Chapter 3

Seaside sparrow

Refuge Resources

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Introduction

We begin this chapter with a brief description of the refuge management units to provide a context for the discussions that follow. Then we describe the surrounding physical environment, which includes the refuge's geographic setting, its hydrogeomorphic features, soil information, and air and water quality. Next we describe the role of prehistoric and historic climatic influences, cultural setting and land use history in and around the refuge. We also review Delaware's remaining natural habitats and the historic context of the refuge's wetlands as they have been influenced by human activity and management. We finish the description of the physical environment by summarizing the vegetation communities on the refuge.

Rapid climate change is proving to be the defining conservation issue of the 21st century, and climate change adaptation strategies used by the refuge must anticipate an increasingly different physical environment than the one we have managed in the 20th century. To that end, this chapter also contains extensive reviews of the relevancy of global climate change, sea level rise, local coastal storm activity, refuge shoreline dynamics, and vulnerability assessments of some of the refuge's coastal habitats. These factors influence the physical environment of the refuge, but also are directly related to the conservation and management of the refuge's fish, wildlife, and plant resources in the near future. We also investigate, throughout the remaining chapters of this CCP, how sea level rise is likely to affect the refuge's wetland habitats and clarify how managing for and facilitating ecological transitions in the refuge's physical environment will be an increasingly significant part of our adaptation to climate change.

Next we represent the biological environment of the surrounding area. We describe the biological resources within the context of the Delaware Bay Estuary, associated with the current condition of the refuge's plant and animal populations. We also map out the different vegetation communities found on the refuge and their associated rare plant species relationships. We end with an analysis of the socioeconomic environment of the refuge, including the economic benefits of refuge visitation to local communities and refuge administration details.

Refuge Management Units

The refuge can be described as an elongated coastal strand covering 10,144 acres that lies parallel to the Delaware Bay. For management purposes and to facilitate understanding of the descriptions of habitats and biological resources within management areas, Prime Hook NWR is divided into four management units delineated by four State roads which transect the refuge and run perpendicular to the bay (map 1-1).

UNIT I. This area comprises the northern most end of the refuge and is delineated by Slaughter Beach Road as its northern boundary, overwashed barrier dunes and a portion of the Slaughter Beach community houses on the east, Fowler Beach Road on the south, and an upland fringe of scrub-shrub areas on the western boundary. There is currently no water level management capability in Unit I, which contains about 1,400 acres of salt marsh. Tidal saltwater is the primary source of water for the unit, which flows approximately two miles from the Delaware Bay through the Cedar Creek at the Mispillion Inlet and into Slaughter Canal. An overwash formed on the coast of Unit I in 2006, creating a small inlet, creating more direct flow of saline bay water into Unit I.

UNIT II. This management unit is just south of Unit I. It is bounded by Fowler Beach Road on the north, artificial barrier dunes and a sand dike connected to the Prime Hook beach community on the east, Prime Hook Road on the south, and an upland interface on the west. During storm tides, this sand dune system has been breached several times and washouts have deposited sand and saltwater into the Unit II impoundment.

UNIT III. Management Unit III is bounded by Prime Hook Beach Road on the north, Route 16 (Broadkill Beach Road) on the south, upland edge on the western boundary, and the Prime Hook and Broadkill Beach developments immediately adjacent to the refuge's eastern boundary. Unit III consists of roughly 3,600 acres, which include impounded freshwater emergent marsh, red maple-seaside alder swamp, low-lying farmed areas, brush, barrier beach on the east, and 140 acres of flowage easement on the southeastern boundary of Unit III. This flowage easement drains directly into Prime Hook Creek and flows south to the water control structure of this watercourse.

UNIT IV. Management Unit IV is surrounded by Route 16 on the north, the Broadkill Beach community on the east, the Broadkill River on the south and west, and the upland edge on the west. The majority of water and tidal action associated with Unit IV is provided by the Broadkill River, whose salinity ranges from 10 to 30 ppt. Prior to Service ownership, this marsh had been excessively drained by man-made ditches. Rainfall and runoff from Unit III are other sources that provide freshwater. Due to the strong influence of the Broadkill River, this impounded area has a more brackish character with salinities ranging from 5 to 20 ppt.

Further details regarding the soils, hydrological features, wetland and management history, and vegetation of each of these four management units are provided later in this chapter.

Physical Environment

Geographic Setting

The refuge is located in Sussex County, Delaware, within the Atlantic Coastal Plain Province, along the southwestern shore of the Delaware Bay. It is part of BCR 30, which encompasses the New England/ Mid-Atlantic Maritimes and the PIF Physiographic Region 44. Prime Hook NWR is one of two refuges of the Coastal Delaware NWR Complex. The refuge was established in 1963 and historically consisted of tidal marshes and agricultural lands that were grazed by cattle. The landscape surrounding the refuge was dominated by small farms producing vegetables and small grains. From the 1990s to present day, beach and residential development and intensive agricultural operations (corn, soybean, and poultry production) are the dominant land uses bordering the refuge.

The four roads that bisect the refuge have significantly altered the hydrology and other ecological processes of the refuge's wetland habitats. The two interior roads, Fowler Beach and Prime Hook roads have the greatest hydrological impacts on the refuge's impounded marsh complex and management actions. These roads, with their associated culverts and water control structures located in Units II, III, and IV, are directly linked to the refuge's water level management capabilities (map 3-1).

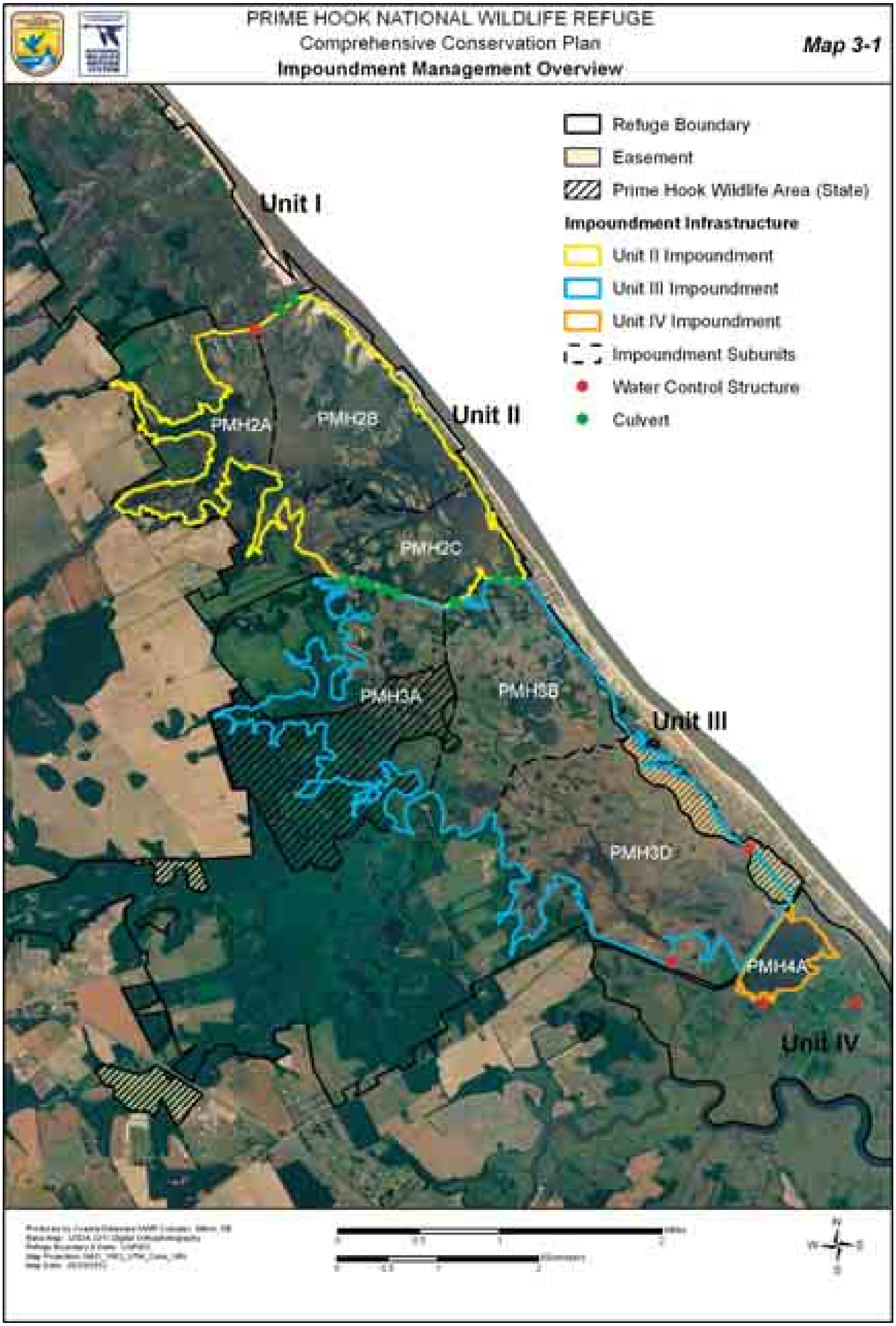
The refuge is representative of the natural vegetation of the Delmarva Coastal Plain ecosystem which is dominated by emergent wetlands interspersed with swamp and forested upland, grasslands and open water habitats. Eighty percent of Prime Hook NWR's vegetation cover types are shaped by tidal and freshwater creek drainages that discharge into the Delaware Bay with associated coastal barrier island habitats. The remaining 20 percent are composed of upland habitats. NVCS cover typing of the refuge has resulted in the delineation of 37 land cover types including vegetation and anthropogenic communities and water surface coverages (map 3-2).

Other natural wildland habitats and managed wetlands immediately adjacent to or near Prime Hook NWR include:

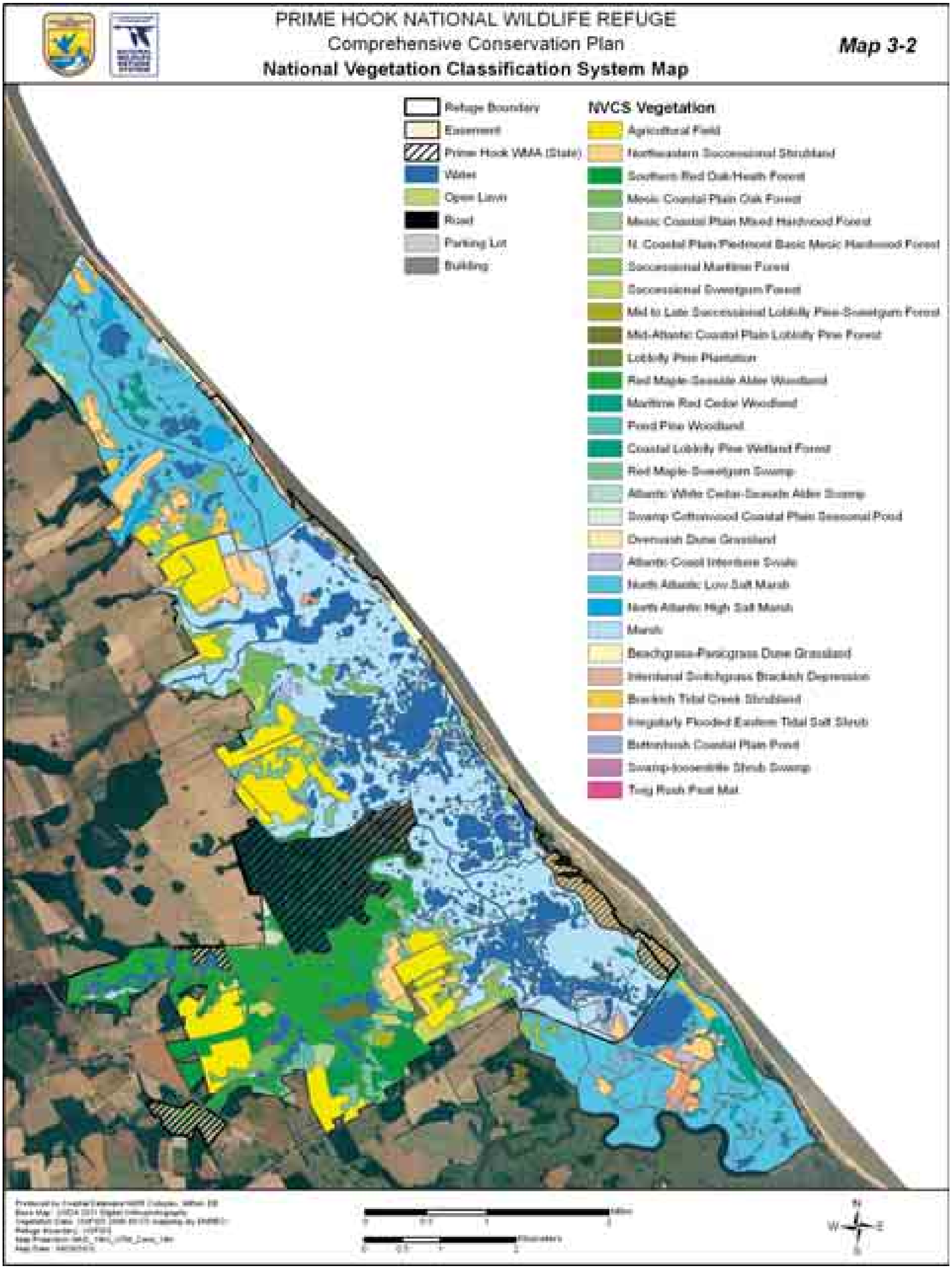
- The Great Marsh (1,000 acres of salt marsh, owned by the town of Lewes) located just south of the refuge.

- Milford Neck Wildlife Management Area (WMA) (5,459 acres), 3 miles north of the refuge above Mispillion Inlet.

Map 3-1. Impoundment Management Overview



Map 3-2. Vegetation Community (NVCS) Overview



- Ted Harvey Conservation Area (2,661 acres), 9 miles north of Prime Hook NWR above Bower's Beach.
- Little Creek WMA (4,721 acres), 15 miles north of Prime Hook NWR above Port Mahon.
- Prime Hook WMA (698.2 acres), adjacent to Prime Hook NWR.
- Bombay Hook NWR (16,000 acres), 25 miles north of the refuge.

Geology and Hydrology

Past geological events in Delaware have created two distinct physiographic provinces; the northernmost 5 percent is in the Appalachian Piedmont Province and the Atlantic Coastal Plain Province covers the remaining 95 percent. Appalachian mountain building episodes between 500 and 200 million years ago formed the Piedmont, which is composed of metamorphosed, igneous, and sedimentary rocks. The Piedmont region is characterized by low, rolling hills and steeply incised stream valleys. A fall zone occurs at the junction of the Piedmont and Coastal Plain in the proximity of Route 2, Kirkwood Highway, in New Castle County, which is an ecological transition area between these two provinces (Thompson 1976) (map 3-3).

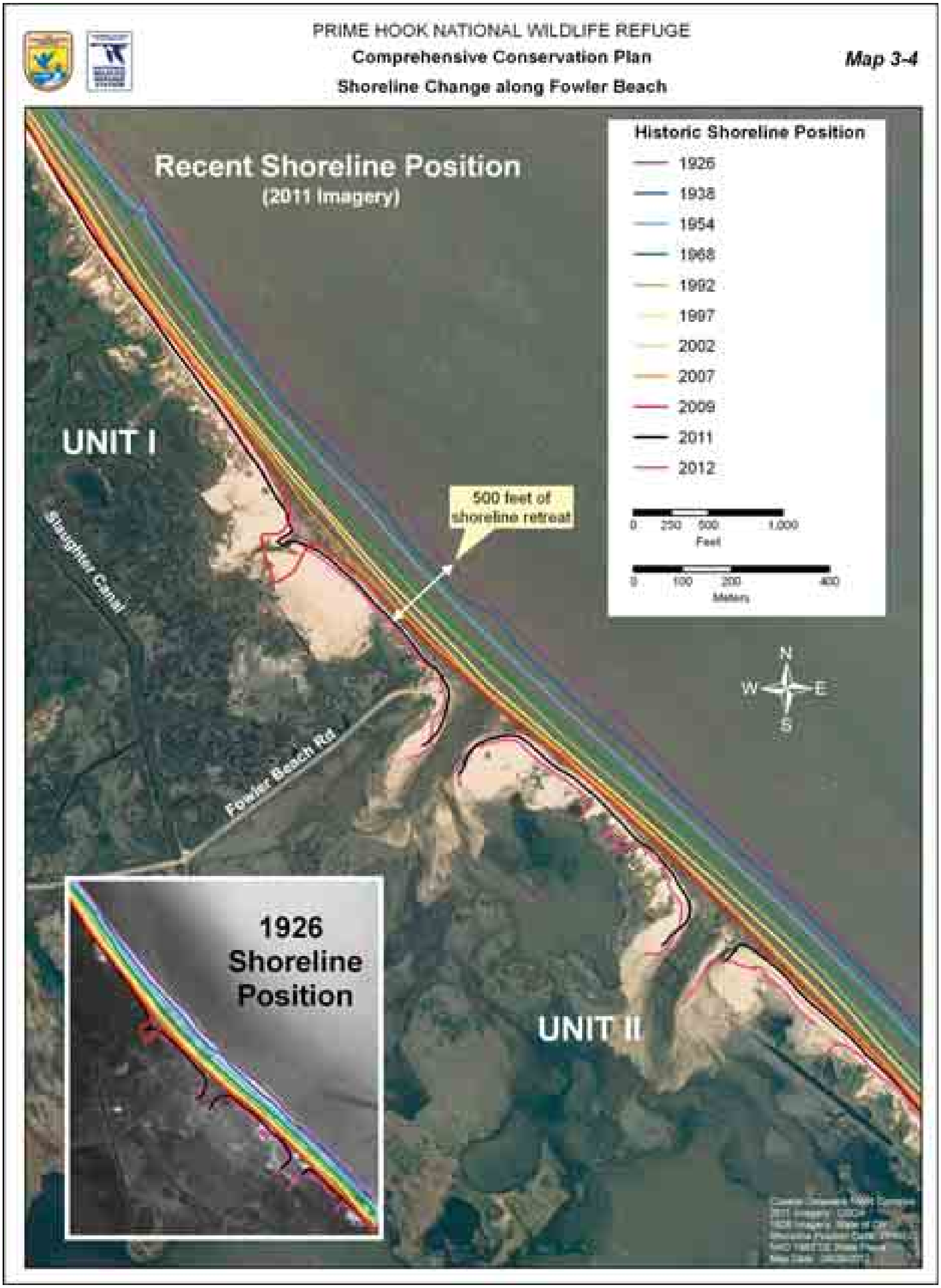
The Coastal Plain Province lies south of the fall line and makes up the vast majority of the State's land area, including the refuge. Much younger than the Piedmont, the coastal plain consists of unconsolidated sediments that have accumulated as a result of erosion of the Appalachian Mountain chain, and marine sediments deposited as a result of frequently fluctuating sea levels. The deposition of the unconsolidated sediments of the coastal plain began 120 to 150 million years ago. Eroded waterborne sands, silts, and clays were deposited, followed by marine sediment shifting during periods alternating between sea encroachment and retreat. With the advance and retreat of continental glaciers and dramatic changes of sea levels, the flowing sediments were capped by fluvial sands and gravels during the Pleistocene (1.8 million years ago). During the past 10,000 years, rising sea level has filled coastal valleys with sediment, forming extensive tidal marshes. The coastal plain today is a region of little topographic relief, with broad, slow-moving streams and extensive tidal estuaries (Hess et al. 2000).

About 5,000 years ago, the current refuge shoreline was located 3 to 4 miles east of its current position, resting what is now in the middle of the Delaware Bay. Retreating shorelines and rising sea levels systematically began to drown the ancient Delaware River valley, gradually transforming the narrow river into the wide Delaware Bay as it is currently shaped. Atlantic Coastal Plain creeks and streams meander broadly in shallow channels and the landscape is generally flat, with elevations ranging from sea level to 125 feet. The highest point in Delaware is 448 feet, located north of Wilmington near the Pennsylvania State line (Ebright Azimuth). Prime Hook NWR has very flat terrain typical of Atlantic Coastal Plain areas. The highest point within the refuge is about 15 feet mean sea level but the majority of refuge lands lie below the 9-foot contour. The uplands are gently sloping with very few steep grades; these are mostly limited to areas immediately adjacent to drainage ditches and creeks.

Along the immediate shoreline of the refuge's barrier island habitats from Slaughter Beach to Prime Hook Beach, the topography is highly variable. Natural dune ridge areas sloping away from mean high water level of the Delaware Bay vary from 1 to about 10 feet, interspersed with overwash areas ranging from 0.5 to 3-foot elevation contours based on DNREC topographic maps of Delaware beaches (1979). Short-term geological events like coastal storms and long-term geological processes of marine transgression and landward movement of the coastline have and will continue to constantly change coastline position and elevations along the refuge's sandy beach ecosystem (map 3-4).

Map 3-3. Delmarva Peninsula Hydrology and National Wildlife Refuges

Map 3-4. Shoreline Change Along Fowler Beach



The directional flow of Delaware's rivers south of the Piedmont is dictated by a dividing ridge, which is a visually unimpressive land form that rises only a few feet above the surrounding countryside. Acting as the watershed of central and southern Delaware, the dividing ridge bisects the State so that all of flat Delaware's significant river systems flow eastward into the Delaware Bay or the Atlantic Ocean, with the exception of the Nanticoke River, which drains into the Chesapeake Bay (map 3-3).

The directional flow of water bodies and upland runoff drainage patterns traveling eastward toward the Delaware Bay places the refuge at the receiving end of watershed runoff and stream flows. Therefore heavy rainfall events not tied to coastal storm events can also have significant impacts on the refuge's physical environment.

The geology of the Delaware Bay's coastline is part of larger geological structure known as the Atlantic coastal plain-continental shelf geosyncline. This shoreline of the entire lower Delaware Bay is migrating in geologic time, in a landward direction. This is caused by many geological processes. The first is subsidence or sinking. The continental shelf and Atlantic Coastal Plain are known to be subsiding. The second process is sea level rise relative to the land. A third coastal process is the erosion and redistribution of sediments in the active coastal littoral zone as the shoreline shifts in a landward and upward direction (Kraft et al. 1976).

The Beers Atlas (1868) showed the two creeks (Prime Hook and Slaughter) feeding freshwater through the marsh system flowing directly through the barrier beach into the Delaware Bay. These outlets provided unimpeded flows of freshwater from the uplands to the west; they also provided ample primary inlets for the saline waters of the Delaware Bay to inundate the lowland marshes on each high tide.

Overtime, however, with changes in the Delaware Bay shoreline, these inlets would occasionally close with sand, stopping the general eastward flow of water from the uplands. This interferred with the drainage and ultimate cultivation of the lands bordering the marshes. Around 1911, both outlets were sealed shut by a storm. The Broadkill River meandered to a new outlet two miles south. This new outlet was later improved by man and called the Rossevelt Inlet. Prime Hook Creek ended, which histocially flowed near California Avenue in the Broadkill community, in Unit III marsh with the Petersfield Ditch then taking over as the major water outlet emptying into the Broadkill River.

Attempts were made, first at the outlet of Slaughter Creek on the northern end of the marsh, to build structures that would keep the natural outlets of the creek open to the Delaware Bay. This project was subsequently abandoned and a new, man-made channel, Slaughter Ditch, was dug. This ditch carried the waters of Slaughter Creek and Cedar Creek into the Mispillion River.

As with Slaughter Creek, the mouth of Prime Hook Creek also closed premanently. With no major draingage outlet, therefore the freshwaters flowing off the uplands backed up over the marsh extending flood waters from Broadkill Road to Fowler Beach Road.

Origin and Evolution of Estuarine Washover Barriers of Delaware Bay and the Refuge

Initiation of sandy barriers along the shoreline of the Delaware Bay requires a source of coarse-grained sediment, and sufficient wave and current energy to redistribute sediments to the nearshore zone. Evolution of the estuarine barrier island habitats along the bay varies spatially and temporally as factors change in space and time. Field observations and analysis of historic data suggest that wave erosion of pre-Holocene headlands and longshore transport of sediment are the principal mechanisms for estuarine barrier formation. A conceptual model representing three stages of the development of estuarine barrier islands along the western shore of the Delaware Bay, including the project area, has been described (Maurmeyer 1978). This sequence is controlled by pre-Holocene topography and variable rates of sea level changes represented by the following stages:

(1) Initial formation of barrier as a beach abutting a pre-Holocene headland.

(2) Salt marshes surround the headland as sea level rises and long-shore transport of sand forms barriers against marshes.

(3) Burial and/or erosion of headland as sea level rises; barrier migrates landward and upward across marshes by overwash.

At the present time, stage one occurs on the northern barriers of the bayshore to Bowers Beach. Stage 2 occurs in the vicinity of headlands surrounded by marshes such as Woodland Beach, Kitts Hummock, and Big Stone Beach, along centrally located barriers along the bay shorelines. However, most of the southern barriers along the western shore of the bay are in the third stage and are dominated by overwash processes, including the refuge (Maurmeyer 1978).

Rates of Coastal Change of the Delaware Bay Shoreline

Hydrogeomorphic studies conducted by University of Delaware coastal scientists provide a baseline about the rates of shoreline transgression or migration landward of Delaware Bay shorelines. Over the 120-year period from 1834 to 1954, the bay shoreline from Slaughter Beach to Roosevelt Inlet retreated at a rate of from 1 to 25 feet per year. The refuge lies just below the Slaughter Beach community location, and the shoreline position bracketing the refuge has experienced a total change of -1,100 feet or roughly a loss of about 10 feet/year on average (Kraft et al. 1976).

This is one of the higher erosion rates along the bayshore and similar to Slaughter Beach coastal change rates. The only two areas along this stretch of the Delaware Bay shorelines that have been or are presently accreting are the Broadkill Beach groin field and the area behind Cape Henlopen near the Lewes Breakwater. Most shoreline erosion in the Delaware Bay is caused by waves generated across the Bay by local winds. Wave velocities during normal and storm events push excessive water onto the shore. The highest rates of erosion tend to occur in areas where marsh sediments and old remnant peat covered by sand form the shoreline (Kraft et al. 1976). These coastal change rates serve as a fairly precise baseline indication of the present and future refuge shoreline rates of erosion. However, a 10-foot/year rate may be too conservative in light of recent and predicted future climate change and sea level rise rates as discussed later in this chapter.

Refuge Water Level Information

Throughout the refuge, water levels change on time scales that range from minutes to thousands of years. Daily water level changes due to astronomical tides for both Mispillion and Roosevelt inlets vary from -0.7 to 5.8 feet. Even on short time scales (minutes, hours, days), wind energy and wind stress can increase water level changes to deviate significantly from astronomically predicted levels. The coastal geology of an area, bay morphology, and bathymetry are factors that influence and constantly change the periodicity and magnitude of refuge water level changes from day to day under normal conditions and with large variations during storm events. Even coastal storms that never make landfall can cause refuge water levels to change in excess of those normally predicted monthly variations in the lunar phase.

Based on averaged predicted tidal fluctuations and other geological factors, the refuge coastal zone can be characterized as a mesotidal (between 2 to 4 meters) coastal area. Massilink and Huges (2003) define coastal zone tidal ranges as microtidal (0 to 2 meters), mesotidal and macrotidal (greater than 4 meters).

Water level ranges are much more restricted within refuge impounded marshes. However, correlations between impoundment water levels are difficult to make because the Unit II water control structure was surveyed in its present location in 1988, referencing the National Geodetic Vertical Datum of 1929 (NGVD 29), and the Units III and IV water control structures were surveyed into location, including staff gauge positioned on the concrete structures, in 1984 and 2005 respectively, using a tidal (mean sea level) datum. Because the water gauges used to measure water levels in the impoundments do not all reference the same elevation datum, it is currently difficult to make direct comparisons between water level measurements in different impoundments for water management purposes.

Soils

The soils of Delaware are made up of differing combinations of sand, silt, and clay. Sand was the most abundant of the three components, proportionally increasing from the Christiana Valley to Sussex County. The soils of eastern Kent and Sussex Counties from the coast to 10 miles inland tend to have more clay and less sand components than soils located further west, especially those areas flanking the dividing ridge.

The soils of the Piedmont, which are derived from the underlying gneiss and schist bedrock, are older and tend to be more fertile than soils of the coastal plain. Piedmont soils in the valleys are rich and loamy, while the soils at higher elevations are often eroded and stony. The soils of the coastal plain vary a great deal depending on geography and habitat. Sandy soils dominate much of the region, but areas of clay or loamy texture are not uncommon. Soil drainage ranges from that which is excessively drained in beach sands and on sand ridges, to very poorly drained soils in tidal marsh and swamp muck (Matthews and Ireland 1974).

Delaware's soils are classified into four major soil orders: Ultisols (well developed, acidic mineral soils), Histosols (organic soils), Inceptisols (mineral soils in early development) and Entisols (mineral soils in late development). They are grouped into associations by location, drainage characteristics, and parent material. A soil association is a landscape that has a distinctive proportional pattern of soils. It consists of one or more major soils and at least one less extensive soil, and it is named for the major soils. Two major associations found within the refuge include the Broadkill-Mispillion-Acquango Association and the Unicorn-Carmichael Association (USDA/NRCS – D. Shields, personal communication).

Broadkill-Mispillion-Acquango Association consists of mineral and organic soils that are regularly subject to tidal flooding by saltwater, and narrow areas of loose, salty beach and dune sands. This association occupies about 80 percent of the refuge and about 5 percent of the total land area in Sussex County. The Broadkill, Mispillion, and similar soils occur on open grassy tidal marsh areas dissected by tidal creeks and streams and crisscrossed in places by mosquito-control ditches. In many places there is a brush border adjacent to higher ground. The soils consist of mostly peat or mucky remains of vegetation, some loamy soil material, and large amounts of sulfate. The marshes range from strongly saline to almost fresh along the upper reaches of streams.

A smaller portion of this association includes the Acquango soils and associated beach areas. It occupies a narrow band separating the tidal marsh areas from open water. This part of the association consists of shifting, loose, salty sand that is moved by waves and wind. The part regularly washed by waves and tides is smooth and slopes gently up from the water. That part above normal high tide consists of dunes and hummocks constantly changed by the wind. The vegetation is a sparse cover of beach grass, a few forbs, and scattered low shrubs. The beaches and dunes are used intensively for summer recreation activity and as sites for beach houses. The marshes are on the Atlantic Flyway of migratory waterfowl. Recreational activities in these marshes include waterfowl hunting, crabbing and fishing. Less extensive in this association are Purnell, Sunken, and Saltpond soils (USDA/NRCS – D. Shields, personal communication).

Unicorn-Carmichael Association consists of well-drained and poorly drained soils that have a moderately permeable subsoil of loam to sandy loams. This association accounts for about 15 percent of the total refuge area and occupies about 10 percent of the total land area in Sussex County. This association consists of approximately 55 percent Unicorn soils, 25 percent Carmichael soils, and 20 percent less-extensive soils.

Unicorn soils have a surface layer of grayish-brown loam and subsoil of strong-brown sandy loam or loam. In most areas they are nearly level to gently sloping and are moderately permeable and well-drained. Carmichael soils have a surface layer of gray to dark grayish-brown loam and a subsoil of gray loam or sandy loam. They are nearly level, moderately permeable, and poorly drained. The water table is at or near the surface for long periods during the year. Less extensive in this association are Greenwich, Pineyneck, and Longmarsh soils. Longmarsh soils are on flood plains. Well-drained Greenwich soils and moderately well-drained Pineyneck soils are intermingled with areas of the major soils and do not appreciably affect overall land use. They differ primarily in drainage class (USDA/NRCS – D. Shields, personal communication).

Coastal plain soils vary widely in the proportions of sands, silts, and clays in their location relative to the water table. Soils with high amounts of clays and silts have a tendency to be wetter because water percolates poorly. The mineral organic materials of tidal and freshwater marshes comprise three associations of very poorly drained soils rimming Delaware's coastline from Wilmington down to Fenwick's Island, surrounding the inland bays and the confluence of the Broadkill River (Matthew and Ireland 1974).

Soil associations are further delineated into more specific soil map units (map 3-5). Additional information about soils of the refuge can be found in the Prime Hook NWR Final CCP/EIS, Volume 1, chapter 3 *(http://www.fws.gov/northeast/planning/Prime%20Hook/finalccp.html)*.

Air Quality

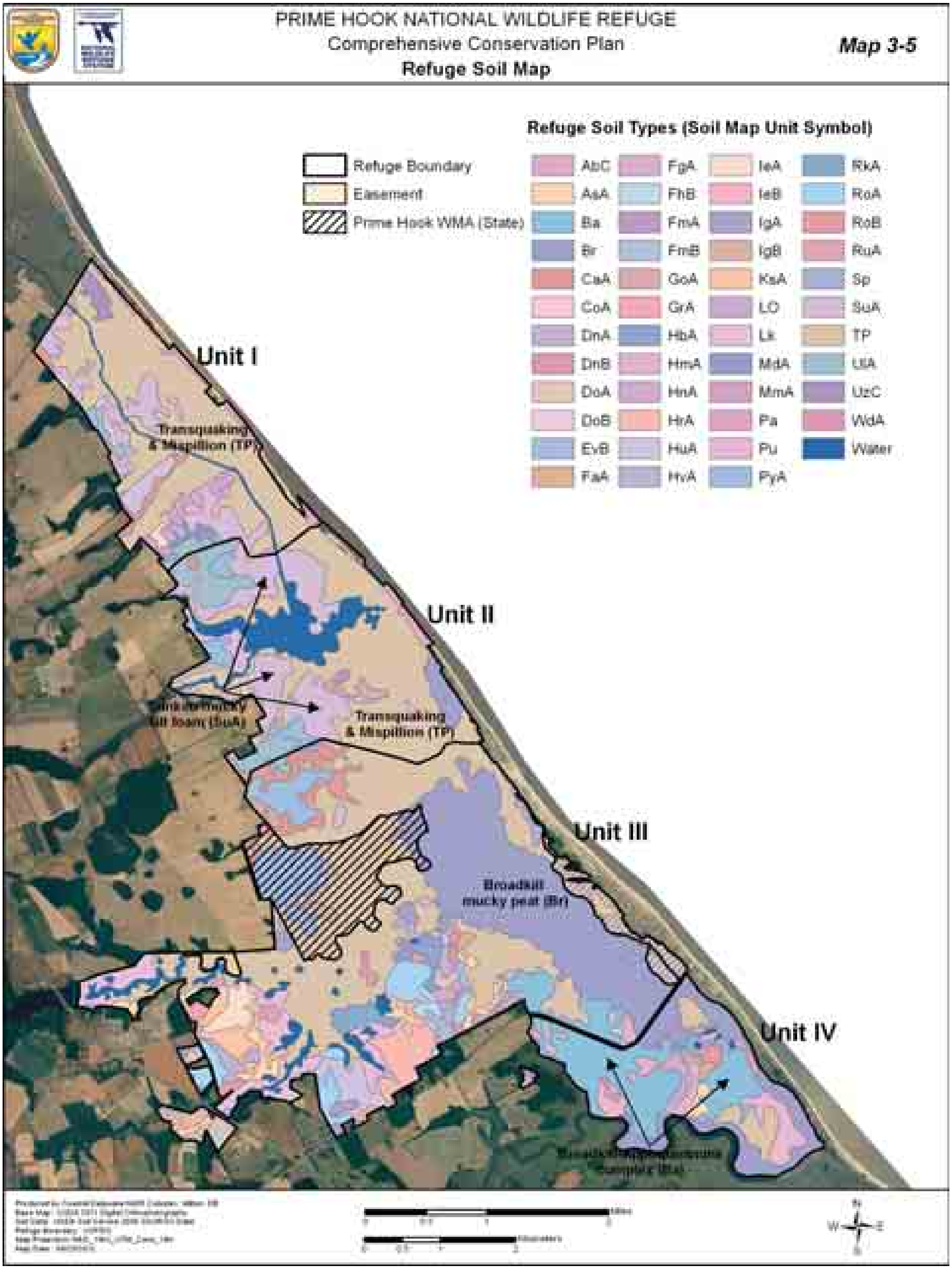
The mission of the Service's air quality program is to protect and enhance air quality in support of ecosystem management in the Refuge System. The Service's vision "is a Refuge System free of impacts from human-caused air pollution and is consistent with the Refuge System Improvement Act, which requires that 'the biological integrity, diversity, and environmental health of the [Refuge] System are maintained…'" *(http://www.fws.gov/refuges/AirQuality/index.html;* accessed January 2012).

Prime Hook NWR's greatest contribution from human-caused air pollution would occur from prescribed fire activities as a short-term intermittent source of fine particulate concentrations. Prescribed fire is an important tool to decrease dead fuel load accumulations of wildland vegetation for public safety and to improve the health of natural ecosystems. Full consideration of air quality values has been made in Prime Hook NWR's fire management plan for all prescribed fire planning and operations (see Smoke Management Section 4.2.1.5 of Prime Hook NWR's Wildland Fire Management Plan (March 2009)).

The Air Quality section of DNREC's Division of Air Quality and Waste Management monitors levels of ozone and particle pollution from nine locations throughout the State. The Lewes monitoring station is the closest to the refuge. These sites have been monitoring air quality since the late 1960s. Air monitoring stations are used to house continuous monitoring instruments that measure criteria air pollutants.

A criteria air pollutant has a national ambient air quality standard (NAAQS) established for it by the EPA. There are currently seven criteria pollutants: sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, lead, particulate matter less than 10 microns in diameter (PM10) and particulate matter less than 2.5 microns (PM 2.5).

Map 3-5. Refuge Soil Types



Local air quality is affected by regional issues. In general, air quality in Sussex County is good during the winter and spring, but only fair in summer and fall. From Memorial Day to Labor Day, Sussex County is often in non-attainment state for NAAQS, meaning pollution limits set by the EPA have been exceeded for several consecutive years. Limiting smoke impacts resulting from prescribed fire is important to protect public health and safety. For this reason, prescribed refuge burns usually occur in late winter or early spring.

Water Quality

DNREC's Division of Water Resources manages and protects the State's water quality through seven sections. The Water Assessment Section protects water from nonpoint source pollution and plans monitoring and management actions to improve water quality on a watershed scale to protect human health and the State's environment. There are 45 delineated watersheds in Delaware and Prime Hook NWR is influenced by three: Mispillion River, Cedar Creek, and Broadkill River watersheds. The most recent water quality assessments performed by this Section (State of Delaware 2008 Combined Watershed Assessment Report 305(b) and Determination for the Clean Water Act Section 303 (d) List of waters needing TMDLs) indicates that a majority of the State's water resources are suffering from poor water quality.

Water quality monitoring has shown that more than 92 percent of Delaware's waterways are considered impaired. Impaired waters are defined as polluted waters based on EPA water quality standards. Of 2,506 miles of rivers and streams tested for water quality attainment, 2,497 miles have been documented as impaired. Of the 2,954 acres of lakes, ponds and reservoirs, 2,798 acres were found to be impaired (State of Delaware 2008 303(d) Impaired Waters List pp. 89 to 125).

Pathogenic indicators (bacteria) are the most widespread pollutants in the State. The pathogen indicator monitored by DNREC for primary contact recreation is *Enterococcus* bacteria. Other pathogen indicators (total and fecal coliform bacteria) are monitored to regulate shellfish harvesting areas.

Although pathogenic indicators are the most widespread in Delaware, nutrients and toxics pose the most serious threats to water quality. All of the State's estuarine waters are considered nutrient-enriched. Water quality and negative impacts to aquatic organisms from nutrient enrichment include eutrophication and low dissolved oxygen levels. Large portions of nutrients are transported to estuaries and ponds via rivers and ground water.

The presence of toxic substance concentrations above EPA standards for human health triggers the publication of fish advisories by the State. In 2007, the State fish consumption advisories included, for the first time, waterways within Prime Hook NWR or immediately adjacent to the refuge. These included Prime Hook Creek, Slaughter Creek, and Waples Pond (see table 3-1 below).

Table 3-1. State of Delaware Fish Consumption Advisories

State of Delaware Fish Consumption Advisories			
Waterbody	**Species**	**Geographic Extent**	**Contaminants**
Mouth of Delaware Bay	Striped Bass White Perch American Eel White Catfish	South of C and D Canal entire Delaware Bay to Mouth of Atlantic Ocean	PCBs, Mercury
Waples Pond	All Finfish	Entire Pond	Mercury
Prime Hook Creek	All Finfish	Entire Creek	Mercury
Slaughter Creek	All Finfish	Entire Creek	PCBs, Dioxin, Furans

Multiple sources are cited for poor water quality of Delaware's waterways. These include nonpoint sources of agricultural runoff, septic system failures, animal feed lot operations, urban runoff, and municipal and industrial point sources as the primary origins of nutrients and toxic substances.

The Delmarva Peninsula is one of the largest poultry production areas in the U.S., generating more than 600 million chickens and 1.6 billion pounds of manure annually. The State of Delaware ranks 7th in the Nation in the number of broilers produced. Statewide, this industry is represented by about 900 chicken farms with the largest portion found in Sussex County. There are four chicken farms immediately adjacent to Prime Hook NWR that produce 500,000 to 1 million birds per year. Within a 6-mile radius of the refuge, about 19 poultry farms are located that produce 3 to 5 million birds annually (DDA 2007).

Water quality problems associated with the animal feeding operations were investigated on Prime Hook NWR by contaminant biologists in the Chesapeake Bay Field Office concerned that excessive land application of poultry litter has resulted in severe water quality problems in surface and groundwater on the Delmarva Peninsula (McGee et al. 2003). The study provided direct evidence for transport of tetracycline compounds found in waterbodies from poultry litter applied on the fields in the Delmarva peninsula. It should be noted the data are very limited, both in terms of the number of samples and the geographic coverage.

Cladophora **Algal Bloom Event During Winter, Spring, and Summer of 2010**
Large mats of native *Cladophora* algae began to develop in early February in the Unit II impoundment. By April, the bloom expanded to encompass 700 acres immediately adjacent to Prime Hook Road. Since the algal mats emerged in late winter, robust thick mat growth developed by early spring, effectively allowing the *Cladophora* to out-compete other marsh plants during the growing season.

The bloom remained confined to the southern portion of Unit II until early May when it spread into the northern part of the Unit III impoundment adjacent to Prime Hook Road. The spread was probably facilitated by the hydrological connection between Units II and III via several road culverts. By mid-July, the algal mats began to decrease in size and disappear. This was the first time that such an algal bloom event occurred on the refuge, and was probably triggered by a combination of changing environmental conditions in Unit II and climatic influences.

The breaching of Unit II dune line in 2009 changed the salinity conditions of the impoundment where ranges of 20 to 25 ppt became the norm throughout the entire 1,500-acre impoundment. Then heavy snowfall in January and early February triggered extensive runoff from upland areas into the refuge. Marine *Cladophora* species have an optimal temperature range that maximizes development (50 to 77 ^{0}F). Snow melt and extensive runoff spiked phosphorus loading into the system and perfect growth conditions triggered the bloom. When temperatures exceeded 80 ^{0}F by August, algal mats began to disappear.

As a result of the algal bloom, refuge staff was concerned about excessive nutrient loads within Unit II. Water samples were taken at three locations on May 19, 2010. The samples were analyzed by the University of Maryland, Center of Environmental Science, Chesapeake Biological Laboratory in Solomons, Maryland. Two of the samples were located on the refuge and one on upper Slaughter Creek, which flows into the refuge.

Delaware has no numeric water quality standards for total nitrogen or different forms of phosphorus. For ammonia (NH4), the numeric values are pH and temperature-dependent. The results for the three water bodies (pH 8; 25 ^{0}C) are found in table 3-2.

Table 3-2. Results of water quality testing in May 2010

Sample Id	CBL	NO2	NH4	PO4	NO23	TDP	TDN
	NUMBER	(mg N/l)	(mg N/l)	(mg P/l)	(mg N/l)	(mg P/l)	(mg N/l)
UNIT II	1	0.0009	0.016	0.0027	1.094	0.0336	2.36
SLAUGHTER CREEK	2	0.0495	0.746	0.0530	4.940	0.1213	6.70
UPPER SLAUGHTER CREEK	3	0.0594	0.091	0.0476	5.640	0.1423	6.81

Total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), nitrite plus nitrate (NO23), phosphate (PO4), and nitrite (NO2) are all nearly equal in the creek, but Slaughter Creek is nearly 10 times higher in ammonia content. The bloom in Unit II does not correspond with high nutrient concentrations, as the concentrations for all nutrients in Unit II are the lowest of the three areas.

Geochemical changes associated with the intrusion of saltwater back into these wetland areas are potentially evident in these water quality findings. Sediment subsidence is of particular concern in diked flooded marshes following tidal restoration, which could lead to prolonged flooding and sulfide toxicity (Portnoy et al. 1997). Plant death and peat collapse have been noted after saltwater intrusion in Louisiana brackish marshes. Ferrous iron toxicity, which may also inhibit *Spartina* growth, is also a concern. As for sulfide, however, FE (II) and Al phytotoxicity could be offset by abundant nutrients, especially NH4. The potential large mass of nutrients mobilized by increased decomposition, cation exchange, and phosphate mineral dissolution during saltwater intrusion could depress dissolved oxygen in surface waters by promoting algal production and organic loading (Portnoy et al. 1997).

Portnoy's research emphasizes that saltwater intrusion can substantially affect estuarine plants and animals. These changes include sulfide accumulation, metal increases, and nutrient mobilization as well as subsidence.

Concerns were also raised regarding the algal mats containing *Enterococcus* and *E. Coli* bacteria. These bacteria are naturally occurring in the environment. The refuge contracted with DNREC's Division of Water Resources to analyze water samples from July through August. The results concluded that neither bacteria exceeded State or EPA standards.

Ground-Water Contamination from Lead Shot

For 37 years, the Broadkiln Sportman's Club, which is adjacent to Prime Hook NWR on the southwestern corner of the headwaters of the Prime Hook Creek, operated a trap-shooting range. Clay target launchers were oriented so that expended lead shot dropped into a forested wetland and upland grassland areas on Prime Hook NWR. After many years of lead shot deposition, it was discovered that lead shot concentrations were as high as 57,868 pellets per square foot in many areas on the refuge lands adjacent to the Club.

The club was founded in 1962 in Pikes Neck, Sussex County. The club used five trap houses, each with five shooting stations. Shotgun rounds were projected across a grassy field toward a wooded wetland intending to hit airborne clay targets above the field. Numerous lead shot pellets from misses and overshot trajectories often hit trees inside the refuge boundary, fell to the ground, and accumulated through the years.

The portion of Prime Hook NWR bordering the club, which is down range from the trap-shooting area, consists of a forested wetland along a small tributary or slough draining into Prime Hook Creek. The slough varies in size and shape with the seasonal rise and fall of the water table, and dries up completely on occasion.

This slough is heavily forested and used by migratory birds, small mammals, and amphibians.

The trap-shooting range was operated from 1962 to 1998 until a proposed land swap with the Service was initiated by the club. Upon this request, the Service initiated a level one contaminant survey of refuge lands. In August and October of 1998, Service personnel collected soil samples to determine the extent of lead shot deposition and lead soil concentrations. Results showed significant lead contamination. The Service ordered the club to discontinue depositing lead shot onto refuge lands, and in 2000 initiated a 3-year refuge cleanup project.

A preliminary assessment in 2000 determined that an affected area of 22 acres down range of the club had accumulated most of the lead shotgun pellets with the highest densities concentrated in a zone approximately 26,200 square feet referred to as the drop zone (Crowley and Richardson 2001), as part of an environmental risk assessment prepared by Service contaminants biologists and USGS investigated the potential for lead soaked soils to leach into the groundwater.

Results from 2 sampling rounds of 19 wells (May 2000 and April 2001) showed that elevated levels of dissolved lead were present in the groundwater on Prime Hook NWR. The USGS study was designed as a field screening to give the Service some indication of the scope of the groundwater lead problem. Lead transport through shallow ground is an unusual occurrence, as metallic lead is generally considered immobile. USGS further investigated the chemistry of the process of lead mobilizing from the surface down to the groundwater.

Study results verified that low pH values were recorded in the groundwater ranging from 4.8 to 6.4. These acidic environmental conditions were responsible for dissolving the lead carbonate from the pellets. Because of the lack of buffering capacity and adsorption sites in the silica-rich sediments of the area, the dissolved lead was mobilized and moved into the groundwater on the refuge.

A biomonitoring study was initiated in the spring of 2002, prior to removal of the contaminated uplands that occurred in 2003. The study was repeated the following 2 years to document changes in the levels and bioavailablity of lead in the downgradient wetland sediments. Southern leopard frog *(Rana sphenocephala)* tadpoles at Gosner stage 24 were collected from an unimpacted pond on the NWR and placed in enclosures in wetlands at a reference site and at two wetland sites within the shooting trajectory with different concentrations of lead. The amphibians were removed when those at the reference site completed metamorphosis. The gut was removed, and the body analyzed for lead and the liver analyzed for amino levulinic acid dehydratase (ALAD) activity. We found statistically significant differences in ALAD in 2002 among the three sites, indicating inhibition at both the hot and warm locations (less than 0.015 nmol porphobilinogen/per gram liver per hour) relative to the reference (0.20 nmol). In 2004, both sites had significantly lower activity than the reference. The warm site improved in 2005 (0.18 nmol) but was still significantly lower than the reference (0.25 nmol). The hot location average also improved to an average of 0.086 nmol, about five times the initial average. Lead concentrations were significantly different at sites (p less than 0.001) in each of the 3 years. In 2002, the average whole body lead concentration was 59.9 ppm at the hot location, 1.34 ppm at the warm location, and 0.176 ppm at the reference location. At the hot site, there was a steady decrease in whole body lead concentrations from 2002 to 2004 and 2005, but average concentrations were still 350 times that for the reference. Warm site average concentrations decreased and then increased back to the 2002 concentration, which was about 17 times the reference. The study is planned to be repeated in 2011 to note any changes.

The Service has physically excavated and removed part of the pellet-contaminated soils on Prime Hook NWR, which has since re-vegetated with native plants. The major source of groundwater contamination has been remediated on Prime Hook NWR. The attenuation of high lead concentrations in the ground water will require long-term monitoring to confirm the potential of natural attenuation of the system (Soeder and Miller 2003). Water quality monitoring by the Service's Chesapeake Bay Field Office is still ongoing. The refuge has not acquired any of the lands owned by the shooting club, so it does not control all of the impacted or unremediated lands affected by the lead shot deposition. Today, the gun club is no longer operating as such, and the private lands remain unremediated.

History of Vegetation on and Around the Refuge

Prehistoric Climatic Influences on Delmarva Landscape Vegetation

Prehistoric climatic influences that shaped the landscape of the Delmarva Peninsula and refuge lands revolved around the rise and fall of sea levels. All of the Delmarva Peninsula south of Elkton, Maryland and Newark, Delaware is essentially a large sandbar built from sediment left by the sea or eroded off the ancient Appalachian continent over the past 150 to 200 million years. The peninsula is located in the Atlantic Coastal Plain, itself a relatively recent emergence of the continental shelf (Scott 1991).

For tens of millions of years, the sea continued to rise and fall and the rivers washed sediments off the land creating today's features of the Delmarva Peninsula. The last Ice Age on Delmarva occurred about 25,000 years ago with the Wisconsin Glacier. Each time the climate warmed, the amount of water released by this melting ice floe caused sea levels to rise high enough to flood the entire peninsula. During these melting phases the water rose 30 to 40 feet above its present levels, depositing a thick layer of maritime sediment sandy soil on southern Delmarva.

During freezing periods, so much of the earth's available water was incorporated into ice that the sea dropped hundreds of feet below current sea level. The receding of the sea from the peninsula often left behind the poorly drained depressions that are now known as Delmarva bays (Scott 1991). A well-known Delmarva bay adjacent to the refuge (Huckleberry Swamp) and several similar depressional swamp areas on the refuge (total of six depressional wetlands) have been recently mapped by DNHP botanists in 2005 and 2006 (McAvoy et al. 2007).

These depressional wetland types are an important natural resource in Delaware and are considered a top priority for protection by DNREC. They are today becoming rare because they are not regulated and are easily destroyed by ditching, draining and filling. Important groundwater recharge areas also provide habitat to State rare plant species and are extremely valuable to amphibians that utilize refuge depressional wetlands for breeding purposes (McAvoy et al. 2007).

Delaware Bay and adjacent land surfaces have undergone substantial environmental and vegetative changes. During the Late Pleistocene geological epoch, approximately 15,000 years before present (BP), continental ice sheets of the Late Wisconsin Glacier advanced south to New York and northern Pennsylvania. The glacier stopped just north of Trenton, New Jersey. It was a veritable mountain of ice, several thousand feet thick. Ice sheets, which covered the entire globe, incorporated so much of the earth's available water that the sea dropped more than 300 feet and caused the continental shelf to emerge from the sea east of the Delmarva Peninsula. Pollen samples dating 11,500 BP when the Wisconsin Glacier was at its height, show that extensive grasslands covered its exposed face and were interspersed with patches of pine, spruce, fir, and hemlock tree species representative of a boreal forest stand (Scott 1991).

During the 1970s, John Kraft and his students from the University of Delaware conducted stratigraphic coring on and near the refuge. These studies indicated the magnitude of coastal changes during the Holocene period of human occupation of the southern Delaware coastal environments. Slaughter Beach is underlain by 40 feet of soft mud deposited by estuaries during the early and middle Holocene. From Prime Hook Beach south to Broadkill Beach, modern barrier beaches cover estuarine mud from depths of 10 to 60 feet. At Fowler Beach, Pleistocene sand and gravel of the former Slaughter Neck headland occur at depths of 8 feet below present mean sea level (Kraft et al. 1976).

Hoyte (1980) extracted nine stratigraphic cores on the refuge along Slaughter Creek and has suggested that lagoons behind barrier beaches changed from freshwater marshes to brackish marshes over the past five centuries. In upland area, core samples near the creek (Slaughter Neck) contained Delmarva fox squirrel bone fragments, identified by their unique feature of glowing under black light. In March 2004, Tetra Tech Research, Inc. extracted six additional vibracores from streamsides and near-shore wetlands, and excavated four machine trenches on adjacent refuge uplands to examine erosion and sediment accretion related to sea level rise and associated vegetative changes.

Prehistoric and Historic Cultural and Environmental Setting and Human Land Use History

While the Service's mission is conserving wildlife, all Federal agencies are responsible for stewardship of the important archaeological sites and historic buildings on Federal land. The Service's Regional Historic Preservation Officer reviews activities which include alterations to historic buildings or ground disturbing activities for their potential to affect sites and structures. Based on this review and consultation with State Historic Preservation Offices, the Service may conduct archaeological and architectural surveys and may mitigate impacts to these cultural resources. The Service maintains an inventory of known archaeological sites and historic structures on its land in the Regional Office and at refuges.

In 2004, the Service contracted an archaeological overview of Prime Hook National Wildlife Refuge. The Report, "Archaeological, Historical and Geomorphological Study of Prime Hook National Wildlife Refuge," includes information about the dates and rates of sea level rise at Prime Hook, as well as information about where people used the refuge land at different points during the past. At Prime Hook NWR, we know of 44 archaeological sites, and there are likely to be many more. There are no historic structures at the refuge. Fifteen of the refuge's 44 known archaeological sites are in what is today the salt marsh.

People may have been at the refuge at least 10,000 years ago, based on the recovery of an Early Archaic Kirk spear point from the salt marsh during Open Marsh Water Management by the State of Delaware in 1989 and 1990. At that time, the refuge was far from the shore of the ocean, and people would have oriented themselves to sources of fresh water on the refuge. Cara Blume, then of the Delaware Department of Parks and Recreation, developed an archaeological site sensitivity map based on a model of former fresh water sources at the refuge (Tetra Tech FW 2004:Figure10). Both sea level rise and land subsidence have affected the refuge. The refuge's archaeological sites also provide evidence of Native American occupation through the Woodland II Period 1000–500 years ago. European settlers' land ownership records for the refuge can be traced to the 1680s. Many of these locations are now located in seasonally wet soils or in actual salt marsh. As sea level and ground water rose, and the land subsided, once-dry locations became no longer habitable. The loss of salt marsh to erosion will not only affect habitat at the refuge, but also archaeological sites.

Understanding what the historic natural vegetation types were in refuge areas, how they were distributed, and what ecological processes influenced them prior to major human-induced influences provides a reference point to manage for BIDEH. These can pinpoint a baseline framework to evaluate future restoration and management options. However, we have noted that, when considering the restoration of areas to native vegetation, ecologists caution against selecting one point in time and instead recommend managing for a historical range of variation for each habitat type (Egan and Howell 2001).

Historic range of variability is a method used in restoration ecology to describe how natural ecosystems have a range of historic conditions in which they are self-sustaining and beyond which they move to a state of unsustainability due to degraded biological integrity, low biodiversity, or impoverished environmental health (Egan and Howell 2001).

Agriculture was the primary cause of deforestation and draining of wetlands. Soil fertility over much of the Delmarva Peninsula continued to decline as the soils had no time to recover from tobacco cultivation followed by the intensive plantings of wheat and corn. Many of Delmarva's rivers became clogged with silt as deforestation and agriculture facilitated erosion of uplands, so once prosperous shipping and coastal towns became economically stranded.

Negative impacts to wildlife continued as natural habitats were destroyed. With the elimination of natural predators, squirrel populations increased. Bounties were established for squirrels, which were damaging crops. Deer numbers were drastically reduced due to overharvesting. Wild turkeys, estimated at more than 10,000 birds in Delaware before the advent of European settlement (Williams 2008), were hunted nearly to extinction by the early 19th century, along with Delmarva fox squirrels.

Sussex County underwent substantial development during the 20th century. The advent of the automobile funneled large numbers of tourists and vacationers to coastal areas. Most 19th century structures continued to be occupied into the 20th century. The Service has identified several sites constructed during the 20th century, including sport-hunting camps and other historic sites on the refuge (Tetra Tech 2004).

Increased beach resort development and beach home construction continued in the latter part of the 20th century and into the 21st, shrinking the size of undeveloped sandy beach ecosystems remaining in the State. Undeveloped bay and ocean shorelines represent a disappearing natural habitat type in Delaware.

History of Agricultural Management on and around the Refuge

In pre-settlement North America, waterfowl were dependent on aquatic, marsh, and shoreline vegetation and the mast and seeds of terrestrial plants of seasonally flooded bottomland forests for food. The conversion of North American forests and wetlands to agricultural lands, and the degradation and loss of wetland habitats to development, drainage, and pollution, gradually changed North American waterfowl feeding habits. As wetlands diminished and farmlands increased, many waterfowl adapted to foraging in croplands, i.e., in crop stubble, on waste grain, and on the weedy herbs that colonize fields between crop rotations.

Game agencies use farming to attract and provide forage for waterfowl on wildlife management areas. On the Delmarva Peninsula, crop or food plot management has been conducted largely to attract Canada geese, and to a lesser extent, dabbling ducks. Cropland management has also been a traditional habitat management tool on national wildlife refuges nationwide. Refuges have used farming to attract and feed waterfowl species to support migrating goose and duck populations, as well as to provide hunting and viewing opportunities for the public. Prime Hook NWR began a cooperative farming program when the refuge was created in the 1960s. At that time, the refuge also managed the farming program to support duck production, with croplands in grass/clover stages of rotations designed to provide nesting habitats for ducks. At its peak in the 1970s, 1,070 acres were in agricultural production on the refuge. In 2006, the last year of the cooperative farming program, the refuge farmed 485 acres.

Historically, waterfowl were the most closely monitored and managed bird populations on national wildlife refuges. Much of the Refuge System's land acquisition and management capability was funded by an interest in game birds. Emerging status and trends data on many migratory bird groups, such as songbirds, colonial waterbirds, shorebirds, and raptors, as well as other wildlife, including mammals, fish, herpetiles, insects and plants, has expanded the conservation mission of the Refuge System beyond waterfowl alone. The current purposes and mission of Prime Hook NWR include conserving all processes and organisms comprising healthy ecological communities of coastal Delaware.

At its peak, the cooperative farm program at Prime Hook NWR managed 48 small fields averaging 22.3 acres each, for a total of 1,070 acres, or 0.073 percent of the total cropland (2007 acres) on the Delmarva peninsula. As part of a cooperative agreement on Prime Hook NWR, farmers historically planted several hundred acres of nonnative cover crops (barley, clover, or wheat) as green browse for geese after the harvest of the corn or soybean crop. In 2007, Sussex County alone managed nearly 35,000 acres of green browse; there was a total of 306,120 acres of green browse on Delmarva.

Prior to establishing a cropland management program, Refuge Policy 6 RM 4 states the refuge must develop a cropland management plan. The plan must describe how refuge wildlife population objectives will be achieved through the production of grain. Prime Hook NWR's cropland management plan was approved in 1970. Since its development, the refuge cropland management expanded to include additional lands acquired in the 1970s to the present. Farming techniques, pesticides, best management practices, etc., have changed tremendously since the original cropland management plan. Prime Hook NWR's cropland management plan has been outdated and obsolete for many years; it did not include the use of more advanced agricultural techniques and best management practices, such as integrated pest management.

In addition to Refuge Policy 6 RM 4, two acts of Congress also play a role in the cropland management program: NEPA and Refuge System Improvement Act (1997). NEPA requires the government to evaluate the impacts of its management actions to the affected environment. The Improvement Act requires the refuge to ensure that cooperative farming is compatible with the purpose for which the refuge was established. Cooperative farming is also considered an economic use and Refuge Policy 5 RM 17 plays a role in the formation of cropland management planning.

In 2006, the Delaware Audubon Society, Center for Food Safety, and Public Employees for Environmental Responsibility filed suit against the Service for the refuge's failure to comply with these acts and policies. In 2009, the judge enjoined the refuge from farming and planting genetically modified organisms until the refuge completed compatibility determinations and environmental assessments dealing with the impacts. The refuge ceased all farming operations in 2006, and this CCP serves as the required NEPA analysis of farming as a management option.

History of Refuge Wetlands and Wetland Management

The wetlands on and around the refuge have been shaped by many natural and human-caused factors over the last century. Table 3-3 provides a summary of wetland history.

Table 3-3. Summary of Historic Wetland Survey Findings in the Prime Hook NWR Area. 1976 DE Wetland Atlas Designations: Zone I dominated by salt marsh cordgrass *(Spartina alterniflora)*; Zone II dominated by salt hay *(Spartina patens)* and spike grass *(Distichlis spicata)*; Zone III dominated by salt bush species *(Iva frutescens* and/or *Baccharis halimifolia)* mixed with salt hay or spike grass; Zone IV dominated by giant reed grass *(Phragmites australis)*; Zone V is a transitional wetland type with no dominant species.

	Early 1900s	1951 Survey of Delaware Wetlands Findings			Wetland Survey Work Conducted by the University of Delaware and DNREC in the 1970s	
Refuge Unit(s)	**Compiled from early narratives and accounts**	**Dominant Vegetation Species**	**Salinity Range**	**Additional Comments**	**1973 Vegetation Map Dominant Species**	**1976 DE Wetland Atlas Zone(s)***
Unit I	Slaughter Canal was dug by landowners to improve drainage on nearby uplands, thus altering and limiting tidal flow in the salt marsh.	big cordgrass, salt marsh cordgrass, salt hay, cattail, *Phragmites,* three-square, panic grass, marsh mallow, high tide bush, groundsel bush; **In the brackish portions:** duckweeds, pondweeds, bur-reed, cattail, water willow, wild rice, pond lilies, rushes, smartweeds	1.7 – 38.8 ppt	In spite of the large acreage encompassed by this marsh survey unit, use of the area by waterfowl was low compared to other parts of the State.	*Spartina patens* *Spartina alterniflora* *Phragmites australis* *Iva frutescens* *Spartina cynosuroides* *Typha* spp. *Panicum virgatum* *Hibiscus palustris*	Zone I Zone II Zone III Unit I shoreline categorized as Zone IV
Unit II	Slaughter Creek flowed through this marsh directly into the Delaware Bay until the outlet was closed by a storm. Much of the marsh was grid-ditched for mosquito control.	big cordgrass, salt marsh cordgrass, salt hay, cattail, *Phragmites,* three-square, panic grass, marsh mallow, high tide bush, groundsel bush; **In the brackish portions:** duckweeds, pondweeds, bur-reed, cattail, water willow, wild rice, pond lilies, rushes, smartweeds	1.7 – 38.8 ppt	In spite of the large acreage encompassed by this marsh survey unit, use of the area by waterfowl was low compared to other parts of the State.	*Phragmites australis* *Spartina alterniflora* *Spartina patens* *Iva frutescens* *Spartina cynosuroides* *Hibiscus palustris*	Zone I Zone II Unit II shoreline categorized as Zone IV
Unit III	Prime Hook Creek flowed through this marsh and through the barrier beach directly into the Delaware Bay. It brought tidal water into this salt marsh daily, until the outlet was closed by a storm.	**In the saline portions:** *Phragmites,* big cordgrass, salt marsh cordgrass, cattail, salt hay, groundsel bush, marsh mallow; **In the fresher portions:** cattail dominates; also, bur-reed, pondweeds, smartweeds, chufa, wild millet, three-square, sweet pepper bush, rushes, common ragweed	0.1 – 18.6 ppt	A high barrier along the coast is cited as the reason there as less true salt marsh vegetation in this unit than in areas north and south. Occasional influx of saltwater through breaks in the dune are also noted. Expansion of *Phragmites* is noted. Survey unit contains areas recommended for future water level management.	*Phragmites australis* *Spartina alterniflora* *Iva frutescens* *Spartina patens* Mixed Species *Typha* spp. *Hibiscus palustris*	Zone IV Zone V Southern portion of Unit III categorized as Zone II
Unit IV	Much of this marsh was grid-ditched in the 1930s for mosquito control.	**In the coastal portion:** salt hay, big cordgrass, salt marsh cordgrass, high tide bush, groundsel bush, marsh mallow, panic grasses **In the small fresher areas:** cattails, smartweeds, swamp dock, water willow, pondweeds, *Phragmites*	1.4 – 29.0 ppt	Low muskrat production was attributed to presence of mosquito control ditches that were cleaned each year.	*Spartina patens* *Spartina alterniflora* *Iva frutescens* *Phragmites australis* *Typha* spp. *Hibiscus palustris* *Spartina cynosuroides*	Zone I Zone II

Refuge Vegetation Resources

Mapping Refuge Vegetation

Mapping of vegetation communities was conducted from 2005 to 2007 by DNHP and NatureServe on the refuge, excluding about 827 acres of easements. Mapping was conducted according to the NVCS, which is the Federal standard. This system classifies vegetation on a national scale for the United States and is linked to the international vegetation classification. The NVCS provides a uniform name and description of vegetation communities found throughout the country and helps determine relative rarity. The NVCS classification standard is organized into a natural vegetation hierarchy that consists of eight levels based on floristic and physiognomic criteria that include:

(1) Formation class
(2) Formation subclass
(3) Formation
(4) Division
(5) Macrogroup
(6) Group
(7) Alliance
(8) Association

The NatureServe group generated a report summarizing a subset of the international classification standard covers of vegetation associations attributed to Prime Hook NWR in 2006. Their report includes vegetation community element descriptions, element distributions along the Mid-Atlantic and Northeast, and global rarity rankings of refuge communities (McAvoy et al. 2007). Vegetation communities were described using 2002 aerial photography and field studies.

It should be noted that, as a result of the recent shoreline changes in Unit II (overwashes, inlets), these vegetation communities may be changing in composition and in size. With many of these areas in transition, the exact nature and extent of these changes are not known.

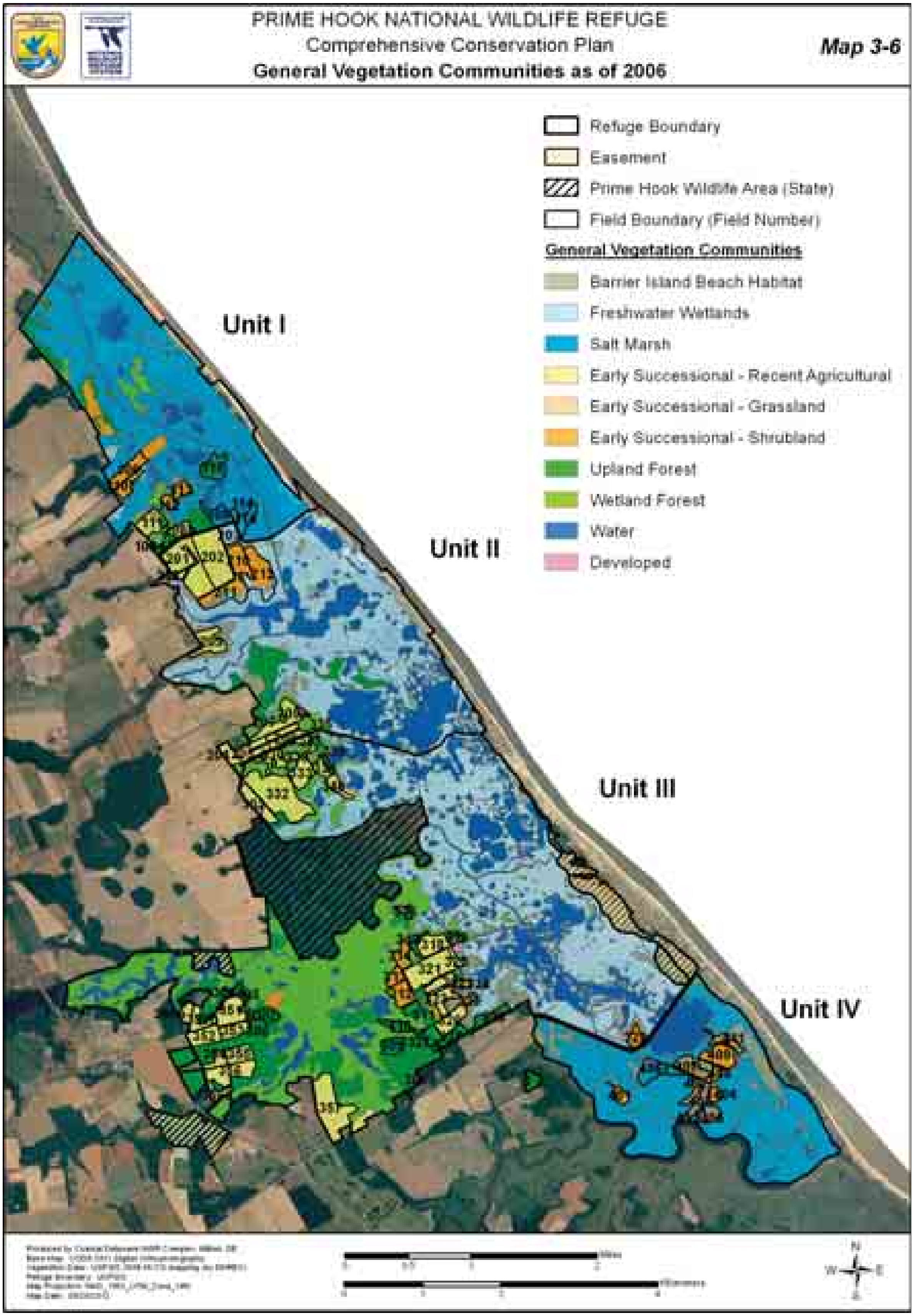
Prime Hook NWR General Flora Description

Refuge plant surveys conducted in 2004 and 2005 by DNHP botanists provided data on vegetation conditions and species composition at that time (McAvoy et al. 2007). Natural habitats dominate refuge vegetation. Approximately 80 percent of habitat cover types represented by emergent wetlands are shaped by tidal and freshwater creek drainages that discharge into the Delaware Bay. These coastal marsh habitats are also interspersed with swamps, upland forests, shrublands, and grasslands representative of the Delmarva coastal plain ecosystem. NVCS cover typing delineated 37 distinct vegetation community types, including anthropogenic communities and water surface coverages (map 3-2). For more general discussions during the CCP development, a less detailed map combined the NVCS communities into 10 broad vegetation and land cover classes (map 3-6).

The flora of Prime Hook NWR is represented by 100 families and 247 genera. The largest families are the sedge family (Cyperaceae) with 60 taxa and 11 genera, followed by the aster family (Asteraceae) with 57 taxa and 34 genera, and the grass family (Poaceae) with 45 taxa and 30 genera. The largest genera include *Carex* (28 taxa), *Quercus* (nine taxa), *Eleocharis* (eight taxa), *Polygonum* (eight taxa), *Bidens* (seven taxa), *Eupatorium* (seven taxa), *Juncus* (seven taxa), *Asclepias* (six taxa), *Cyperus* (six taxa), and *Rhynchospora* (six taxa) (McAvoy et al. 2007).

The majority of refuge plants are perennial broadleaf herbs with 131 taxa, followed by annual broadleaf herbs with 58 taxa. Graminoids (grasses, sedges, and rushes) are a large component of the refuge's flora, equaling 112 taxa, (45 taxa of grasses, 60 taxa of sedges, and 7 taxa of rushes). Trees and shrubs

Map 3-6. General Refuge Vegetation Communities



are also very prominent in the flora, with 29 taxa of deciduous trees, 6 taxa of evergreen trees, 32 taxa of deciduous shrubs, and 5 taxa of evergreen shrubs. True ferns [e.g., cinnamon fern *(Osmunda)*] and their relatives [e.g., tree club-moss *(Lycopodium)*] form a unique assemblage of the flora with 16 taxa.

Most of the refuge's flora is wetland plants (wetland indicator status of facultative-wet and obligate) represented by 236 taxa, compared to 189 that occur either occasionally in wetlands, or never occur in wetlands. Documented rare plants included 44 species (seven-S1, 20-S2, and 17-S3).

National Vegetation Classification Standard Refuge Communities

Thirty-four natural NVCS vegetation communities were found on Prime Hook NWR in addition to three anthropogenic communities (open lawn, agricultural field, and loblolly pine plantation) (table 3-4; map 3-2). The *Spartina* low marsh (1,685 acres) was the largest association and the buttonbush coastal plain pond was the smallest (1 acre). Four associations **(*)** were identified on the refuge that are unique in Delaware and found nowhere else in the State. These include the red maple/seaside alder (799 acres), pond pine woodland (8 acres), coastal bay shore/succulent beach (150 acres), and twig rush peat mat (10 acres) associations.

Table 3-4. List of NVCS Associations Mapped on Prime Hook NWR

Habitat Type Common Name	NVCS Association
Overwash dune	*Spartina patens, Schoenoplectus pungens, Solidago sempervirens* Herbaceous vegetation
Beachgrass/panicgrass dune grassland	*Ammophila breviligulata, Panicum amarum* Herbaceous vegetation
Atlantic Coast interdune swale	*Morella cerifera, Spartina patens* Shrubland
Interdunal switchgrass brackish depression	*Morella cerifera, Panicum virgatum, Spartina patens* Herbaceous vegetation
Mid-Atlantic maritime salt shrub	*Baccharis halimifolia, Iva frutescens, Spartina patens* Shrubland
Maritime red cedar woodland	*Juniperus virginiana, Morella pensylvanica* Woodland
Successional maritime forest	*Prunus serotina, Sassafrass albidum, Amelanchier Canadensis, Quercus velutina, Smilax rotundifolia* Forest
Southern red oak/heath forest	*Quercus alba, Q. falcate (Pinus taeda), Gaylussacia frondosa* Forest
Mesic coastal plain oak forest	*Quercus falcate, Q. phellos/Ilex opaca* Forest
Coastal loblolly pine	*Pinus taeda, Morella cerifera, Vitis rotundifolia* Forest
Mesic coastal plain rich forest	*Liriodendron tulipifera, Quercus rubra, Fraxinus Americana/, Uvularia perfoliata* Forest
Mesic coastal plain mixed hardwood forest	*Fagus grandifolia, Quercus (alba,rubra), Liriodendron tulipifera /Polystichum acrostichoides* Forest
Successional sweetgum forest	*Liquidambar styraciflua* Forest
Pond pine woodland*	*Pinus serotina, Magnolia virginiana, Vaccinium corymbosum, Carex atlantica* Woodland
Red maple/seaside alder swamp*	*Acer rubrum, Alnus maritima* Woodland
Coastal plain depression swamp	*Liquidambar styraciflua, Acer rubrum, Quercus phellos/Leucothoe racemosa* Forest
Coastal loblolly pine wetland forest	*Pinus taeda, Morella cerifera, Osmunda regalis* var. *spectabilis* Forest
Atlantic white-cedar swamp	*Chamaecyparis thyoides, Alnus maritima* Woodland
Cottonwood swamp	*Populus heterophylla, Acer rubrum, Quercus palustris, Liquidambar styraciflua* Forest
Atlantic Coast wild rice marsh	*Zizania aquatica* Herbaceous vegetation
Cattail brackish marsh	*Typha angustifolia, Hibiscus moscheutos* Herbaceous vegetation
Brackish meadow	*Panicum virgatum, Spartina patens* Herbaceous vegetation

Habitat Type Common Name	NVCS Association
Pickerelweed marsh	*Peltandra virginica, Pontedaria cordata* Herbaceous vegetation
Pond lily marsh	*Nuphar lutea ssp. advena* Herbaceous vegetation
Cattail marsh	*Typha anustifolia, latifolia, Schoenoplectus spp.* Sparse vegetaion
Coastal bay shore/succulent beach*	*Sesuvium maritimum, Atriplex spp., Suaeda spp.* Sparse vegetation
River seedbox marsh	*Ludwigia leptocarpa* Semipermanently flooded herbaceous vegetation
Twig rush peat mat community*	*Cladium mariscoides, Eriocaulon decangulare, Eriophorum virginicum* Herbaceous vegetation
Water willow shrub swamp	*Decodon verticillatus* Semipermanently flooded shrubland
Buttonbush coastal plain pond	*Cephalanthus occidentalis, Polygonum hydropiperoides, Panicum verrucosum* Shrubland
Brackish tidal creek shrubland	*Morella cerifera, Baccharis halimifolia, Eleocharis fallax* Shrubland
Spartina high salt marsh	*Spartina patens, Distichlis spicata (Juncus gerardii)* Herbaceous vegetation
Spartina low salt marsh	*Spartina alterniflora/ (Ascophyllum modosum)* Herbaceous vegetation
Salt panne	*Salicornia (virginica, bigelovii, maritima), Spartina alterniflora* Herbaceous vegetation

We have listed the NVCS community associations and habitat descriptions that apply to each of the four refuge management units. These vegetation inventories and resulting maps represent the best available information regarding vegetation cover on the refuge. As stated above, we recognize that the information is already outdated for portions of our managed wetland impoundments that have been affected by recent coastline changes. Detailed NVCS maps for each refuge unit are found in the HMP (appendix B).

Vegetation in Refuge Management Units

NVCS Vegetation Communities in Management Unit I

Unit I totals 1,624.9 acres (table 3-5). Of the total acres, 1,504.7 acres are natural communities and 120.2 acres are anthropogenic communities. Unit I receives tidal, brackish water inputs from Slaughter Creek, which results in the development of *Spartina* low salt marsh, which is the largest vegetation community in Unit I. A small wax-myrtle shrub swamp, located at the south end of the unit, is the smallest vegetation community mapped. Part of this unit experienced an arson-set marsh fire under high wind conditions (45 + mph) on March 10, 2002, that burned approximately 1,500 acres.

Table 3-5. Natural and Anthropogenic Communities in Management Unit I

Natural Community	Unit I acreage (hectares)
Atlantic Coast interdune swale	0.3 (0.1)
Beachgrass-panicgrass dune grassland	12.5 (5.1)
Brackish tidal creek shrubland	73.9 (29.9)
Coastal loblolly pine wetland forest	34.2 (13.8)
Coastal plain depression swamp	39.9 (16.1)
Marsh	33.2 (13.4)
Mesic coastal plain oak forest	49.6 (20.1)
Mesic rich forest	10.6 (4.3)
Mid-Atlantic maritime salt shrub	10.8 (4.4)
Overwash dune	5.1 (2.0)
Successional sweetgum forest	31.2 (12.6)

Natural Community	Unit I acreage (hectares)
Spartina high salt marsh	75.2 (30.4)
Spartina low salt marsh	982.0 (397.4)
Water	146.2 (59.2)
Natural Community Total	***1,504.7 (608.9)***
Anthropogenic Community	
Agricultural Field	25.6 (10.4)
Northeastern Successional Shrubland	90.1 (36.4)
Road	4.5 (1.8)
Anthropogenic Community Total	***120.2 (48.6)***
Unit 1 Total	**1,624.9 (657.5)**

NVCS Vegetation Communities in Management Unit II

Unit II is just south of Unit I and is an impounded, nontidal freshwater system that is manipulated by water control structures. Freshwater input is from Slaughter Creek, which flows from the west. Total acreage of Unit II is 1,997.5 acres, of which 1,681.8 acres are natural communities and 315.7 acres are anthropogenic communities (table 3-6). The generic marsh cover type is the largest vegetation community and the smallest is the maritime red cedar woodland. As of 2006, this unit is being overrun (approximately 100 acres) by river seedbox *(Ludwigia leptocarpa)*, a native plant of the south, but is considered nonnative in Delaware; it has invasive characteristics at the refuge. Furthermore, storms in 2008 and 2009 created overwashes along the coast of Unit II, which have formed inlets. The resulting flow of saltwater into Unit II killed much of the freshwater vegetation that was present when the NVCS mapping was done. This list represents a baseline inventory of cover types in Unit II as of 2005 when the mapping work was conducted.

During late February and early March 2010, an algal bloom started in the most southern areas of Unit II, adjacent to Prime Hook Beach Road. By the end of May, the algal bloom had continued to expand, covering about 700 acres in Unit II and 300 acres in Unit III. This algae has been identified as *Cladophora*, a genus of reticulated filamentous Ulvophyceace (green algae) found naturally along coastline habitats within the littoral zone (open water areas near shorelines). A common component of freshwater ecosystems, *Cladophora* can provide food and shelter for invertebrates and small fish. Problems arise when environmental conditions of light, substrate, and nutrients (especially phosphorus) suddenly change and become favorable for luxuriant growth of algal mats over extensive areas. This is the first time such a nuisance bloom has occurred on the refuge. *Cladophora* itself does not present a risk to human health but decaying *Cladophora* can promote bacterial growth and a pungent septic odor like sewage. Nuisance *Cladophora* outbreaks indicate an ecosystem under stress.

Table 3-6. Natural and Anthropogenic Communities in Management Unit II

NVCS - Natural Community	Unit II acreage (hectares)
Atlantic Coast interdune swale	20.1 (8.1)
Beachgrass-panicgrass dune grassland	22.6 (9.1)
Brackish tidal creek shrubland	3.3 (1.3)
Coastal plain depression wwamp	47.2 (19.1)
Maritime red cedar woodland	1.9 (0.8)
Generic marsh	918.9 (371.8)

NVCS - Natural Community	Unit II acreage (hectares)
Mesic coastal plain oak forest	99.0 (40.0)
Mid-Atlantic maritime salt shrub	7.2 (2.9)
Overwash dune	4.2 (1.7)
Successional maritime forest	71.3 (28.8)
Successional sweetgum forest	9.4 (3.8)
Water	476.7 (192.9)
Natural Community Total	***1,681.8 (680.6)***
Anthropogenic Community	
Agricultural field	221.8 (89.8)
Northeastern successional shrubland	82.2 (33.2)
Open lawn	0.2 (0.1)
Road	11.5 (4.6)
Anthropogenic Community Total	***315.7 (127.7)***
Unit II Total	**1,997.5 (808.3)**

NVCS Vegetation Communities in Management Unit III

Unit III is the largest of the units and lies between Unit II and Unit IV. Like Unit II, it has been managed as a nontidal freshwater system since the mid-1980s. It is 4,431.0 acres, of which 3,822.6 acres are natural communities and 608.4 are anthropogenic communities (table 3-7). The generic marsh is the largest cover type and an overwash dune at the north end of the Unit is the smallest. Generic marsh consists of various freshwater and brackish wetland species, mostly annuals, which can vary each year based on growing conditions. Biologically and ecologically, Unit III is the most important of all the units. (Note: Generic marsh and open water roughly correspond to impounded wetland areas.) Unit III supports three vegetation communities that are currently known in Delaware only from Prime Hook NWR. These include the twig rush peat mat, pond pine woodland, and red maple-seaside alder woodland. Prime Hook Creek flowing west to east roughly divides this unit into a northern half and southern half. This unit contains the largest amount of anthropogenic communities at 608.4 acres, more than the other three units combined.

Table 3-7. Natural and Anthropogenic Communities in Management Unit III

NVCS – Natural Community	Unit III acreage (hectares)
Atlantic Coast interdune swale	15.8 (6.4)
Atlantic white cedar-seaside alder woodland	9.8 (4.0)
Brackish tidal creek shrubland	1.3 (0.5)
Buttonbush coastal plain pond	0.8 (0.3)
Coastal loblolly pine forest	41.5 (16.8)
Coastal loblolly pine wetland forest	56.3 (22.8)
Coastal plain depression swamp	248.7 (100.6)
Interdunal switchgrass brackish depression	0.7 (0.3)
Loblolly pine plantation	10.6 (4.3)
Loblolly pine-sweetgum semi-natural forest	39.0 (15.8)
Maritime red cedar woodland	7.8 (3.2)

NVCS – Natural Community	Unit III acreage (hectares)
Marsh	1314.7 (532.0)
Mesic coastal plain mixed hardwood forest	19.2 (7.8)
Mesic coastal plain oak forest	43.8 (17.7)
Mesic rich forest	24.5 (9.9)
Mid-Atlantic maritime salt shrub	1.5 (0.6)
Overwash dune	0.2 (0.1)
Peat mat	9.0 (3.6)
Pond pine woodland	7.2 (2.9)
Red maple-seaside alder woodland	699.3 (283.0)
Reed canarygrass eastern marsh	1.9 (0.7)
Southern red oak/heath forest	289.1 (117.0)
Successional maritime forest	90.6 (36.6)
Successional sweetgum forest	88.0 (35.6)
Swamp cottonwood coastal plain pond	1.5 (0.6)
Water	797.9 (322.7)
Water-willow shrub swamp	2.2 (0.9)
Natural Community Total	***3,822.6 (1,546.9)***
Anthropogenic Community	
Agricultural field	507.1 (205.2)
Building	0.3 (0.1)
Northeastern successional shrubland	73.4 (29.7)
Open lawn	5.0 (2.0)
Parking lot	1.6 (0.6)
Road	21.0 (8.5)
Anthropogenic Community Total	***608.4 (246.2)***
Unit III Total	**4,431.0 (1793.1)**

NVCS Vegetation Communities in Management Unit IV

Unit IV is the southernmost management unit and is the smallest of all the units with a total area of 1,176.4 acres, of which 1,111 acres are natural communities and 65.3 acres are anthropogenic communities (table 3-8). Unit IV receives tidal and brackish input from the Broadkill River and as a result, the largest natural community in Unit IV is the *Spartina* low salt marsh. The smallest natural community is an interdunal switchgrass brackish depression. A coastal bay shore/succulent beach is located within the impounded portion of Unit IV and is covered under the generic marsh category. Unit IV at Prime Hook NWR is the only known location for this community in the State of Delaware.

Table 3-8. Natural and Anthropogenic Communities in Management Unit IV

NVCS - Natural Community	Unit IV acreage (hectares)
Atlantic coast interdune swale	30.5 (12.3)
Brackish tidal creek shrubland	17.7 (7.1)
Coastal loblolly pine forest	9.7 (3.9)

NVCS - Natural Community	Unit IV acreage (hectares)
Interdunal switchgrass brackish depression	5.7 (2.3)
Maritime red cedar woodland	66.2 (26.8)
Marsh	4.1 (1.6)
Mid-Atlantic maritime salt shrub	40.4 (16.3)
Spartina high salt marsh	7.8 (3.1)
Spartina low salt marsh	774.8 (313.5)
Successional maritime forest	22.0 (8.9)
Water	132.2 (53.5)
Natural Community Total	***1,111.1 (449.6)***
Anthropogenic Community	
Building	0.2 (0.1)
Northeastern successional shrubland	58.7 (23.7)
Road	6.4 (2.6)
Anthropogenic Community Total	***65.3 (26.4)***
Unit IV Total	**1,176.4 (476.0)**

Federal and State-Listed Plants and Communities

In addition to producing high-quality vegetation cover maps of the refuge, the Service contracted the DNHP to collect baseline data on rare, endangered, or threatened flora and fauna. During 2004 and 2005, rare plant surveys were conducted through areas that mapped rare vegetation community elements, and zoological surveys were conducted that assessed the presence and location of rare herpetafauna, odonates, lepidopterans, small mammals, and other invertebrates. A final report summarizing composite data was submitted to the Service in June 2007 (McAvoy et al. 2007).

Modern scientific resource programs using the principles of conservation biology are premised on understanding and mapping the elements of rarity across the landscape. Determining which plants and animals are thriving and which are rare or declining is crucial for targeting conservation actions toward those species and habitats of greatest conservation need. The rankings provide an estimate of extinction risk to protect species before they become listed as threatened or endangered. Status is assessed and documented at three geographic scales: global (g), national (N), and state (S). Status assessments are based on the best available information and consider a variety of factors, such as abundance, distribution, population trends, and threats.

Exemplary Natural Communities

Exemplary natural communities are those that have been minimally impacted by humans and contain an exceptional diversity of rare plant species. The most significant community found on the refuge was the twig rush peat mat. These sites (six were mapped by McAvoy and Coxe 2007) support many State rare plant species (table 3-9) and occur in open water within a shrub-dominated swamp matrix. This unique habitat develops on deep, mucky, peat that appears to float (true “quaking bog”). Of the six quaking bogs inventoried and mapped, the most exemplary was the Prime Hook Bog. The Prime Hook Bog is about 1.5 acres in size and is floristically diverse with 66 species and varieties documented. Twig rush sedge *(Cladium mariscoides)* is the dominant herb associated with many rare plants (24 species), including several insectivorous plants like purple pitcher-plants, round-leaf sundew, fibrous bladderwort, and southern bladderwort. In addition, a subspecies new to the flora of the State of Delaware and the Delmarva Peninsula was discovered here: bushy bluestem *(Andropogon glomeratus* var. *hirsutior)*.

Table 3-9. State Rare plants associated with Twig Rush Peat Mat Community on Prime Hook NWR

Scientific Name	Common Name	State Rank	Habit & Duration	Wetland Indicator Status
Alnus maritime	Delmarva alder	S3	deciduous shrub	OBL
Andropogon glomeratus var. hirsutior	bushy bluestem	S1	perennial grass	FACW+
Bartonia paniculata	twining bartonia	S2	annual broadleaf herb	OBL
Bidens coronata	tickseed sunflower	S3	annual broadleaf herb	OBL
Bidens mitis	small-fruit beggar-ticks	S2	annual broadleaf herb	OBL
Cyperus diandrus	umbrella flatsedge	S1	annual sedge	FACW
Drosera rotundifolia	round-leaf sundew	S2	perennial grass	OBL
Eleocharis robbinsii	Robbins spike-rush	S3	perennial grass	OBL
Eriocaulon decangulare	ten-angle pipewort	S1	per broadleaf herb	OBL
Eriophorum virginicum	tawny cotton-grass sedge	S1	perennial sedge	OBL
Eriocaulon parkeri	Parker's pipewort	S2	perennial sedge	OBL
Fuirena pumila	hairy umbrella-sedge	S2	annual sedge	OBL
Fuirena squarrosa	dwarf umbrella sedge	S3	perennial sedge	OBL
Juncus pelocarpus	brown-fruited rush	S2	per broadleaf herb	OBL
Lycopus amplectens	sessile-leaved bugleweed	S2	perennial broadleaf herb	OBL
Pogonia ophioglossoides	rose pogonia	S2	per broadleaf herb	OBL
Rhynchospora alba	white beakrush	S2	perennial sedge	OBL
Rhynchospora scirpoides	long-beaked beakrush	S2	perennial annual	OBL
Sagittaria engelmanniana	Engelmann's arrowhead	S2	perennial aquatic herb	OBL
Sagittaria graminea	grass-leaf arrowhead	S2	per aquatic herb	OBL
Sarracenia purpurea	purple pitcher-plant	S2	per broadleaf herb	OBL
Spiranthes cernua	nodding ladies'-tresses	S3	perennial broadleaf herb	FACW
Utricularia fibrosa	fibrous bladderwort	S2	per aquatic herb	OBL
Utricularia juncea	southern bladderwort	S2	per. broadleaf herb	OBL

Other Rare Plant Communities

Survey data identified a diverse assemblage of rare flora and fauna in the following refuge forest community types: red cedar maritime forest, coastal plain depression swamp, Atlantic white cedar/seaside alder saturated forest, swamp cottonwood coastal plain seasonal pond, and coastal loblolly pine. Based on current knowledge the red-maple/seaside alder woodland occurs only at Prime Hook NWR and may not occur anywhere else in Delaware or North America. Other rare and unique communities mapped on the refuge include the coastal bay/succulent beach and pond pine wetland communities.

Red Maple/Seaside Alder Community

This community is typified by the dominance of red maple in the overstory and seaside alder on the edges and in the understory within a swamp environment of standing water. The substrate is peat and muck characterized by hummock-and-hollow microtopography. The shrub layer consists of water willow, sweet pepperbush, southern bayberry, and occasionally buttonbush and fetterbush. The herbaceous layer forms on hummocks and hollows and is dominated by royal fern, northern marsh St. John's wort, cardinal flower, weak stellate sedge, three-way sedge, and mild water-pepper.

Rare plant species that occur in this community include seaside alder, Mitchell's sedge, green-fringe orchis, and gibbous grass. Seaside alder occurs on hummocks along the edges of open water, green-fringe orchis is found at base of trees within the understory and blooms in mid-summer, and Mitchell's sedge is found within the interior of this community growing on hummocks in the shade of the understory. The gibbous grass grows in sun and shallow water on the edges of this community and at times forms dense, pure stands. For a complete description of all NVCS vegetation alliances and associations mapped on the refuge see the NatureServe 2006 report in McAvoy et al. 2007.

Coastal Bay Shore/Succulent Bush

This community is dominated by sea purslane with patches of spearscale, panic beachgrass, barnyard grass, brackish sprangletop, small spike-rush, and salt marsh fleabane. Although this community is located within a 200-acre impoundment in Unit IV, it is surrounded by salt marsh habitats and is often irregularly flooded by storm tides from the Broadkill River and Delaware Bay waters. As to its current Statewide distribution, this community is not known to occur anywhere else in Delaware.

Other rare plants found on the refuge are included in table 3-10. Within the coastal plain depression swamp community type about 25 individuals of the State-rare cattail-sedge *(Carex typhina*, S3) in Unit III and scattered colonies of slender blue-flag iris *(Iris prismatica*, S2) were recorded by DNHP. Both species are growing in closed canopy and would prefer more sun to expand populations (McAvoy and Coxe 2007). Several rare plants were inventoried in Atlantic white cedar/seaside alder saturated forest growing in association with Atlantic white cedar. These species included: seaside alder, *(Alnus maritima*, S3, G1), coast sedge *(Carex exilis*, S1), bayonet rush *(Juncus militaris*, S2), and flattened pipewort *(Eriocaulon compressum*, S2) (McAvoy 2007). Within coastal loblolly pine wetlands, the southern twayblade orchid's *(Listeria australis*, S3) distribution and abundance is significant. Two locales have been documented, with 500 to 1,000 plants occurring between both locations. This species can easily be overlooked due to its small size (15 cm/6 inches) and ephemeral nature (blooms in early spring and persists for only a few weeks). Also growing here is Walter's greenbriar *(Smilax walteri*, S3), an uncommon woody vine in Delaware that is an obligate wetland species and prefers swampy habitats. The fruit of Walter's greenbriar is red in color, as opposed to other greenbriar species with black fruit.

Table 3-10. Other Rare Plants found on Prime Hook NWR

Scientific Name	Common Name	State Rank	Habit & Duration	Wetland Indicator Status
Asclepias lanceolata	lance-leaf orange milkweed	S1	perennial broadleaf herb	OBL
Bartonia paniculata	twining bartonia	S2	annual broadleaf herb	OBL
Carex exilis	coast sedge	S1	perennial sedge	OBL
Carex typhina	cattail sedge	S3	perennial sedge	FACW+
Conoclinium coelestimun	blue boneset	S3	perennial broadleaf herb	FAC
Eriocaulon compressum	flattened pipewort	S2	perennial broadleaf herb	OBL
Helianthus angustifolius	swamp flower	S3	perennial broadleaf herb	FACW
Helianthus giganteus	tall sunflower	S3	perennial broadleaf herb	FACW
Hudsonia ericoides	golden heather	S1	evergreen shrub	UPL
Iris prismatica	slender blue-flag	S2	perennial broadleaf herb	OBL
Juncus militaris	bayonet rush	S2	perennial aquatic rush	OBL

Scientific Name	Common Name	State Rank	Habit & Duration	Wetland Indicator Status
Listeria australis	southern twayblade	S3	perennial broadleaf herb	FACW
Passiflora lutea	passionflower	S3	herbaceous vine	UPL
Platanthera lacera	green-fringe orchis	S3	perennial broadleaf herb	FACW
Polygonum ramosissimum	bushy knotweed	S3	annual broadleaf herb	FAC
Pyrrhopappus carolinianus	Carolina false-dandelion	S3	annual broadleaf herb	UPL
Smilax walteri	Walter's greenbriar	S3	woody vine	OBL
Utricularia radiate	small swollen bladderwort	S3	perennial aquatic herb	OBL

Moist-Soil Management and Production

Moist-soil management provides plant and animal foods that are a critical part of the diet of wintering and migrating waterfowl and shorebirds, and has been a significant part of wetland management of the project area of Prime Hook NWR for the last 20 years. Native moist-soil wetland plants provide seeds and other plant parts (leaves, roots, and tubers) that generally have low deterioration rates after flooding and provide substantial energy and essential nutrients to wintering waterfowl, unlike common agricultural grains (corn, mile, soybeans) and nonnative cover crops (Strader and Stinson 2005).

Moist-soil management also supports diverse and abundant populations of invertebrates, which are an important protein source for waterfowl, shorebirds, and other waterbirds. For the moist-soil impounded habitats on the refuge, the annual seed yield production and foraging values greatly vary in each of the sampled areas from year to year depending on weather, rainfall patterns, and snow goose herbivory, which all affect moist-soil plant production, annual seed yields, and food availability for target bird species.

Water level manipulations make food resources available to waterfowl, shorebirds, and other wetland-dependent birds at critical times of the year. The plants and invertebrates available year-round in moist-soil impoundments provide food resources necessary for wintering and migrating birds to complete critical aspects of their annual cycles such as molt and reproduction.

During the past decade, the primary wetland habitat management focus of the refuge has been to increase the foraging carrying capacity of its impoundment complex for waterfowl and shorebirds using impoundment-specific strategies for water level manipulations (Fredrickson 1994). An integrated management approach using moist-soil management techniques has consistently generated annual seed production of moist-soil plants that provide a range from 689 to 2,630 pounds of native wetland plant seeds per acre within 4,000 acres of impounded marsh.

A seed estimator sampling technique was used to quantify annual moist-soil seed production as discussed in *Waterfowl Management Handbook,* chapter 13.4.5 entitled, "A Technique for Estimating Seed Production of Common Moist-soil Plants." For 7 consecutive years, annual moist-soil seed production was monitored on the refuge within several impoundment subunits (PMH2A, PMH2C, PMH3A, PMH3B, PMH3D, and PMH4A), documenting the successful annual production of native plant food resources available to waterfowl and other wetland dependent bird species (table 3-11, figure 3-1).

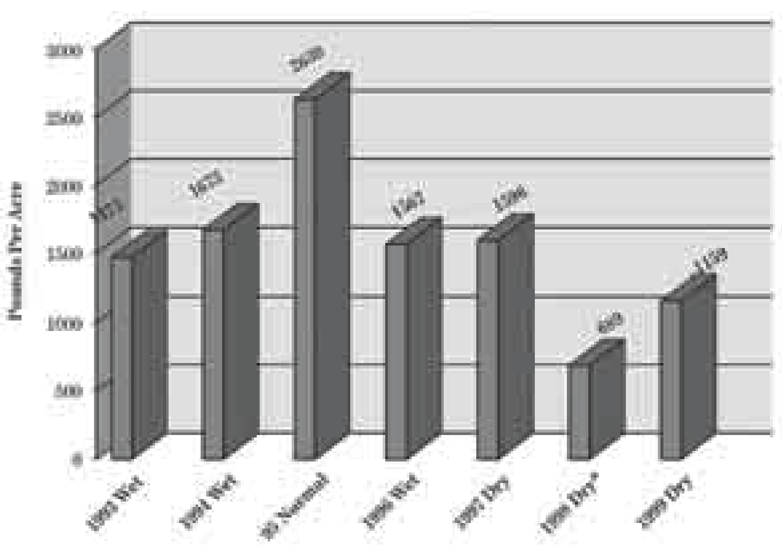
Table 3-11. Moist-Soil Production Data (Impoundments)

Comparison of Seed-Yields (lbs/acre) during Adverse Weather Conditions							
Year	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
PMH2A	1,442	3,020	2,229	2,290	1,574	1,567	962
PMH2C	5,443	2,572	5,147	2,524	2,778	0	484
PMH3A	0	1,671	2,891	872	1,740	458	1,159
PMH3B	1,306	1,670	2,470	2,001	1,548	158	667
PMH3D	0	0	799	648	949	948	596
PMH4A	648	1,107	2,246	1,069	985	0	0
Weather	WET	WET	NORM	WET	DRY	DRY**	DRY
Total Avg. Production	2,209	2,008	2,630	1,567	1,596	522	645

*** Extreme flood conditions in early winter followed by 6 months of extreme drought.*
{Mean for wet years: X_{wet} = 1,928 lbs/acre} {Mean for dry years: X_{dry} = 921 lbs/acre}
{Grand Mean for all years = 1,425 lbs/acre}

Quantified seed yields were estimated by measuring a few dominant moist-soil plants: *Echinochloa walteri* (Walter's millet), *Cyperus esculentus* (nutsedge), *Leptochloa fasicularis* (Sprangletop), *Panicum dichloromiflorum* (Fall panicum), *Polygonum* sp. (smartweeds), and *Setaria* sp. (foxtail) (Laubhan and Fredrickson 1992). Therefore, seed production estimates were very conservative as calculated, using the data contained in Prime Hook NWR's Annual Marsh and Water Management Program Reports from 1993 through 2000.

Figure 3-1. Average Seed Yields Sampled in Prime Hook NWR Impoundment Subunits



**Note: 1998 depressed seed yields were attributed to extreme drought conditions experienced during 6 months of the growing season preceded by a severe Nor'easter season.*

Invasive Plants

The presences of invasive plants can have a major adverse impact on the biological integrity, diversity, and environmental health of refuge lands and other natural areas.

Of the 426 plant taxa listed in refuge plant inventories, 45 are nonnative, of which 10 are considered to be invasive and negatively impacting native habitats. These include spotted knapweed, Canada thistle, kudzu, mile-a-minute, Japanese honeysuckle, river seedbox, Japanese stilt-grass, reed canary grass, alien common reed, usually referred to in this document as *Phragmites*, and multi-flora rose.

Spotted knapweed, Canada thistle, mile-a-minute, Johnson grass, and kudzu are restricted to roadside areas, fallow agricultural fields, edges of hedgerows, and early successional fields throughout the refuge. Japanese honeysuckle is ubiquitous throughout the refuge in mostly wooded habitats. Japanese stilt grass (about 50 acres) is mostly found on Oak Island, where it dominates the herbaceous layer.

River seedbox, a new addition to the flora of Delaware first discovered on the refuge in 2005, is an adventive plant species that has at times dominated portions of impounded marsh Unit III. River seedbox is native further south in the eastern U.S. but is not considered native in Delaware.

By fall 2006, this species had spread to about 500 acres in Units II and III impounded wetlands parallel to Prime Hook Beach Road. River seedbox is similar to alien common reed *(Phragmites australis)* in its aggressiveness. It is surmised that river seedbox became established on the refuge by waterfowl, who are attracted to this plant's large seeds. A single plant can produce thousands of seeds. One positive outcome of the May 11, 2008 nor'easter storm is that saltwater intrusion into river seedbox colonies has eliminated existing stands. As with all aggressive invasive plants, we must remain vigilant to their presence and spread and continue our active programs to control them.

Reed canary grass, which is another adventive species in Delaware, dominates an old field habitat in Unit III (corners of field 328). This is the same location where the State-rare plant, lance-leaf orange milkweed, grows. The lance-leaf orange milkweed is abundant here and is the largest known population in the State (100+ individuals). Current annual mowing late in the growing season appears to be favoring this milkweed species by suppressing woody vegetation. Encroachment by reed canary grass should be monitored and hand-treated. Multi-flora rose is widespread throughout the refuge, growing in scattered areas within hedgerows, thickets, early successional fields

***Phragmites* control**
Since the era of no management early in the refuge's history, *Phragmites* control has been a major concern and activity on Prime Hook NWR. From the late 1960s to 1982, *Phragmites* cover expanded by 34 percent and 3,000 acres of the refuge were covered in dense stands of *Phragmites* (figure 3-2). In 1983, the refuge prepared an environmental assessment to deal with this problem. The assessment described a rehabilitation program to reclaim the 3,000 acres of *Phragmites*. The project's primary objectives were to chemically treat 2,000 acres in Unit II and 1,000 acres in Unit III and reduce the severe fire hazard near private property.

Figure 3-2. Condition of refuge marsh near Fowler Beach in 1978, showing dense stand of *Phragmites*

Prior to this rehabilitation project, the refuge conducted several years of research to find effective and economical methods to control *Phragmites* on Prime Hook NWR. Refuge staff began consulting and coordinating a refuge-specific *Phragmites* control program in June 1978 with representatives of Delaware, New Jersey, North Carolina, and Rhode Island fish and game departments.

During the initial coordination sessions, Prime Hook NWR was selected as a test area to be sprayed with the then-new chemical glyphosate (N-phosphonomethyl glycine). A pilot spraying program was granted and experimental use permit (24-EUP-29) issued by the EPA in 1978. From 1976 to 1982, the before-mentioned State agencies, Monsanto researchers, and refuge personnel consulted and coordinated research activities by experimenting and assessing the effectiveness of herbicide treatments to control *Phragmites*.

Biologists with the Delaware Division of Fish and Wildlife provided technical and physical assistance in conducting trial applications of glyphosate to assess its efficacy in several wetland plots on the refuge. Prior to these field tests, Monsanto had also conducted extensive field studies on the effects of glyphosate on fish, wildlife, and vegetation. Short-term and long-term toxicity tests had been conducted on a wide variety of aquatic, avian, and mammalian wildlife species. The aquatic test organisms included fresh and saltwater species, as well as vertebrates and invertebrates. Waterfowl, upland game, fish, shrimp, and shellfish are some examples of the wildlife guilds included in these tests (USFWS 1983).

Acute (short-term) testing conducted on avian species, honey bees and fish showed that glyphosate was essentially non-toxic to these organisms. Chronic (long-term) toxicity tests also showed that glyphosate does not cause cancer, tumors, or reproductive problems in mammals (USFWS 1983). Further ecotoxicity studies of non-target impacts of glyphosate on birds, fish and aquatic life, mammals, and terrestrial invertebrates have demonstrated the same trends of minimal non-target effects (Sullivan et al. 1997). The most recent data for reregistration eligibility decision data for glyphosate maintain these past results of the nontoxicity of glyphosate on fish and wildlife species (NPIC 2011).

The timeframe for reclaiming Prime Hook NWR's marshes from *Phragmites* in the early 1980s was 3 years. From 1984 to 1986, approximately 3,000 acres were treated with consecutive double spray treatments between years and some prescribed fire used to reduce hazardous dead cane fuels. The program was a success.

Twenty years later, a second large-scale *Phragmites* control project was undertaken by the refuge to reduce or eliminate expanded stands located on refuge lands and private lands adjacent to the refuge. In close cooperation with the Delaware State Forestry Division and other partners, the refuge was funded for a 3-year, million dollar wildland urban interface project, which was executed from 2002 to 2004. During that project, approximately 3,000 acres were treated on refuge lands and 1,000 acres were treated on private properties immediately adjacent to the refuge, resulting from the refuge partnering with 255 landowners in the Prime Hook, Broadkill, and Slaughter Beach communities.

Influence of Climate Change on Physical Environment and Refuge Management

Current Climate, and Local Coastal Storm Activity

Delaware's climate is generally mild, continental weather moderated by the effects of the Atlantic Ocean, causing brief periods of sustained hot or cold temperatures. Extreme temperatures are moderated by the Delaware Bay, the Atlantic Ocean and the Chesapeake Bay. On Prime Hook NWR, weather conditions are mild year-round with temperatures ranging from 32 ^{o}F to 80 ^{o}F. Normally, summer ocean breezes keep the refuge cooler than inland areas and most winter days are mildly attenuated by the same breezes.

Annual and seasonal precipitation is highly variable. Average annual refuge rainfall is 41.98 inches. Snowfall is usually light, averaging 10 to 15 inches per year. Prevailing winds from March through October are from the northwest except during summer months when they become more southerly. Prevailing winds from November through February are northeast. Average annual wind speed is about 9 miles per hour, but winds can reach 50 to 60 miles per hour or higher during summer thunderstorms, hurricanes, or intense winter northeasters. These climatic conditions correspond to U.S. Department of Agriculture (USDA) plant hardiness zone 7a. Native plant and ecological restoration biologists refer to the USDA zones for guidance in selecting appropriate species and planting times.

The entire refuge lies within Delaware's coastal zone and is subject to periodic flooding by coastal storms. Most of the refuge lies within the 100-year floodplain. The refuge's coastal environments such as beaches, barrier islands, wetlands and estuarine ecosystems are closely linked to the local climate conditions created by coastal storms. Stronger and more frequent coastal storms are posing immediate threats and challenges to impounded wetland management schemes used on the refuge in the last three decades.

Hurricanes are usually more powerful than coastal storms along the Atlantic Coast, but coastal storms are more frequent in Delaware, last longer, and impact larger areas. While hurricane season runs from June 1 to November 30, coastal storms called nor'easters are a year-round threat to coastal Delaware. Prolonged flooding and extensive property damage are serious hazards more associated with nor'easters than hurricanes along the Delaware coast.

In Delaware, tidal flooding, or storm surge, associated with a nor'easter can actually exceed the levels associated with hurricanes. Storm surge is the result of water being dragged onto the shoreline by the storm's strong winds coupled with very low atmospheric pressure at the storm's center. Storm surge heights of 3 to 10 feet above normal are especially damaging when they bracket several high tide full and new moon cycles. The torrential rainfall from nor'easters can also cause extensive flooding in both coastal and inland areas and increase coastal erosion of sandy beach ecosystems (Carey and Dalrymple 2003).

It has been documented in the past that normal daily tide cycles and coastal storm processes actively change the configuration of the coastline. Normal low-energy processes move small volumes of sand and are both erosional and depositional in nature. High-energy coastal storm processes involve large volumes of sediment movement (Kraft et al. 1976).

Delaware's most damaging coastal storm on record occurred over a 3-day period and five extreme full moon, high tide cycles March 6 to 8, 1962. Winds reached speeds of 70 miles per hour. Offshore waves were recorded at higher than 40 feet, while waves in the surf zone were 20 to 30 feet high. The storm surge associated with the storm was 9.5 feet, the highest tide ever recorded in Breakwater Harbor (Lewes Tide Gauge) at the mouth of the Delaware Bay (Carey and Dalrymple 2003).

Coastal storms with sustained winds can lead to prolonged flooding of refuge impoundments and roads and increase the erosion of refuge dunes. The surge of storm water landward results in heavy saltwater intrusion of freshwater wetlands and adjacent upland habitats. Long-term geologic changes from these coastal storms include beach erosion, dune erosion, and possible inlet formation from stronger flood and ebb tide surges.

Wind and saltwater intrusion, nearshore channeling, and sedimentation associated with coastal storms also cause landscape changes. In the past, this scenario and associated geological changes may have been experienced every other decade. Overwash at barrier coastlines is determined by the height and wave parameters. In 1978, Maurmeyer noted that "barriers along the southwestern shore of the bay generally require tide levels in excess of 3.0 meters (about 9 feet) above mean low water, which occur approximately once in 25 to 30 years before they overwash."

Since the 1990s, the refuge has been experiencing more frequent nor'easter activity with multiple big coastal storms making landfall during a single season, creating more rapid landscape and coastal changes. For example, the coastal storms of December 10 to 14, 1991 and January 4, 1992 had associated storm surges of up to 8.5 feet above mean high water. After these two storms, washovers and breaching of dunes occurred at scattered locations along the Delaware Bay. Geologic observations made by Delaware Geological Survey (June 1992) included the following notes relevant about the refuge (Ramsey et al. 1992):

> *The dunes were flattened between the north end of Prime Hook Beach and the south end of Slaughter Beach. Washovers were observed to extend 20 to 30 feet into the marsh throughout this area. An artificial earthen berm that originally stood approximately 8 to 10 feet high at the end of Road 199 at Fowler Beach was almost completely removed. Based on the relative position of a concrete structure at the south end of Fowler Beach (WWII tower) to the beach profile after the October 31 1991 storm and the January 4, 1992 storm, beach retreat in this area may be as much as 20 feet inland.*

Six years later, another set of back-to-back coastal storms occurred again on January 27 to 29 and February 4 to 6 in 1998. Recorded storm surges from 1999 topped the 1992 storm surges, peaking at 9.0 feet above mean higher high water. Both storms produced near-record high tides, but the January 28 storm was slightly higher than the February 5 storm; ironically, the February 5 storm was more damaging. From a comparison of Lewes Tide Gauge data, the February 5 storm was more severe because the low tides were exceptionally high before the storm developed off the coast. Of all the storms of record, even the 1962 storm, this particular phenomenon is very unusual and this makes this storm unique among those recorded to date in Delaware (Ramsey et al. 1998). Damage and erosion of artificial dunes was extensive, as the entire duneline was flattened and large overwashes developed similar to those of the 1992 storms.

Not until the category one hurricane Ernesto in 2006 did a distinctive inlet form north of Fowler Beach Road in 2006. A relatively mild storm, Ernesto made landfall with little rain. However, Ernesto blew off shore for several days, generating higher than normal tide cycles that intensified flood and ebb tide water surges even before making landfall. Since Delaware Bay is a relatively shallow body of water, waves build up more quickly than in the open Atlantic (Kraft et al. 1976). The water level continued to rise and waves attacked the shoreline for several days with increasing intensity. Finally, when landfall did occur, a new inlet broke through the refuge's sandy barrier in Unit I.

A year and half later, a severe Mother's Day coastal storm on May 11, 2008, caused considerable coastal erosion and overwashed all refuge marshes in Units I and II. One year later, two more back-to-back nor'easters occurred on October 15 to 19 and then November 12 to 15, 2009. Both nor'easters generated tide surges of 9.0 feet above mean higher high water. Sand in the form of washover fans was transported across the flattened beach dunes back into the adjacent marsh and a new tidal water flow channel was created in Unit II just south of Fowler Beach Road. Several tide cycles after the second storm hit, high tide cycles continued to pile water across the barrier, intensifying flood and ebb tide water surges that etched out two additional mini-inlets further south of the first inlet, across the Unit II duneline.

The increased frequency and severity of coastal storms over the past decade has a direct impact on the management options and capability along the refuge shoreline and in the adjacent coastal wetlands.

Climate Change, Sea Level Rise and Refuge Shoreline Dynamics

In 2007, the IPCC projected that average global sea level will likely rise between 19 and 59 centimeters (7 and 23 inches) by the end of the century (2090 to 2099), relative to the base period (1980 to 1999), excluding any rapid changes in ice melt of Greenland and Antarctica ice floes. According to the IPCC, the average rate of global sea level rise is very likely to exceed the average rate recorded over the past four decades [IPPC Fourth Assessment Report-AR4] (USCCSP 2009).

The U. S. Climate Change Science Program has generated a synthesis and assessment report in 2009 (product 4.1) determining coastal sensitivity to sea level rise and climate change scenarios with a focus on the Mid-Atlantic region. Accelerated rates of sea level rise with stronger and more frequent storms pose increasing impacts to coastal communities, infrastructure, beaches, wetlands, and natural ecosystems.

Two major processes cause global mean sea level rise: ocean temperature increases causing water to expand and increase in volume, and land reservoirs of glaciers and ice sheets melt due to rising earth temperatures.

At the same time, the land in coastal areas is subsiding. When the rates of actual sea level increase is combined with the subsidence of land areas, scientists add these two factors and refer to the total as "relative sea level rise," i.e., that the actual impact is the net of the two processes.

Global sea level rise rates rose to an average of about 1.7 mm/year over the 20th century. However, in the Mid-Atlantic region from New York to North Carolina, tide-gauge observations indicate that relative sea level rise rates ranged from 2.4 to 4.4 mm/year, or about 0.3 meters (1 foot) during the same time frame (USCCSP 2009), which is higher than the global mean. Although the body of research supporting concerns regarding global climate change and sea level rise is substantial, the Service recognizes that there is not necessarily worldwide scientific consensus regarding global or even regional sea level rise rates and predictions. Locally in Delaware, the rate of relative sea level rise has been estimated to be 3.2 ±0.28 mm/yr, (2.92 to 3.48 mm/yr, 95 percent confidence interval), which is approximately 1.5 mm/yr higher than the average global rate of seal level rise alone (NOAA Lewes, DE, Tide Gauge: *http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8557380;* accessed August 2012).

It is this current, local rate of sea level rise which will direct many of the refuge's management decisions regarding achieving sustainable future conditions along the refuge shoreline and coastal wetlands. However, scientific projections for the 21st century are even higher, with predicted global sea level increase rates ranging from 2 to 7 mm/year (Rahmstorf 2007). Increasing sea level rise would greatly stress coastal wetlands, leading to either accelerated migration landward or wetland disintegration. Quantitative predictions of these future coastal changes remain difficult due to the complexity of coastal systems (Ashton et al. 2007). Predicting sea level rise impacts on shoreline changes or associated wetland losses with quantitative precision and certainty is not yet possible. If existing wetland habitats cannot keep pace with sea level rise through vertical accretion, the result will likely be extensive loss of coastal wetland habitats on the refuge and across the Mid-Atlantic. Also the quality, quantity, and spatial distributions of other coastal habitats will change as a result of erosion, shoreline and salinity changes, and wetland loss (USCCSP 2009).

Regardless of the future rate of sea level rise locally, it is not simply a rise in sea levels, per se, that poses the most significant threat to refuge management. Higher sea levels will also provide an elevated base for storm surges to magnify flooding effects and diminish the rate and capability at which low-lying coastal areas can drain water. This will further intensify the magnitude of flooding and erosion effects from coastal storms. Rapid sea level rise will exacerbate existing problems experienced by coastal areas from waves, storm surges, shoreline erosion, wetland loss, and saltwater intrusion.

Natural coastal ecosystems evolved under conditions of sea level rise. Barrier islands and salt marshes can sustain their features, but not necessarily their location or configuration, in the face of more frequent coastal storm events, provided they are healthy and processes such as vertical accretion are not hindered.

Increased coastal storm-generated wind, waves, and higher astronomical tides will continually modify and change the refuge's physical shoreline and sandy beach templatesthrough breaching (inlet formation) and overwash processes with greater frequency. The refuge's undeveloped barrier island habitats may become completely reconfigured geomorphologically after each coastal storm. This reconfiguration will directly affect habitat availability and functionality and contribute to the redistribution of sediment along sandy beaches, shorelines, and refuge back barrier wetlands. This is how coastal ecosystems adjust to climate change, sea level rise, and more frequent storm surges (USGS 2010). Narrow, low-elevation barrier island communities, as found on the refuge, will become more susceptible to storm overwash development, barrier segmentation, the formation of new tidal inlets, and closing of previous inlets. These physical and geomorphic responses expedite landward migration or roll-over of shorelines as they readjust their equilibrium position in relation to rising sea levels and local storm conditions (USGS 2010).

In the past, the refuge coastal area was generally managed under the premise that sea level was relatively stable, shorelines remained static, and storms were regular and of predictable magnitude. Significant changes along the shoreline happened infrequently, and were considered to be unusual events. Within that scenario, little to no thought was given to shoreline and coastal monitoring or management. However, today it is recognized that refuge shoreline dynamics will be increasingly dominated by overwash and inlet processes as the coastline responds to the increased storm frequency and severety and relative sea level rise associated with climate change.

Refuge Shoreline Dynamics

Overwash and inlet processes are both integral parts of shoreline dynamics. Overwash processes deposit large sand fans across the beach and adjacent wetlands and serve to build barrier island elevation, widen beach width, and accrete sand in back barrier marshes. Storm overwash events assist in expanding barrier island width and also contribute to island roll-over or migration landward. Overwash deposition in many studied barrier island marsh systems have increased sedimentation rates that have promoted relatively stable marsh communities by enhancing vertical accretion mechanisms in the face of increased local rates of sea level rise (Ashton et al. 2007). Throughout Delaware, evidence of these coastal processes is prominent in the historic aerial imagery (appendix J). For example, portions of the Broadkill Beach community are constructed on sediments deposited naturally by the closure of an inlet that was present as recently as the 1940s (figure 3-3). The formation, recovery, and reformation of overwashes in the Fowler Beach area is illustrated in figure 1-1 in chapter 1.

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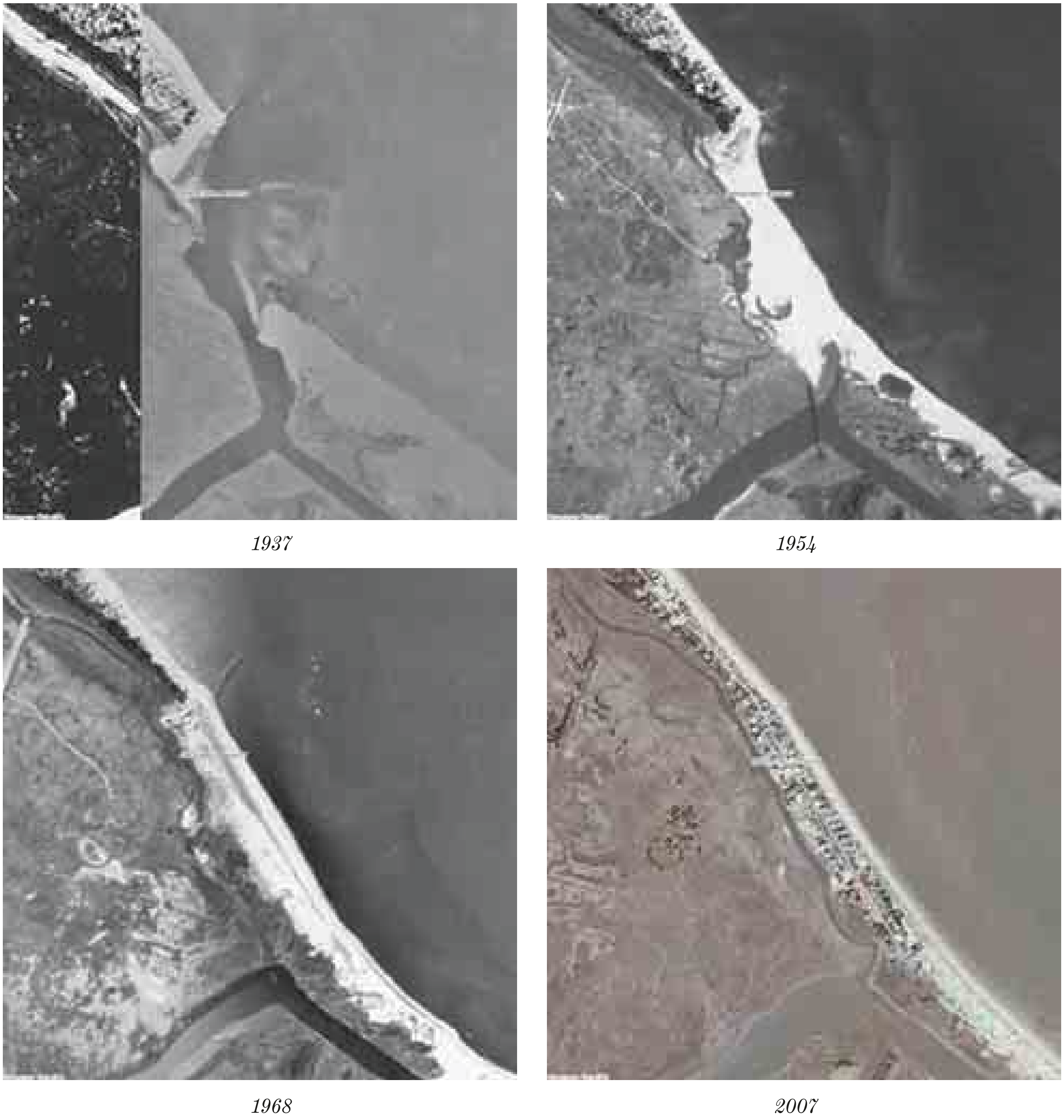
American bittern

Inlet formation is also vital to the short-term maintenance of barrier island ecosystems and their estuaries, and long-term barrier island evolution necessary to maintain and conserve coastal wetlands (Mallinson et al. 2008). Once an inlet is created, usually during a storm event, active flood and ebb tide deltas form in association with an inlet. As the inlet closes, the ebb-tide delta collapses, causing temporary and localized shoreline accretion while adjacent shoreline areas may erode (map 3-7).

The floodtide delta, which provides a platform for the colonization of salt marsh, is abandoned and the marsh redevelops behind the newly positioned shoreline. This increases the barrier island's width and continues the evolutionary succession of the barrier island, while facilitating the vertical accretion of back barrier wetlands (Mallinson et al. 2008).

Figure 3-3. Former inlet at south end of Broadkill Beach, dated 1937, 1954, 1968, and 2007 showing pattern of natural inlet filling, overwash, revegetation, and subsequent island community development



1937 *1954*

1968 *2007*

The most important impacts on the physical environment resulting from overwash and inlet formations are the natural transport and deposition of sand to back barrier wetlands. Overwash fans and inlets that develop across wetlands and adjacent beaches are in equilibrium with the coastal dynamics of rising sea levels, more frequent storm surges, and local geomorphic conditions. If a barrier island is not allowed to roll back or migrate landward and provide back barrier marsh environments with the only potential to accrete sand, the barrier island shoreline will eventually collapse and back barrier marshes will not be able to keep up with sea level rise.

Map 3-7. Development of Overwash and Breaches near Fowler Beach

Where shoreline regression landward is not allowed, sea level rise can expedite coastal fringe marshes reverting to open water habitats sooner and quicker. Where wetlands are degraded, the reversion to open water can be even more rapid. As described in more detail in the next section, this disruption of natural coastal processes and resulting consequences in adjacent wetlands has become evident in the impoundment complex on the refuge.

Climate Change Adaptation and Vulnerability Assessment of Refuge Wetland Impoundments

Climate change and associated impacts such as sea level rise and increased storm frequency and severity are proving to be the defining wetland management issue for the refuge, increasing our challenges to managing the refuge's impounded wetland complex. Future climate change adaptation strategies used by the refuge must anticipate an increasingly different physical environment than the one in which we managed our impounded marshes from 1988 to the present. Numerous factors associated with climate change and coastal processes are interacting to affect the refuge's ability to conduct wetland management as it has been for recent decades, particularly in Unit II.

During the last phase of establishing the refuge impoundment in Unit II in 1988, DNREC required that the Service build up the duneline from the last house in Slaughter Beach (Unit I) to the first house on Prime Hook Beach in Unit II, which incorporated about 3 miles of shoreline. Although the Service felt it was not necessary, the State of Delaware reconfigured the natural barrier island berm in 1988 in anticipation of the potentially erosive effects of natural barrier beach movement. Artificial dunes were again rebuilt in 1992, 1998, 2006, and 2008 by the State, in coordination with the refuge. In 2006, a breach (mini-inlet) developed across the Unit I duneline, and in 2009 several breaches (1 large and 2 smaller inlets) of the duneline across Unit II occurred (map 3-7). Efforts to restore the dune line one more time while management and restoration plans could be developed were made by DNREC, in coordination with the refuge, in September 2011. However, Hurricane Irene (August 2011) had further depleted the affected shoreline of sand and the dune restoration failed shortly after completion, during a period of high tides and strong winds. As of the completion of the final CCP/EIS, the Unit II shoreline contains several persistent breaches, permitting saltwater to continue entering Unit II. Much of Unit II has converted to open water as a result.

Numerous factors are influencing our management capability and the response of the managed wetland ecosystem. We have been striving to better understand the various components of this comprehensive system, which includes natural elements and processes as well as human-controlled infrastructure. Information about the state of the ecosystem, the physical processes at work, and the management investments that would be necessary to maintain the Unit II impounded marsh are outlined below. Although these management challenges most imminently affect Unit II, it is clear that the future of management in Unit III will be affected by these same factors.

Washover and Beach Migration:
Starting in 2006 with tropical storm Ernesto, the natural beach barrier has been breached or overwashed numerous times. The physical forces that shape, move, and maintain barrier beach systems have been recognized by many government agencies and studied by coastal geographers for decades. Lewis et al. (2005), described the nature of fetch limited barrier islands, or those barrier islands typical of estuaries, in contrast to the ocean front. Of particular note is the relatively thin veneer of sand laid over a salt marsh base and the lack of significant wave energy outside of storm events necessary to maintain a relatively consistent beach profile. Large, continuous dunes, such as found along the Atlantic Ocean coast, are rare in estuarine environments.

Fetch limited barrier islands are backed by salt marshes and maintained in part by the overwash of beach and marine sediments. The direction of beach movement as periodic storms occur is landward. These events are natural and outside the control of refuge management. However, they impact refuge coastlines through creation of overwashes and landward migration of the shoreline. It is well established that these processes are natural and beneficial to salt marsh communities (Ashton et al. 2007), and are common along the Delaware Bay shoreline (appendix J).

The rate of erosion and landward migration of the refuge shoreline along Unit II, in the vicinity of Fowler Beach, from 1937 to 2012 has been quantified using a series of historic aerial images (DNREC Coastal Programs unpublished data), and more recently ground measurements and observations (Psuty et al. 2010). It has been clearly demonstrated that the rate of shoreline erosion and retreat has been increasing during that time frame. Whereas the shoreline at Fowler Beach eroded 50 feet in the 17 years between 1937 and 1954, it later eroded 50 feet in only 5 years between 2007 and 2012 (figure 3-4). The rate of erosion between 1937 and 1954 was under 3 feet/year, and increased steadily to a rate of 10 feet/year between 1997 and 2012 (figure 3-5). This non-linear increase in the erosion rate will be problematic for refuge management for many years into the future (figure 3-6).

In 2011, the refuge began tracking shoreline position seasonally following a detailed protocol developed and used widely by the National Park Service (Psuty et al. 2010). That protocol will allow more detailed observation of seasonal and annual changes in shoreline position, as well as shoreline responses to management and restoration actions in the future.

Figure 3-4. Shoreline erosion in the vicinity of Fowler Beach Road in Unit II. Shoreline position from 1937 was determined using aerial imagery. Shoreline position in 2012 was determined through ground measurements and observations (Courtesy of DNREC Delaware Coastal Programs)

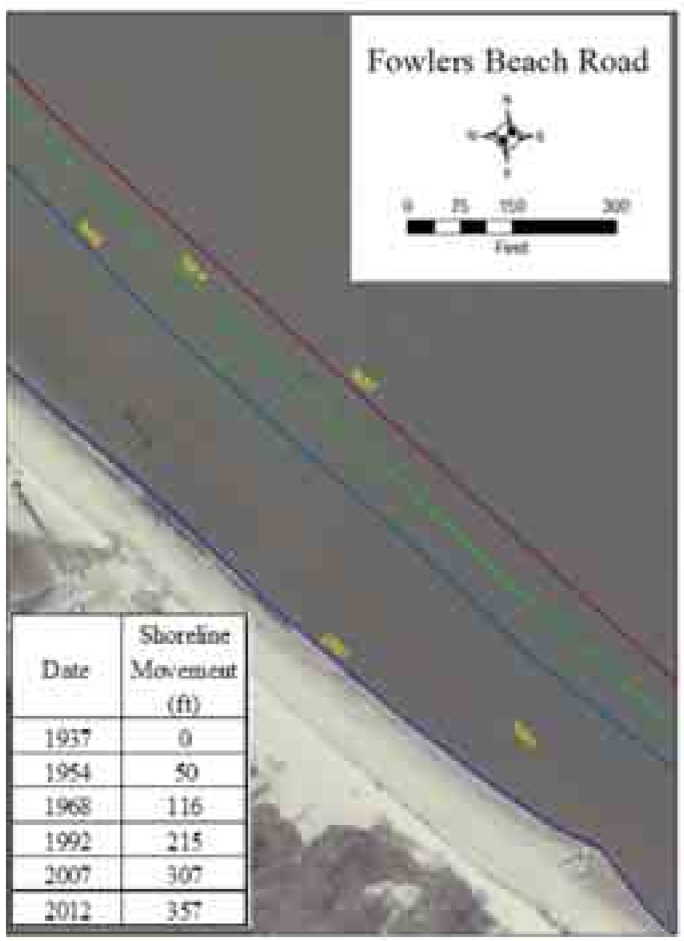


Figure 3-5. Annual shoreline erosion rates in the vicinity of Fowler Beach Road in Unit II. Shoreline position from 1937 was determined using aerial imagery. Shoreline position in 2012 was determined through ground measurements and observations (Courtesy of DNREC Coastal Programs)

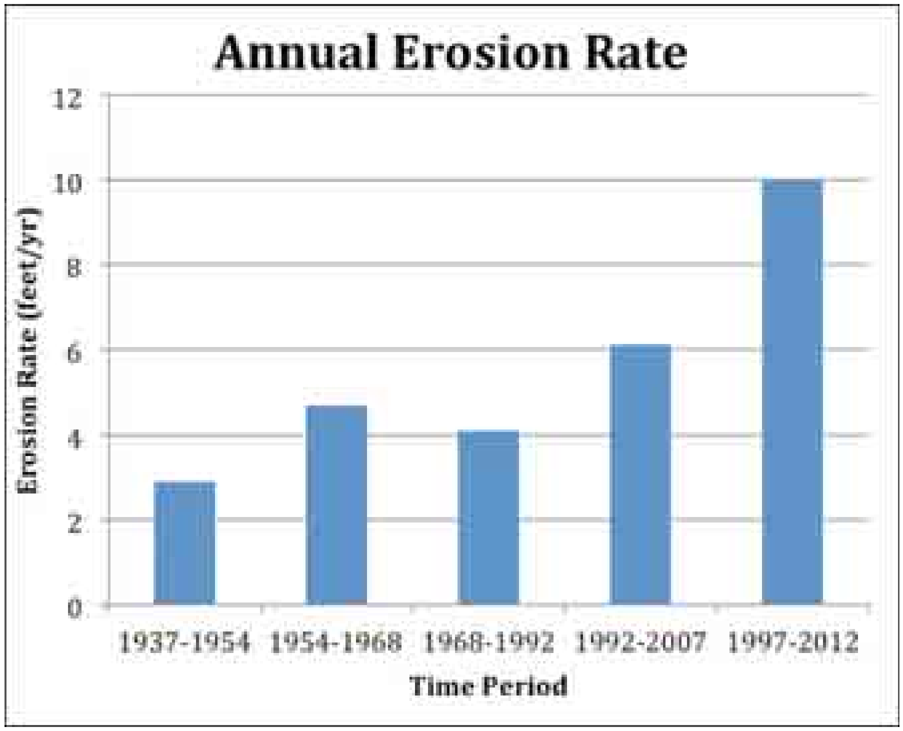
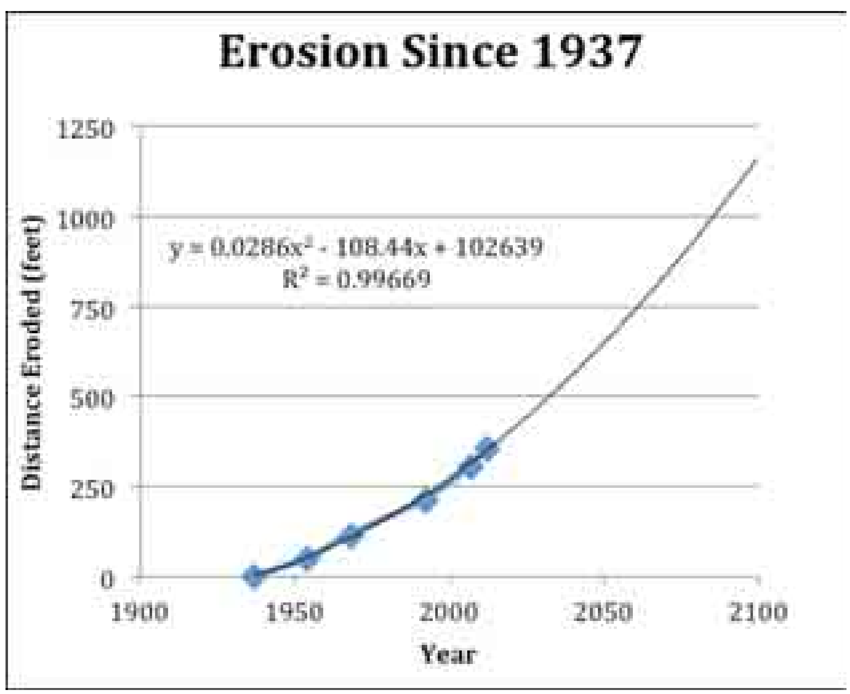
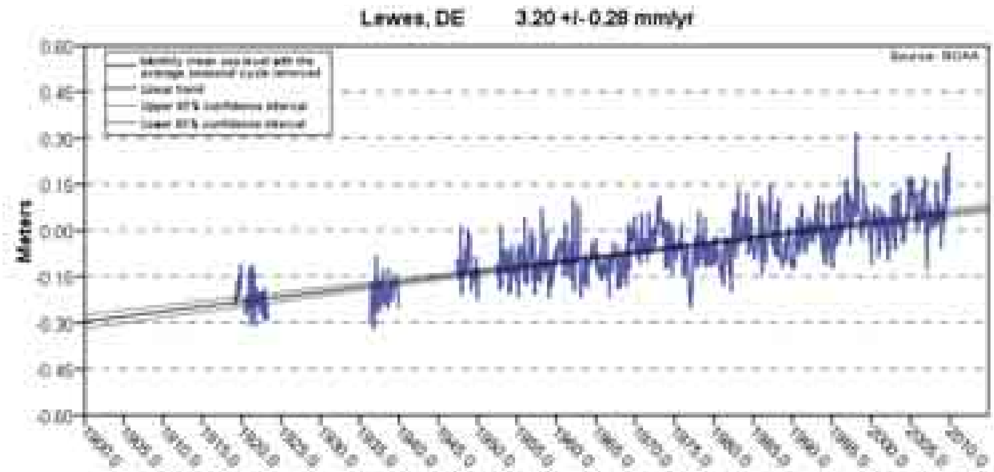


Figure 3-6. Trend of increasing annual shoreline erosion rates in the vicinity of Fowler Beach Road in Unit II. Shoreline position from 1937 was determined using aerial imagery. Shoreline position in 2012 was determined through ground measurements and observations (Courtesy of DNREC Delaware Coastal Programs, unpublished data)



Sea Level Rise:
Sea levels have been rising due to melting of major ice sheets after the last major glaciation 20,000 years ago and thermal expansion of ocean water as it warms (CCSP 2009). The Atlantic coast was located about 180 miles to the east of its present location during the immediate post-glacial period and the ocean has risen over 100 meters (330 feet) since that period. Currently, the average annual local sea level rise (figure 3-7), as measured at the NOAA tide gauge in Lewes, is 3.20 mm/yr since 1919, or 1.05 feet in 100 years *(http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8557380;* accessed January 2012).

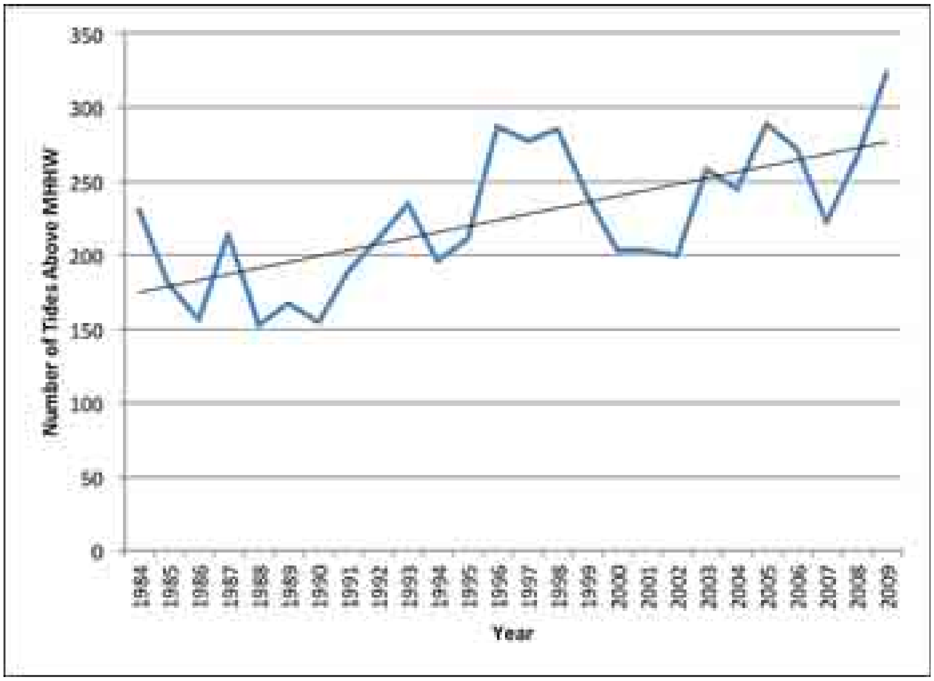
Figure 3-7. Mean Sea Level Trend for NOAA Tide Station 8557380—Lewes, Delaware Increasing Frequency of Above Average High Tides:



No official tide data is currently being collected on or in the immediate vicinity of the refuge. Tide data for the nearby gauge at Lewes have been collected by NOAA since 1919. Although tides at the Lewes station are likely to read somewhat lower than at the refuge for high tide, the data will be adequate for analysis of long-term trends. We acquired the daily high and low tide data for Lewes for the period 1984 to 2009. We selected this period because all data were available in a format relative to a single baseline elevation, referred to as an epoch, and coincides with the history of impoundment management on the refuge. NOAA's Web-based interface *(http://tidesandcurrents.noaa.gov/;* access January 2013) outputs all high and low tides in relation to the mean higher high tide, or the average of the higher of two high tides that occur per day. We extracted all individual tidal events falling at or above mean higher high water. Figure 3-8 plots the total number of individual events by year for the period 1984 to 2009, and shows an increase over time in the frequency of higher than average tidal events. The total number of individual events above mean higher high water ranged from a low of 152 in 1988 to 323 in 2009.

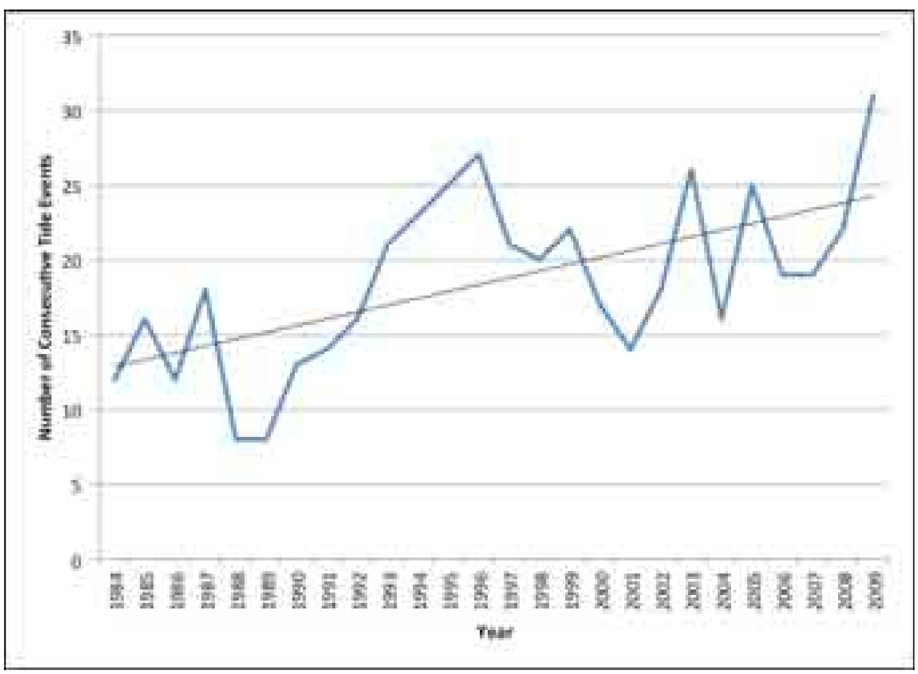
Short-billed dowitchers

Figure 3-8. Number of Individual High Tides Per Year Above Mean Higher High Water Recorded at the Lewes, DE Tide Gauge



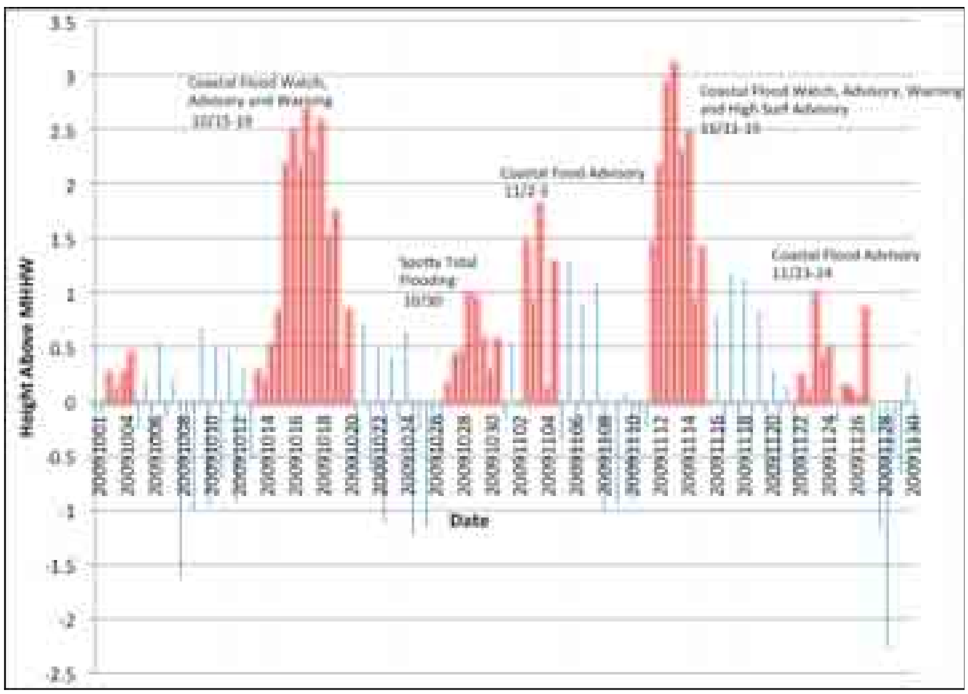
We also compiled consecutive above-normal high tide events, which are two or more consecutive high tides that were recorded at or above mean higher high water. Figure 3-9 shows an increase over time of the frequency of these events. The consecutive events ranged from 2 to 24, or the equivalent of 1 day to 12 days of consecutive high tides above mean higher high water. The total number of such events ranged from 8 in 1988 and 1989 to 31 in 2009.

Figure 3-9. Number of Consecutive High Tide Events Above Mean Higher High Water Per Year Recorded at the Lewes, DE Tide Gauge



These figures show a general trend toward a higher frequency of individual above-average high tides, but perhaps more importantly, a higher frequency of consecutive above-average tides. This has important implications for the dynamics of tidal flooding, overwash, and beach migration along the Delaware Bay shore. More frequent periods of sustained high water in combination with high wave energy associated with storms contribute to erosion and overwash of natural beaches. To illustrate one period of particularly active high tide events, we have graphed all high tides occurring during October to November 2009 (figure 3-10). The zero line on the Y axis represents mean higher high water. All highlighted red lines above mean higher high water represent periods of consecutive above average tides. The periods range from 4 to 14 consecutive tides, or the equivalent of 2 to 7 days. As noted, five of the seven highlighted periods were accompanied by NOAA coastal flood watches, advisories, warnings, and in one case during the period November 11 to 15, a high surf advisory. Much of the undeveloped region along the Delaware Bay shore sustained significant breaching and overwash during these events. As a result of a breach, much of refuge Unit II was opened to daily tidal flow.

Figure 3-10. Consecutive High Tide Events Above MHHW During October to November 2009



Wetland Elevation:
Under natural conditions, salt marshes build elevation by trapping sediment during flood events, building up below ground biomass (e.g., roots and rhizomes), and accumulating organic matter (Cahoon et al. 2009). The accretion of marsh elevation must be maintained in relation to sea level or the marsh will drown, deteriorating and leaving open water in its place. Analysis of sediment cores for the presence of radioisotope fallout (^{137}Cs and ^{210}Pb) deposited at a known time in the past can provide a measure of marsh accretion over recent decades. Preliminary data from radiometric coring conducted by DNREC's Coastal Program, in partnership with the University of Delaware, indicate that the salt marshes in refuge Units I have been accreting over approximately the last 50 years at a rate nearly equal to or greater than the current local sea level rise of approximately 3.2 mm/yr (figure 3-11). However, the average rate of accretion for the same period in the Unit II is 1.7 mm/year, nearly half of the sea level

rise rate. While the average accretion rate for the southern half of Unit III was determined to be 3.85 mm/year, a core in the northern half of Unit III suggests accretion in that portion is only 1.6 mm/year – the lowest recorded anywhere in the State of Delaware during the DNREC/University of Delaware study (figure 3-11). It should be noted that these estimated accretion rates are an average for about the past 50 years, and the current management regime has only been in place for a portion of that time.

Figure 3-11. Historic accretion rates within refuge wetlands and impoundments as determined by analysis of radiometeric core (137Cs content) (Courtesy of DNREC Delaware Coastal Programs and University of Delaware, unpublished data).

In addition to radioisotopic cores, the Delaware Coastal Program conducted elevation surveys of the various wetland units utilizing real-time kinematic GPS survey techniques. The surveys documented the difference in elevation between the wetland vegetation and open water areas. In some areas, less than an inch of elevation stands between the existing vegetation and open water/mud flat (appendix K). Marshes with such a small amount of elevation capital are the most vulnerable to increases in sea level (Cahoon and Guntenspergen 2010). As of the preparation of the final CCP/EIS, elevation/bathymetric data throughout the wetland complex was being updated again using new sonar technology ideal for collecting such data in shallow water environments. Because the elevation of the impoundments is barely above sea level, they are susceptible to saltwater inundation in the short term during coastal storm events, unless and until additional sediment is present to increase the elevation. New and proposed marsh elevation monitoring (surface elevation tables and marker horizons) on the refuge will add additional critical data to our understanding of short-term accretion within the impoundments under current management regimes, as we evaluate refuge wetland management options, and as we monitor the impacts of future management actions.