Herring River system is planned to begin in 1998 to 1999 (Mather, 1998).

Most of the research effort should focus on Gull Pond assuming that the anadromous fishery in downstream lakes and flowing systems will not change significantly. However, this project should include sufficient data collection to verify that assumption.

For Gull Pond, standard procedures for determining a nutrient budget by measuring all inputs and outputs should be followed. Measurements of atmospheric inputs should be made on an event basis. Measurements of watershed inputs and outputs will necessarily focus on ground water flow input and outlet loss. Anadromous fish will be a net input, necessitating counts and average size estimates for incoming and outgoing fish. Trophic structure analysis will require collection, identification and counting of phytoplankton and zooplankton at monthly intervals, at least.

Model development should reflect the steady-state endpoints of both changes in biomass and qualitative characteristics (gross species composition) because both are key to determining if there is ecological benefit. Downstream analysis is complicated by tidal influences. Consequently, it is suggested that this portion of the study might be confined to qualitative estimates of steady-state endpoints.

When a management decision is made to either maintain the sluiceway or let it close naturally, a monitoring program should be initiated that will be sufficiently detailed to reveal changes prior to ecological effects becoming irreversible. Model analysis should estimate the parameters required for follow-up monitoring.

Budget		
	Year 1	$90,000
	Year 2	$90,000
	Year 3	$60,000
	Year 4	$25,000

Cape Cod National Seashore Infrastructure

Project Statement 9.1
Update All Water-related Facilities within the National Seashore and Monitor their Efficiency

Problem Statement

The Cape Cod National Seashore has three types of properties within its boundaries. One is National Park Service owned facilities including houses, waste disposal systems, and storage tanks. There are also homes within the National Seashore which are federally-owned, but privately occupied. The National Park Service will gain occupancy of a number of these homes within a specified period of time. Many of the dwellings are located adjacent to ponds and marshes, have septic systems, and in some cases, underground storage tanks. Finally, there are grandfathered private properties or "in-holdings" that will always exist within the National Seashore, but will never fall under the ownership of the National Park Service unless donated or sold to the Cape Cod National Seashore. What all of these properties have in common is that they exist and function within the National Seashore, and have a potential impact on water resources within the park. For this reason, it is important to inventory all properties, regardless of ownership status, within the National Seashore boundaries.

On-site septic systems located in seasonal and permanent housing, as well as all buildings on the National Seashore include conventional leaching systems such as cesspools, drain pits, septic tank systems and leaching galleries. There are also a peat leaching system and a Waterloo filter, which are nutrient reduction systems. The majority of the systems were installed prior to 1960, with some dating back to 1920. Capacities (design flows) range from 500 to 15,000 gallons.

Limited supplies of fresh water on the Cape make water conservation an important part of water resource management for the park as well as the towns on the lower Cape. Provincetown has taken the lead on this aspect of water management and has worked collaboratively with the National Park Service on the public education component of water conservation. Water conservation strategies can be used and exemplified for the public at the National Seashore, placing the park in a natural position as educator and role model. Annual water use at each of the main visitor centers for 1993 to 1995 was highly variable and suggests the possibility that a water conservation program will have significant impact. The septic system at the Salt Pond Visitor's Center had been declared "failed" in 1996 (C. Phipps, 1996, pers. comm., Cape Cod National Seashore). A new septic system was completed in 1998. This provides opportunities for using its design and implementation for public outreach.

Water conservation within the park has occurred to some degree. Funding is the major barrier to parkwide implementation of water conserving devices. Low flow shower heads have been installed in all of the houses that are owned and occupied by the National Park Service staff and low flush toilets have been placed in some of the seasonal homes.

There are approximately 80 National Park Service-owned housing units within the National Seashore that are suitable for year-round or seasonal residence. All of these units were privately owned before the establishment of Cape Cod National Seashore.

There are 68 homes within the National Seashore that were under long-term agreements with former owners. About 45 of the use and occupancy permits run out between 1998 and 1999. Many of these homes are on pond shorelines or close to other surface waters which could be receiving negative impacts from their use. The National Seashore has determined criteria for management based on financial constraints and demographic needs within the park. Water quality is not part of these criteria.

Currently, there are over 600 homes within the National Seashore that represent private, improved properties. These private properties cannot be acquired by the National Park Service through eminent domain if they have a certificate of suspension from condemnation, and owners of the properties are allowed to sell their properties to others. There is no formal management or collaboration between these residents and the National Park Service. Some of the residents serve on committees for the National Park Service and are active in the political process on the Cape. However, the National Park Service does not recognize this sizable infrastructure as part of their own in databases. These homes must conform to the regulations of the town in which they are located.

Description of Recommended Project

Update the existing inventory of water and wastewater related infrastructure and underground storage tanks to eliminate incorrect, incomplete or missing information. Include all National Park Service facilities, contract houses, and in-holdings. Include information relevant to the assessment of risk to water resources. Incorporate the location of each facility or house in a parkwide geographic information system data layer.

Budget: $10,000

Install flow meters in all National Seashore facilities and use as a research tool to evaluate the effect of different hardware and behavioral approaches to water conservation.

Budget $20,000

Assess the risk to National Seashore water resources of existing infrastructure and housing. Develop water resource-based criteria for management of National Seashore facilities and housing. Recommend appropriate strategies for encouraging similar management of private in-holding infrastructure.

Budget $20,000

Model Home Case Study

Project Statement 9.2
Use a National Seashore-owned Home(s) to Showcase a Living Laboratory for the Public

Problem Statement

Many of the environmental issues facing Cape Cod National Seashore cannot be resolved solely by the implementation of management practices within the National Seashore boundaries; they are problems common to all of the lower Cape. These problems include heavy demand on the ground water resource, ground water contamination from specific major contaminant sites and from diffuse individual homes, and eutrophication of ponds. To date, the National Seashore has lagged in implementing appropriate best management practices. To be effective, solutions must be undertaken that reduce these impacts both within and outside park boundaries. Since both water use and wastewater disposal are largely non-point pollution source issues, solutions cannot be put into effect in a few places. Solutions require a combination of infrastructure change and education. There is an opportunity for the National Seashore to lead by example, using its advantage of being a principal destination for visitors and residents of the lower Cape.

Description of Recommended Project

The goal would be to create a demonstration program that would help the public learn about available methods of water conservation and alternative waste disposal, reduction of surface runoff, shoreline buffers and other best management practices. The demonstration program would be combined with a research effort that would provide the National Seashore and the public with information on the efficacy and economics of a variety of approaches. An education program would make this information attractive to the National Seashore visitor, provide a learning experience for school groups, and be available to all residents through a newsletter.

Budget

Some demonstrations that could be initiated include:

- Indigenous species vegetation planting and landscaping that minimizes the use of water and fertilizers, and maximizes nutrient uptake.
  $15,000

- Roof top collection of rainfall to be used for grounds maintenance, waste disposal systems and anywhere else where human ingestion would be unlikely.
  $5,000

- Installation of denitrifying septic systems.
  $20,000/system

- Installation of composting toilets and recycling of resulting gray water.
  $30,000

- Reduction of impervious surface area and replacement with pervious durable material (i.e., shell grit), especially in parking lots and pathways. Landscape parking lots with plantings to provide shade, increased evaporation, reduce erosion and improve aesthetics.
  $5,000/lot

- Install water conservation devices; install meters to provide statistics; and, initiate competition for minimizing water use.
  $500/house

- Plant shoreline buffer strips to reduce nutrient input to ponds.
  $3,000/pond

- Use National Seashore buildings and grounds as a showcase to the public, as well as living laboratories for research and monitoring. Collection of before and after data and between modified buildings or ponds and unmodified ones on effectiveness and cost would provide results pertinent to the homeowner on the lower Cape.
  $5,000 (staff only)

The educational component would include:

- Production of a regular newsletter to be distributed to visiting public and all households within the National Seashore that discusses environmental issues, provides statistics, provides advice on lifestyle alternatives, new household technologies, etc.

- Development of workshops for visiting school groups that covers:
  a) the importance of the lower Cape;
  b) threats to the Cape - sources and seriousness;
  c) what the National Seashore is doing; and,
  d) what the individual can do.
  Include guided National Seashore visits to provide field and facility experiences. Many of the demonstrations would necessarily be dispersed throughout the National Seashore; all should be included as part of educational information presented at the visitor centers and on a guided visit.
  $10,000/year

Impacts of Estuary Tidal Restrictions

Estuarine Habitat Restoration
Project Statements 10.1 through 10.2

Problem Statement

Salt marshes are very productive ecosystems, providing a rich food base and cover to resident and migratory shellfish as well as finfish and birds (Portnoy and Soukup, 1988). Fifty percent of the nation's coastal wetlands have been lost and even more have been significantly impacted (Roman et al., 1995). Many of the marshes within the Cape Cod National Seashore have been altered with dikes and/or tide gates and subsequently drained. This practice of "marsh reclamation", started in the late 1600s, was meant to reduce mosquito populations, increase productive agricultural acreage, and improve roadways (Portnoy and Soukup, 1988). As a result, native habitat has been lost and freshwater wetland and upland plant species have invaded the diked areas.

Research by the National Park Service since 1980 has documented that restricted seawater flow into salt marshes dramatically changes plant and wildlife habitat (Portnoy and Soukup, 1986; Portnoy et al., 1987b). Salt marshes depend on sediment from the ocean in order to stay above sea level rise. Dike structures prevent this process from occurring, in turn causing the marshes to be vulnerable to flooding when dikes are breached. Additionally, salt marsh peat left after the marsh is drained periodically releases toxic acids and aluminum as it decomposes, resulting in massive fish kills (Soukup and Portnoy, 1986). Diking also reduces or eliminates tidal flushing of nitrogen from salt marsh estuaries with consequent eutrophication and potential oxygen depletion. Constant summertime oxygen stress (Portnoy, 1991), from lack of tidal flushing, reduces both fish and invertebrate numbers as well as diversity in diked and drained wetlands.

Restoration of salt marshes provides resource managers with a valuable tool for maintaining and enhancing coastal zone habitat diversity (Roman et al., 1995). According to Roman et al. (1995), numerous studies in other regions have shown that degraded coastal wetlands and small estuaries can be successfully restored. Hydrologic modeling is one method used to predict tide height levels and tidal flooding elevations that can occur as a result of salt marsh restoration. Roman et al. (1995) successfully used this method to predict the effects of dike and tide gate removal at Herring River in Wellfleet and Hatches Harbor in Provincetown. Hydrologic modeling combined with research and interagency planning since 1986, has resulted in a program to restore up to 90 acres of salt marsh at Hatches Harbor in Provincetown and provide flood protection for the town's airport that was built in the floodplain.

There are three estuary systems currently in various stages of consideration for tidal flow restoration: the Herring River, Hatches Harbor and Pamet River. There are both estuary-specific research issues and general issues common to all three.

Herring River Restoration

The history of human alterations to the Herring River system has been well documented by the Cape Cod National Seashore scientific staff who have completed extensive research on past and proposed management of the system (reviewed in Portnoy and Reynolds, 1997). The Herring River was diked completely at the mouth by 1910 primarily to reduce breeding habitat for salt marsh mosquitoes (*Aedes sollicitans, A. cantator*). While salt hay production and fisheries productivity decreased, the mosquitos did not. As a further attempt to eradicate the mosquitos, drainage ditches were dug in the marsh behind the dike structure. By the mid-1930s, the Herring River's mainstream, now flowing with freshwater, was channelized and straightened. A golf course and two residential dwellings were constructed in the floodplain. The wetland became dominated by freshwater vegetation and upland shrubs and trees. In 1984, the Massachusetts Department of Environmental Protection was given control of the tide gates by the town of Wellfleet.

After a major fish kill in fall 1980, the National Park Service began to examine salt marsh restoration alternatives. As a result, the National Park Service discovered that dramatic water quality problems existed due to diking and reduced tidal flushing of the salt marshes. The problems were surface water acidification, oxygen depletion that led to massive fish kills, and the persistence of abundant mosquito populations (Roman et al., 1995). In 1980, the dissolution of sulfurous compounds from the old salt marsh deposits and consequent acidification of the Herring River and tributaries by oxidized sulfur (sulfuric acid) caused a massive eel kill (Soukup and Portnoy, 1986). In addition, aluminum, leached from native clays by the high acidity, was at lethal levels.

Reduced flushing at the Herring River has also caused oxygen stress and summertime oxygen depletions (Portnoy and Soukup, 1988). Starting in mid-May to early June, temperature increases in the stream, decreasing mid-day dissolved oxygen levels from 100 percent to 50 percent saturation levels and creating a hypoxic state (Portnoy, 1991). During times of heavy precipitation and consequent high flow in the river, wetland runoff, which is high in oxygen demand, is at its greatest (Portnoy, 1991). These periods of high stream flow provide an opportunity for juvenile herring to leave natal headwater ponds. However, if the stream is anoxic at the time of migration, massive fish kills ensue. In both 1984 and 1985, entire juvenile herring runs were killed in the Herring River as a result of anoxic stream conditions (Portnoy and Soukup, 1988). A fish gate is now in place that prevents juvenile herring from entering the river during anoxic episodes (Portnoy et al. 1987a). Tidal flow restoration would permit testing the hypothesis that periods of anoxia would be reduced, and survival of juvenile herring would improve.

Dike construction was historically undertaken in order to reduce and eliminate saltwater mosquito habitats. Despite these efforts, studies have found that the mosquito populations continue to thrive (Portnoy, 1984). Surface water acidification by high sulfate limits fish populations which are natural predators of mosquitos. Additionally, acid tolerant mosquitos were favored in the stagnant waters and continued to survive. Based on the information presented, Portnoy predicts that mosquito populations will decrease after tidal flushing is restored. John Doane, Cape Cod Mosquito Control District, supports this conclusion and adds that for the past 20 years, the district has believed that it is easier to reduce mosquito populations in well flushed tidal marshes than in restricted systems (J. Doane, 1997, pers. comm., Cape Cod Mosquito Control District). Portnoy (1984) concluded that by restoring the Herring tidal marsh, typical marsh-estuarine vegetation would increase, stream anoxia and acidification would decrease, and estuarine fish, nursery habitat and shell fish populations would be restored. Mosquito populations would actually decrease due to natural fish predation and enhanced tidal circulation. Tidal flow restoration would present a unique opportunity to test this hypothesis.

Roman et al. (1995) state that while restoration is an appropriate management tool for degraded salt marshes, there are several concerns that must be addressed before restoration can take place. One concern surrounding restored tidal flushing of the Herring River is salt water intrusion of private wells in the diked salt marsh. However, a U.S. Geological Survey investigation found that the freshwater lens at the very edge of the upland is 60 feet (20 m) thick and, therefore, projected tide height increases of 1.5 feet (0.5 m) after restoration would not impact wells outside of the floodplain (Fitterman and Dennehy, 1991). A second concern was flooding of the golf course and private homes within the floodplain. A 1992 report by Nuttle shows that the golf course which occupies a portion of the Herring River floodplain along a Mill Creek tributary can be protected by rebuilding an old dike at the mouth of Mill Creek, however, protection of the two private homes is an unresolved issue. The tide height and the mixing models were both used to predict changes in the Herring River system that would occur as a result of increased tidal flow (Roman, 1987). The results of these two models allow all parties involved to evaluate and consider ecological and socioeconomic impacts (Roman, 1987; Roman et al., 1995).

Hatches Harbor Restoration

Prior to 1930, Hatches Harbor was a productive 200-acre salt marsh and open water embayment. During the 1930s, the natural status of this embayment was destroyed as a dike closed off half of the acreage from the sea in an attempt to reduce salt marsh mosquito habitat. Subsequent to diking, a small airfield, now Provincetown Municipal Airport, was constructed on the floodplain above the dike. Flood protection for the airport became the primary role of the dike structure which was repaired twice for this purpose, once in 1946 and again in 1978 (Portnoy, 1990).

The 1987 reconstruction of the dike prompted dialog between both airport and natural resource interests, who explored the possibility of salt marsh restoration. These discussions, facilitated by Coastal Zone Management, led to the conclusion that the dike structure provided more than adequate protection for the airport against flooding. Further research by the National Park Service found that the salt marsh above the dike had become largely degraded, with decreased natural salt marsh species and habitat for benthic fauna, fish, and native waterfowl. Research also showed that the reduction in sediment normally imported to the marsh had led to the subsidence of the marsh bed, waterlogging, and plant stress. Two primary objectives became clear to all parties involved in the cooperative research: 1) restore the floodplain to salt marsh; and, 2) protect the airport from flooding (Portnoy, 1990a).

Since both objectives are defined by land and surface elevations (Portnoy, 1990b), bathymetric mapping as well as tide height studies were used to determine the magnitude of restoration. According to Portnoy (1990a), these models showed that 90 acres of the floodplain, within a ten foot contour, could be reflooded by semi-diurnal tides and restored to an intertidal salt marsh with no additional impacts to the airport. Flooding of the salt marsh would occur via four concrete box culverts, each allowing ample tidal flow and flood protection to the airport. Landing system structures located in two swales near the runways would receive added flood protection from earthen berms.

In addition to the plan for restoration of Hatches Harbor salt marsh, a monitoring plan, consistent with the National Seashore's Inventory and Monitoring Program and the Memorandum of Agreement with the Town of Provincetown, was developed. A Resources Management Plan (National Park Service, 1996) project statement for Hatches Harbor salt marsh restoration outlines a plan for semi-annual monitoring of the estuarine system that includes analysis of hydrology and water quality, wetland vegetation, benthic macrofauna, shellfish, finfish, mosquitoes, sedimentation, and migratory water birds. The first phase of monitoring under that plan has been completed.

A description of this restoration project is not complete without a summary of the project's significance to the National Seashore and the State of Massachusetts. Portnoy (1990a) describes the restoration of Hatches Harbor as "the largest single wetland restoration project in the history of Massachusetts." The 10-year planning process behind the restoration proposal for Hatches Harbor is a significant multi-jurisdictional achievement among eleven different local, state and federal agencies (Portnoy, 1990a). Cape Cod National Seashore has placed this restoration project first on the park's priority list of resource management projects (National Park Service, 1998).

Pamet River Restoration

Pamet Harbor, located on Cape Cod Bay, was once a viable commercial port that served a large fleet of local fishing vessels (Giese et al. 1993) operating in the cod and mackerel industry (Giese et al., 1985). During the mid-1800s, commercial fishing fleets were competing for space to anchor in Pamet Harbor, and many had no room. As a result, the fishing industry declined and human population numbers decreased. Remaining residents began to alter the hydrology of the Pamet in hopes of restoring and increasing the capabilities of the harbor (Giese et al., 1985). From 1850 to 1930, major portions of the estuary were diked and dredged. Wilder's Dike was built in 1869 to replace a rotting bridge across the mid section of the Great Pamet River and in 1950, a clapper valve and dike structure were built to accommodate the construction of Route 6 (Giese et al., 1993).

The diking of the Pamet established two distinct hydrological reaches, the Upper Pamet and the Lower Pamet (Livingston, 1996). East of the tide gate located just west of Route 6, the Upper Pamet is freshwater (Figure 10.3) with a watershed encompassing approximately 192 acres. Many upland species of salt-intolerant plants have invaded the area. Ground water discharge from the Pamet and Chequesset lenses, as well as precipitation are continuously recharging this section of the Pamet. The Upper Pamet flows slowly west into the Lower Pamet, a salt marsh estuary (National Park Service, 1986).

The Lower Pamet is an intertidal estuary, greatly stressed by past alterations that have reduced natural tidal circulation and in turn increased shoaling and sedimentation (Giese et al., 1993). Tidal channel beds, except for the outermost section of the inlet channel, are higher than the mean low tide in Cape Cod Bay (Livingston, 1996). According to the 1996 Resource Management Plan, restoring tidal flow to the Pamet River has many beneficial effects including increased natural flushing in the estuary which would in turn improve water quality, maintain habitat diversity, and balance sediment loads in the Pamet River Valley. Additionally, restoration of natural flows would allow the salt marsh to regain a state of equilibrium between sea level and wetland elevations in the Upper Pamet.

Project Statement 10.1
Topographic Survey And Hydrodynamic Modeling for
Estuarine Habitat Restoration at Herring River, Wellfleet

Background Information

The Herring River ecosystem comprises the park's largest (600 ha) estuary on Cape Cod Bay and is unique in extending to a chain of freshwater kettle ponds and in including both anadromous (three species) and catadromous (American eel) fish runs. Before historic diking (1908) and drainage (1910 to 1980s), the system supported productive migratory fish runs, shellfish beds and hundreds of hectares of intertidal salt marsh habitat for finfish as well as riparian mammals. Culturally, the marshes provided sea foods for native Americans over many millennia, plus animal fodder and storm surge protection for the surrounding community of fishermen-farmers throughout the 17th to 19th centuries.

At present, hundreds of hectares of original intertidal salt marshes have been converted to upland vegetation, eliminating habitat for estuarine animals including shellfish and finfish (Portnoy et al., 1987b; Roman, 1987). Since the blockage of seawater, salt-intolerant grasses, forbs and woody vegetation have increased even in the river channel, restricting recreational boating and anadromous fish habitat (Portnoy and Reynolds, 1997). Meanwhile surface waters have been acidified by drainage and the oxidation of sulfur in diked salt marsh peat (Soukup & Portnoy, 1986; Portnoy & Giblin, 1997a). High acidity leaches toxic metals from native clays to surface water. In summer, oxygen depletions are common due to the dike's reduction of tidal flushing (Portnoy, 1991). Acidity, metals and episodes of anoxia cause fish kills, including resident, anadromous and catadromous species (Portnoy et al., 1987a). High acidity and episodic hypoxia restrict fish access to mosquito breeding sites. Thus, despite the 1908 intent of diking to control mosquitoes, nuisance mosquitoes can be abundant (Portnoy, 1984) and their control comprises a major National Seashore issue. Drainage has also caused wetland subsidence amounting to nearly a meter caused by increased decomposition, dewatering and pore-space collapse, and reduced sediment supply.

Recognizing the original value of this resource to native fauna and people, and understanding the severity of degradation caused by 20th century hydrologic alterations, the National Park Service has funded or cooperated on a large number of multi-disciplinary studies regarding diking impacts and alternatives for restoration since 1980 (Table 11.2 and References). Besides detailing the ecological effects of diking and drainage, and evaluating alternatives for tidal restoration (Roman et al. 1995), research has addressed social concerns for the protection of ground water quality and private properties adjacent to the floodplain (Fitterman and Dennehy 1991, Nuttle 1990). These efforts have made it apparent that these impacted conditions can be reversed by restored tidal flow (Roman et al., 1995; Portnoy and Giblin, 1997b; Sinicrope et al., 1990).

As part of a parkwide program of salt marsh restoration, National Seashore managers, the public and local and state environmental authorities have renewed interest in restoring estuarine habitats at Herring River. Although over 80 percent of the floodplain affected by diking and drainage is within National Seashore boundaries and nearly all federally-owned, critical features, including adjacent homes, a golf course and the dike structure itself, are outside National Park Service control. Furthermore, even within National Park Service lands other jurisdictions apply. Therefore, the National Park Service cannot undertake restoration without the full understanding and cooperation of private interests plus municipal, state, and federal regulators. These potential cooperators require a scientifically rigorous, comprehensive and clearly articulated restoration plan. The proposed project is a fundamental component of this plan.

The approach described here has already been used successfully at the National Seashore to develop a restoration program for the diked portions of Hatches Harbor (Roman et al., 1995) where inter-agency agreement and funding have been achieved and dike opening will begin this year.

Earlier observations and modeling of the floodplain as affected by existing gates and culverts (Roman et al., 1995) showed that full restoration will eventually require the complete removal of the principal dike (at Chequesset Neck), reconstruction of a dike along a tributary of Herring River (Mill Creek) to protect a golf course, and possibly other physical changes, e.g. culvert enlargements or removals. However, limited topographic information was available during earlier studies to confidently predict the estuary's hydrography and salinity regime with the removal of all restrictions on tidal flow. Without detailed topography for the entire flood plain, and without subsequent modeling to clearly map the extent and duration of tidal flooding, both social and ecological consequences of tidal restoration cannot be assessed. Also, because 90 years of diking and drainage have caused about a meter of sediment subsidence (Portnoy and Giblin, 1997a), managers need to understand how restored tidal velocities can maximize sediment accretion, to bring the diked wetland surface back into equilibrium with the modern sea level.

The ecological problems which have persisted at Herring River since diking in 1908 can be solved by an incremental, carefully monitored and adaptive program of restored tidal flow (Roman et al., 1995; Portnoy and Giblin, 1997b; Portnoy and Reynolds, 1997). The proposed hydrodynamic work is essential for design of an incremental approach which minimizes adverse effects (e.g., soil waterlogging, anoxia, or damage to roads or structures) and optimizes conditions for recolonization by salt marsh halophytes and fauna. Detailed topography is also needed to confidently answer recurrent questions about the extent and degree of restoration effects on structures and on the salt-sensitive vegetation which has invaded the floodplain since diking. These outstanding questions have effectively blocked management progress despite the large body of information documenting the adverse effects of past water management.

Objectives of this work are: 1) to produce detailed topography of the floodplain affected by restored tidal flow; 2) to use topographic and tide height data to predict (model) tide height and salinity regimes with full and partial dike removal; 3) to use predicted tide heights and tidal velocities to map sedimentation patterns; and, 4) to recommend adaptive management strategies given both natural and constructed physical constraints. Herring River's ecological problems associated with diking are not unique and are often cited by environmental regulators throughout New England to urge tidal restoration of the region's many diked wetlands. (Only about half of New England's coastal marshes have survived 300 years of alterations since European settlement; about 10 percent of remaining salt marshes are diked.) Further, the National Park Service has the data base to document and learn from restoration results. Due to the long and detailed record of research and monitoring in this system, its history, past management, and current status are well known. Thus, the National Seashore's experience with restoration will comprise a widely-applicable model for the assessment of the impacts of diking, for tidal restoration methods, and for the evaluation of project success. More specifically, this study will highlight and promote the ecological and social advantages of a carefully researched and phased approach to hydrologic restoration in these long-disturbed and biogeochemically complex coastal systems.

Description of Recommended Project

This project is an intensive investigation of the physical processes attendant to the return of tidal flow to Herring River and includes the following:

1) The collection of detailed topographic data for the entire floodplain (elevations < 3 m-NGVD) above the Chequesset Neck Dike including the Mill Creek tributary. Work by Roman and others (1995) to predict the effects of opening the existing culverts in the Chequesset Neck dike relied on topographic profiles for only the bottom third of the floodplain. In addition, sampling intensity and precision were limited by available technology (auto-level and manually-read rod). With modern electronic distance-measuring instruments, highly precise and intensive topography can be collected rapidly for the large (600 ha) study area.

2) Numerical modeling of tide heights and salinities based on, and encompassing the area of, detailed topography. New models will incorporate updated tide height and newly-refined topographic data and, as with Roman (1987), will show the effects of a range of alternative levels of increase in tidal prism. Predicted tide heights will be compared to the elevations of road grades, spoil piles and other structures within the floodplain to suggest management actions which optimize estuarine restoration and avoid social conflicts.

3) An assessment of hydrography after tidal restoration, including digitized mapping of principal tidal creeks, expected flood- and ebb-tide velocities and the likely areal extent and rate of sediment deposition both in creeks and on the wetland proper. Modeling will produce estimates of the flow velocities throughout the normal tidal cycle and during storms for various levels of tidal restoration. Sediment transport and deposition will be assessed from flow velocities and from the grain sizes of sediment from local sources.

4) Recommendations should be made for:

   a) the optimum rate of increase in tidal flow given historic subsidence, the predicted rate of sediment accretion, and ecological constraints on hydroperiod (e.g., to minimize soil waterlogging and anaerobiosis at low tides);

   b) tide height monitoring and physical adjustments to tidal flow during the restoration process to ensure that high tide heights do not exceed the accretion capacity of the subsided wetland.

   c) the need for the removal of other structures (e.g., spoil piles, road beds, small culverts) within the floodplain to maximize habitat restoration without damaging private property;

   d) the need to re-establish original creek meanders, cut off by channelization in the 1930s, and consequently to achieve more natural hydrography.

Budget	Task 1	Topographic survey of the floodplain (6 months)	$10,000
	Task 2	Numerical modeling and calibration of predicted tide heights and salinities (1 year)	$20,000
	Tasks 3a-b	Predict effects of various physical restoration scenarios on cultural and natural features, especially roads, structures and sedimentation. Recommendations for the implementation of restoration (6 months) $20,000. Total cost:	$50,000

Table 1. Summary of past Herring River research.

Date	Research Institution	Research Topic
1972	Massachusetts Division of Marine Fisheries	Finfish and shellfish (seaward of dike)
1975	Association for the Preservation of Cape Cod (APCC)	Salt marsh vegetation
1980-81	National Park Service, Wellfleet Shellfish Department, Massachusetts Audubon Society	Tide heights above dike
1980-86	National Park Service, Massachusetts Division of Marine Fisheries	Eel kill, acidification
1981	Williams College	Freshwater wetland vegetation
1983	Boston University, Association for the Preservation of Cape Cod	Salt marsh vegetation
1984	Massachusetts Department of Environmental Protection	Water quality, fauna
1982-84	National Park Service, Cape Cod Mosquito Control	Mosquito breeding ecology
1985-97	National Park Service	Water chemistry Oxygen depletion
1983-87	Rutgers University, National Park Service	Surface water hydrology Salinity, Vegetation, Fin- and shellfish Restoration alternatives
1990	Massachusetts Institute of Technology, National Park Service, Chequesset Yacht & Country Club	Mill Creek (golf course) water budget
1991	U.S. Geological Survey, National Park Service	Ground water, saltwater intrusion
1994	University of Wisconsin, National Park Service	Post-glacial development of marsh and ponds
1995	National Park Service, U.S. Geological Survey	Sediment chemistry, Effects of restoration

Project Statement 10.2
Monitoring Estuarine Restoration Projects

Description of Recommended Project

Hatches Harbor

In preparation for on-going modifications to the Hatches Harbor Dike, a comprehensive pre-restoration monitoring program has been in implementation since 1997. The program includes monitoring of surface elevation, tide heights, vegetation, fish, benthic invertebrates (including harvestable shellfish), coliform bacteria, and salinity and sulfide sampling (in over 100 1-m^2 plots) on both sides of the dike. The U.S. Geological Survey, Biological Resources Division has also established Sedimentation Erosion Tables (SETS) as part of the Cape Cod National Seashore's Inventory and Monitoring Program, to follow erosion and accretion of the wetland surface. However, post-restoration monitoring is not explicitly funded and is currently patched together using existing staffing and volunteers. Dedicated funding for biannual surveys of vegetation and other variables is required to maximize the benefits and knowledge gained by this large program of tidal restoration.

Budget

Year 1	$15,000
Post-restoration and biannually thereafter	

Herring River

Current monitoring of the Herring River includes surface water quality and fish. Past surveys also covered salt-fresh ground water relationships, benthic invertebrates, mosquitoes, vegetation, and some elevational work. The U.S. Geological Survey, Biological Resources Division has also established Sedimentation Erosion Tables (SETS) as part of Cape Cod National Seashore's Inventory and Monitoring Program, to follow erosion and accretion of the wetland surface. As the National Seashore continues to resolve the remaining social concerns and moves toward dike removal and tidal restoration, regular monitoring both pre- and post-restoration will become important. Past surveys should be repeated biannually. The National Seashore is presently embarked on an intensive research effort (Washington Office, Water Resources Division funded) to model the system's hydrodynamics and predict the hydrography and sedimentation of a restored system. Topographic surveys and regular monitoring is essential to this project and to future adaptive management.

Budget

Year 1	$20,000
And biannually thereafter	

Pamet River

Historic monitoring of the Pamet River included elevational surveys and some porewater quality (salinity) after the barrier beach overwashed in 1991 and 1992. The overwashes made it clear that though this system is diked, it still functioned as a back-barrier wetland. The retention of seawater between the overwashed dune and the dike pointed out the inadequate size of present culverts for water discharge. Proposals to restore the Pamet River prompted the recently completed U.S. Army Corps of Engineers study (Kedzierski et al., 1998) of culvert alternatives, which predicted hydrological, ecological, and social effects of tidal restoration. Nevertheless, monitoring is necessary to assess the system's current functions and values as freshwater wetland habitat and to further evaluate the need for tidal restoration. Especially important is the question of *Phragmites* spread on the floodplain. This invasive grass is well established in the Pamet River floodplain and could form a monoculture, particularly if present freshwater vegetation is stressed by occasional overwashes of seawater. Monitoring should concentrate on topography, vegetation, soil conditions, hydrology and surface water chemistry.

Budget

Year 1	$20,000
And at five-year intervals unless management changes	

Pilgrim Lake and Salt Meadow

Past studies of this highly altered system have centered on limnology, sedimentation, ground water hydrology, insect breeding ecology, and phytoplankton; however, the only recent effort to characterize the current system was a salinity survey (Jones, K., 1997, unpublished data, Cape Cod National Seashore). To assess the estuary's present functions, time-extensive data sets are needed which describe surface water hydrology and chemistry. To evaluate the merits of restored tidal flow, comprehensive data sets which include topography/bathymetry, tidal forcing, sediment budge and freshwater inflow are needed. Interpretations of present water quality and the merits of increasing tidal flow, require data on current nutrient dynamics and on the plankton community. Two years of data collection are required to characterize the present system, with subsequent monitoring of selected variables at five-year intervals.

Budget

Year 1	$30,000
Year 2	$20,000
Recurrent sampling at five-year intervals	$20,000

Pilgrim Lake Management
Project Statements 10.3 through 10.5

Problem Statement

Pilgrim Lake is a 51.5 acre coastal lagoon that functioned as a tidal back barrier estuary and salt marsh system when it was connected to Cape Cod Bay by an inlet at the western end (National Park Service, 1996). East Harbor, as it was once called, was isolated from Cape Cod Bay completely in 1868 with the construction of a solid-fill causeway for a road and railroad. Since the construction of the dike, the waters of Pilgrim Lake have become brackish and eutrophic (Applebaum and Brinnekmeyer, 1988). The eutrophic condition of the lake is believed to be the result of natural and human factors such as the shallow depth (2.5 ft in 1987), stirring of lake sediments by coastal winds, nutrient input from septic system effluent and animal feces, and salt water intrusion from malfunctioning weir boards (Mitchell and Soukup, 1981). There are fairly consistent blue-green algal blooms and periodic outbreaks of midges (*Chironomidae*). The lake's water level likely affects its ecological processes. Lake level is determined by: 1) the height of the water level control structure located on the bay side of the lake and operated by the Cape Cod Mosquito Control Project; and, 2) the opening of tide gates in the dike operated by the Massachusetts Division of Waterways (National Park Service, 1996).

Pilgrim Lake is highly eutrophic. The algal blooms occur in all seasons except winter and give the lake its blue-green color. High values of total phosphorus and ammonia-nitrogen have been recorded (Mozgala, 1974). The source of these high values has not been determined but may be from organic bottom sediments, septic systems, and leaching from old salt marsh sediment. The nutrient buildup from these sources nourishes a large algal population which dominates the system and controls a large part of the water chemistry. Additionally, the shallow depth of the lake, decreasing rapidly, also contributes to the eutrophication by increasing nutrient regeneration.

The significance of the lake’s water level to the ecological community was highlighted in 1968 when weir boards were removed from the water level control structure. After the boards were removed, there were massive outbreaks of midges, whose larvae live in lake bottom sediments (Portnoy, 1991). Water depth, salinity levels, midge larval counts, oxygen levels, and nutrient levels were examined after the fish kill and midge outbreak. Emery and Redfield (1969) compiled a thorough set of data at this time, however, the studies were not continued. The 1969 midge outbreaks were controlled with pesticides, a practice that is not feasible for the National Park Service today because of concerns for non-target organisms.

The three major management concerns for Pilgrim Lake are sand deposition, eutrophication, and nuisance insects (National Park Service, 1996). Sand deposition continues to decrease the depth of this already shallow lake. The extensive migrating dune system upwind of Pilgrim Lake may be partly responsible for the 1.5-foot decrease in depth from 1948 to 1987. While past and present infilling rates have been poorly recorded, a 1987 assessment determined that the lake will fill in completely in 25 years (Applebaum and Brinnekmeyer, 1988).

Project Statement 10.3
Determine Bathymetry and Sedimentation Patterns in Pilgrim Lake

Description of Recommended Project

The rate, patterns, and sources of sediment accumulation in Pilgrim Lake must be determined to make accurate predictions about the ultimate fate of this water body. To this end, detailed maps of present sediment distribution and water depth are fundamental prerequisites. The lake is to be surveyed with a fathometer to determine water depth, and several transects across the lake will be established to sample the bottom sediments. These samples will be analyzed for grain size, bulk mineralogy, and organic matter content so that accurate maps can be made of these characteristics. Sediment traps are to be deployed in strategic portions of the lake and monitored periodically for at least one year. The contents of the traps will be measured to determine sedimentation rates in different parts of the basin as well as the aggregate rate of sediment accumulation in the lake as a whole. Short core samples from various parts of the lake will reveal historical changes in sedimentation rates, and these can be dated using appropriate methods, such as ^{210}Pb.

Budget		
	Year 1	$45,000
	Year 2	$35,000
	Year 3	$25,000

Project Statement 10.4
Study Controls of Midge Production

Description of Recommended Project

The midge (*Chironomid*) problem in Pilgrim Lake has defied both control and understanding. It is likely produced by either intentional or accidental changes in lake management strategy. A systematic synecological study of the midge population has not been done in the context of the conditions found in Pilgrim Lake. The research should proceed in stages by completing: 1) a detailed description of the species present, their breeding ecology, habitats and seasonal changes in population structure, accompanied by relevant water and sediment chemistry and predaceous fish densities; 2) laboratory studies to determine the optimum salinity and dissolved oxygen requirements of larvae for comparison to historical data; and, 3) a controlled field experiment to determine the relative role of predaceous fish on midge populations using limnocorrals to exclude predators. Based on these results and in cooperation with the Town of Truro and the Commonwealth of Massachusetts (Marine Fisheries, Department of Public Works, and Cape Cod Mosquito Control), the final phase of study will be to manipulate conditions in Pilgrim Lake, e.g., through increased seawater flow, to determine if experimental results accurately predict field response.

Budget		
	Year 1	$20,000
	Year 2	$18,000
	Year 3	$20,000

Project Statement 10.5
Evaluate the Cause of the Eutrophication Problem in Pilgrim Lake

Description of Recommended Project

Pilgrim Lake has three principal problems: sedimentation, nuisance insect outbreaks and excess eutrophication. There are reasons to believe that the three are not independent and are at least weakly connected.

Pilgrim Lake or East Harbor is a highly altered system resulting from variably restricted tidal flow, possible non-point nutrient sources, shallow depth, and limited biota. The lake is highly eutrophic with blooms of blue-green algae throughout the year. Past management has not controlled the eutrophication. It is unclear whether nutrients from the developing watershed, sea water intrusion, the existence of an anadromous fish run, or proximity of nutrient rich sediments to the photic zone serve to exacerbate the eutrophication problem. It is also unclear whether the system might regain some balance if allowed to flush more freely with the ocean.

Emery and Redfield (1969) provide some provocative information regarding the source of nutrients. Most freshwater lakes are strongly phosphorus-limited; Emery and Redfield found that Pilgrim Lake had 83 mg/m^3 of total phosphorus - a level more than 4 times higher than most eutrophic lakes in Massachusetts. Most marine waters are nitrate-limited and have excess phosphorus, but Emery and Redfield also observed that phosphorus levels in Pilgrim Lake were twice the levels of the North Atlantic. They also found that nitrate-nitrogen levels were 4.8 mg/m^3 , a level generally below that in freshwater lakes but somewhat high for seawater. With salt levels at 6.8 percent or about 20 percent of seawater, it may be that Pilgrim Lake provides ideal conditions for outbreaks of blue-green algae. Much of the phosphorus may be contributed by the limited Cape Cod Bay exchange and/or waterfowl, and since it is quickly taken up by algae in excess of their needs, brief or small exchanges may serve to "bioaccumulate" phosphorus in the system. By the same token, seawater provides little nitrate, but surrounding development and atmospheric deposition provide some. Since the salinity is between fresh and seawater, many salt-intolerant algae common to freshwater will be non-competitive, but given the rich phosphorus supply, salt-tolerant and nitrogen fixing blue-green algae would find the right blend of conditions for excessive blooms.

It seems reasonable from the few reports available (e.g., Emery and Redfield, 1969) that returning Pilgrim Lake to a well-flushed estuarine system would eliminate the problem of excess blue-green blooms, since currently high reserves of nutrients within the impounded system would be flushed out. Most of the fish would be replaced with marine species. Nutrient chemistry would take on the characteristics of Cape Cod Bay and shellfish may return. Midge production should decrease as salinity increases. However, there may be negative consequences for sand deposition in Provincetown Harbor (the original reason for restricting flow to East Harbor).

By the same token, a reasonable trophic balance may be achieved by allowing the lake to become freshwater with no connection to the sea, if the connection is a major source of phosphorus.

Allowing the lake to become more fresh with limited phosphorus inputs by closing the tidal gates permanently may also replace the blue-green algae problem with more aesthetically and ecologically desirable species. The fish population would change little. However, the sediment accumulation problem would remain.

Before taking either drastic action, the system should be modeled for hydrologic and nutrient responses to either choice. Part of this study would involve modeling the interaction between hydrologic flushing, sand transport and water chemistry; part would involve a detailed nutrient budget of the system under existing conditions, with restored tidal flow, or as a closed fresh water system with consequent biological effects.
Additional data collection would be required in the first and second year of the study.

Budget	Year 1	$45,000
	Year 2	$30,000
	Year 3	$20,000

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APPENDICES

APPENDIX A : LEGISLATIVE AND REGULATORY RESPONSIBILITIES

Federal Laws

National Park Service Organic Act (1916) was passed in 1916 and the National Park Service was created. As the act clearly states, the National Park Service has the responsibility to:

> promote and regulate the use of the Federal areas known as national parks, monuments, and reservations ... conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations. (National Park Service Organic Act, 16 USC 1).

Legislation in reinforcing this act states that all parklands are united by a common purpose, regardless of title or designation. Under this law, all water resources of the park are protected by the federal government. Only an act of Congress can change this fundamental responsibility of the National Park Service.

Public Law 87-126: Cape Cod National Seashore Enabling Legislation (August 7, 1961) provides for the establishment of the Cape Cod National Seashore. The legislation provides a detailed description of the lands included within the National Seashore boundaries:

> Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, that the area comprising that portion of the land and waters located in the towns of Provincetown, Truro, Wellfleet, Eastham, Orleans, and Chatham in the Commonwealth of Massachusetts, and described in subsection (b), is designated for establishment as Cape Cod National Seashore.

Safe Drinking Water Act (1974) and Amendments (1986) set national minimum water quality standards. This law requires regular testing of public drinking water supplies.

Federal Water Pollution Control Act (Clean Water Act) 1972 and Amendments (1977,1987) provide for actions needed to restore and maintain the chemical, physical, and biological integrity of the nation's waters.

Coastal Zone Management Act (1972) and Amendments (1990) provide coastal states with assistance in careful protection and development of the coastal zone.

Water Quality Improvement Act (1970) requires federally regulated activities to have state certification stating that the activity will not violate water quality standards.

National Environmental Policy Act (1969) requires that all major federal actions which significantly effect the quality of the human environment be evaluated by an environmental impact statement which is reviewed by the public and approved by a federal agency.

Executive Orders on Wetlands and Floodplain Management, and Pollution Control (1977) - Executive Order 11990, "Protection of Wetlands" requires all federal agencies to minimize the destruction, loss or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands. Federal agencies must avoid activities which could adversely effect the integrity of a wetland ecosystem unless no other practical alternative exists. Executive Order 11988, "Floodplain Management" requires federal agencies to implement floodplain planning and properly mark where flood plains occur in order to increase public's awareness of flood hazard areas. Executive Order 11752 requires the Park Service to exercise leadership in the prevention, control, and abatement of environmental pollution from activities including sewage treatment and disposal, disposal of solid waste, and electrical power generation.

Massachusetts State Laws

Massachusetts Clean Water Act (Mass. G.L. Chapter 21, Section 26-53) is a set of regulations which classifies all surface waters of Massachusetts and sets minimum criteria for water quality. These water quality standards designate all surface waters in and adjacent to the Cape Cod National Seashore as National Resource Waters (Regulation 4.4 of the Massachusetts Water Quality Standards). This regulation is meant to preserve the value of surface waters by prohibiting all new additional pollutants and requiring the elimination of existing discharges unless alternative means of disposal are not reasonably available, or unless the discharges do not affect the quality of the water as a natural resource.

Ocean Sanctuaries Act, 1978 (Mass G.L. Chapter 132A, Section 13-16 and 18) establishes the Cape Cod Ocean Sanctuary, which completely surrounds Cape Cod National Seashore. Under this designation, certain activities such as excavation, drilling, construction and dumping are prohibited within the sanctuary.

Massachusetts Wetlands Protection Act (Mass. G.L. Chapter 131, Section 40) gives local Conservation Commissions the authority to protect wetland areas as well as consider impacts on public water supplies and marine resources in their review of proposals for activity in or adjacent to wetland areas. The Wetland Restriction Acts (Mass G.L. Chapter 131, section 40A and Mass. G.L. Chapter 130, section 105) allow the Commissioner of the Department of Environmental Management (DEM) to place deed restrictions on development in significant inland and coastal wetlands.

Massachusetts Community Sanitation Program (Mass. G.L. Chapter 111, State Environmental Code, Title 5) enables Massachusetts Department of Environmental Protection (DEP) and local Boards of Health to set standards and issue permits for subsurface discharge for the protection of water quality from subsurface waste disposal.

Colonial Ordinance of 1641, amended 1647 states that a pond greater than 10 acres located within the Commonwealth of Massachusetts is a "great pond". Under this designation, the title of the pond bed is held under the jurisdiction of the Commonwealth. Massachusetts has the right to control and regulate the use of the great ponds and can limit their use under certain circumstances.

APPENDIX B: SPECIAL DIRECTIVE 78-2

To: Field Directorate and all Park Superintendents

From: Director

Subject: Sale or lease of services, resources or water available within an area of the National Park System

Section 3(e) of Public Law 91-383, 84 Stat 827, authorizes the Secretary to enter into contracts which provide for the sale or lease to persons, States or their political subdivisions, of services, resources, or water available within an area of the National Park System if such person, State or its political subdivision:

1. Provides public accommodations or services within the immediate vicinity of an area of the National Park System to persons visiting the area; and,

2. Has demonstrated to the Secretary that there are no reasonable alternatives by which to acquire or perform the necessary services, resources, or water.

On the basis of the Assistant Solicitor's comments and findings, which are applicable Servicewide, see enclosed February 2, 1978 memorandum, relative to Public Law 91-383, the November 24, 1970 "Standards for Implementation" memorandum signed by former Director Hartzog is hereby rescinded. The revised standards for implementation of New Authorities under Public Law 91-383 are as follows:

> In the granting of permits for services, resources or water, the Directors of the Regions will have exercised this authority satisfactorily when the following conditions have been met:
>
> 1. The services provided by the applicant are of direct benefit to the park, or to the National Park Service for the direct or indirect benefit of park visitors;
>
> 2. It has been determined that the applicant has no reasonable alternative to the use of park resources or services;
>
> 3. Effects of use of the resource or service on the park's environment, administration, management and protection, and visitors have been examined and these effects have been determined to be acceptable. The environmental impacts of the use or service will be assessed and an environmental impact statement prepared if required according to NPS Guidelines for Environmental Assessment and Statements;

4. When it is determined that use of water by the applicant will be in accordance with laws and regulations governing ownership and use of Federal water and rights;

5. Charges have been established for services, resource or water use that permit recovery of the full cost to the government of providing the services, resource or water use in accord with 31 U.S.C. 483 a and OMB Circular A-25;

6. An application docket containing a draft of the special use permit, background materials and recommendations has been received by the Washington Office for submission to appropriate congressional committees for review and concurrence prior to consummating any legally or morally binding commitments. The application docket should reflect multidisciplinary regional involvement and clearance of the proposed application.

7. The permitted use is for a short term period (one year or less) and is revocable at the discretion of the Secretary at any time without compensation and no permanent property rights are conveyed to the user for any resource or water within an area of the National Park Service. Water use agreements provide for National Park Service review and approval of planned development by the applicant that would create increased water demands.

It should be emphasized, that while Public Law 91-383 conditionally allows the Secretary of Interior to authorize the sale of services, resources or park water, the Secretary's primary commitment, as mandated by the Congress, is the preservation and protection of National Park System resources which includes the conservation of System area water resources and related water dependent environment. In this regard, Service management policy limits water development and use, assuming no adverse impact on the natural environment, to the minimum required to meet visitor and employee water needs. In essence, water is a vital part of the park environment and a natural resource the Service is committed to protect and in reality cannot be "excess" or "wasted" water, as viewed by some applicants.

APPENDIX C: GROUND WATER MODELING

Summary of Groundwater Modeling on Cape Cod

Management of ground water resources is made difficult by several problems: (1) hydrologic properties of aquifers are fundamentally dependent on geology, and their determination is usually complex and expensive; (2) local stresses can have regional hydraulic effects on an aquifer; (3) ground water movement is slow, and therefore, the consequences of management decisions may not be seen for decades, at which time, the results may be irreversible; and, (4) ground water can not be observed directly and must be inferred from indirect measurements and abstract mathematical reasoning (Guswa and LeBlanc, 1981).

Computerized ground water models attempt to circumvent these difficulties and simulate aquifer dynamics as accurately as possible. The aquifer is divided into discrete blocks or cells, each of which is assigned an approximating finite difference equation to describe flow into and out of it. A computer is utilized to simultaneously solve large numbers of these equations and converge on a numerical answer and to calculate the hydraulic head in the aquifer at specified locations under specified conditions. The hydraulic properties, boundaries and water budget for the model area must be defined and used as input data for the model. The reliability of the model is dependent on the accuracy of the input data, the size of the aquifer element which the flow equations describe, and the discretization scheme (scale of the blocks within the model grid) (Guswa and LeBlanc, 1981; Barlow, 1994a). The model scale determines the level of detail at which hydrogeologic boundaries can be represented, the accuracy of velocity calculations, and the ability to represent internal boundaries and sinks accurately (Barlow, 1994a).

Many of the input variables in the computer simulations are unknown or at least imprecisely known. Of these, recharge and hydraulic conductivity are probably the most influential (Masterson and Barlow, 1994). Most ground water models broadly apply an average recharge value over a wide area and a long time period rather than accurately reflecting recharge variability. Average recharge is estimated principally by observing precipitation records rather than directly observing recharge. Hydraulic conductivity is exceptionally spatially variable and must be estimated over broad areas based on limited point data and an interpretation of the geologic processes that formed the deposits. There are few deep boreholes on the lower Cape to provide the necessary subsurface information (Masterson and Barlow, 1994; Barlow, 1994a; Guswa and LeBlanc, 1981). Estimates of hydraulic conductivity are, however, limited to a range of values experimentally determined at various locations on the lower Cape. Horizontal conductivity ranges between 100 to 300 feet per day with a large horizontal to vertical conductivity ratio between 10:1 and 30:1. Vertical conductivity through silt and clay lenses has been estimated to range from 10^{-5} to 10^{-3} feet/day (Guswa and LeBlanc, 1981; Masterson and Barlow, 1994). Both recharge and hydraulic conductivity are adjusted in the calibration procedure in order to minimize the differences between observed and computed head values at specific locations. Model accuracy might be improved if recharge rates and hydraulic conductivity were better constrained.

Two types of computer ground water modeling programs have been used to model the lower Cape lenses. Most models have been developed in MODFLOW, the modular, three-dimensional, finite difference, single fluid flow model created by McDonald and Harbaugh (1988) of the U.S. Geological Survey. The model can be used to predict the response of the system to any variety of stress scenarios. On the lower Cape, the program has been used to simulate water table declines, freshwater discharge reductions, zones of contribution for a well, and travel times to a well. SHARP, the three-dimensional, finite difference, dual fluid flow model developed by Essaid (1990) of the U.S. Geological Survey has been used to simulate the movement of the freshwater-saltwater interface in response to pumping (Masterson and Barlow, 1994; Sobczak and Cambareri, 1995).

Conceptual Modeling - Lower Cape Ground Water Models

Guswa and LeBlanc, 1981

Guswa and LeBlanc (1981) created the first computer simulations of the lower Cape lenses using a predecessor of MODFLOW. In their models they utilized a set of assumptions and basic input parameters that have been more or less mimicked by all subsequent modelers. Their model is three-dimensional, because existing hydrogeologic information indicated that the aquifer was too variable for two-dimensional modeling, and steady state, because there were not sufficient long- term records of head and stress changes to accommodate a transient model. The model's approximation of the fresh water-salt water interface as a static, no flow boundary is valid only for equilibrium conditions (Guswa and LeBlanc, 1981). Eighteen inches of average annual recharge were applied universally across the land surface except in dry low lying areas, where recharge was reduced by 10 percent to approximate the effect of locally high evapotranspiration rates, and submerged low lying areas, which were treated as discharge zones with no recharge capability. Additional artificial recharge was simulated to occur in areas where the water disposal site is not in the same model cell as the withdrawal site (i.e., disposal lagoons of wastewater treatment plants and private homes serviced by public water but using a private septic system) (Guswa and LeBlanc, 1981). The models were calibrated to steady state conditions by comparing calculated values with 150 observed head measurements, 27 positions of the fresh water-salt water interface, and 2 measurements of ground water discharge rates. Model head calculations at most locations are within a few tenths of a foot of observed measurements and only a few are off by more than a foot (Guswa and LeBlanc, 1981).

LeBlanc (1982) utilized the model to assess the impacts of ground water withdrawals on water table elevation, aquifer discharge, and movement of the fresh water-salt water interface. The model indicated that, except in the immediate vicinity of the pumping wells, changes in water levels caused by simulated ground water withdrawals are smaller than the water table fluctuations caused by seasonal and long term recharge variability. Average modeled water table elevations declined less than 0.6 feet in the Pamet lens under the following scenarios: (1) with only Test Site #4 Wellfield running between 0.75 MGD and 1.08 MGD; (2) with Knowles Crossing and North Truro Air Base running at the 1979 average year round rate of 0.88 MGD; (3) with combined pumping from all four wellfields at the 1979 average summer rate of 1.44 MGD (LeBlanc, 1982). LeBlanc suggested that water table elevations within 700 feet of the pumping wells may decline by more than a foot, but the model grid resolution was not fine enough to quantify these changes. Aquifer discharge to Pilgrim Lake and the Salt Meadow area was decreased by more than 50 percent in the peak summer pumping scenario and by as much as 20 percent in the 0.88 MGD average pumping scenario (LeBlanc, 1982). Large withdrawals of 1.0 MGD at Test Site #4 were modeled to interfere with withdrawals from Knowles Crossing and contribute to saltwater intrusion at both wellfields. Modeled changes in the position of the fresh water-salt water interface were greatest in the immediate vicinity of the wells (LeBlanc, 1982).

Wilson and Schreiber, 1981

This model is also a MODFLOW predecessor and uses a similar protocol and set of assumptions as the Guswa and LeBlanc work. The regional impacts of ground water withdrawals were modeled to be similar to the impacts of recharge reduction. Freshwater discharge to streams and marshes is shown to be more sensitive to long term changes in natural recharge than changes in water table elevations, fresh water-salt water interface depths or freshwater storage volume. When modeled recharge dropped from 18 inches per year down to 12 inches per year, a 33 percent "drought" reduction, total freshwater discharge dropped a full 33 percent in order to preserve the freshwater mass balance. Local discharges to the Pamet River and Little Pamet River were reduced by more than 50 percent. In contrast, the freshwater volume in storage dropped by only 16 percent, the water table declined 20 percent and the interface rose about 20 percent of the way to mean sea level (Wilson and Schreiber, 1981). Simulated ground water withdrawals at maximum "safe yield" from either Long Nook Road or South Hollow produced smaller reductions of discharge than those simulated for the drought recharge conditions outlined above (25 percent reduction to the Pamet River and a 40 percent reduction to the Little Pamet River). Simulated pumping at maximum safe yield from either Knowles Crossing or Test Site 4 reduced discharge to Salt Meadow to almost zero this is within the range predicted for drought recharge conditions. Long term average pumping rates at Knowle's Crossing indicate a current 50 percent reduction in discharge to Salt Meadow compared to the undisturbed, pre-development value (Wilson and Schreiber, 1981).

Because of the Ghyben-Herzberg Principle (refer to section 2.5.6), the volume of freshwater in storage is primarily dependent on the position of the fresh water-salt water interface. Stress induced changes in water table elevations are predicted to fall orders of magnitude faster than the interface will rise. Consequently, the volume of water in freshwater storage also does not respond quickly. As modeled, it would require a sustained drought of 10 years or more with only 14 inches of annual recharge to raise the interface 10 feet and seriously deplete storage volume. The worst drought in recent memory occurred in the mid-1960's, lasted 6 years, and averaged 15.5 inches per year of recharge (Wilson and Schreiber, 1981).

Long term, simulated, sustained pumping above safe yield often led to a rapid and significant localized rise in the interface, particularly under the influence of multiple well withdrawals. In general, the influence of one well on the fresh water-salt water interface location at another is determined by the pumping rates, geographic proximity, and distances to the coastline. Wells near the coastline have a lower "safe yield" than those located inland. All wells were modeled to be susceptible to accelerated salt water intrusion with a greater than 10 percent increase in pumping over safe yield (refer to Chapter 4, page 66) (Wilson and Schreiber, 1981). The Knowles Crossing Well field was found to be especially sensitive to sea water intrusion. The combined use of Test Site #4 Well field with Knowle's Crossing Well field increased the degree of salt water intrusion at both locations. Use of South Hollow Well field showed a marginal effect on the interface position at Knowle's Crossing. Withdrawals from the Long Nook Road Wellfield and the North Truro Air Force Base Wellfield had almost no effect on the degree of salt water intrusion at Knowle's Crossing Well field or Test Site #4 Well field and vice versa. Combined withdrawals from the North Truro Air Base, South Hollow, and proposed Long Nook Road wells are modeled to contribute to salt water intrusion at each other. A conservative maximum "safe yield", in the absence of all other pumping, is estimated at 0.5 MGD for Knowle's Crossing, 0.7 MGD for Test Site # 4, 1.5 MGD for South Hollow, and 0.75 MGD for Long Nook Road (Wilson and Schreiber, 1981)(refer to figure 4.3 for well field locations).

Cambareri, Belfit, Janik, Irvin, Campbell, McCaffery and Carbonell, 1989a

The Cape Cod Planning and Economic Development Commission also utilized a MODFLOW predecessor and followed a similar protocol as the prior models. In the calibration procedure, however, the Commission monitored 47 usable observation wells in the Pamet lens. This is an increase of 15 wells or a 50 percent increase in data points over prior modeling efforts. Additional data points improved the calibration procedure and significantly expanded the accuracy and precision of the ground water contours for the Pamet lens. The new (1989) contours are at a half foot interval and more accurately reflect the interaction between the Pamet River, Little Pamet River, Salt Meadow, and Pilgrim lake with the edge of the ground water lens (Cambareri et al., 1989a). The new information was used to model the Zones of Contribution (ZOC) and travel times to each of the public wells. Two potential new well locations were identified based on water quality criteria without consideration of ecological impacts. Both locations are outside of but in close proximity to National Seashore boundaries.

Martin, 1993

Martin used MODFLOW to simulate the effects of ground water withdrawals from 4 existing well fields and two potential well fields on freshwater discharge to the perimeter of the Pamet aquifer. He did not attempt to simulate movement of the freshwater-saltwater interface. The model utilized a very dense grid spacing of 416 feet per cell edge to obtain better resolution near sensitive discharge areas (Martin, 1993). The model grid consists of only one layer with a single value of hydraulic conductivity because sufficiently detailed hydrogeologic data did not exist to accurately portray the variability of hydraulic conductivity. The hydraulic conductivity value was adjusted in the calibration procedure to best match calculated with observed head measurements. The limited input data restricts model accuracy on a site specific basis but large scale results should not be affected. Simulated changes in aquifer discharge were not verified with field measurements and the calculated results are intended for comparative purposes only (Martin, 1993).

Simulated discharge to the Salt Meadow area is most greatly reduced by withdrawals from the Knowles Crossing Well field. At a withdrawal rate of 0.25 MGD almost half the water withdrawn from the well is predicted to come from a reduction of discharge to Salt Meadow. Withdrawals from the South Hollow and North Truro Air Base Well fields will reduce discharge to Salt Meadow by 0.03 MGD. Simulated discharge to the Little Pamet River is reduced most by withdrawals from the South Hollow, North Truro Air Base and Long Nook Road wellfields. Combined withdrawals from the three wellfields of about 1.25 MGD, regardless of distribution, produced a reduction in discharge by about 10 percent of the withdrawal rate (0.12 MGD). Simulated discharge to the Pamet River is most greatly reduced by withdrawals from the proposed well fields at Long Nook Road or the Mitre site. Modeled discharge declined by about 15 percent of the amount removed from these two wellfields. Simulated withdrawals from existing well fields create a negligible reduction of discharge to the Pamet River. Simulated reductions in discharge to Bound Brook and the Herring river occur only from use of the proposed Mitre site (about 30 percent of the withdrawal rate) (Martin, 1993).

Barlow, 1994a & b

Barlow's model is intended to assess the effectiveness and limitations of numerical flow modeling coupled with particle tracking for the delineation of contributing areas to existing and hypothetical supply wells. Two flow systems were selected that were representative of the range of hydrogeologic complexity of Cape Cod flow systems. The simple system is the Nauset lens located in Eastham and Wellfleet. It was modeled as a 100 foot thick single layer aquifer with near ideal boundary conditions and no large capacity public supply wells. The complex system is the Sagamore (West Cape) lens in Barnstable and Yarmouth. It was modeled as a 250-500 foot thick multi- layered aquifer with non-ideal boundary conditions (including streams, ponds, wetlands and spatial variability of recharge rates) and multiple public supply wells. The two-dimensional model for each system is, by definition, only one layer thick. The three-dimensional model of the simple system consisted of five layers, while that for the complex system had eight layers. Precipitation is the only source of recharge to the simple system while the complex system receives wastewater return flow as an additional recharge component. Contributing areas were delineated using the U.S. Geological Survey particle tracking program MODPATH (Barlow, 1994a; 1994b).

The choice of either a two-dimensional or three-dimensional model for the delineation of contributing areas depends largely on the complexity of the flow system in which the well is situated. Contributing areas calculated for the two-dimensional and three-dimensional models in the simple system did not differ significantly provided the pumping rate was greater than 0.25 MGD. In the complex system, however, contributing areas from the two-dimensional models were not always accurate because two-dimensional models did not account for vertical flow and did not adequately represent many of the hydrogeologic and well design variables present. In particular, accurate delineation of contributing areas was complicated by the presence and continuity of discrete lenses of low hydraulic conductivity, non-ideal ratios of horizontal to vertical conductivity, shallow streams, partially penetrating supply wells, pumping rates less than about 0.1 MGD, and spatially variable recharge rates (Barlow, 1994a; 1994b).

Time related capture zones delineated by the two-dimensional models substantially under predict the size of the land area contributing water to a well over a specific time interval for both the simple and complex flow systems. This effect is most likely caused by the inability of two-dimensional models to account for the high horizontal : vertical conductivity ratio common in most aquifers. During the calibration procedure for the two-dimensional model the single value of horizontal conductivity must be artificially lowered to match the calculated heads to the observed heads influenced by the low vertical conductivity. The unrealistically low horizontal conductivity utilized in a two-dimensional model artificially lengthens modeled travel times and under represents contributing areas (Barlow, 1994b).

Masterson and Barlow, 1994
Massachusetts Department of Environmental Management, 1994

Both studies utilize the same model and employ the SHARP program to assess the regional response of the boundary between the fresh water and salt water flow systems to changing stress conditions. SHARP is a transient, 3D, finite difference model capable of simulating dual density fluid flow separated by a sharp interface (Masterson and Barlow, 1994). The Pilgrim lens was not modeled. The Nauset and Chequesset lenses, which currently contain no large capacity wells, were modeled to simulate only natural, pre-development conditions. For these lenses, the MODFlow program was used to calculate the current position of the fresh water-salt water interface and the amount of discharge to salt water borders of the aquifer. That information was then used as boundary conditions for MODFLOW freshwater flow models. The Pamet lens, where salt water intrusion at the Knowles Crossing Wellfield precludes MODFLOW's assumption of a static fresh water-salt water interface, was modeled using only the SHARP program. The model grid subdivided the aquifer into seven layers to accurately reflect lithology and extended from the water table to the contact between unconsolidated sediments and bedrock (Masterson and Barlow, 1994).

On a regional scale, both seasonal and climatic (drought) conditions have a greater simulated impact on surface waters than do current or future water supply withdrawals. Simulated seasonal reductions in discharge, declines in water table elevations, and increases in interface elevations resulting from increased pumping at constant recharge were negligible on a regional basis. The greatest regional impacts were produced by the cumulative effects of a hypothetical 30 percent drought lasting five years, when winter and spring replenishment of the aquifer did not occur, combined with in-season withdrawal demands. At the small scale however, impacts in the immediate vicinity of a pumping well may be severe. Under 1975 pumping and recharge conditions at Knowles Crossing, for example, the simulated water table decreased by 2 feet and the simulated fresh water-salt water interface rose by 55 feet contaminating the well (Masterson and Barlow, 1994; Massachusetts Department of Environmental Management, 1994).

Sobczak and Cambareri, 1995

In 1995, the Lower Cape Task Water Management Task Force, a multi-jurisdictional group of state, local and national agencies, undertook a resource-based screening process to select potential new well sites without regard for political boundaries. The criteria used for site selection were: (1)water table elevation greater than 4 feet; (2) low density land use areas; and, (3) significant distance from surface water features. The selected sites were ranked based on their impact to surface water natural resources. A computer model for each of the three aquifer lenses was constructed and the various well positions tested with all other factors remaining constant from simulation to simulation (well depth, recharge, and pumping rate =0.5 MGD). The impact of multiple pumping wells was not addressed (Sobczak and Cambareri, 1995).

Model results are only useful for comparing relative impacts of one site with those of another. Absolute impact on any specific resource cannot be accurately determined (Sobczak and Cambareri, 1995). Of the 32 selected sites, five were modeled to have an insignificant impact and 15 to have a moderate impact. Significant impacts created discharge reductions of greater than 10 percent of natural discharge rate and water table declines greater than one foot. Moderate impacts created discharge reductions of greater than 5 percent and water table decline greater than six inches. Moderate and insignificant impact sites received further consideration. In the Nauset lens, three sites (the NE Eastham, Marconi Beach, and Nauset Road sites) were modeled as optimal well locations with insignificant impact to identified surface water resources. In the Chequesset lens, no sites were identified with insignificant impacts to surface water bodies. There were, however, six sites with moderate impacts which might warrant further consideration provided that individual well yields are small, withdrawals are well spaced, and return flow occurs in appropriate areas. These sites are the Great Pond, Dyer Pond, Coles Neck, Ryder Pond, Mitre and Prince valley sites. In the Pamet lens, two sites (the North Truro Air Base (already in use) and the Coast Guard sites) were modeled to have insignificant impacts. South Hollow site (already in use) and Long Nook site are modeled to have moderate impacts. Knowles Crossing (already in use) and Test Site #4 were modeled to have significant impact and to experience saltwater intrusion (Sobczak and Cambareri, 1995).