3.1. WETLANDS OF THE INLAND BAYS

3.1.1. General Introduction

The wetlands surrounding Delaware's Inland Bays are extremely important to both the environmental and economic health of the Inland Bays region. Over the last twenty to thirty years, much information has been obtained to increase our knowledge and understanding of wetlands' functions and values. Widespread recognition of wetlands' benefits to the natural and human environment has resulted in increased awareness of the importance of preserving wetlands; this was not the case 150 years ago when draining and filling wetlands was accepted as a beneficial use of wetlands. Wetlands are now recognized as important natural resources, providing many benefits: they provide habitat essential to a wide variety of plants and animals, including many threatened and endangered species; they serve as spawning and nursery areas for great numbers of finfish and shellfish species, of both commercial and recreational importance; they provide important areas for breeding, nesting, and feeding habitat for waterfowl and other birds. Wetlands also provide direct values to humans: wetlands contribute to improving water quality by removing excess nutrients, sediments, and chemicals; they provide natural flood control (flood conveyance and storage) along streams and in coastal areas; they provide erosion control along shorelines; they are important as a source and reservoir of ground and surface water; they provide recreational opportunities for hunting, fishing, and observing wildlife.

Wetlands Definition

Wetlands, or wet environments in the Inland Bays drainage basin include tidal marshes and mud flats along the shoreline areas (coastal areas); as well as freshwater marshes in upper reaches of tidal streams, bottomland hardwood forests, wet meadows, and ponds. Wetlands are defined as "semi-aquatic lands that are saturated or flooded for varying periods of time during the growing season." Within the geographic range of the Inland Bays watershed, the required duration of continuous saturation and/or flooding for an area to be considered a wetland is a period of seven continuous days. Wetlands are characterized by specific types of soils and hydrologic conditions, which in turn affect the types of plants that grow in wetlands. When not completely flooded, wetlands are usually characterized by soils that are saturated near the land surface, i.e. within the root zone, or within the top 10"-12" of sediment. The environmental conditions caused by wetlands hydrology results in the development of hydric soils (saturated or periodically flooded soils), and colonization of wet areas by hydrophytic plants (those plants adapted for life in wet soils). Thus, a combination of soil type, vegetation type, and hydrology creates a wetland situation or a specific wetland type.

In general, two broad categories of wetland types are recognized in the Inland Bays region: 1) coastal wetlands, and 2) freshwater, or inland wetlands. Coastal wetlands are generally thought of as the tidal marshes and mudflats that are inundated by tides, resulting in either a regular daily or periodic flooding by salt, brackish, or fresh water. They are closely tied to the estuarine system, and are directly impacted by their environment, controlled by salt water and fluctuating water levels. Coastal wetlands are found along the margins of the Inland Bays, in areas influenced by tides (normal tides as well as storm surges and wind driven storm tides). Freshwater or inland wetlands are generally non-tidal wetlands, consisting of freshwater marshes, swamps, ponds, and bottomland hardwood forests. They are usually located in upper reaches of streams and rivers, throughout floodplains along rivers and streams, along edges of ponds, lakes, and in low-lying depression or areas of low elevation.

The term "wetland" is often used interchangeably with terms such as marsh, tidal marsh, and swamp. The word "wetland," as used in this report is actually a defining term for an area that falls within one of the following 5 categories (as defined in Tiner, 1985): 1) areas with both hydrophytes and hydric soils including marshes dominated by grassy vegetation, and swamps dominated by woody vegetation; 2) areas without hydrophytes, but with hydric soils (e.g. tidal flats, and farmed wetlands); 3) areas with hydrophytes, but with non-hydric soils (e.g. recently flooded impoundments); 4) areas without soils, but with hydrophytes (e.g. seaweed covered rocky shorelines); and 5) periodically flooded areas without soil and without hydrophytes (e.g. sandy/gravelly coastal shorelines). Throughout this document, the term "wetland" is used in an all encompassing sense, while terms such as marsh or swamp are used to further define a wetlands type or area.

To further clarify the definition of wetlands, the National Wetlands Inventory Maps classify wetlands on the basis of ecological system and ecological characteristics (Cowardin et al, 1979). Coastal and freshwater wetland types in the Inland Bays drainage basin are grouped and depicted on the NWI maps as part of the major wetlands classification systems: Marine (open tidal bays and coastlines), Estuarine (salt or brackish tidal water marshes and associated waters/sediments), Palustrine (freshwater marshes, swamps, and shallow ponds), Riverine (freshwater rivers and streams), and Lacustrine (freshwater lakes, reservoirs, and large ponds) (Tiner 1985). The predominant wetland groups in the Inland Bays regions include both estuarine wetlands and palustrine wetlands. The four major estuarine wetland types are aquatic beds, tidal flats, emergent wetlands, and scrub-shrub wetlands. Palustrine wetlands represent nontidal emergent wetlands, scrub-shrub wetlands, forested wetlands, and ponds, with palustrine forested wetlands the predominant wetland type throughout the Bays' drainage basins. Preliminary data from the National Wetlands Inventory's study of recent (Colonial times to present) wetland changes within Sussex County (not specific to the Inland Bays watershed) reveal a 17% loss of estuarine wetlands, primarily due to development; a 62% loss of vegetated palustrine wetlands, caused by agricultural and forestry activities; and an unknown % gain in nonvegetated palustrine wetlands, resulting from pond construction (Tiner, 1987). Recent trends in wetland changes that need to be addressed at the present time include: 1) changes in areal extent of freshwater wetlands due to developmental pressure (as opposed to the calculated estimates lost to agricultural and forestry activities); and losses of wetlands due to sea level rise, which are thought to be significant (D. Saveikis, personal communication). Similarly, of critical importance is identification of regionally important and valuable threatened wetland types, such as freshwater tidal wetlands (B. Anderson, personal communication).

General Functions and Values

Wetlands within the Inland Bays' drainage area are important for water quality, flood protection, fish, shellfish , and wildlife resources, and a variety of other public values. Both tidal and non-tidal wetlands are considered to be some of the most productive ecosystems in the world. The benefits, functions, and values of wetlands are generally divided into three basic categories:

1) fish and wildlife values; 2) environmental quality values; and 3) socio-economic values. A more detailed description of wetlands wildlife habitat values, is included later in this chapter. A brief overview of wetlands functions and values is described here.

Wetlands provide many fish and wildlife values, including reproduction, spawning, and nursery grounds, feeding areas, resting areas, escape cover, migration corridors, and habitat for endangered plant and animal species. Both tidal and non-tidal wetlands have been found to be essential to maintaining fish populations in the state. According to state fisheries biologists, approximately 98% of Delaware's commercially important fisheries are dependent on wetlands (Delaware Conservationist, 1987). Many species of fish and shellfish feed in wetlands or on wetland-produced food, and many species utilize wetlands as spawning and nursery grounds. Similarly, tidal and non-tidal wetlands provide breeding grounds, overwintering areas, and feeding grounds for waterfowl and other birds. Mammals, amphibians, and reptiles utilize and depend on wetland areas for food, cover, migration corridors, and habitat.

Wetlands are crucial to maintenance of high environmental quality to other habitats, especially for adjacent aquatic habitats in the Inland Bays. Along with the major food value of wetlands plants themselves (leaves, stems, roots, and rhizomes), adjacent aquatic shallow water nearshore habitats are dependent upon the productivity of wetlands plants and associated decayed plant material and detritus. Wetlands also act to improve and maintain water quality through: 1) removing and retaining nutrients such as nitrogen and phosphorus; 2) processing and filtering wastes; and 3) reducing sediment loads from adjacent waters, and stabilizing deposited sediments.

Socio-economic values associated with wetlands include: flood and storm damage protection, erosion control, water supply and groundwater recharge, hydroperiod regulation, and recreational and aesthetic considerations. Wetlands are extremely effective in temporary storage of flood waters and protection of downstream property owners from flood damage. The flood storage function of wetlands also acts to diminish the velocity of waters in adjacent rivers and streams, thereby causing a reduction in streambank erosion. Along more open shorelines surrounding the bays and lower reaches of tidal rivers and creeks, wetlands are considered to be effective erosion control agents. In low energy environments, wetlands can reduce shoreline erosion through: creating a cohesive sediment mat and/or matrix with tree and plant roots, dampening waves through friction, and reducing current velocity alongshore through friction. Although many wetlands are areas of groundwater discharge, the recharge potential of wetlands to groundwater is dependent upon several factors, including wetlands type, geographic location, season, soil type, water table levels, and precipitation. Unfortunately, perhaps the most appreciated functions and values of wetlands are those that are attached to greatest human use, enjoyment and pleasure, such as recreational opportunities and aesthetics: fishing and hunting, hiking; nature observation; photography; canoeing; and boating.

Table 3.1 provides a listing of general wetlands functions.

3.1.2 Major Wetlands Types

This section provides an overview of wetlands within the Inland Bays watershed, focusing on: 1) major wetland types and associated habitats; and 2) current status and recent trends in wetlands losses.

The 300 square mile Inland Bay watershed contains a variety of wetlands that have

WETLANDS FUNCTIONS

A. *Flood conveyance*—Riverine wetlands and adjacent floodplain lands often form natural floodways that convey flood waters from upstream to downstream points.

B. *Barriers to waves and erosion*—Coastal wetlands and those inland wetlands adjoining larger lakes and rivers reduce the impact of storm tides and waves before they reach upland areas.

C. *Flood storage*—Inland wetlands may store water during floods and slowly release it to downstream areas, lowering flood peaks.

D. *Sediment control*—Wetlands reduce flood flows and the velocity of flood waters, reducing erosion and causing flood waters to release sediment.

E. *Fish and shellfish*—Wetlands are important spawning and nursery areas and provide sources of nutrients for commercial and recreational fin and shellfish industries, particularly in coastal areas.

F. *Habitat for waterfowl and other wildlife*—Both coastal and inland wetlands provide essential breeding, nesting, feeding, and predator escape habitats for many forms of waterfowl, other birds, mammals, and reptiles.

G. *Habitat for rare and endangered species*—Almost 35 percent of all rare and endangered animal species are either located in wetland areas or are dependent on them, although wetlands constitute only about 5 percent of the nation's lands.

H. *Recreation*—Wetlands serve as recreation sites for fishing, hunting, and observing wildlife.

I. *Water supply*—Wetlands are increasingly important as a source of ground and surface water with the growth of urban centers and dwindling ground and surface water supplies.

J. *Food production*—Because of their high natural productivity, both tidal and inland wetlands have unrealized food production potential for harvesting of marsh vegetation and aqua-culture.

K. *Timber production*—Under proper management, forested wetlands are an important source of timber, despite the physical problems of timber removal.

L. *Historic, archaeological values*—Some wetlands are of archaeological interest. Indian settlements were located in coastal and inland wetlands, which served as sources of fish and shellfish.

M. *Education and research*—Tidal, coastal, and inland wetlands provide educational opportunities for nature observation and scientific study.

N. *Open space and aesthetic values*—Both tidal and inland wetlands are areas of great diversity and beauty and provide open space for recreational and visual enjoyment.

O. *Water quality*—Wetlands contribute to improving water quality by removing excess nutrients and many chemical contaminants. They are sometimes used in tertiary treatment of wastewater.

Source: Adapted from Kusler, 1983.

Table 3-1 **Generalized Listing of Wetlands Functions (Conservation Foundation, 1988)**

developed over the last 8,000 to 10,000 years. The predominant groups (as defined by Cowardin, et al., 1979) are estuarine wetlands and palustrine wetlands, with peripheral marine wetlands on the easternmost portions of the Inland Bays areas. The extent of riverine and lacustrine wetlands is limited within the Inland Bays watershed. Riverine wetlands are found in the uppermost reaches of the drainage basin, and they are usually associated with man-made, or excavated ditches. Lacustrine wetlands are even more limited in their areal extent, and only a few isolated lacustrine wetlands are delineated by the National Wetlands Inventory. The Cowardin (1979) classification system groups wetlands according to ecologically similar characteristics. Within each group, there are many wetland types based on differences in vegetation and hydrology. This report presents a simplified overview of the U. S. Fish & Wildlife Service's wetland classification system, as described by Tiner (1985). For additional technical detail applied by the U. S. Fish & Wildlife Service to its wetland classification system, the reader is referred to Cowardin et al (1979).

3.1.3. Riverine Wetlands

Riverine wetlands are usually restricted to nonpersistent emergent wetlands, aquatic beds, and unvegetated shallow water or exposed areas in freshwater rivers and creeks (salinity < 0.5 ppt) (Tiner, 1985). Although many freshwater wetlands are found along the borders of rivers and creeks, only a small portion of these are defined as riverine wetlands; these include aquatic beds within river channels and fringes of nonpersistent emergent plants growing on river banks or in shallow water (Tiner, 1985).

Riverine wetlands within the Inland Bays watershed are limited to the western fringes of the watershed, or the upper reaches of the drainage basin, with most riverine designations found

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in the Indian River Bay drainage area. These riverine wetlands, comprising less than 2 percent of the Inland Bays total wetland area, are classified as non-tidal (lower perennial), open water of unknown bottom, and may be either permanently flooded or intermittently exposed (subaerially). Most riverine wetlands that are tributaries to Indian River Bay are excavated ditches, such as sections of Iron Ditch, Whartons Ditch, Laurel Ditch, Horse Pound Ditch, and portions of the upper reaches of Vines Creek and Pepper Creek. Several unditched riverine wetlands are also delineated, including Herring Branch of Vines Creek.

Typical nonpersistent emergent vegetation in riverine wetlands include, in shallow water: burreed (Sparganium spp.), pickerelweed (Pontederia cordata), arrowhead (Saggitaria spp.), arrow arum (Peltandra virginica), rice cutgrass (Leersia oryzoides), and smartweed (Polygonum spp.). Submerged aquatic bed vegetation is likely to include pondweed and riverweed (Potamogeton spp.), spatterdock, and white water lily (Nymphaea ordorata).

3.1.4. Lacustrine Wetlands

Lacustrine wetlands are found in shallow waters and along exposed shorelines of lakes, reservoirs, and deep ponds. Typical lacustrine wetland vegetation includes: 1) free-floating plants and rooted vascular floating-leaved plants (spatterdock, white water lily, water shield, duckweed), and submergent plants (pondweeds, waterweeds, water milfoil, and Hydrilla) in lacustrine aquatic beds; and 2) emergent plants (arrowhead, spatterdock, sedge, smartweed, pickerelweed, arrow arum, burreed, spikerush) in nonpersistent emergent lacustrine wetlands along lake/pond shorelines (Tiner, 1985).

Lacustrine wetlands, like riverine wetlands, are not frequently found within the Inland

Bays drainage basin, and comprise less than 2 percent of the watershed's total wetland area. Most of these lacustrine wetlands are found in diked, impounded, or excavated ponds/lakes, including Burton Pond (tributary to Rehoboth Bay), and Betts Pond, Drain Ditch, and several other unnamed ponds in the Indian River Bay drainage system. Within the Little Assawoman Bay drainage system, 35 Acre Pond (located near Sassafras Landing) is delineated as a limnetic, nontidal intermittently exposed/permanently flooded lacustrine wetland.

3.1.5. Marine Wetlands

Marine wetlands in the Inland Bays vicinity are limited to sandy intertidal beaches located along the Atlantic coastal shorelines adjacent to Rehoboth, Indian River, and Little Assawoman Bays. Marine habitats are exposed to the waves and currents of the open ocean, and to water regimes that are determined primarily by the ebb and flow of oceanic tides. Salinities often exceed 30 parts per thousand, with little or no dilution, except directly at the mouth of Indian River Inlet. Vegetation commonly found in this type of wetlands along beach areas include: sea rocket (Cakile edentula), saltwort (Salsola dali), sandbur (Cenchrus tribuloides), beach grass (Ammophila brevigulata), beach orach (Atriplex arenaria), cocklebur (Xanthium strumarium), sea purslane (Sesuvium maritimum), and beach bean (Strophostyles helvola) (Silberhorn, 1982; Tiner, 1985).

Although marine wetland habitats may at first appear to be devoid of organisms, there are many species of animals that utilize this habitat. Many insects and reptiles are found among beach vegetation, and small mammals such as mice, raccoons, rabbits, opossum, and fox frequent this habitat in search of food. Shorebirds are dependent on the marine wetland habitats for food, cover, and nesting/breeding habitat. The piping plover, and endangered species in Delaware, is dependent on this habitat for cover, nesting, and brood rearing.

3.1.6. Estuarine Wetlands

Estuarine wetlands consist of tidal wetlands adjacent to deepwater tidal habitats that are usually semi-enclosed by land, but have an open connection to the ocean. In estuarine wetland areas, ocean waters are usually diluted by freshwater runoff from adjacent uplands, but salinities may occasionally increase during periods of low precipitation and high evaporation. Estuarine wetlands are associated with tidal waters of the Inland Bays, which extend along the fringes of the Inland Bays and upstream in coastal creeks to a point where the water contains less than 0.5 parts per thousand (ppt) of ocean derived salts. Estuarine wetlands in the Inland Bays are subject to periodic flooding by the tides, on a semi-diurnal basis (low marsh) or during storms and extreme tide events (high marsh). The five major estuarine wetland types in the inland bays are : 1) aquatic beds; 2) intertidal flats; 3) emergent wetlands; 4) scrub-shrub wetlands; and 5) forested wetlands.

1) Aquatic Beds.

Aquatic beds are subtidal areas vegetated mainly with rooted aquatic plants. Eelgrass (Zostera marina), and widgeongrass (Ruppia maritima) are the only reported submerged aquatic species that historically have been reported in the Inland Bays (See Living Resources Chapter for more detail on SAV's). A survey conducted in 1985/1986 demonstrated that there were no known surviving beds of eelgrass or widgeongrass in Delaware's Inland Bays. Other subtidal wetlands types mapped in the Inland Bays include unvegetated subtidal open water and unconsolidated bottom zones. These areas are typically found in the flood tidal delta area of Indian River Bay, along the relict flood tidal deltas of Rehoboth Bay, and in shallow nearshore areas along the shorelines of the bays. Delaware DNREC has made recent (1989-1991) attempts to reestablish SAV's in the Inland Bays (B. Anderson, personal communication). Further experimentation, along with written documentation of results and monitoring programs should provide much needed information on the status of aquatic bed wetlands within the Inland Bays.

2) Estuarine Intertidal Flats/Bars

Estuarine intertidal flats are largely unvegetated areas subject to tidal flooding twice daily, and are exposed to air between times of high tide. They occur between the intertidal emergent wetlands and subtidal estuarine waters, and most macrophytes (with the exception of occasional clumps of smooth cordgrass (Spartina alterniflora)), do not inhabit these zones. Rather, estuarine intertidal flats and bars are typically colonized by algal communities. Microscopic vegetation, such as dinoflagellates, blue-green algae, green macro-algae, and diatoms are often abundant and important plants in this habitat. Estuarine intertidal flat/bar wetlands habitats are found along the intertidal perimeter of the three Inland Bays. Although not as expansive in area as adjacent estuarine emergent wetlands, intertidal flats and bars are widespread and found almost continuously around the borders of Rehoboth Bay and Indian River Bay. The areal extent of estuarine intertidal flat/bar environments in and around Little Assawoman Bay, however, is much more limited. These habitats are primarily restricted to the northern perimeter of Little Bay, and to isolated pockets in Dirickson Creek. Estuarine intertidal flats and bars are not necessarily connected to contiguous emergent upland wetlands (B. Anderson, personal communication).

3) Estuarine Emergent Wetlands.

Estuarine emergent wetlands are the dominant wetland type along the Inland Bays shorelines, and along tidal creeks that are tributary to the bays. Around Rehoboth Bay, extensive estuarine emergent wetlands can be found in eastern sections (Rehoboth Marsh), along the northern perimeter (Dodd's Marsh), all along the western bay shoreline (Sally Burton Pond vicinity, Shell Cove Landing, Sloan and Sally Cove vicinity, Arrowhead Point, Burton Point), and along the southern bay shoreline (Nats Marsh, Raccoon Point). Estuarine emergent wetlands are also prevalent along the edges major and minor tidal creeks and tributaries to Rehoboth Bay, such as Love Creek, Herring Creek, Guinea Creek, and Wilson Creek. Indian River Bay estuarine emergent wetlands are seen as backbarrier marshes along the eastern perimeter (Mare Marsh, Beach Cove marshes, marshes surrounding Burton Island), and narrow marshes fringing uplands along the southern and northern perimeter (Pasture Point Cove vicinity, Big Marsh Point, Walter Point marshes, Blackwater Point, Lingo Point). More extensive estuarine emergent wetlands are common along Indian River Bay's tidal rivers and creeks, such as Whites Creek, Blackwater Creek, Vines and Pepper Creeks, Indian River, Warwick Gut, and Emily Gut. Along Little Assawoman Bay's perimeter, estuarine emergent wetlands include backbarrier marshes, such as Daisy Marsh and adjacent unnamed marshes, extensive marshes in the vicinity of Assawoman Bay Wildlife Area along the northwestern perimeter, and marshes fringing uplands at Bennett Point, Laws Point, Peppers Landing, Conch Point, Point of Ridge/Tubbs Cove vicinity, and

Lighthouse Cove. Estuarine emergent wetlands can also be found along Dirickson Creek, and other minor tributary streams.

Estuarine emergent wetlands are the low-lying grassy areas around the bays' perimeters that are either regularly or irregularly flooded by tidal waters. They are flooded for varying periods depending on elevation, and are vegetated by a variety of macrophytic plants depending on frequency and duration of tidal flooding, substrate, and salinity. Emergent wetlands can be divided into two general zones based on elevation and general physiographic conditions. These lateral zonations are commonly referred to as: low marsh, or regularly flooded wetlands; and high marsh, or irregularly flooded wetlands. The low marsh areas extend from about mean sea level to the mean high tide level, and are alternately flooded by the tides and exposed subaerially at least once (usually twice) daily. In high and moderate salinities, the low marsh is dominated by the tall form of smooth cordgrass (Spartina alterniflora).

The high marsh ranges from above the mean high water mark to the extreme spring high tide level. This zone is less frequently flooded by the tides, usually during the semi-monthly spring tides or during storm conditions, and is generally exposed to air. Vegetation composition will vary in high marsh zones depending on elevation relative to the tide, drainage characteristics of the substrate, and salinity. A greater diversity of plant life is found in the high marsh zone than in the low marsh, including: the short form of smooth cordgrass, salt hay cordgrass (Spartina patens), spike grass (Distichlis spicata), black needlerush (Juncus roemerianus), glassworts (Salicornia spp.), sea lavender (Limonium carolinianum), orach (Atriplex patula), marsh elder (Iva frutescens), groundsel bush (Baccharis halimifolia), common reed (Phragmites australis), and switchgrass (Panicum virgatum). Giant cordgrass (Spartina cynosuroides), narrow-leaved cattail

(Typha angustifolia), Olney three-square (Scirpus olneyi), rose mallow (Hibiscus mosheutos), and water hemp (Amaranthus cannabinus) are common in moderate and low salinity marshes.

4) Estuarine Scrub/Shrub Wetlands.

Estuarine scrub-shrub wetlands are dominated by either high-tide bush (Iva frutescens and/or Baccharis halimifolia) or wax myrtle (Myrica cerifera). The former plant occurs in moderate salinities, while the latter commonly forms a thicket in low salinity areas and occurs along the upland edges of salt marshes. Estuarine scrub/shrub wetlands are usually influenced by the tides only during storm events.

The areal extent of estuarine scrub-shrub wetlands within the Inland Bays watershed is restricted to small, isolated pockets, usually adjacent to (or on the upland edge of) estuarine emergent wetlands. Estuarine scrub-shrub wetlands are found most extensively along upper sections of backbarrier marshes of Rehoboth and Indian River Bays; few or none are delineated along the eastern shore of Little Assawoman Bay. They are also found along the upper reaches of tributaries to the bays, usually associated with upper fringes of estuarine emergent wetlands.

5) Estuarine Forested Wetlands.

Estuarine forested wetlands are found in areas where the salt marsh is advancing into adjacent lowland pine forests due to rising sea level. Loblolly pine (Pinus taeda) is the dominant tree, while spike grass commonly covers the underlying ground. Black needlerush, salt hay cordgrass, and other estuarine plants may also occur beneath the pines. Estuarine forested wetlands, although not specifically shown within the Inland Bays watershed on the National

Wetlands Inventory maps, are probably found around the bays as transitional wetlands; between estuarine emergent and scrub-shrub wetlands, and adjacent upland environments.

Habitats of the Tidal Salt Marsh and Associated Wetlands

The tidal salt marsh is a unique habitat, comprised of and influenced by many biological, physical, and chemical interactions. The dynamic characteristics of estuarine tidal marshes and their location between terrestrial and aquatic zones make them unique habitats for a great variety of organisms. Under the influence of tides as well as freshwater inflow from adjacent uplands, they are accessible to both marine and terrestrial plants and animals. Research has demonstrated that tidal wetlands are extremely important to the health and welfare of fish and shellfish populations, as well as to insects, amphibians, reptiles, waterfowl, shorebirds, song birds, and mammals. Tidal wetlands provide habitat for feeding, nesting, migration, and spawning activities of numerous organisms, a few of which will be described here.

Unvegetated subtidal and intertidal flats and bars, as well as marsh creek banks, provide estuarine habitat to many benthic and epibenthic invertebrates, such as razor clams, hard clams, a great variety of worms, and crustaceans. Many other animals utilize these "flats" as feeding habitat: fish, shorebirds, wading birds, insects, gulls and terns (see Living Resources Section).

In vegetated areas, the unique habitat provided by a tidal wetland is tied to the complex relationship between vegetative zones, salinities, and tidal inundation. Zonation patterns established by vegetation within a wetlands are also reflected in animal distribution throughout a wetland area. Although the distribution of animals in a wetland is not as distinct as plant distribution, animals are none-the-less tied into vegetative and physical habitat zonation. For example, many invertebrates, such as ribbed mussels (Geukensia demissa), snails (Melampus bidentatus), marsh crabs (Sesarma), and fiddler crabs (Uca spp.) are commonly found in low marsh portions of tidal wetlands. While the ribbed mussel, commonly found along creek banks and drainage ditches, is dependent on tidal inundation for its food source, snails and crabs utilize plant detritus, micro-algae, and smooth cordgrass as a food source. Many species of birds are also dependent upon low marsh, or intertidal areas, for habitat. Clapper rails (Rallus longirostris) feed, nest, and brood their young in low marsh zones. Various sparrows, red-winged blackbirds, willets, herons, and many waterfowl (e.g. blackducks) are dependent upon tidal wetlands for feeding habitat, consuming smooth cordgrass seeds, or low marsh invertebrates such as worms, crabs, and snails. Many species of fish depend on and utilize low marsh habitat. Mullet (Mugil cephalus), mummichogs (Fundulus heteroclitus), sheepshead minnows (Cypriinodon variegatus), striped killifish (Fundulus majalis), and juveniles of other species feed over the low marsh during periods of high tide. Ephemeral pools in high marsh areas are inhabited by F. heteroclitus, F. lucia, Gambusia, and C. variegatus. Research has also demonstrated that some species, such as the mummichog, lay eggs at the base of smooth cordgrass stalks, and in empty ribbed mussel shells.

A great variety and number of insects are dependent upon the tidal marsh for habitat. Although insects are usually considered nuisance species to humans, they are extremely important to the food chain, and are an important source of food to many organisms. Insects commonly found in Inland Bays tidal marsh habitats include: mosquitos such as Calex salinarius and Aedes sollicitans which are high marsh breeders, dragonflies (Anax spp.), greenhead flies (Tabanus nigrovittatus), and deer flies (Chrysops spp.), which are both high and low marsh breeders.

The high marsh, or Spartina patens dominated vegetation zones are inhabited and utilized by many small mammals such as the white footed mouse, deer mouse (Peromyscus spp.), meadow vole (Microtus pennsylvanicus), otter (Lutra spp.), and the muskrat (Ondatra zibethica). Many mammals that utilize tidal wetlands are upland species that are dependent on wetlands for food sources. Examples of upland mammals that often frequent wetlands include: raccoons (Procyon lotor), opossums (Didelphus marsupiala), woodchucks (Marmota monax), fox (Vulpes sp. and Urocyon sp.), deer (Odocoileus virginiana), and rabbits (Sylvilagus floridanus).

Many transient, or migratory, species are dependent upon tidal wetlands for feeding and nesting habitat. Wetlands surrounding the Inland Bays are commonly used by many species of waterfowl, including but not limited to: mallards (Anas platyrhynchos), pintails (A. acuta), blue and green-winged teals (A. carolinensis and A. discors), black ducks (A. rubripes), gadwalls (A. strepera), canvasbacks (Aythya valisineria), redheads (A. americana), mergansers (Mergus spp.), loons (Gavia immer), brant (Branta bernicla), Canada geese (B. canadensis), and snow geese (Chen hyperborea).

Brackish Water Wetland Habitat Values

Brackish tidal wetlands (mesohaline; 5 ppt to 18 ppt salinity) are normally found upstream from more saline wetlands, and downstream from non-tidal freshwater wetlands. Brackish water wetlands in the Inland Bays area are generally dominated by two species of vegetation: smooth cordgrass (Spartina alterniflora), giant cordgrass (Spartina cynosuroides), and salt meadow hay (Spartina patens). These grasses (both seeds, roots, and plants) provide important food and protective and nesting cover for many species of birds, waterfowl, mammals, reptiles, and fish.

Waterfowl and shorebirds utilize seed and rootstock of saltmarsh vegetation for a food source, while other birds such as sparrows, feed on the seeds. The grasses themselves are eaten by deer, mice, and other mammals. Predators such as fox, raccoons, and skunk prey on birds, their eggs, and smaller mammals.

The vegetated and unvegetated intertidal mud flats commonly associated with brackish water Spartina wetlands provide additional habitat. Crustaceans, bivalves, worms, and snails are consumed by mammals and birds. Fish commonly found in tidal creeks and ditches within the Spartina marsh include the striped killifish (Fundulus majalis), bay anchovy (Anchoa mitchilli), and hogchoker (Trinectes maculatus), as well as the American eel (Anguilla rostrata). These species feed on worms, shrimp, phytoplankton, zooplankton, and organic material produced by the wetlands plants. The fish also serve as food for predators (birds, waterfowl, snapping turtles, mammals, etc.). Brackish wetlands are very similar biotically to estuarine wetland, and many of the same organisms described in the estuarine wetlands habitat section (just preceding this section) would also utilize brackish wetland habitats.

Tidal Wetlands: Processes of Change

Natural Processes

Tidal wetlands along Delaware's Inland Bays have formed naturally in response to sea-level rise or subsidence, and tidal inundation of surrounding low-lying lands. Fringing marshes form as the "leading edge" of the marine transgression, and represent the landward encroachment of tidal environments. These wetlands migrate landward and upward relative to sea level rise, gradually encroaching onto upland necks surrounding the Inland Bays. Anecdotal accounts of croplands around Indian River Bay slowly turning into marshlands have been documented by Lanan and Dalrymple (1976). This natural process of marsh formation in response to sea-level rise generally results in an increase in wetlands area.

Another natural process of wetlands formation resulting in an increase in tidal marsh acreage in the Inland Bays system is formation of backbarrier marshes on flood tidal deltas and/or washover fans along the eastern margins of the bays. Sediment deposition by flood tidal currents or storm overwash may result in formation of an intertidal or supratidal lobe or deposit of sand, which is then colonized by salt marsh vegetation. In the Inland Bays, an example of this type of marsh formation is Rehoboth Marsh, a relict flood tidal delta of an ancestral Indian River Inlet (Carey, 1979). However, human development and habitation pressures essentially eliminate the possibility of future new inlet/flood tidal delta development in the Inland Bays area. It is not likely that broad expanses of new marsh will form in the future on flood tidal deltas and extensive washover deposits. However, the process of overwash, even if limited to extreme storm events, is important to sediment accumulation and to maintaining the elevation of backbarrier marshes relative to relative sea level rise. It is only during extreme storm events, with associated waves, storm surge, and wind driven tides that sandy material is carried into back barrier environments and onto adjacent wetlands or intertidal flats/bars.

Natural processes contributing to wetlands loss around the Inland Bays include storm wave erosion of wetlands shorelines, "drowning" of wetlands caused by rapid sea-level rise, and grazing and/or grubbing by snow geese.

Human Activities

In recent decades, human activities have altered the extent of tidal wetlands in Delaware's Inland Bays. The major human activities impacting tidal wetlands in the Inland Bays are dredging and bulkheading; spoil disposal; impounding; ditching; waste disposal; residential, commercial, and industrial development; marinas; and agriculture (Daiber and others, 1976). Boat wake erosion is also believed to be a significant source of wetlands loss in the Bays (see Littoral Environments/Habitats Section 3.4). In the 1950's and 1960's, prior to establishment of Delaware's Wetlands Act and implementation of the Department of Natural Resources and Environmental Control Tidal Wetlands Regulations, and enforcement of existing and new Federal wetland programs (e.g. Section 10 and Section 404) dredging probably had a significant impact on the tidal wetlands of Delaware's Inland Bays. Dredging of wetlands, with associated placement of fill and dredge spoil material directly on wetlands, had been used as a mechanism to create waterfront property for housing developments on man-made canals and artificial lagoons, and to create marinas and boatyards. Dredging of tidal wetlands not only resulted in physical destruction of habitat, but also had peripheral impacts on water quality, estuarine salinities, bottom sediments, and associated benthic communities. Wetlands were also used as spoil sites for dredged material. Deposition of spoil on wetlands results in direct loss of wetland habitat, and has longranging and significant impacts on many associated components of the estuarine ecological system. Fortunately, most dredge/fill activities are now strictly regulated by Delaware DNREC and the U.S. Army Corps of Engineers.

Even when dredge/fill activities do not occur directly on wetlands, increased human pressure for development (residential and commercial) in areas contiguous to Inland Bays wetlands may have significant impacts on estuarine wetlands. Activities associated with site preparation in upland areas adjacent to tidal wetlands can result in severe ecological impacts, including: increased sedimentation into wetlands via erosion of cleared land; water quality problems carried into wetlands via surface water runoff and its associated toxic substances; changes in waterflow and freshwater input patterns due to hydrologic changes adjacent to wetlands; and sewage, septic tank, and solid waste impacts that accompany human development of uplands adjacent to wetlands. The general physical characteristics of the Inland Bays and fringing tidal wetlands (relatively shallow, restricted exchange with ocean waters, narrow fringes of estuarine wetlands adjacent to uplands) make them susceptible to human impacts. The relatively slow flushing rates characteristic of the Inland Bays, causes pollutants to become trapped in the bay system, rather than being flushed into the ocean (Daiber and others, 1975).

Other human activities, such as ditching, channelization, and drainage projects, have generally resulted in net losses of wetlands, and secondary negative impacts on adjacent and contiguous intertidal and subtidal habitats. In the 1930's, approximately 44,000 acres of Delaware's tidal marshes were indiscriminately ditched by the Civilian Conservation Corps (CCC) for the purpose of mosquito control. At that time, ditching was considered to be a beneficial practice, intended to improve wetlands for human use and purposes. Sussex County had 75% of the estuarine emergent wetlands ditched for mosquito control; mosquito ditches are evident in most tidal wetlands surrounding the Inland Bays.

Swisher (1982) reports that from the 1920's to the early 1930's, workers, including members of the CCC, hand dug parallel ditches spaced every 45 meters with channel dimensions of 25 cm x 50 cm throughout the marshes surrounding the Inland Bays. Later, from the mid 1930's to the early 1960's, backhoes were used to construct new ditches perpendicular to the old ones, creating a checkerboard pattern. Old ditches were maintained and some were dimensionally enlarged to 45 cm x 60 cm (Stachechi, 1982). After the 1962 storm, a major clean-up of the mosquito ditches took place, utilizing backhoes and cranes to remove the large volumes of sand and storm debris from the channels. Channel dimensions were again increased, some up to a 3-4 foot width. Since the 1970's, a rotary excavator has been used to maintain and construct mosquito ditches (Stachechi, 1982). This indiscriminate mosquito ditching program and its performance are controversial subjects. Although the ditches may have curbed mosquito populations in Delaware, the ditches have altered the hydrology and elevation of tidal wetlands, resulting in significant impacts on tidal wetland habitat. Daiber and others (1976) report the indiscriminate ditching and draining of wetland areas has resulted in major changes in animal populations. Use of ditched wetland areas by invertebrates, mammals, and many birds has declined, as many animals do not utilize "ditched" habitats. Daiber and others (1976) report that extensive studies conducted in Kent County marshes before and after ditching operations showed that in most vegetative zones, the numbers of invertebrates found were significantly lower after ditching operations had been complete. However, another study (Daiber and others, 1976) reported that certain invertebrates, such as fiddler crabs and salt marsh snails, were more numerous in ditched marshes than in unditched marshes. The study concludes, however, that ditching, by lowering the water table of the marsh, is more detrimental to the majority of invertebrates on the marsh. In general, past indiscriminate ditching practices led to associated declines in invertebrate, bird, and mammal populations that normally utilize marsh habitat. Small ponds in the marshes may have been drained completely, and drainage patterns across broad expanses of tidal wetlands have been altered; sediment excavated from the marshes has created new ponds in some areas and changed vegetational zones in others. In addition, there is speculation that mosquito ditches may have accelerated shoreline erosion in some areas (Swisher, 1982).

Recent changes in methods to control mosquitoes through marsh management (e.g. Open Marsh Water Management (OMWM)) are applied more judiciously and are more compatible with maintaining wetland systems. Selectively performed, OMWM can result in enhanced mosquito control through facilitating natural fish predation of mosquito larvae while reclaiming marsh hydrology and enhancing select habitat functions (e.g. feeding, breeding, and cover habitat for fish and waterbirds) (D. Saveikis, personal communication).

Some human activities may actually result in a net gain in wetland areas, or enhancement of degraded wetland habitats. These include colonization of dredge spoil material by wetlands vegetation, and intentional restoration of wetlands habitats. Other activities, such as creation of impoundments, can be used in attempts to restore degraded wetlands or create wetlands of improved biological and ecological value. For example, many Phragmites dominated wetlands, along the upper edges of tidal influence, have been impounded in an effort to control the extent of Phragmites, and to enhance waterfowl utilization of an area. In these areas, embankments or other physical barriers have been used to effectively control natural tidal flow, frequently resulting in the transition of a saltwater habitat to a freshwater or brackish habitat, and the transition from a vegetated wetland area to a shallow pond habitat. The permanent or semi-permanent flooding of a marsh area with freshwater results in significant changes in floral and faunal habitat; these changes can have many beneficial as well as adverse effects. A serious adverse effect with significant secondary impacts would be the resultant loss of the flow of nutrients and energy from the impounded area into the estuary. Many functions and values of tidal wetlands are altered when an impoundment separates a wetland from the estuarine system (Daiber and others, 1975).

Tidal Wetlands: Trends

The drainage basin of Delaware's Inland Bays includes 6,573 acres of tidal wetlands (Daiber and others, 1976). Of the total, Daiber classifies 6,252 acres, or 95% of these wetlands as low marsh (regularly and irregularly flooded), of Spartina alterniflora dominated wetlands. The remaining 312 acres of tidal wetlands surrounding the Inland Bays (5%) were mapped by Daiber as "higher" wetlands, dominated by marsh elder bush (Iva frutescens).

Between 1938 and 1973, the State of Delaware lost over 8,000 acres of tidal wetlands, due to natural processes and human activities (Daiber and others, 1976; Hardisky and Klemas, 1983). Over 2,000 acres of the areal loss occurred in the Inland Bays drainage basin (Daiber and others, 1976). Table 3.2 summarizes tidal wetlands acreage and tidal wetlands loss for the State of Delaware and the Inland Bays drainage basin. In 1938, 91,672.1 acres of tidal wetlands existed in Delaware, of which 8,646.7 acres (representing 9.4% of the State's total) were located in the Inland Bays drainage basin (Daiber and others, 1976). Between 1938 and 1973, 8,251.8 acres of tidal wetlands were lost throughout Delaware, representing 9.0% of the State's tidal wetlands area. In the Inland Bays, the proportion of tidal wetlands lost during this period was

	State of Delaware	Inland Bays	Ref.
Tidal wetlands acreage, 1938:	91,672.1	8,646.7	(1)
Tidal wetlands acreage, 1973:	83,420.3	6,572.4	(1)
Total acres lost, 1938-1973	8,251.8 (9.0%)	2,074.3 (24.0%)	(1)
Average annual loss, 1938-1973 (acres/yr):	235.8	59.3	(1)
Average annual loss, 1954-1971 (acres/yr):	444	N/A	(2)
Total acres lost, 1973-1979	177.3	N/A	(3)
Average annual loss, 1973-1979 (acres/yr):	29.6	N/A	(3)
Net acres lost, 1973-1979:	136.3	N/A	(3)
Average annual net loss, 1973-1979 (acres/year):	22.7	N/A	(3)

References: (1) Daiber and others, 1976
(2) Lesser, 1971
(3) Hardisky and Klemas, 1983

Table 3.2 Tidal Wetlands Loss in the State of Delaware and in the Inland Bays Drainage Basin

24.0%, or a loss of 2,074.3 acres. The average annual loss of tidal wetlands in the Inland Bays amounted to 59.3 acres per year from 1938 to 1973, and 258.8 acres per year in Delaware. Lesser (1971) estimates that statewide tidal wetlands loss was 444 acres per year during the period from 1954 to 1971. This high rate suggests that much of Delaware's tidal wetland loss took place in the late 1950's and the 1960's. This appears to be supported by qualitative comparison of selected aerial photographs from 1938, 1954, and 1968 (as presented in Swisher, 1982). Hardisky and Klemas (1983) attribute the high rate of destruction of tidal wetlands to construction activities designed to "accommodate the building of vacation homes near the coast."

Adoption of the State Wetlands Act in 1976, and enforcement of Federal Section 10 and Section 404 programs, sharply reduced the loss of tidal wetlands in Delaware. Hardisky and Klemas (1983) compared tidal wetland loss rates prior to the enactment of legislation with rates of tidal wetlands afterwards (1973-1979). From 1973 to 1979, total tidal wetlands loss in Delaware amounted to 177.3 acres, of which 120.0 acres were attributed directly to human activities; 57.3 acres were lost to natural erosion. During this time period (1973-1979), 41.0 acres of tidal wetlands formed through natural marsh building processes. Thus, the net loss of tidal wetlands in Delaware from 1973 to 1979 was 136.3 acres, at a rate of 22.7 acres/year. This figure is less than one-tenth the rate of wetlands loss from 1938-1973, and approximately 5% of the rate from 1954-1971.

3.1.7. Freshwater (Palustrine) Wetlands

Freshwater wetlands have received far less scientific investigation than tidal salt marshes, but available research has demonstrated that the two ecosystems are equally important in function and value. A significant, yet unquantified, amount of freshwater wetlands are found in the Inland Bays drainage basin and along the upper reaches of tributaries to the Inland Bays. These habitats are productive and vegetatively diverse, with many ecological functions and values that are similar to salt marshes. These values include: 1) contribution of detritus to the estuarine food web (Whigham et al., 1978; Odum et al., 1984); 2) serving as spawning and nursery areas for anadramous fish (Silberhorn, 1977); 3) acting as sinks for sediments, nutrients (e.g. nitrogen and phosphorus), and pollutants running off uplands (Sloey et al., 1979; Kadlec and Kadlec, 1979); and 4) functioning as habitats for various species of wildlife, including waterfowl, mammals, and many others. Freshwater wetlands also support a great abundance and diversity of plant species.

The palustrine wetland system surrounding the Inland Bays includes all nontidal wetlands dominated by trees, shrubs, and persistent and non-persistent emergents. Palustrine wetlands in the Inland Bays watershed are generally found along the upper reaches of creeks and streams which ultimately flow into the Inland Bays, in lowlying depressions, and in seepage areas. These freshwater wetlands may occur in isolated pockets, or may be seen as linear corridors along margins of old dune systems, and along rivers, streams, and creeks. In the Inland Bays drainage basin area, freshwater wetlands are dominated by palustrine forested wetlands. Less common, but still an important ecological component in the Inland Bays region are palustrine emergent wetlands, palustrine scrub-shrub wetlands, and palustrine open water areas. Flooding ranges from permanent, to seasonal, to temporary. Major palustrine wetlands include: 1) emergent wetlands; 2) scrub-shrub wetlands; and 3) forested wetlands.

1) Palustrine Emergent Wetlands.

In general, palustrine emergent wetlands are dominated by erect, rooted, perennial, herbaceous, or grassy, hydrophytic vegetation. These wetland areas may be flooded for variable periods throughout the year, from as little as a couple of weeks to a permanently flooded condition. Palustrine emergent wetlands are found extensive throughout the Inland Bays watershed, in isolated lowlying areas in uplands, along the margins of streams, rivers, and ponds, at the base of gently sloping uplands, and adjacent and contiguous to estuarine wetlands, above the influence of salinity and tides.

Beyond the reach of the tides, these plants and others grow around the Inland Bays in nontidal emergent wetlands. Some important emergent wetland plants include woolgrass (Scirpus cyperinus), spatterdock (Nuphar luteum), arrow arum (Peltandra virginica), willow (Salix spp.), burreed (Sparganium spp.), broad-leaved cattail (Typha latifolia), spikerushes (Eleocharis spp.), jewelweed (Impatiens capensis), tearthumbs (Polygonum arifolium and P. sagittatum), smartweeds (Polygonum spp.), beakrushes (Rhynchospora spp.), boneset (Eupatorium spp.), Joe-Pye weeds (Eupatorium spp. and Eupatoriadelphus spp.), reed canary grass (Phalaris arundinacea), sedges (Carex spp.), asters (Aster spp.), goldenrods (Solidago spp.), redtop (Agrostis alba), and sensitive fern (Onoclea sensibilis). Shrubs, such as willow (Salix spp.), buttonbush (Cephalanthus occidentalis), swamp rose (Rosa palustris), elderberry (Sambucus canadensis), smooth alder (Alnus aerrulata), silky dogwood (Cornus amomum), and red maple (Acer rubrum) may also be found scattered within these emergent wetlands (Tiner, 1985).

2) Palustrine Scrub-Shrub Wetlands.

Scrub-shrub wetlands are found in tidal and nontidal areas surrounding the Inland Bays, and are characterized by dominance of woody vegetation less than 20' tall. This woody vegetation includes true shrubs, young trees, and trees and shrubs that are small or stunted due to stressful environmental conditions such as wind driven salt shear. Early successional stages of developing forests are also considered scrub/shrub wetlands. Although not as common as palustrine emergent wetlands and palustrine forested wetlands, they do occur throughout the Inland Bays vicinity.

Buttonbush (Cephalanthus occidentalis) is common in both freshwater tidal and nontidal wetlands, while wax myrtle is more common in tidal situations. Important dominance types of shrub wetlands in the nontidal areas of the Inland Bays region include willows (Salix spp.), dogwoods (Cornus spp.), alders (Alnus spp. and Alnus maritima), ash (Fraxinus spp.), Atlantic white cedar (Chamaecyparis thyoides), and red maple (Acer rubrum). Grassy/herbaceous plants often found in the understory of palustrine scrub-shrub wetlands include: rice cutgrass, woolgrass, smartweeds, skunk cabbage, jewelweed, dodder, sedges, soft rush, sensitive fern, and mosses (Tiner, 1985).

3) Palustrine Forested Wetlands.

Palustrine forested wetlands are the dominant freshwater wetland type in the Inland Bays vicinity. Although they are not specifically designated by name, they exist persistently and extensively throughout the drainage basins of Rehoboth, Indian River, and Little Assawoman Bays. The greatest concentration of palustrine forested wetlands in one area can be found in the outer perimeter of the Indian River Bay drainage basin, south and west of Millsboro. They are commonly found along lowlying areas adjacent to rivers, streams, and creeks, and are also found in other areas of lowlying topography, such as upland depressions. These forested wetlands are dominated by trees, both deciduous and evergreen, taller than 20', and are found in both intermittently or seasonally flooded areas. The extent of flooding, soil saturation, and inundation in forested wetlands is highly variable (permanent, seasonal, and temporary), and dependant on such factors as local climate (precipitation), topographic position, and local hydrology (groundwater and surface water), and vegetation type.

Temporarily flooded forested wetlands are common within the Inland Bays watershed. These wetlands, although located in somewhat "drier and higher" wet areas than seasonally flooded wetlands, are representative of wetlands where hydrology may have been affected by human-induced drainage, such as channelization projects in agricultural areas and from stormwater control and drainage alterations in urban and sub-urban residential development. These temporarily flooded forested wetlands are important as buffers to absorb upland flow from adjacent agriculture and residential development. Dominant trees in temporarily flooded forested wetlands include: red maple, sweet gum, tulip poplar, ash, black gum, oak, and loblolly pine. Understory plants commonly include: sweet pepperbush, inkberry (Ilex glabra), elderberry, blueberry, poison ivy (Toxicodendron radicans), greenbriar (Smilax rotundifolia), and honeysuckle (Lonicera japonica).

Seasonally flooded, nontidal forested wetlands are the predominant wetland type throughout the Inland Bays drainage area, and red maple is the most common wetland tree. Other trees representative of seasonally flooded forested wetlands include black gum, loblolly pine, Atlantic white cedar, sweet gum (Liquidambar styraciflua), black willow (Salix nigra), various oaks (Quercus bicolor, Q. falcata, Q. michauxii, Q. palustris, and Q. phellos), American beech (Fagus grandifolia), silver maple (Acer saccharinum), box elder (Acer negundo), sycamore

(Platanus occidentalis), ashes (Fraxinus spp.), river birch, tulip poplar (Liriodendron tulipifera), and elm (Ulmus americanus). Common understory shrubs and trees include sweet bay (Magnolia virginiana), sweet pepper bush (Clethra alnifolia), highbush blueberry (Vaccinium corymbosum), arrowwood (Viburnum spp.), and American holly (Ilex opaca). Herbs, such as skunk cabbage (Symplocarpus foetidus), tussock sedge (Carex stricta), sensitive fern, and royal fern (Osmunda regalis), may be locally abundant.

Permanently flooded palustrine forested wetlands are rare in Delaware, but when they are found, they are located in Sussex County. Although the largest stands of these permanently flooded forested wetlands are known to exist in the Trussum Pond/Trap Pond area, outside the Inland Bays drainage basin, any small areas of permanently and semi-permanently flooded palustrine forested wetlands within the Inland Bays drainage basin should be noted and preserved. The dominant vegetation in these wetlands is bald cypress (Taxiodium distichum). Associated vegetation includes: water lily, spatterdock, pickerelweed, burreed, and pondweeds (Tiner, 1985).

Palustrine Wetlands Habitat Values

Biologically, palustrine, or freshwater wetlands, are considered to be some of the most diverse, productive, and unique habitats in the world. The fluctuating water levels relative to surface elevations create a variety of habitats, resulting in the great diversity of plant and animal life characteristic of freshwater wetland areas (Hardin, 1985). The complexity and variety of vegetational communities that occupy freshwater marshes, swamps, and bogs, coupled with the presence of open water often associated with palustrine wetlands, attracts a multitude of animals (insects, fish, reptiles, amphibians, birds, and mammals) to these areas. Not all wildlife utilizing freshwater wetlands live entirely within specific physical boundaries of the "wet" area; an important aspect of wetlands use by wildlife involves occasional, transitory, and migratory applications such as resting, feeding, breeding, spawning, brood rearing, and cover.

The abundance and diversity of plant life and unique hydrology and soils in non-tidal freshwater wetlands provide for an extremely productive wildlife habitat. The freshwater wetlands surrounding Delaware's Inland Bays provide high quality wildlife habitat for fish, waterfowl, aquatic furbearers, as well as many species of upland, or terrestrial, wildlife. As upland areas surrounding the Inland Bays are continually developed into residential and commercial areas, traditionally "upland" wildlife may be forced to utilize undeveloped freshwater wetland areas more frequently.

Freshwater wetlands along rivers, creeks, and tributaries to the Inland Bays provide essential water, food, and cover for a diverse variety of wildlife. These riparian wetlands also provide corridors, or pathways, along which wildlife (e.g. birds, bats, deer, small mammals) may travel between other habitats. Numerous bird species utilize wetland trees and shrubs for roosting, nesting, and foraging. Neotropical bird migrants are very important species which utilize and are dependant on freshwater wetlands habitats (D. Saveikis, personal communication). Terrestrial mammals, such as white tail deer (Odocoileus virginianus), gray squirrel (Sciurus carolinensis), and eastern cottontail (Sylvilagus floridanus) utilize the food and shelter provided by freshwater wetlands. The variety of prey species (mice, quail, woodcock, waterfowl) found in wetlands attracts predators such as the red fox, skunk, and raccoon.

The unique hydrologic characteristics of freshwater wetlands are important to wildlife diversity found in wet areas. Soil moisture and hydric soils, along with the presence of surface water, have been found to provide for great productivity and species diversity in wetlands areas, as compared to uplands (Brinson et al., 1981; Gill, 1985). Areas with high moisture content are generally more productive habitats because food (vegetation, seeds, insects) are more abundant, and vegetative structure is more favorable to a greater number of species (Odum, 1950; Hardin, 1975; Dickson, 1978; Swift, 1980; Gill, 1985).

Habitat Value of Wetlands to Endangered Species in the Inland Bays

The freshwater and tidal wetlands in the Inland Bays drainage basin area have intrinsic value to wildlife as both a permanent habitat and/or temporary feeding, nesting, foraging grounds. Hundreds and marsh and swamp dwelling species inhabit the region, including many different varieties of birds, reptiles and amphibians, and mammals. Similarly, many upland species benefit indirectly from the wetlands' hydrologic and biological values (Brinson et al, 1981).

A number of endangered or threatened animal species are be found within the Inland Bays drainage basin and associated wetland areas. Although the endangered and threatened species may not be permanent residents of freshwater and saltwater wetlands surrounding the bays, it is likely that the species visit or utilize the wetlands habitats in some way, depending on wetlands for food, water, and cover.

Some of the animal species that may utilize the wetlands in some way are likely to be listed by the federal government as either rare, endangered or threatened. Rare and endangered transient species such as the peregrine falcon (Falco peregrinus spp.) are likely users of Inland Bays wetlands habitats. Other transient species, such as the eastern brown pelican (Pelicanus occidentalis carolinensis), though no longer considered an endangered species along the Atlantic coast, are similarly likely users of the wetlands habitats surrounding the bays. An important endangered species, the bald eagle (Haliaeetus leucocephalus), has been noted nesting adjacent to freshwater and brackish-water wetlands within in the Inland Bays system.

Several other federally listed endangered animals, or formerly threatened species, are likely to be spotted utilizing wetlands habitats. The osprey (Pandiaon haliaetus) population, once threatened primarily due to uncontrolled pesticide use (e.g. DDT), has now recovered. Ospreys are frequently spotted hunting in the bays and nesting in wetlands of the Inland Bays. Similarly, the northern harrier is depended on tidal wetlands for nesting and feeding. Non-tidal freshwater wetlands may provide important habitat (food and/or cover) for the Delmarva fox squirrel (Sciurus niger cinereus), which utilizes wooded wetland areas. Any rare, endangered, or threatened fishes in the Inland Bays watershed would be dependent (directly or indirectly) upon the nutrients, primary productivity, and food web supplied by tidal and non-tidal wetlands. Similarly, rare and endangered species of sea turtles which are sighted in Atlantic coastal areas adjacent to Indian River Inlet, or pinnipeds, which are frequently seen in the Inland Bays estuary, may be indirectly dependent upon the wetlands fringing the Inland Bays.

The importance of wetlands to endangered and threatened species should not be overlooked. On a national level, more than 50% of the fishes and amphibians, 30% of the reptiles and birds, and 15% of the mammals endangered or threatened in the United States are dependent on wetlands for survival (Williams and Dodd, 1979). Wetlands habitat destruction and degradation via drainage for agriculture, timbercutting and logging, land clearing, construction and fill activities for development sites, and pollution may have significant impacts on rare and endangered species. This should be considered when developing policy and regulatory programs for the Inland Bays wetlands which may provide significant habitat for breeding, feeding, cover, and migration.

Habitat Quality Evaluation

Maintenance and restoration of habitats surrounding the Inland Bays is critical to the existence, preservation, and support of all associated biological organisms. Research has demonstrated that the quality of a physical habitat in an area is of primary importance to the biological quality of a site. An investigation of biological integrity and habitat quality of nontidal streams in Kent and Sussex Counties was conducted in 1991 by Delaware DNREC (Maxted et al, 1992). In this study, biological assessments (utilizing aquatic invertebrate communities) of 62 nontidal streams were made in Sussex County, Delaware. While 31% of these nontidal streams were found to have "good" biological quality, 39% were found to exhibit "fair" biological quality, and 31% of the sites had "poor" biological quality indicators (i.e. low diversity; high percentage of invertebrates groups that are tolerant of poor water quality conditions; and low number and percentage of invertebrate groups that are intolerant to poor water quality conditions). Similar results were found in assessment of habitat quality for the 62 nontidal streams in Sussex County: 24% demonstrated "good" habitat quality characteristics; 34% demonstrated "fair" habitat quality characteristics; and 42% of the sampled Sussex County non-tidal streams were determined to be of "poor" habitat quality. Further evaluation of the data showed that 84% of the sites characterized by "poor" biological quality also had "poor" physical habitat scores, thereby demonstrating the direct relationship between biological integrity and habitat quality.

This examination of the relationship between biological quality and physical habitat quality provides important baseline data for future research regarding status and trends of habitats in Delaware. The data provide an essential evaluation of the status quo of nontidal stream environments in Sussex County; i.e. that 76 percent of perennial streams are not attaining their full potential, that existing stream status is indicative of impaired biological conditions, suggesting a relationship to water quality conditions. Stream channelization, habitat alteration, and other human impacts have resulted in degradation of water quality conditions and physical habitat in the Inland Bays watershed. When compared to streams that have undergone limited physical and hydrologic alterations, these degraded streams provide a reference for comparison, or for establishment of historical trends. Maxted (1993) states that "it is clear that current habitat condition of nontidal streams is the result of channelization and agricultural development over the last 150 years. This has resulted in the loss of palustrine wetlands (Tiner 1985) and the degradation of habitat and biological conditions (DNREC 1992). While we cannot measure the loss or degradation incrementally over time, we certainly can conclude that the impact has occurred during the period."

The results of the investigation clearly demonstrate that the biological quality of an area is strongly dependent upon the status or quality of the physical habitat. In addition, the environmental quality of nontidal streams in the Inland Bays watershed has a direct impact on habitat, biological quality, and water quality of the bays themselves. Therefore, protection of and restoration of physical habitat is essential if the full biological potential of nontidal streams, as well as downstream waterbodies, in the Inland Bays is to be achieved (Maxted et al, 1992).

Freshwater Wetlands: Water Quality and Flood Prevention

Special mention should be made concerning the importance of freshwater wetlands to water quality and flood prevention in and around the Inland Bays. Along with providing wildlife habitat and food chain support to the many animals in and around the Inland Bays, freshwater wetlands are an essential and critical component to general hydrologic characteristics of the Inland Bays watershed. Freshwater wetlands have significant impacts on flood control, water supply, and water quality of the Inland Bays, and, when left undisturbed, may provide natural and ecologically sound solutions to many of the anthropogenically induced problems of the Inland Bays. Many of the pre-existing freshwater wetlands surrounding the Inland Bays have been converted to agricultural use, or have been filled for residential and commercial developments over the last 150 years. As wetlands are drained and filled, their capacity to remove and retain pollutants, to process wastes, to reduce sediment loads, to retain stormwater runoff, and to provide temporary flood water storage is eliminated.

Because of the nature of their soils and vegetation, wetlands have the capacity to absorb and retain large volumes of excess runoff during rainy periods, slowly releasing water, and/or extending hydroperiod, to streams and rivers during dry seasons, and maintaining stable groundwater levels and flow. Wetlands also play an important role in cleansing water polluted by industrial wastes, sewage, and runoff from urban and agricultural lands; various chemicals, pesticides, heavy metals, and excess nutrients are bound or broken down in the wetland soils and by wetland vegetation. The acres of destroyed and disturbed wetlands within the Inland Bays watershed could possibly have helped to correct many existing problems of flood control and water quality in and around the Inland Bays; only future preservation and restoration of these environments can begin to resolve such problems.

Freshwater Wetlands: Processes of Change

Freshwater wetlands can be greatly impacted by both natural processes and human interference and alteration. Wetlands are altered physically, chemically, or biologically (Table 3.3). Physical alterations include: placement of fill and other materials in wetlands, converting them prematurely to uplands; excavation; drainage or inundation; or the disruption of natural supplies of sediment to wetlands needed to maintain their elevation relative to sea level. Chemical alterations can be caused by changes in nutrient loadings, by placement of hazardous or other chemical wastes in the wetland, and by the inflow of contaminants from upland or upstream areas. Biological alteration can result from the removal of natural vegetation and the introduction of non-native plants and animals. The dynamic balance between hydrology, soils, and vegetation within a freshwater wetland is easily impacted, resulting most often in degradation of habitat quality, biological diversity, or total loss of wetlands habitat.

Natural Processes

The primary natural processes affecting freshwater wetlands involve water and the hydrology of wetlands. Rising sea-levels in coastal areas impact adjacent riparian wetlands through salt water intrusion and increases in frequency and duration of inundation, resulting in both flooding of existing wetland areas and possible creation of new wetlands on previously upland surfaces. Increases or decreases in the amount of rainfall over a period of time can control the extent of freshwater wetlands in an area. Rainfall and runoff, and associated increases

METHODS OF ALTERING WETLANDS

Physical

1. Filling:
   – adding any material to change the bottom level of a wetland or to replace the wetland with dry land;

2. Draining:
   – removing the water from a wetland by ditching, tiling, pumping, etc.;

3. Excavating:
   – dredging and removing soil and vegetation from a wetland;

4. Diverting water away:
   – preventing the flow of water into a wetland by removing water upstream, lowering lake levels, or lowering groundwater tables;

5. Clearing:
   – removing vegetation by burning, digging, application of herbicide, scraping, mowing or otherwise cutting;

6. Flooding:
   – raising water levels, either behind dams or by pumping or otherwise channeling water into a wetland;

7. Diverting or withholding sediment:
   – trapping sediment, through construction of dams, channelization or other types of projects; thereby inhibiting the regeneration of wetlands in natural areas of deposition, such as deltas;

8. Shading:
   – placing pile-supported platforms or bridges over wetlands, causing vegetation to die;

9. Conducting activities in adjacent areas:
   – disrupting the interactions between wetlands and adjacent land areas, or incidentally impacting wetlands through activities at adjoining sites;

Chemical

1. Changing nutrient levels:
   – increasing or decreasing levels of nutrients within the local water and/or soil system, forcing changes in wetland plant community;

2. Introducing toxics:
   – adding toxic compounds to a wetland either intentionally (e.g., herbicide treatment to reduce vegetation) or unintentionally, adversely affecting wetland plants and animals;

Biological

1. Grazing:
   – consumption and compaction of vegetation by either domestic or wild animals;

2. Disrupting natural populations:
   – reducing populations of existing species, introducing exotic species or otherwise disturbing resident organisms.

Table 3-3 Generalized Listing of Common Methods of Altering Wetlands (Conservation Foundation, 1988)

in surface water/groundwater levels and flow rates can contribute to sediment deposition in wetlands, or bank erosion of existing wetland areas. Natural biotic processes such as vegetative succession can alter the nature of a wetlands community, and episodes of fire can have dramatic impacts on the vegetation, fauna, and surface sediments of a wetland.

<u>Human Activities</u>

Human alterations are likely to have far greater impacts on freshwater wetlands due to the magnitude and duration of the "human process" (as compared to natural processes). The long lasting and often permanent nature of man's activities in and around wetlands are of great significance to trends of wetlands loss in the Inland Bays areas. Direct human impacts resulting in degradation or loss of freshwater wetlands include: discharge of material (chemicals, nutrients, sediment, etc.) into wetlands; filling of wetlands; channelization for flood control, agricultural use, and crop production; silviculture practices; and alterations to general hydrology of an area through construction of dams, dikes, roadways, etc. (Tiner, 1985).

Within the Inland Bays drainage basin, much attention has been focussed on the ditching of lowlying areas to increase and improve agricultural use of the land. Tiner (1985) estimates that in Sussex County, 13% of palustrine forested wetlands have been affected by channelization and ditching projects. Based on the distribution and dominance of hydric soils within the Inland Bays watershed, and data collected by DNREC (Maxted 1993), all of the Inland Bays watershed has been affected by tax ditch/drainage programs. According to the Delaware GIS database, the construction of lateral ditches has been most extensive in areas on the southern side of Indian River Bay, and the land areas surrounding Little Assawoman Bay. Although the ditching of lowlying land areas (i.e. wetlands) has resulted in a definitive loss of wetland habitat, it should be noted that most of the current tax ditch systems are draining and maintaining areas that have been converted to agricultural use since colonial times. Over the last 200 years, substantial drainage of wetlands in Sussex County can be attributed to channelization and ditching for agricultural purposes (R. Smith, personal communication). The soils maps clearly show the ditch networks associated with agricultural fields in hydric soils areas, especially around Little Assawoman Bay. The historic loss of wetlands to agricultural conversion over the last 150 years has been significant and extreme, and management recommendations must be developed and implemented for improvement of existing wetland areas, as well as improving potential habitat functions and values of the tax ditches themselves.

The historical loss of freshwater wetland and riparian habitat to agricultural ditch programs has had a definitive impact on adjacent waterbodies (e.g. increased turbidity, nutrient content), due to the loss of associated wetlands functions and values. It is likely that thousands of acres of freshwater wetlands in the Inland Bays watershed have been converted to agricultural use over the last 150 years. Not only have the wetlands themselves been lost to agricultural use, but their functions and values (both direct and indirect) are lost as well. The impact of agricultural use (channelization and drainage; direct conversion of wetlands; sedimentation; chemical input, etc) on adjacent waterways is made even more significant because of these wetlands losses, and concurrent loss of the wetlands' function and value as natural buffers and filters, to water quality improvement, to flood prevention, and as wildlife habitat. However, future maintenance, restoration, and proper management of remaining riparian (wetlands) habitat, as well as the tax ditches themselves, can possibly restore some of these lost functions and values, and improve water quality and biological potential of the Inland Bays watershed. However, improvements to the ditch network and associated marginal agricultural lands (i.e. converted wetlands) will only serve as an attempt to restore or accommodate a vestige of the thousands of acres of wetlands and resource parameters that had previously existed within the Inland Bays watershed. Because agricultural use of converted and marginal wetlands around the Inland Bays is likely to remain, consideration of best use of remaining wetlands and wet environments associated with agricultural use is the only way to enhance the lost functions and values of farmed wetlands (see Sec. 3.9.3).

With regard to the tax ditch network, Maxted et al (1992) report on the level of biological activity in some of the channelized waterways. Their report noted that: "These waterbodies are capable of supporting a high level of biological activity including support for aquatic animals, aquatic plants, birds, and mammals. ... They {ditches} are important water resources that need to be managed, improved, and protected for multiple uses including drainage, water quality, and biological support" (Maxted et al, 1992). This suggests that: 1) even poor quality resources support aquatic life and wildlife; 2) tax ditches are lower in water quality/habitat quality/biodiversity than higher quality resources; and 3) degraded waterways and channelization sites can be improved with best management practices (BMPs) (Maxted 1993). It is suggested that the most effective BMP is to allow these channelized streams to naturally revegetate; however, "it can take approximately 40 years for the habitat quality of a channelized stream to recover to a pre-altered condition" (Maxted 1993).

It has been suggested that management and maintenance of these ditches can be improved, resulting in improvements to associated habitat quality, biological integrity, and water quality which has been so adversely affected by channelization projects. For example, the maintenance practice of total clean out of agricultural drainage ditches, with concurrent loss of vegetation, bottom sediment, and living resource communities, should be modified to improve and enhance the habitat that these ditches provide (B. Anderson, Personal Communication). Improvements in agricultural drainage management techniques may actually offer a partial solution to the negative impacts that drainage from cultivated lands has historically had on adjacent bays and estuaries. Proper drainage management techniques may serve to reduce nutrient loads and sediments that flow into adjacent waterways. Additional research is needed to determine if physical modifications to drainage control techniques would result in mitigation of the negative effects ditching programs. New drainage water management techniques and initiatives may improve water quality in the streams and bays adjacent to converted wetland/agricultural land areas.

Another critical human impact on freshwater wetlands in the Inland Bays area is silviculture, or timber harvest. Although the areal extent of palustrine forested wetlands lost to timber cutting is not known, logging operations have definitive impacts on forested wetlands sites through removal of vegetation, destruction of soil structure, blocking drainage, damaging seedlings, and transporting nutrients. Destruction of high quality wildlife habitat, along with associated beneficial functions of forested wetland areas, is a direct result of timber cutting. Again, proper management techniques are essential to preservation and maintenance of palustrine forested wetland habitats. In addition, it should be recognized that some forested wetland sites should not be subject to standard logging/forestry practices, to avoid destruction of wildlife habitat, loss of water quality, reduced flood protection, and other values.

Palustrine, or Freshwater Wetlands: Trends

Delaware's wetlands, like wetlands nationwide, are dynamic environments easily altered by natural processes and human activities. The forces acting on wetlands result in areal and physical gains and losses; in Delaware, the overall effect has been wetlands loss and degradation, specifically with regard to nontidal and tidal freshwater wetlands; Dahl (1990, 1991) reports that 54 percent of Delaware's wetlands were lost between 1780 and 1980. Throughout historical time, freshwater wetlands have been viewed as wastelands; commonly considered to be little more than mosquito havens to be drained or filled. Little or no economic or environmental value was placed on these "swampy" areas, and they became prime targets for commercial and residential development; waste disposal; highway development; and landfills. In agricultural areas, low-lying wet areas were drained, cleared, ditched, and put into crop production. These are practices that have going on for 150 years, and conversion of hydric soil/wetlands areas to agricultural use continues today. As a result, studies indicate that, nationwide, more than half of the wetlands that existed in colonial America have been lost. Although specific numbers for acres of wetlands lost in the Inland Bays drainage basin are not presently available, it is likely that wetlands status and trends for the Inland Bays may follow the nationwide, statewide, and countywide data that has been collected over recent years. However, caution should be used in direct application of existing and available statewide and countywide estimates to the Inland Bays watershed. It is highly recommended that specific numbers for freshwater wetlands losses within the Inland Bays watershed should be documented.

While wetland changes in Delaware's tidal coastal wetlands have been well documented, information on inland nontidal wetlands did not exist until recently. Reliable estimates of status and trends of Delaware's freshwater wetlands are available through the U. S. Fish & Wildlife Services' National Wetlands Inventory Project, which was created in 1974. Its primary purpose was to produce a series of maps showing the location, type, and distribution of the nation's wetlands. Most of the following information is summarized from the research conducted by Tiner (1985) in conjunction with the National Wetlands Inventory Project.

Regional Trends

In late 1983, the NWI initiated a study of recent wetland changes with a five state region: Virginia, Maryland, Delaware, Pennsylvania, and West Virginia (Tiner, 1987). Preliminary estimates for the five-state region show a five percent loss of estuarine wetlands and an eight percent loss of vegetated palustrine wetlands between the mid-1950's and the early 1980's, with a 200 percent gain in nonvegetated palustrine wetlands (freshwater ponds). Urban development was the prime cause of estuarine wetland losses, while forestry activities and channelization were responsible for most of the vegetated palustrine wetland losses. The gain in nonvegetated palustrine wetlands resulted from farm pond construction throughout the five-state study area (Tiner, 1987).

Statewide Results

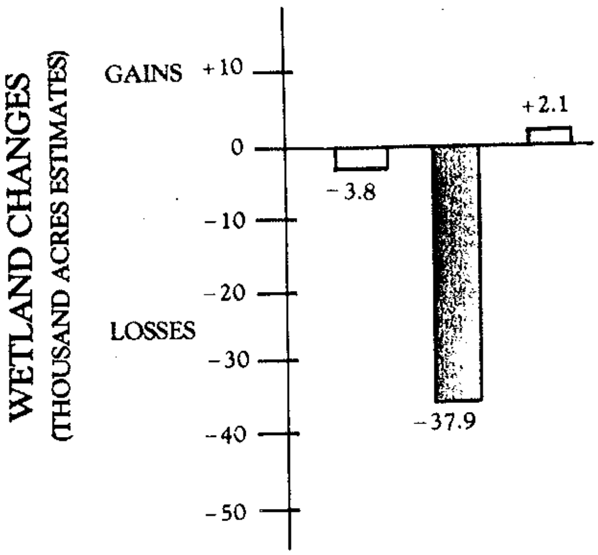
In 1982, the U. S. Fish & Wildlife Service initiated a wetlands inventory in Delaware which involved a mapping project that included inland non-tidal freshwater wetlands as well as coastal wetlands (Tiner, 1985). The purpose of the inventory was to identify the current status of all Delaware's wetlands and serve as a base from which to monitor future changes. The study interval for Delaware was 26 years, utilizing 1955 and 1981 aerial photographs to determine extent of change (Figure 3.1).

Tiner's 1985 report states that in 1981, Delaware contained approximately 216 thousand acres of wetlands, which covered 17% of the state's land area. Palustrine wetlands represented 68% of the state's total wetland area (148,000 acres), with palustrine forested wetlands being the most common and widespread wetland type. Trends in Delaware's freshwater wetlands were calculated utilizing photointerpretation of wetlands changes between the mid-1950's and the late 1970's/early 1980's. Much of the losses in freshwater wetlands involved forested swamp areas, which declined by 17%, or 28,000 acres. Scrub-Shrub swamps dropped by nearly 55%, or 7,000 acres. Results suggest that, statewide, Delaware has lost approximately 21% of its palustrine vegetated wetlands (freshwater marshes and swamps) between 1955 and 1981 (Tiner, 1987), and has gained approximately 400% in pond areas between 1955 and 1981 (Tiner, 1987). These figures represent an average net loss rate of approximately 1,500 acres of palustrine vegetated wetlands per year (Tiner, 1985). These losses are commonly attributed to channelization projects which are usually associated with agriculture practices, forestry practices, urban development, and "other" development. Statewide, 28% of inland vegetated wetland losses were due to direct conversion of wetlands to farmland, while in Sussex County, Tiner's (1985) estimate of direct loss of inland forested wetlands to agricultural channelization and ditching projects drops to 13% (Figure 3.2).

3.9.3 Countywide Results

It has been reported (Delaware Conservationist, 1987) that Sussex County has the largest portion of non-tidal wetlands in the State (67,195 acres). The majority of these non-tidal

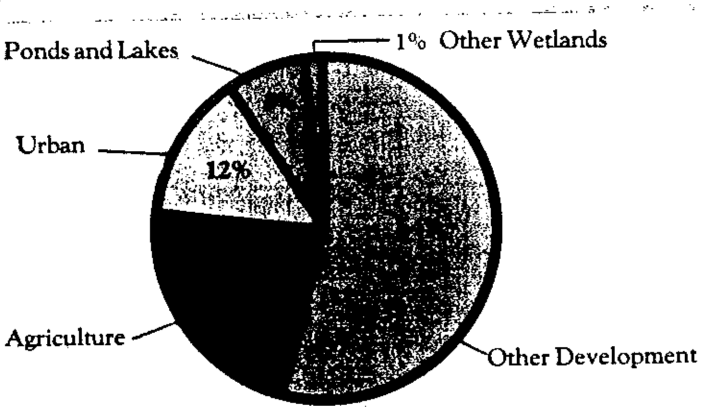
Wetland Trends
DELAWARE



☐ COASTAL WETLANDS
▩ INLAND VEGETATED WETLANDS
☐ FRESHWATER PONDS

Between 1955 and 1981, Delaware lost about 42,000 acres of coastal wetlands and inland vegetated wetlands, for an average annual loss of 1,600 acres. During this time, pond acreage increased by 2,000 acres for a 400 percent gain. The vast majority of the wetland losses involved inland wetlands, particularly forested wetlands which decreased by about 17 percent. Statewide, 21 percent of Delaware's inland vegetated wetlands and six percent of its coastal wetlands recently disappeared.

CAUSES OF INLAND VEGETATED WETLAND LOSSES



Other development, mainly channelization and ditching projects related to agriculture, were responsible for over 50 percent of the recent losses of inland marshes and swamps. Direct conversion of wetland to farmland caused 28 percent of the losses.

CAUSES OF COASTAL WETLAND LOSSES

Urban development of coastal wetlands caused almost two-thirds of the state's losses of these wetlands. Many coastal wetlands were also converted to coastal waters by coastal impoundments, dredging projects, and rising sea level.

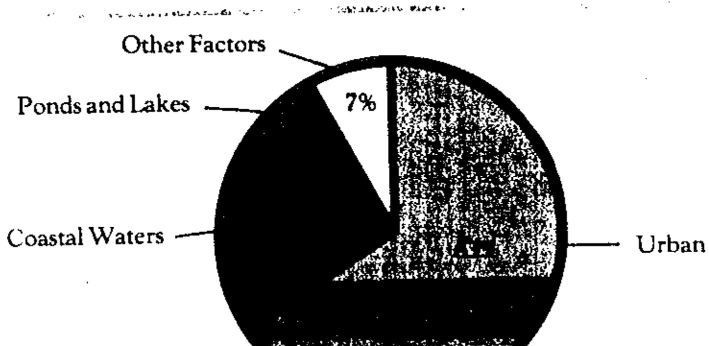
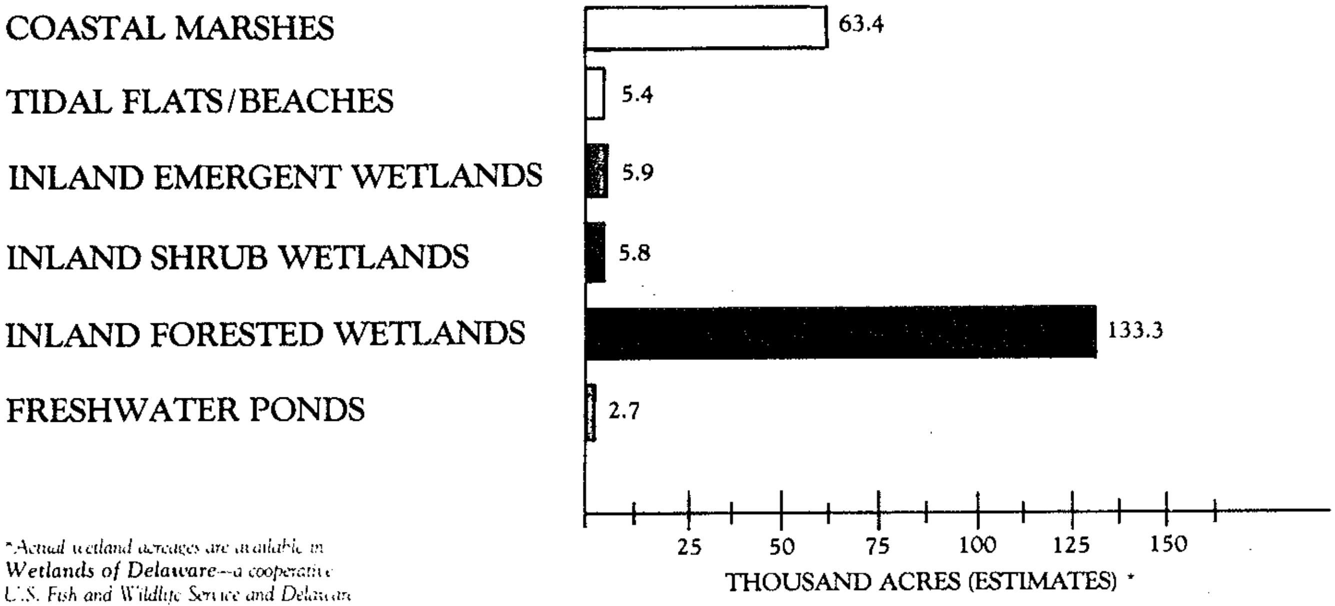


Figure 3.2. Data presented by Tiner (1987) depicting wetlands trends in Delaware, including wetlands changes, and causes of inland and coastal wetland losses (Tiner, 1987).

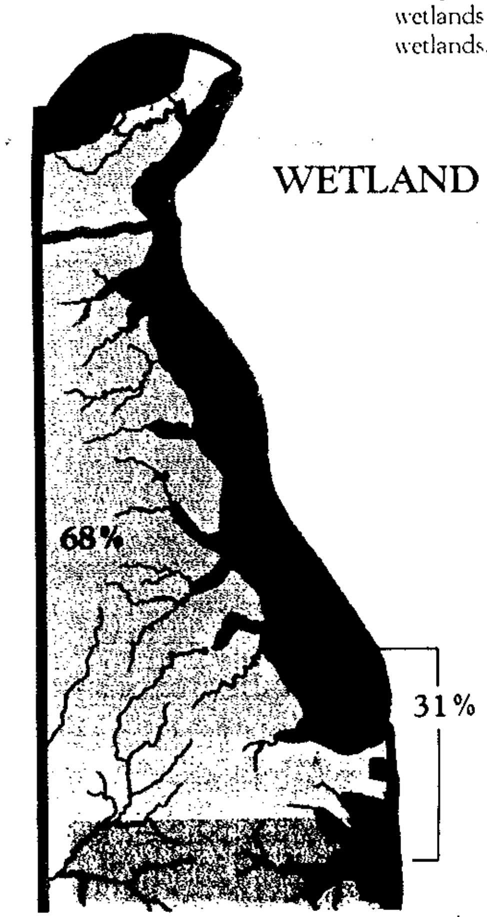
Current Status of Wetlands
DELAWARE



*Actual wetland acreages are available in **Wetlands of Delaware**—a cooperative U.S. Fish and Wildlife Service and Delaware Department of Natural Resources and Environmental Control publication

Roughly 216,000 acres of wetlands exist in Delaware. Coastal wetlands represent slightly less than one-third of the state's wetlands, while the majority are inland forested wetlands

WETLAND DISTRIBUTION



About 17 percent of the state's land area is wetland. Most of the coastal wetlands lie along Delaware Bay, while most of the state's inland wetlands occur in the Coastal Plain region.

Figure 3.1. Data presented by Tiner (1987) depicting current status of wetlands in Delaware (Tiner, 1987).

wetlands are palustrine forested wetland areas, dominated by red maple, sweetgum, and loblolly pine. Tiner (1985) provides data specifically for Sussex County, comparing the currently calculated acreage for National Wetlands Inventory wetlands (late 1970's/early 1980's) with hydric soil acreage summaries from the Soil Conservation Service's Sussex County soil survey (1950's). Tiner (1985) calculates that in the 1950's, there were 186,150 acres of hydric soil areas in Sussex County. By the time the NWI inventory was completed (1980's), there were only 71,123 acres of palustrine wetlands in Sussex County, suggesting that possibly 62% of previously existing palustrine wetlands areas (based on the assumption that hydric soil = wetland area), had been lost over a 20 - 30 year period. Tiner (1985) does acknowledge that there may be problems in utilizing these data for comparison purposes. However, it is highly likely that there have been large losses in the areal extent of freshwater wetlands.

General Estimates for Inland Bays Drainage Areas

General percent estimates for the areal extent of major wetland types (estuarine emergent and palustrine forested) within each Inland Bay drainage area were made, based on National Wetland Inventory maps. Estimates were calculated to estimate the relative percentage of the following wetlands types within each watershed: 1) estuarine intertidal emergent wetlands; 2) palustrine scrub/shrub and palustrine emergent wetlands (combined); and 3) palustrine forested wetlands. Actual acreage figures are not reported due to the limitations in methodology employed. However, relative percent coverage of each wetland type within and between the Inland Bays watersheds is useful in establishing trends. The following results were obtained:

Wetlands within Rehoboth Bay drainage area: 50% estuarine intertidal emergent wetlands, 5% palustrine scrub/shrub and palustrine emergent wetlands, and 45% palustrine forested wetlands. Wetlands distribution within Indian River Bay watershed: 36% estuarine intertidal emergent wetlands, 8% palustrine scrub/shrub and palustrine emergent wetlands, and 56% palustrine forested wetlands. Relative percent of wetlands types within Little Assawoman Bay drainage basin: 61% estuarine intertidal emergent wetlands, 4% palustrine scrub/shrub and palustrine emergent wetlands, and 35% palustrine forested wetlands. Although the actual acreage of each wetland type should be calculated with exact and precise methods, these figures provide general information on the distribution of each major wetland type within a watershed. Within the entire Inland Bays watershed, 44% of dominant wetlands types are estuarine intertidal emergent wetlands, 6% are palustrine scrub/shrub and palustrine emergent wetlands, and 50% are palustrine forested wetlands. 45% of the estuarine emergent wetlands are found in the Indian River Bay watershed; 36% are within the Rehoboth Bay drainage basin; and 19% are found within the Little Assawoman Bay drainage area. The follow distributions were determined with regard to palustrine scrub/shrub and palustrine emergent wetlands within the entire Inland Bays watershed: 67% Indian River Bay; 24% Rehoboth Bay; and 9% Little Assawoman Bay. The relative distribution of palustrine forested wetlands within the entire Inland Bays watershed is as follows: 62% of the palustrine forested wetlands are found in the Indian River Bay drainage area; 28% are within the Rehoboth Bay drainage basin; and Little Assawoman Bay watershed represents only 10% of the palustrine forested wetlands within the entire Inland Bays system. This low percentage of palustrine forested wetlands in the Little Assawoman Bay area is directly related to the extensive channelization and agricultural conversions that have taken place within this watershed.

Channelization has been accomplished through a "tax ditch" program created in 1793 wherein property owners, by paying a tax, have ditches dug to drain wet forested land. In 1951 the Delaware legislature established perpetual maintenance of these ditches, which generally filled with sediment and vegetation in 25 years. At the present time there are approximately 225 miles of tax ditches that drain 35,000 acres of Inland Bays watershed, principally from southern Indian River and Assawoman watersheds. (R. Smith, personal communication).

We have attempted a conversion of the relative percentages previously measured to an absolute area of wetlands types. Using the areas measured by Ritter (1986) for scrub/shrub and estuarine wetlands, we have computed the total forested wetlands in the watersheds and the sum of all wetlands in the drainage basins.

Table 3.4

Wetlands of the Inland Bays

hectares (x2.47 = acres) with percentages in ( ).

	Total Wetlands[1]	**Forested**[2]	**Scrub/Shrub**[2]	**Estuarine**[2]
Indian River Bay	2897 (.6%)	1622 (56%)	232 (8%)	1043 (36%)
Rehoboth Bay	1996 (10%)	898 (45%)	100 (5%)	998 (50%)
Little Assawoman Bay	800 (8%)	280 (35%)	32 (4%)	488 (61%)

[1] The percentage is $\frac{\text{total wetlands}}{\text{total drainage area}}$

[2] The percentage is $\frac{\text{wetland type}}{\text{total wetland}}$

Application of Regional, Statewide, and Countywide Trends to the Inland Bays Drainage Basin

Because specific data on palustrine wetland losses for the Inland Bays drainage basin area are not available, general regional, statewide, and countywide data are typically utilized for the Inland Bays. These figures certainly serve as an important and essential indicators of general trends, but caution should be used when considering application of % loss directly to the Inland Bays watershed area. Calculation of specific wetlands loss numbers for the Inland Bays should be accomplished. Countywide data and estimates of palustrine wetlands as well as calculations of percent losses, though useful in conceptualizing trends of wetlands loss, may not be directly applicable to the Inland Bays region. Direct impacts to and loss of freshwater wetlands to urban and rural residential/commercial housing and development would likely be higher within the Inland Bays watershed than in western Sussex County. Distribution of hydric soils areas in Sussex County also needs to be considered carefully.

For example, much of Sussex County's palustrine forested wetlands are found in southwestern and western portions of Sussex County, associated with the Nanticoke River drainage basin. An examination of SCS soils maps also demonstrates that although there are large areas of hydric soils mapped in the Inland Bays drainage basin, a great percentage of the hydric soils in Sussex County are found in western and southwestern Sussex County, and are associated with the Nanticoke River drainage basin, rather than the Inland Bays.

Similarly, many areas of farmed hydric soil, areas of probable historic wetland locations, are present within the Inland Bays watershed. These areas, through no longer mapped as wetlands, are important to calculations of historic wetlands loss in the Inland Bays vicinity. These areas also offer ample opportunities for wetlands restoration, enhancement, mitigation, or a wetlands "bank" area. They should be considered when calculating the areal extent of Inland Bays wetlands, as they do fit Tiner's (1985) definition of a wetland as an area without hydrophytes, but with hydric soils.

Soils

The SCS Soil Survey of Sussex County, Delaware (1974), provides a general survey of soil types surrounding Delaware's Inland Bays. The hydric soils in the Inland Bays drainage basin, i.e., those likely to support (or have supported) wetland vegetation, include: Tidal marsh, swamp, Fallsington, Pocomoke, and Woodstown soils. These hydric soils are defined as soils that are saturated, flooded or ponded long enough during the growing season (March 1 - October 30) to develop anaerobic conditions in the upper sections, or root zones (USDA, SCS, 1974).

Most of the land area directly adjacent to and surrounding the periphery of the Inland Bays is comprised of tidal marsh soils and coastal beach and dune sediment associations. These are the low areas that are regularly flooded (daily or monthly) by salt water (tidal marshes), and areas of loose, salty beach and dune sands (sandy pocket beaches). Tidal marsh soils are extensive in low coastal areas around the Inland Bays and along tidal reaches of adjacent streams along the estuaries. These tidal marsh soils are likely representative of the locations of the tidal wetland acreage calculations made for the Inland Bays by Daiber and others (1976).

While the tidal marsh soils are typically found along the periphery of each of the three inland bays, the soils located landward of the tidal marsh and coastal beach/dune soils are highly variable. The SCS general map depicts soils landward to tidal marsh soils around Indian River Bay to consist primarily of the Evesboro-Rumford association. These soils are upland soils, typically excessively drained and somewhat excessively drained, composed of a rapid permeable subsoil of sand to sandy loam. Although there are likely to be areas of hydric soils in lowlying areas and along stream fringes that are not depicted on this general map, a large part of the land area surrounding Indian River Bay is not characterized by wetland-type soils. The extreme outer western fringes of Indian River Bay's drainage area is characterized by both the Fallsington-Pocomoke-Woodstown association (poorly drained to well drained soils that have a moderately permeable subsoil of sandy clay loam or sandy loam). A large percentage of palustrine wetlands surrounding Indian River Bay are likely located in this hydric soil zone. Similarly, soils along the southern portion of Indian River Bay drainage basin are characterized as the Pocomoke-Fallsington-Evesboro association (very poorly drained and poorly drained soils that have a moderately permeable subsoil of sandy loam or sandy clay loam, and excessively drained soils that have a rapidly permeable sandy subsoil). These soils would also support palustrine wetland vegetation. The following general estimates of areal extent of soil type associations were calculated for the Indian River Bay drainage system: 53% Evesboro-Rumford association; 23% Pocomoke-Fallsington-Evesboro association; 14% Fallsington-Pocomoke-Woodstown association; 8% Tidal marsh, salty-Coastal beach and dune association; and 2% Muck-Pocomoke-Swamp association.

The southwestern side of Rehoboth Bay is similarly dominated by the Evesboro-Rumford association, representing upland, not wetland habitat areas. However, the northern and northwestern portions of Rehoboth Bay land areas are typified by the Sassafras-Fallsington association (well drained and poorly drained soils that have a moderately permeable subsoil of sandy loam to sandy clay loam), which would likely include a greater percentage of palustrine wetland areas than found in the Evesboro-Rumford soil zones. Relative percentages of soil type associations were calculated for the Rehoboth Bay drainage basin area (from general soils map of Sussex County, USDA, 1974): 45% Evesboro-Rumford association; 35% Sassafras-Fallsington association; 19% Tidal marsh, salty-Coastal beach and dune association; and 1% Fallsington-Pocomoke-Woodstown association.

In contrast to the two bays to its north, Little Assawoman Bays drainage area consists primarily of the Pocomoke-Fallsington-Evesboro association of soils. These soils are characterized by very poorly drained and poorly drained soils that have a moderately permeable subsoil of sandy loam or sandy clay loam, as well as excessively drained soils that have a rapidly permeable sandy subsoil. Although smaller in areal extent than the land areas surrounding Indian River and Rehoboth Bays, the drainage basin of Little Assawoman Bay contains a greater relative percentage of hydric soils and should, therefore, contain a greater percentage of palustrine forested wetlands if the hydric soils areas had not been converted to agricultural use. Estimates based on the SCS general soil map for Sussex County (USDA, 1974) show the following distribution of soil type associations for the Little Assawoman Bay drainage basins: 74% Pocomoke-Fallsington-Evesboro association; 22% Tidal marsh, salty-Coastal beach and dune association; and 4% Evesboro-Rumford association.

3.1.8. Research Needs and Information Gaps

Detailed studies of tidal and non-tidal wetlands specific to the Inland Bays drainage system are unavailable, and many reports on wetlands are comprehensive, including the entire State of Delaware, or all of Sussex County. A coordinated inventory of the tidal and freshwater wetlands in the Inland Bays drainage basin should be made, documenting areal extent of wetland types, such as bottomland hardwood swamps and shrub swamps. More information and base-line data should be obtained on the nature of community structure of the Inland Bays' freshwater wetlands.

Data on the location and rate of change of coastal and inland wetlands and associated habitats are crucial to environmental resource managers. Unfortunately, reliable data, especially on a watershed or basinwide basis is extremely rare. Existing data on soil type distribution, areal distribution of emergent and submergent wetland habitats and upland habitats should be interpreted, classified, analyzed, and integrated with other digital data in a geographic information system (GIS). Changes in habitat type and distribution should be monitored on a cycle of 1-5 years. GIS data should be synthesized for the entire Inland Bays watershed, and on an individual drainage basin map for each of the three bays.

Recommendations for future research include:

* Wetlands distribution maps and soils maps should be developed for each Inland Bay watershed. Calculations of areal extent of each wetland type and soil type should be made for Rehoboth, Indian River, and Little Assawoman Bays.
* Develop a natural resource atlas and inventory for Inland Bay habitats by drainage basin; survey flora and fauna specific to each associated habitat.
* Develop assessment and inventory of upland habitats within Inland Bays watershed.

* Inventory, describe, and locate all unique natural communities, and rare, endangered, or threatened plants, animals and communities within Inland Bays watershed (Delaware Natural Heritage Inventory, in progress).
* Identify and map all habitat, including wetlands, terrestrial and aquatic areas, and migratory bird habitat (ref. CCMP for Delaware's Inland Bays).
* Expand effort toward public education on wetlands protection, other habitat protection and enhancement.
* Develop comprehensive habitat protection plan (ref. CCMP for Delaware's Inland Bays).
* Additional research on BMP's for drainage control, and associated improvements to channelization and ditching projects.
* Additional research on palustrine wetlands, and their relationship to geologic setting and hydrologic cycle of the Inland Bays. Develop complete model of palustrine wetland formation and evolution.

Wetlands of the Inland Bays: Existing Data Bases

There are few published data bases that provide information on characterization (acreage and floral composition) specifically for wetlands within the Inland Bays drainage basin. A report produced by Daiber and others (1976) outlines a description of estuarine tidal (coastal) wetlands surrounding each inland bay. Additional information concerning the characterization of tidal (coastal) wetlands, based on county-wide and state-wide data, is provided by Tiner (1985).

State Resources.

The State of Delaware DNREC Wetlands maps depict tidal wetlands under the jurisdiction of the State of Delaware, and serve as a regulatory tool for permitting and enforcement purposes. The first set of DNREC wetlands maps were constructed/interpreted based on 1973 color infrared aerial photographs at a 1:12,000 scale. The interpretation of the color IR photographs was then reconstructed onto black and white aerial photographs at a 1:2,400 (1 inch = 200 feet) scale, which were utilized until recently (1992) as Delaware's State Wetlands Maps for regulatory purposes. State tidal wetlands are identified on the basis of vegetation present, including the following plant species: black grass (Juncus gerardii), bladder wrach (Fucus vesiculosis), cattail (Typha latifolia and Typha angustifolia), saltwort (Salicornia bigelovii, Salicornia europaea, and Salicornia virginica), eel grass (Zostera marina), groundsel bush (Baccharis halimifolia), marsh elder (Iva frutescens), marsh aster (Aster tenuifolius), mock bishop's weed (Ptilimnium capillaceum), marsh mallow (Hibiscus palustrus), orach (Atriplex patula), sago pondweed (Potamogeton pectinatus), salt marsh fleabane (Pluchea purpurascens), salt marsh cordgrass (Spartina alterniflora and Spartina cynosuroides), salt meadow hay (Spartina patens), sea blete (Suaeda linearis and Suaeda maritima), sea lavender (Limonium carolilnianum), seaside goldenrod (Solidago sempervirens), seaside plantain (Plantago aliganthos), spike grass (Distichlis spicata), switchgrass (Panicum virgatum), three-square (Scirpus americanus), Torrey rush (Scirpus torreyi), and widgeon grass (Ruppia maritima). State wetlands contain one or more of these designated wetlands plants; wetlands are classified on the basis of the dominant species of plants. These maps were adopted pursuant to Delaware's Wetland Act on December 23, 1976. The 1973 maps were photo-revised in 1979, and these revised maps were adopted on October 1, 1981.

Delaware DNREC Wetlands and Aquatic Protection Branch has recently (July, 1992) adopted completely revised regulatory maps for Delaware tidal wetlands. The maps are based on newer color IR photography (1988) at a 1:14400 scale, and are GIS adapted for map production and calculation. The newer wetlands maps are typically reproduced/produced at a 1" = 300' scale. Calculation of areal extent of tidal wetlands (at a 1" = 200' scale) within the Inland Bays watershed could be accomplished through GIS if manpower and time were available. These calculations are scheduled to be conducted for Indian River Bay through a 1993 grant from the Inland Bays Recovery Initiative. The work on Indian River Bay tidal wetlands also includes characterization of losses as well as accretion of wetlands (T. Skrabal, personal communication).

Statewide coverage of tidal and freshwater nontidal wetlands, based on 1992 aerial photography, is available at a 1:40,000 scale. This color infra-red photography was flown to NAPP specifications for the DNREC Wetlands and Aquatic Protection Branch as transparencies and 9" x 9" prints. It is anticipated that this photography will lead to DNREC mapping of all freshwater non-tidal wetlands in the Inland Bays watershed, beginning in calendar year 1993 (D. Saveikis, personal communication).

An Inland Bays Recovery Initiative grant has been awarded to the Wetlands and Aquatic Protection Branch to utilize a recently completed database of wetlands/shoreline changes of Indian River Bay. This database was contracted by DNREC Beach Preservation Section from University of Maryland, and will be transferred to the GIS system to calculate historical trends of wetlands changes and identify causes of change (natural vs. human-induced). It is possible that similar studies will be conducted on Rehoboth Bay in future years as grant money becomes

available (T. Skrabal, personal communication).

Federal Resources.

Tidal and freshwater wetlands in the Inland Bays drainage system are depicted on the NWI maps at a 1:24,000 scale (1 inch = 2,000 feet); each NWI map corresponds to the U.S.G.S. topographic quadrangle base map. Wetlands are classified according to the U. S. Fish & Wildlife Service's wetlands classification system (Cowardin et al, 1979). These maps are fairly detailed, and are useful in site-specific wetlands evaluations. The maps were also significant in establishment of wetlands status and trends reports for Delaware.

A detailed status and trends report for the State of Delaware entitled "Wetlands of Delaware" was published in 1985 by the U.S. Department of the Interior Fish and Wildlife Service and the State of Delaware Department of Natural Resources and Environmental Control. This document contains information on wetlands status and trends for the entire State of Delaware, including descriptions of wetland plant communities within the State of Delaware and statewide wetlands trends. Much of the data describing and characterizing wetlands surrounding the Inland Bays, as well as estimates of wetland losses in the State of Delaware and Sussex County were derived from this report.

3.1.9. Wetlands Summary

Tidal and freshwater wetlands are dynamic environments subject to change by both natural processes and human activities. These forces act to cause wetland gains and losses as well as to degrade or improve their quality. Unfortunately, the overall effect in the Inland Bays watershed has been a loss and degradation of both tidal and freshwater wetlands. Natural losses are due to rising sea-level, natural succession, the hydrologic cycle, sedimentation, erosion, and fire. Important human impacts to wetlands surrounding the Inland Bays include: drainage and channelization for flood control and agriculture, e.g. tax ditches; filling for residential and commercial developments; dredging for navigation channels, harbors, and marinas; pond construction; timber harvest; and various forms of water pollution and waste disposal (Tiner, 1985).

As of 1981/82, 75 percent of the wetlands in Sussex County are palustrine (non-tidal, freshwater) wetlands, and 25 percent are estuarine/marine wetlands (Tiner, 1985). Trends have been established on a statewide basis: 1) 54 percent of the pre-settlement wetland area in Delaware has been lost (Dahl, 1990, 1991); 2) 21 percent of Delaware's inland wetlands and 6 percent of Delaware coastal wetlands were lost between 1955 and 1981 (Tiner 1985); and 3) the majority of the inland wetland losses were due to agriculture (82 percent) while the majority of coastal wetland losses were due to urbanization (63 percent) (Tiner 1985, as presented by Maxted, 1993).

Based on preliminary analysis of the National Wetlands Inventory maps, 56% of the major wetlands types within the Inland Bays watershed are palustrine wetlands (palustrine forested, palustrine scrub/shrub, and palustrine emergent), and 44% of the watershed's major wetlands are estuarine intertidal emergent wetlands. Of the palustrine wetlands within the entire Inland Bays watershed, 62% are found in the Indian River Bay drainage area; 28% are within the Rehoboth Bay drainage basin; and only 10% of all palustrine wetlands are found within the Little Assawoman Bay system. Relative distribution of estuarine wetlands within the entire watershed area were estimated to be: 45% within Indian River Bay system; 36% in Rehoboth Bay drainage system; and 19% in the Little Assawoman Bay drainage basin. Accurate estimates of the areal extent of each wetland type, as mapped by the National Wetlands Inventory, should be calculated for each Inland Bay drainage area to establish baseline wetlands resource inventory data. Preliminary unpublished estimates suggest that the areal extent of estuarine emergent wetlands within the Inland Bays drainage basin is greater than the 6,573 acres of tidal wetlands calculated by Daiber et al (1976). Discrepancies in areal calculation are likely due to methodologies and data bases utilized and available at the time the resources were assessed.

The tidal wetlands surrounding Delaware's Inland Bays, and the freshwater wetlands within the Inland Bays watershed, provide both environmental and economic benefits to the Sussex County and the entire State of Delaware. Although public awareness of wetlands as unique natural environments has been steadily increasing, much of the general public's attention is focussed on aspects of wetlands as they affect humans directly. Many wetlands functions and values go unnoticed; their direct and indirect importance to water quality, flood control, and wildlife/fishery species habitat should be recognized as part of an important and essential resource base. In many communities (agricultural, residential, and commercial communities) surrounding the Inland Bays, wetlands are the only remaining areas of open space, and despite their inherent functional values, such areas are often under developmental pressure. To protect wetlands and their associated functional values, public education and awareness, as well as development and enforcement of federal and state laws is essential.

3.2 LITTORAL (SHORELINE) ENVIRONMENTS AND HABITATS

3.2.1 Characterization of Littoral Environments and Habitats

The natural environments in the shore zone of Delaware's Inland Bays consist of sandy beaches and tidal marshes (wetlands). John (1977) mapped the coastal and nearshore characteristics of the Inland Bays, showing distribution of wetlands (marsh) and sandy shoreline areas (Figure 3.3). In general, the Inland Bays littoral environments/habitats are dominated by marsh shorelines, with scattered areas of small sandy pocket beaches. Swisher (1982) examined 1981 aerial photographs of Rehoboth Bay, and determined that 90% of the shoreline consists of marsh; 6% of sandy beaches; and the remaining 4% of the shoreline, artificial forms. Carey and Sadler (1991) conducted a perimeter survey to document shoreline characteristics of Little Assawoman Bay. Field observations, verified by aerial photograph analysis, showed that in 1991, marshes comprise 79% of the shoreline; sandy beaches account for 4%; and 17% of the shoreline consists of artificial structures. No quantitative data on the percentages of marsh, sandy, or artificial structures are available for Indian River Bay shoreline.

Sandy Beaches

The sandy beaches along the northern, western, and southern shores of the Inland Bays are typically narrow pocket beaches, circular to spiral in planform, and located between crenulate marsh "headlands." These beaches typically range from tens to hundreds of feet in length; tens of feet in width,; and 3-6 feet in thickness. The beaches consist of well-sorted, medium-grained quartz sand, surrounded and underlain by tidal marsh muds, with sharp contacts between the sand and mud units. Examples of sandy barrier beaches include Camp Arrowhead Beach, Sloan Cove, and Lingo Cove in Rehoboth Bay; Steel's Cove and Pasture Point Cove in Indian River Bay; and

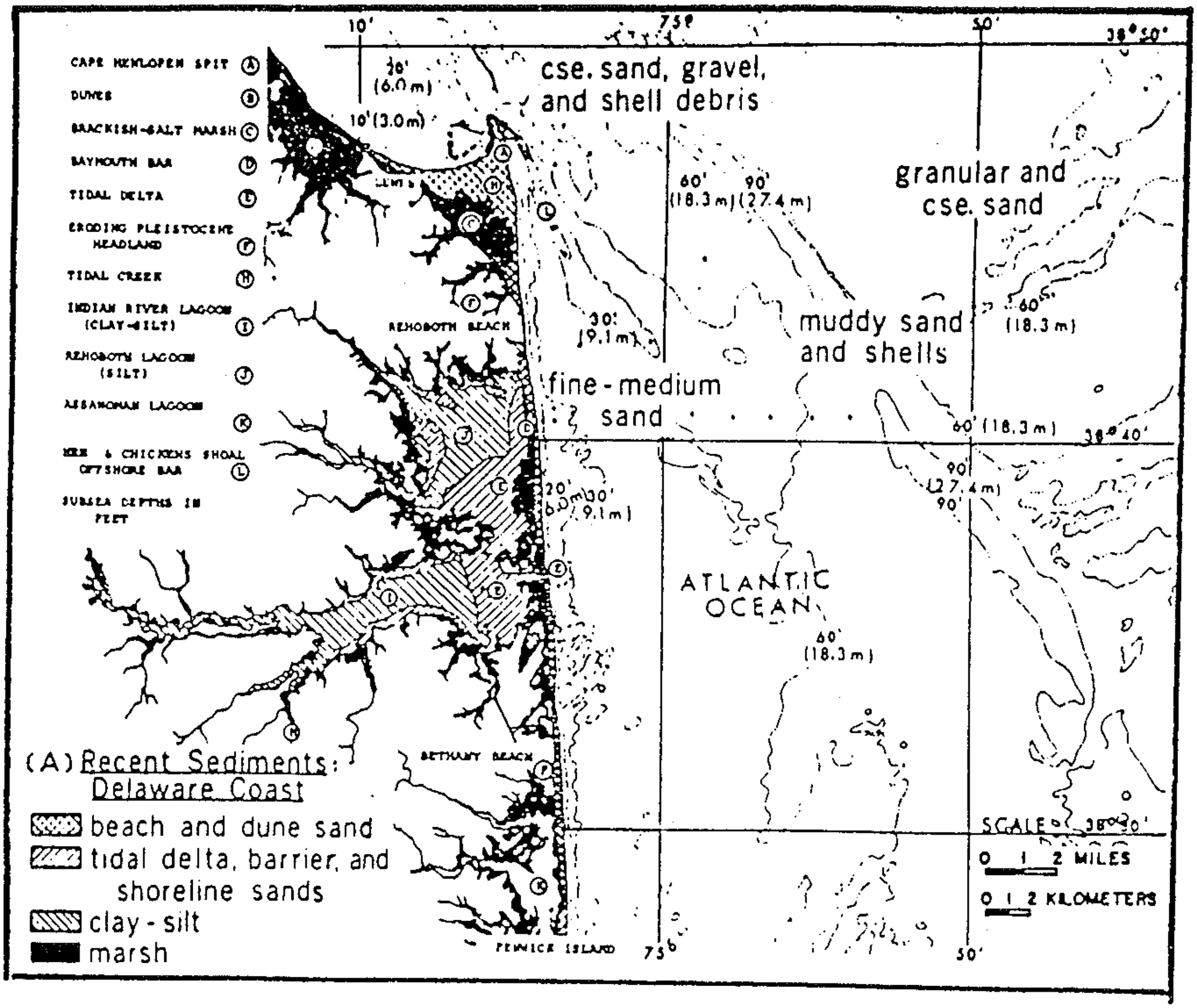


Figure 3.3. Coastal and nearshore environments of Inland Bays showing distribution of wetlands (marsh) and sandy shorelines (from John, 1977).

several small, unnamed sandy coves in Little Assawoman Bay. Sandy barrier beaches along the eastern shores of the Inland Bays are located along the backbarrier of narrow sections of the Atlantic coastal barrier system. Examples include the bay side of Dewey Beach and sections of Delaware Seashore State Park, along the Rehoboth Bay shoreline; the bayside shoreline north of Cottonpatch, along Beach Cove (an embayment of Indian River Bay); and sections of Fenwick Island State Park, in Little Assawoman Bay. Common vegetation along the dry sandy beaches includes beach grass (Ammophila breviligulata), switch grass (Panicum virgatum), giant reed (Phragmites australis), marsh elder (Iva frutescens), and groundsel bush (Baccharis halimifolia).

Some of the sandy beaches along the Inland Bays form at the base of Pleistocene (pre-Holocene) headlands or "necks" which crop out along the shores of the Inland Bays. Examples of sandy beaches associated with headlands include Thompson Island and Burton Island in Rehoboth Bay; Quillen's Point and Holt's Landing State Park in Indian River Bay; and Strawberry Landing and Drum Point in Little Assawoman Bay. The surrounding bluff areas ("necks"), with elevations approximately 10' above sea level, consist of sediments ranging from silty sand to very coarse sand with pebbles (Chrzastowski, 1986). Vegetation includes loblolly pine trees, sweet gum, American holly, and oaks (Fleming, 1978; Swisher, 1982; Gano, 1991).

Marsh Shorelines

The fringing marshes along the northern, western, and southern shores of the Inland Bays are low-lying tidal wetlands. These fringing marshes are irregular to crenulate in planform, and generally exhibit an erosional undercut scarp at the water's edge. The scarps, generally 0.5-1.0' above mean sea level, consist of a dense mat of sediment, peat and roots. Examples of fringing marshes include wetlands along the tidal tributaries of the Inland Bays, such as Love Creek and Herring Creek in Rehoboth Bay; Indian River, Pepper Creek, and White Creek, in Indian River Bay; and Miller Creek and Dirickson Creek in Little Assawoman Bay. The dominant vegetation in the marshes includes salt marsh cordgrass (Spartina alterniflora), salt hay (Spartina patens), spike grass (Distichlis spicata), giant reed (Phragmites australis), marsh elder (Iva frutescens), and groundsel bush (Baccharis halimifolia). A detailed description of tidal wetlands habitat characteristics appears in the tidal wetlands section of this chapter.

Along the eastern shore of the Inland Bays, backbarrier marshes have formed over relict flood tidal delta and overwash sand deposits associated with the coastal barrier system to the east. Examples of backbarrier marsh shorelines include Rehoboth Marsh in Rehoboth Bay; Mare Marsh and Salt Marsh in Indian River Bay; and Daisy Marsh in Little Assawoman Bay. These areas are characterized by numerous marsh islands dissected by channels and ditches. Vegetation on these marsh islands is predominantly salt marsh cordgrass (Spartina alterniflora), with a scattering of Iva frutescens at higher elevations. Wetlands on sandy overwash areas are also contain Distichlis spicata and various species of three-square (Scirpus). Fleming (1978) identified the marsh island complex on the east side of Rehoboth Bay as the most productive osprey nesting colony in Delaware.

3.2.2 Natural Littoral Processes of Change

The action of natural physical forces, such as wind, waves, tides, and currents have affected the Inland Bays habitats over time. Discussions of physical processes in the bays are presented in Polis and Kupferman (1973); Delaware Coastal Management Program (1977); Lanan and Dalrymple (1977); Dennis and Dalrymple (1978); Carey (1979); Swisher (1982); Wong (1987); Crouse (1989); and Raney and others (1990). The following summary is compiled from these sources.

Wind

Analysis of wind data from Indian River Inlet indicates that prevailing winds in the Inland Bays area are from the southwest in spring and summer, and from the northwest and northeast in the winter months. Winds above 30 mph are most frequently from the northwest, and winds of the highest velocities are most frequently from the northeast (Polis and Kupferman, 1973). The velocity, duration, and fetch (distance of open water over which the wind blows) determine the characteristics of waves within the bays. As these wind parameters increase, wave parameters (height, period, and energy) also increase. The fetch (distance of open water over which the wind blows) in the Inland Bays is limited, due to the small size of the bays. Swisher (1982) considered 19,000' (approximately 3.6 miles) to represent the average fetch for Rehoboth Bay. Crouse (1989) calculated fetches for 40 sites along Rehoboth Bay, and documented a maximum fetch of approximately 6.5 miles for winds from the northeast. The Delaware Coastal Management Program (1977) states that the fetch across Indian River Bay is 6 miles for easterly winds, and considerably less for all other directions. No published information concerning fetch for Little Assawoman Bay are available. However, rough measurements indicate that the maximum fetch is less than 3 miles for northerly and northwesterly winds.

Waves

The Inland Bays are generally low-energy wave environments. The shallowness of the water and limited fetch preclude development of extreme wave heights in the Inland Bays. Yet, the presence of wave-generated ripple marks in sections of the bottom of Rehoboth Bay (Swisher, 1982) and Indian River Bay (Carey, 1979) indicates that waves are capable of bottom sediment transport in the bays. According to calculations by Swisher (1982) utilizing wave forecasting curves developed by the U.S. Army Corps of Engineers Coastal Engineering Research Center (1973), wind speeds of approximately 20 mph would generate 1' high waves within Rehoboth Bay. The Delaware Coastal Management Program (1977) calculated that maximum wave heights of 2.5' to 3.5' can be expected for wind velocities of 50 mph in Indian River Bay. Due to the small fetch and shallower water depths, wind-generated waves in Little Assawoman Bay can be expected to be smaller than in the other bays for most wind conditions.

Tides

Tides in the Inland Bays are primarily semidiurnal, with a periodicity of 12.42 hours the dominant constituent. Tides enter Indian River Bay directly through Indian River Inlet. As tides propagate to Rehoboth Bay through the "Ditches", they are constricted and attenuated. Such attenuation results in much lower tidal energy in Rehoboth Bay than in Indian River Bay (Wong, 1987). Lanan and Dalrymple (1977) report a phase lag of 1 3/4 hours at the Ditches for both ebb and flood phases; Karpas (1978) reports phase lags of 3 hours at Massey's Ditch and 5 hours at the entrance to the Lewes and Rehoboth Canal in northern Rehoboth Bay. Raney and others (1990) present field data and results of a numerical model to predict tide ranges at various locations in Rehoboth Bay and Indian River Bay. Figure 3.4 shows prototype tide ranges and periodicity at Indian River Inlet, Pot Nets (north-central shore of Indian River Bay), Vines Creek (southwestern Indian River Bay), Massey's Ditch (Indian River/Rehoboth Bay), and Dewey Beach (northern Rehoboth Bay).

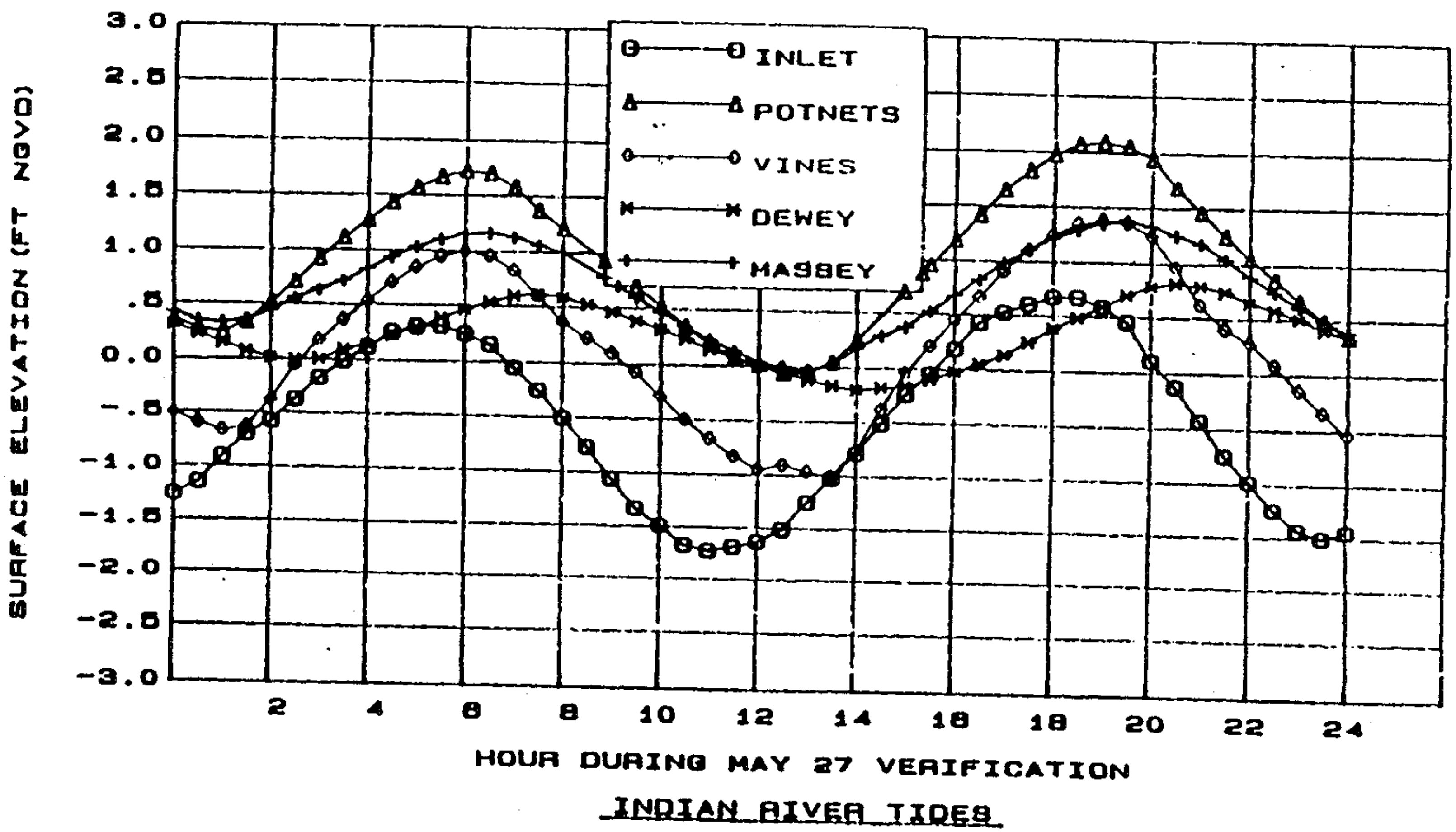


Figure 3.4. Tide data for five Inland Bays locations (from Raney and others, 1990).

The cross-sectional area of the inlet has increased since 1939, exclusively by increasing inlet depth. As the cross section increased over time, the tidal wave passing through the inlet increased and was propagated through the Bays causing higher high tides and lower low tides. Raney, et al. (1990) developed and verified a model of the change in surface elevation in the Bays caused by the enlarging cross-section of the inlet. The same ocean tidal wave acting as the boundary condition and moving through the 1941, 1969 and 1988 inlet produces higher highs and lower lows with an enlarged inlet. In 1941, the spring tide range at the mouth of Vines Creek was 0.5 feet and increased to 3 feet in 1988. For Dewey Beach, the difference for the same time period was from 0.25 feet to 1.5 feet. This means that spring low tide elevations are lower (9 inches for Rehoboth and 12 inches for Indian River Bay) now than they were 50 years ago. Numerous anecdotal testimonials have been presented suggesting that the Bays are becoming more shallow. In addition to shoaling of the Bays caused by sedimentation, the water levels at low tide are lower at present than they were historically and the Bays are more shallow for about half of the time.

Currents within the Inland Bays result from wind-generated waves and the effects of tides, and are significant with regard to water and sediment transport within the bays. Field measurements of current velocities, as well as numerical models predicting current velocities, have been reported for Rehoboth Bay and Indian River Bay by numerous investigators, including Lanan and Dalrymple (1977); Carey (1979); Swisher (1982); Raney and others (1990). Swisher (1982) reports that wave-induced longshore currents in Rehoboth Bay most likely result in net southerly transport along the western shoreline in the winter months, and northerly transport in the summer months, due to seasonal variations in prevailing wind direction. Analysis of current ripple patterns on the bay bottom suggests bottom current velocities approaching 30 to 35 cm/sec (1.0 to 1.1 ft/sec) in the nearshore zone. The tidal currents in Indian River Inlet are important in water exchange between the ocean and the bays, and sediment transport into and out of the bays.

As the tidal wave propagates through the inlet, it moves water into the Bays on flood tide and out of the Bays on ebb tide. The volume of water that is moved is called the tidal prism. On flood tides, in addition to water, substances such as salt and marine organisms are carried into the Bays; on ebb tides, some of these substances as well as estuarine organisms and substances from land drainage are lost to the sea.

In the Inland Bays, the amount of water that passes through the inlet has increased from 1940 to the present. The volume of salt water roughly tripled from 1939 to 1969, then almost doubled again from 1969 to 1988. Raney et al. (1990) find, in their model runs, that the inlet is likely to continue to deepen and increase the tidal prism in the future.

As the inlet has deepened and the cross-section has increased, the quantity of water passing through the inlet over 1 tidal cycle has increased from roughly 13,000 cubic feet per second (1939), to 37,000 cubic feet per second (1969) to 61,000 cubic feet per second (1988). These estimates are based on the model runs developed by Raney et al. (1990). In contrast to these increasing volumes of salt water flushing through the inlet, the fresh water discharge from the entire combined watersheds has remained constant and seldom exceeds 300 cubic feet per second, except during extreme events.

The changes in the tidal prism (4.5 times at Indian River Inlet and 3.8 times entering

Rehoboth Bay) that have been calculated using the computer model, as well as the dredging (in 1951) of a channel 9 feet deep through Indian River Bay from the inlet to Old Landing and then 4 feet deep to the base of the dam at Millsboro have undoubtedly increased the flushing of these bays. In addition, both processes have a tendency to increase the salinity, particularly in low salinity areas. It is possible to compute changes in the salinity in the Raney model, but this was not done in the 1990 study. Smullen (Sec.2) has collected and plotted the historical salinity data that are available. Since 1970, from all of the bays, we can find no seasonal or annual pattern of increase in salinity. This is not surprising for the areas near the ocean that already had high salinities. However, we would expect a trend of measurable salinity increase in the low salinity areas. A trend was not observed, though there are few sampling events. We do note that there has not been an observation of zero salinity in the spring at the first station downstream (about 600 yds) from Millsboro Pond since 1983 and that there have only been six zero salinities observed in the 18 years during which spring observations have been made in spite of the fact that 1989 and '91 represent the top 25% of spring discharges (in the 40 year record analyzed at Millsboro) and that the spring of 1990 is the median spring for the period of record.

There are two major types of storms that affect the Delaware Coast and the Inland Bays: tropical cyclones (hurricanes), and extratropical storms ("northeasters"). Hurricanes originate in the warm waters of tropical regions of the Atlantic Ocean or the Gulf of Mexico, and are characterized by sustained wind speeds exceeding 74 mph blowing in a counterclockwise spiral around a relatively calm central region (the "eye" of the hurricane). Hurricanes are associated with a drop in atmospheric pressure, precipitation, strong winds, high waves, and high water levels (storm surge). Hurricane season in Delaware occurs from June 1 through November 1.

Historically, Delaware has averaged one hurricane per year.

Northeasters are extratropical storms that form as low pressure systems off the coast, in which winds blow from the northeast direction. Like hurricanes, northeasters are accompanied by strong winds, high waves, and storm tides. In Delaware, northeasters are most frequent during the winter months, but can occur throughout the year.

The most destructive northeast storm of record affecting the Inland Bays region (as well as the entire State of Delaware) occurred in March, 1962 ("Ash Wednesday storm"). This storm developed as two low-pressure systems joined off the Atlantic coast, and remained stationary for several days. The sustained high winds generated ocean waves reportedly 20' to 30' (Beach, 1962). The storm occurred during a period of unusually high astronomical tides; the storm surge, which lasted over five consecutive high tides, was 7.9' above mean sea level at Breakwater Harbor (U.S. Army Corps of Engineers, Coastal Engineering Research Center, 1973; Delaware Coastal Management Program, 1977). Anecdotal accounts of storm damage to communities along the Inland Bays are presented in Beach (1962) and Delaware Coastal Management Program (1977). Flooding was extensive in communities bordering the Inland Bays, as water within the bays rose. Oak Orchard, located along the north shore of Indian River Bay, was under 2-3' of water; many of the waterfront homes were surrounded by as much as 5' of water. Flooding also occurred as the coastal barrier was breached in several locations by ocean waves and tides, which washed across to the bays. In Dewey Beach, the ocean broke through the dunes in numerous locations and washed into Rehoboth Bay, which rose and caused back flooding to depths of 3-4'. Beach (1962) reports that Route 14 (now Route 1) was buried under six feet of sand. In Fenwick Island, a break in the dunes occurred in the vicinity of Indian Street. Ocean waters driven across the island and into Little Assawoman Bay caused gradual rising of the bay water, which in turn filled the canals (artificial lagoons) on the bayshore. The rising bay waters then met the ocean waters, so that the town was covered with 2-4' of water both from the ocean and Little Assawoman Bay.

Sea-Level Rise

Sea level has risen and fallen in response to climatic variations over geologic and historic time. At the peak of the last Ice Age, approximately 18,000 years ago, sea level was about 300 feet below present (Hull and Titus, 1986; Kraft, 1971; Belknap and Kraft, 1985), and Delaware's Atlantic Ocean shoreline was located nearly 50 miles seaward of its present position (Kraft and John, 1979). As global temperatures began to warm and glacial ice melted, sea level rose and inundated low-lying coastal areas. Studies by Belknap (1975) and Kraft (1976) indicate that the rate of sea level rise was 3.0 mm/yr from 10,000 to 5,000 years ago; 2.1 mm/yr from 5,000 to 2,000 years ago; and 1.2 mm/yr from 2,000 years ago to present.

In recent decades, human activities may have contributed to global warming, causing an acceleration in the rate of sea-level rise. Many scientists agree that continued global warming will result in an acceleration in the rate of sea-level rise; however, predictions for future rates of sea-level rise vary, based on methodologies and assumptions. Washburn (1991) summarized various scenarios and projected rates of sea-level rise for the Delaware and Maryland coasts (Table 3.5).

A vertical rise in sea level is accompanied by lateral (landward and upward) migration of the Inland Bays and their associated environments (beaches, wetlands, tidal streams). Shoreline erosion and wetlands loss are two direct consequences of sea-level rise that are

Scenarios of Sea-Level Rise in Inches

YEAR	2000	2050	2080	2100
Global				
Current Trends	1	3-4	4-6	5-7
Hoffman et al. 1983				
Low	2	9	—	22
Mid-Low	3	21	—	57
Mid-High	5	31	—	85
High	7	46	—	136
Hoffman et al. 1986				
Low	1	8	—	22
High	2	22	—	145
NAS Estimate (Revelle 1983)	—	—	28	—
Lewes, Delaware				
Current Trends	5	12	17	19
Hull and Titus 1986				
Low	6	18	—	36
Mid-Low	8	30	—	71
Mid-High	9	40	—	99
High	11	55	—	150
NAS Estimate (Revelle 1983)	—	—	40	—
Ocean City, Maryland				
Current Trends	3	10	—	—
Titus et al. 1985				
Mid-Low	5	26	—	—
Mid-High	7	36	—	—

Table 3.5 **Scenarios of Sea-Level Rise Rates (in inches) for the Delaware and Maryland Coasts (from Washburn, 1991)**

occurring in the Inland Bays. In addition, sea-level rise may be a contributing factor to additional alterations of the Inland Bays habitats, including changes in Indian River Inlet hydraulics, sediment transport patterns, and salinity modifications.

3.2.3. Human Alteration of Littoral Environments/Habitats

Shoreline Stabilization Structures

Increasing development along the shores of the Inland Bays has been accompanied by efforts to stabilize eroding shorelines. Artificial shoreline structures in the Inland Bays include bulkheads, groins, jetties, rip-rap (stone) revetments, placement of fill material, etc. These structures are intended to protect the shoreline from continued erosion. Most of these methods have altered the natural shoreline characteristics, resulting in various degrees of modification and in some cases, total loss of natural littoral habitats. Swisher (1982) reported that in 1981, 4% of the Rehoboth Bay shoreline consisted of artificial shoreline structures. Carey and Sadler (1991) reported that in 1991, 17% of the Little Assawoman Bay shoreline consisted of artificial shoreline structures. No quantitative data are available for Indian River Bay.

Bulkheads. Bulkheads are vertical walled structures built parallel to the shoreline to protect the land behind them from erosion. A bulkhead acts as a retaining wall to prevent land from slumping and being washed away by waves. Bulkheads can be constructed from a variety of materials, including timber, steel, plastic, or concrete. Accordingly, bulkhead construction radically alters the nature of the littoral environment, converting it from an unconsolidated sandy or muddy habitat to an artificial hard surface. The new surface may be a suitable habitat for various epiphytes. The effects of bulkheads on the adjacent natural environment and on the benthic community have been documented by several by several investigators (Swisher, 1982;

Coulombe and others, 1982; Crouse, 1989; Weis, 1991) for sites in Delaware's Inland Bays, as well as similar estuarine settings. Results of these studies include the following:

- Wave scour at the toe of a bulkhead can cause erosion and significant lowering of the substrate at the base of the structure. Crouse (1989) documented up to a 3' drop in the offshore profile bayward of bulkheads in Rehoboth Bay. Coulombe and others (1982) documented 2-3' of sediment removal in front of bulkheads in the Chesapeake Bay region. Crouse (1989) comments that "if lowering of the substrate is an inevitable consequence of bulkhead construction, the benthic community is also altered. Specific decisions concerning whether or not the benthic community in Rehoboth Bay has or will change due to bulkhead construction cannot be made until the lowering effect and/or the dynamics of scouring are characterized."

- The wood used in bulkheads (as well as other structures in the shallow estuarine environment, such as docks and pilings) is generally treated with chemicals to prevent or reduce rotting and destruction by marine borers. In the past, creosote was the substance used for treatment. However, studies have indicated that this substance is toxic to benthic organisms, and accumulates in sediments; therefore, it is no longer permitted for treatment of wood placed in waters in Delaware. The predominant method currently in use is pressure-treating the wood with a combination of oxides of copper, chromium, and arsenic ("CCA"). Laboratory and field studies by Weis (1991) examined the potential for CCA-treated wood to leach out toxic materials, and the impacts of this process on estuarine organisms. Results of her research demonstrated that there is evidence that these chemicals do leach; the toxins are absorbed by sediments and by biota. This led to lower density, lower species diversity, and lower biomass of epibiota (algae, bryozoans, barnacles) over time on treated wood structures and in the adjacent benthos. Trophic transfer occurs via export of the chemicals.

- The presence of a vertical wall may contribute to wave reflection back into the bays, and onto vessels, thereby causing additional damage.

- The presence of a "hard structure" such as a bulkhead creates a boundary (physical barrier) between the waters of the bay and the natural littoral zone and upland. Although in the short-term, this may be viewed as beneficial by shorefront property owners, a significant long-term consequence is that such "hardening" of the shoreline will not permit shoreline migration as sea-level in the Inland Bays rises.

Revetments. Revetments are shore-perpendicular structures, generally sloping bayward, and consisting of stone (rip-rap) designed to armor a shoreline or embankment, thereby minimizing erosion. The advantages of stone revetments over bulkheads is that the material (rip-rap) and sloping form allow dissipation of wave energy, reducing or eliminating the problem of scour at the toe of the structure. Moreover, the stones themselves create a new hard surface for colonization by epiphytes; the absence of chemical treatment may make this a hospitable habitat.

The use of low-profile rip-rap revetments, often combined with planting marsh vegetation landward of the structure, is a superior alternative to bulkheads for shoreline stabilization. DNREC shore-erosion control demonstration projects involving this technique have been constructed along the Rehoboth Bay shoreline at Herring Creek (1990), Mulberry Knoll/Love Creek (1991) and Camp Arrowhead (1991-92). In addition, several private project utilizing this technique have also been permitted and constructed in the Inland Bays in the past two years. The combination of rip-rap and marsh vegetation reduces erosion, is cost-effective, provides fish and wildlife habitat, and serves as a physical and chemical buffer between upland runoff and the waters of the bays.

Groins. Groins are structures constructed across a beach, usually perpendicular to the shoreline, designed to rebuild an eroding beach by trapping sand moving alongshore. However, as the beach on one side of the groin accretes, the opposite (downdrift) beach erodes at an accelerated rate. Groins do not add new sand to the system, but merely redistribute the existing sand.

Jetties. Jetties are structures built at inlets to stabilize the location of the inlet. The effects of jetties on the adjacent shorelines are similar to those of groins, resulting in updrift accretion and downdrift erosion. The jetties at Indian River Inlet have had a major effect on the adjacent shorelines; these effects are addressed in section 3.5 of this report. On a smaller scale, the jetties at the entrance to the Lewes and Rehoboth Canal in northern Rehoboth Bay are an example of jetties within the Inland Bays system that have had effects on adjacent shorelines. Following construction of the structures in 1903, sand accumulated on the eastern side of the eastern jetty (Thompson's Island vicinity), and erosion occurred on the west side of the western jetty.

Effects of Boat Wakes and Boating Activities

With increasing development and tourism in eastern Sussex County, recreational use of the Inland Bays has increased. Studies by the Greeley-Polhemus Group (1986) and Falk and others (1987) identified boating as a major form of recreation on Delaware's Inland Bays. The total number of boats registered in Delaware in 1985 was 39,638. Falk and others (1987) surveyed a sample of the boating population, in which 55% of the respondents mentioned that they had boated in the Inland Bays in 1985.

Studies investigating the role of boat wakes on shore erosion in the Chesapeake Bay were conducted for the Maryland Department of Natural Resources (Zabawa and Ostrom, 1980). The study concluded that waves generated by recreational motorboat traffic ranked third behind storm effects and wind waves in causing shore erosion. On an annual basis, boat wake energy represents from 0.5% to 9.6% of total wave energy reaching the shoreline. A schematic diagram illustrating the monthly contribution of boat wakes to the total energy budget at five study sites along the Chesapeake Bay is shown in Figure 3.5. During boating season, boat wakes may account for up to 27.9% of the total wave energy budget. Zabawa and Ostrom (1980) report that the susceptibility of a shoreline to wave erosion appears to be controlled by the physical nature of the sediments comprising the shore, and the gradient of the shore profile. Banks consisting of unconsolidated, easily erodible material such as sand and gravel are most vulnerable to boat wake erosion, whereas marsh banks, consisting of tightly-bound root mass and mud, are more resistant to erosion. A shoreline with a steep gradient is generally more susceptible to erosion than one where the nearshore slope is gentle. Zabawa and Ostrom (1980) listed the following factors contributing to wave energy produced by boat wakes:

- Boat speed: As speed increases, wave energy increases to a maximum value; as their critical speed for planing is achieved, wakes and wave energy are reduced. For a 16' Boston Whaler, the critical speed for which a maximum wake is generated is approximately 6-8 knots.

- Proximity of the boat to the shoreline: The closer a boat passes a shoreline at a

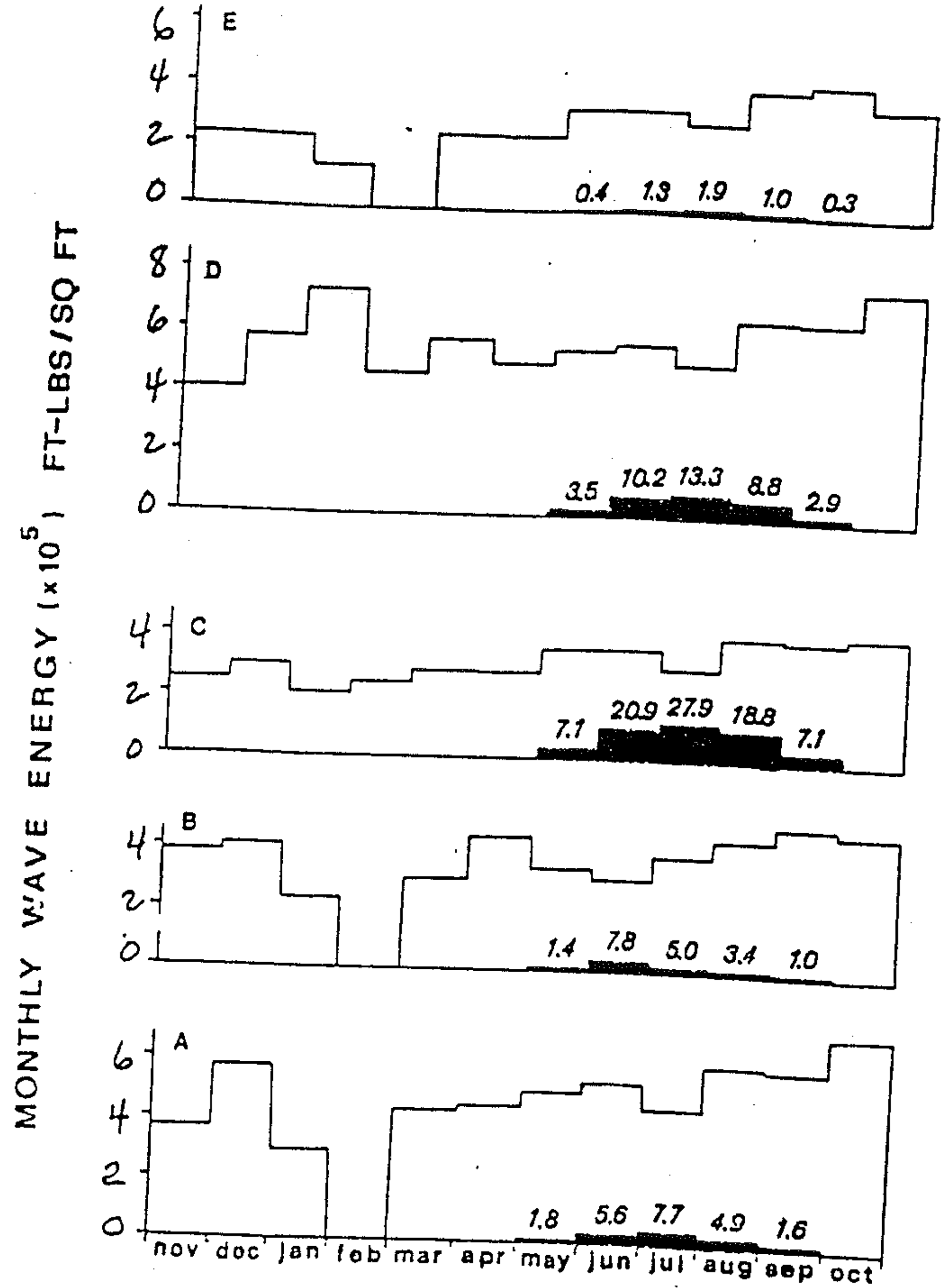


Figure 3.5. Histograms showing proportion of boat-generated wave energy relative to total wave energy at five sites in the Chesapeake Bay area, Maryland (from Zabawa and Ostrom, 1980).

given speed, the higher the wave energy reaching the shoreline.

- Water depth: Maximum wave energy generated by boat wakes varies as water depth (and boat speed) varies. For water depths of 2'-6', maximum wakes are generated at speeds of 2-8 knots.

- Frequency of boat passes: There is a linear relationship between number of boat passes per unit of time, and wave energy striking the shore.

Zabawa and Ostrom (1980) identified site characteristics which would be most susceptible to erosion due to boat wakes:

- An exposed point of land in a narrow creek or cove;
- Fastland consisting of easily erodible material such as sand or gravel;
- Steep nearshore gradient;
- Location adjacent to a high rate of boating, with boat passes relatively close to the shoreline.

An additional impact from boating activity is increased turbidity due to resuspension of sediments.

3.2.4. Trends: Shoreline Changes

Natural processes, as well as human alterations of the shoreline, have resulted in modification and/or loss of littoral habitats in the Inland Bays. Quantitative data on historic rates of shoreline change are available for Rehoboth Bay (Swisher, 1982). A draft report presenting results of metric mapping of the Indian River shoreline is available (Leatherman and Harris, 1991). This report presents historic shoreline positions in graphic form, but a tabulation of shoreline erosion/accretion rates is not yet available. No quantitative shoreline change data are available for Little Assawoman Bay.

A detailed study of shoreline erosion of Rehoboth Bay, based on analyses of aerial photographs from 1938, 1954, 1968, and 1981, was conducted by Swisher (1982). Swisher divided the northern, western, and southern shorelines of Rehoboth Bay into a total of 68 reaches for which average annual rates of shoreline erosion were calculated. Short-term rates are extremely variable, ranging from erosion of nearly 30'/year (Big Piney Island, due primarily to storms) to over 45'/yr of accretion (Johnson Neck, due to placement of fill material). Swisher attributes the variability to the natural shoreline morphology and the degree of artificial modification. Of the 68 reaches, 26 had a history of continuous erosion; 16 had episodes of erosion and stability; 16 had episodes of erosion and accretion; 5 had periods of stability and accretion; 4 had periods of erosion, stability, and accretion; and only 1 reach was entirely stable, with no net change in shoreline position. No reach was continuously accretional throughout the period of Swisher's study. Most areas around the bay, however, have undergone net erosion averaging 3'/year or less (Figure 3.6).

Early maps of Rehoboth Bay depict three islands off of the western shore of the bay: Marsh Island, Little Piney Island, and Big Piney Island. Over the years, these islands have diminished in size, due to the effects of storm erosion, sea-level rise, and subsidence. Two of the islands, Little Piney and Big Piney, have disappeared completely. Table 3.6 (Swisher, 1982) summarizes the areal loss of the islands during the time intervals of 1938-1954, 1954-1968, and 1968-1981.

Ballentine (1975) presents an anecdotal account of the history of Little Piney Island and

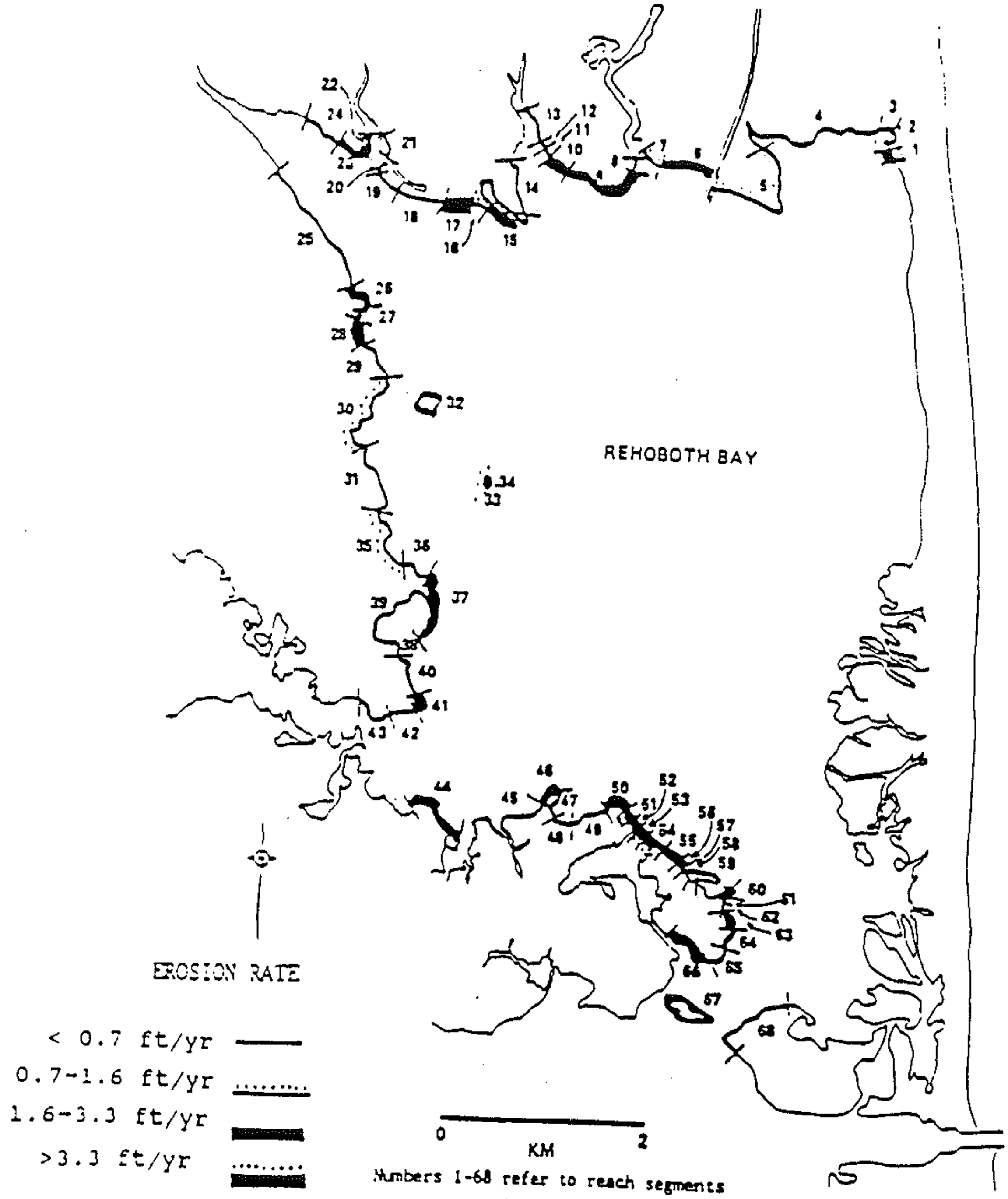


Figure 3.6. Summary of average annual linear erosion rates, Rehoboth Bay, Delaware, 1938-1981 (from Swisher, 1982).

	1938-1954	1954-1968	1968-1981
Big Piney Island	43,363 ft^2 (1.0 ac)	58,857 ft^2 (1.35 ac)	13,325 ft^2 (0.30 ac)
Little Piney Island	15,602 ft^2 (0.36 ac)	4,960 ft^2 (0.11 ac)	--
Marsh Island	73,491 ft^2 (1.69 ac)	53,262 ft^2 (1.22 ac)	21,198 ft^2 (0.49 ac)

Table 3.6 Areal Loss, Big Piney Island, Little Piney Ilsand, and Marsh Island, 1938-1981 (data from Swisher, 1982)

Big Piney Island. The original deed to the islands, dated 1882, was for five acres comprising two islands. Charles S. Horn, who had lived in Rehoboth Beach since 1900, recalled that in the 1920's, the center of Big Piney Island consisted of a dense stand of 25-30' tall pines, greater than two feet in diameter; bushes, reeds, and marsh grasses fringed the perimeter of the island. The island itself was over 300 feet wide. Swisher (1982) calculated that the shoreline of Big Piney Island eroded an average of 1.3 ft/yr from 1938 to 1954; the rate of erosion increased to 4.3 ft/yr in the interval from 1954 to 1968. Areal loss amounted to 1.0 acre from 1938 to 1954, with an additional 1.35 acres lost from 1954 to 1968. By 1975, the island was approximately 85 feet in diameter, according to Ballentine's measurement. Swisher calculated that the shoreline eroded 31.2 ft/yr between 1968 and 1981, for an areal loss of 0.30 acres. In 1981, it was a low marsh island approximately 10 feet in diameter, and slightly above the water level of Rehoboth Bay (Maurmeyer, unpublished data). During the winter of 1981-82, the island disappeared completely; the only remaining indicator of its former presence during the summer of 1982 was a shallow submerged shoal (Maurmeyer, unpublished data).

Swisher (1982) points out that historically, the three offshore islands sheltered the western shore of Rehoboth Bay from erosion by waves approaching from the northeast and southeast. One of the consequences of continued erosion and disappearance of these islands is that the western shore of Rehoboth Bay will become directly exposed to northeast and southeast waves, and shoreline erosion rates along this section of the Bay will increase.

3.3 SUBTIDAL (BENTHIC) HABITATS (BOTTOM SEDIMENTS)

3.3.1. Characterization

The Inland Bays subtidal habitat is characterized as a soft-bottom environment consisting of unconsolidated sediments (sand, silt, and clay), with some areas of shell material. Studies of bottom sediment type (Kraft, 1971; Cole and Spence, 1977; Carey, 1979; Chrzastowski, 1986; Maurmeyer, 1991; DNREC, 1992), combined with studies of the flora and fauna of the bay bottom (including Humphries and Daiber, 1967; Maurer, 1977; Cole and Spence, 1977; EPA, 1987; Bock and others, 1991; Price and Schneider, 1991; Anderson, 1991; and Tinsman, 1991) can be utilized to develop a characterization of the subtidal habitat of the Inland Bays. This section emphasizes bottom sediment type and distribution, with a general description of the flora and fauna characterizing this environment. The "Living Resources" chapter (Section 4) of this report provides greater detail on the biological community inhabiting this environment.

Rehoboth and Indian River Bays

Grain-size characteristics of bottom sediments of Rehoboth and Indian River Bays were determined by laboratory analysis of the upper 2-4 cm of sediment from 82 vibracores by Chrzastowski (1986); sediment distribution in the nearshore area is based on data from Kraft (1971); and characteristics of the Indian River Inlet flood tidal delta and tidal inlet are obtained from studies by Carey (1979) and Lanan and Dalrymple (1977). Additional data concerning presence of shell material are from studies and observations by Cole and Spence (1977), Collier (1978), and Michaels (1992, pers. comm.).

Bottom sediment distribution for Rehoboth Bay and Indian River Bay is shown in Figure 3.7 (Chrzastowski, 1986), based on nomenclature according to Shepard (1954). The percentages of each of the six bottom sediment types (sand; silty sand; sandy silt; clayey silt; silty clay; and sand, silt, and clay) identified by Chrzastowski (1986) for Rehoboth and Indian River Bays are

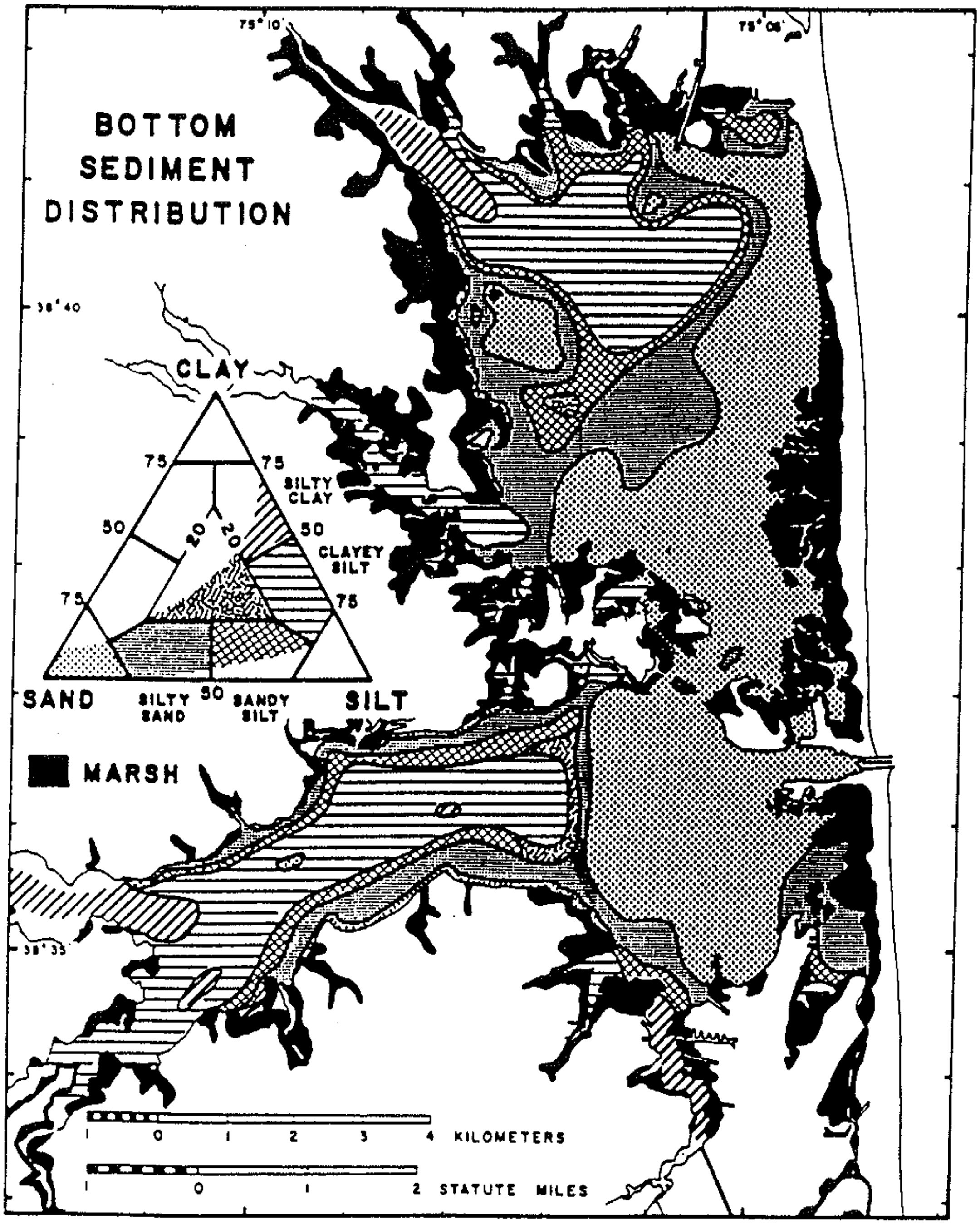


Figure 3.7. Bottom sediment characteristics and spatial distribution, Rehoboth Bay and Indian River Bay, Delaware (Chrzastowski, 1986).

Bottom Sediment Type[1]	Rehoboth Bay	Indian River Bay
Sand	41%	35%
Silty Sand	21%	15%
Sandy Silt	10%	10%
Clayey Silt	25%	30%
Silty Clay	3%	9%
Sand-Silt-Clay	1%	< 1%

[1]Classification according to Shepard (1954)

Table 3.7 **Bottom Sediment Distribution of Rehoboth Bay and Indian River Bay, Delaware, Showing Percent Bottom Area for Each Sediment Type (based on data from Chrzastowski, 1986)**

presented in Table 3.7. The generalized sediment distribution pattern of the two bays is similar, with the eastern section of the bays and the nearshore areas around the perimeter dominated by sand; and the deeper central area, as well as the tidal tributaries, dominated by silt and clay (mud). The sediment distributions are characterized by abrupt lateral transitions between sand- and mud-dominated areas (Chrzastowski, 1986). Cole and Spence (1977) found areas of oyster shell in a zone roughly 1/2 mile wide (north-south dimension) by 2 miles long (east-west) in central Rehoboth Bay, and two small areas in Indian River Bay, off of Grays Point and Rock Point/Piney Neck. Michaels (1992, pers. comm.) reports that these were man-made and were actual living oyster beds in the 1970's; at the present time, the oysters are no longer harvested,but occasional shell material is picked up during sampling.

The bottom sediments of Rehoboth Bay are sand-dominated; approximately 62% of the bottom area consists of sand or silty sand. The sand in the eastern section of the bay represents barrier sands/overwash deposits/relict flood tidal delta deposits associated with Indian River Inlet (Kraft, 1971; John, 1977; Carey, 1979; Chrzastowski, 1986). Localized sand-dominated areas in Rehoboth Bay are interpreted by Chrzastowski to result from wave erosion and reworking of sand from the top of pre-Holocene knolls. These sites (which include the Big Piney and Little Piney Islands) were at one time islands which have disappeared due to erosion and sea-level rise. Mud-dominated sediments (sandy silt, clayey silt, and silty clay) represent approximately 38% of bottom area of Rehoboth Bay. Muds occur in the deeper, north-central section of the bay, in Head of Bay Cove in the northeastern section of the bay, and at the mouths of several of the tidal streams (including Bald Eagle Creek, White Oak Creek, Arnell Creek, Love Creek, Herring Creek, and Wilson Creek).

The percentage of sand-dominated and mud-dominated bottom area in Indian River Bay is nearly equal, 50% and 49%, respectively. (The remaining 1% of bottom area is a combination of sand, silt, and mud.) The eastern third of the bay, as well as the northern and southern shores of the western bay, consist of sand and silty sand. Sandy silt, clayey silt, and silty clay occur in the deeper channel in the western bay; in several small, sheltered coves (Steels Cove and White House Cove); and in the tributary creeks (Pepper Creek, Collins Creek, and White Creek).

Numerous studies have linked bottom sediment type with floral and faunal distribution in Rehoboth and Indian River Bays. Carey (1979) reported that prior to the opening and stabilization of Indian River Inlet in 1938-1940, seagrasses such as Ruppia maritima and Zostera marina grew in Indian River Bay (W. Hocker, personal comm.). This anecdotal observation appears to be valid, based on examination of aerial photographs from the 1940's by Orth and Moore (1988), and by the presence of seagrasses in sediment cores taken by Carey (1979). These grasses inhabited the silty mud bay bottom, which increased in elevation as plant communities took hold. Sediment accumulation occurred as the grasses, acting as baffles, trapped waterborne fine-grained sediment particles. The grasses also served to stabilize the substrate once sediments were deposited (Burrell and Schubel, 1977; Carey, 1979). Seagrasses began to disappear from the Inland Bays after the 1940's. It was during this time that the sandy tidal flats in marginal delta regions evolved from vegetated muddy tidal flats as changes in current flow and sediment supply altered conditions in Indian River Bay (Carey, 1979). The last stands of seagrasses were last noted in the late 1960's/early 1970's (Anderson, 1993, pers. comm.).

Maurer (1977) conducted a comprehensive survey of the benthic community of Rehoboth and Indian River Bays. Non-selective deposit feeding polychaetes dominate in mud and muddy sand. Filter-feeding mollusks were best represented in sands. In terms of density, wet and dry weight, the muddy sand habitat displayed the highest values, while sand values were appreciably low. A more detailed discussion linking bottom sediment type and benthos is presented in Section 4 (Living Resources).

Little Assawoman Bay

Grain-size characteristics of bottom sediments of Little Assawoman Bay are based on laboratory analysis of the upper 20 cm. from 35 sediment cores (Maurmeyer, 1991; DNREC, 1992). Additional information about nearshore bottom characteristics was provided by Carey and Sadler (1991).

Figure 3.8 shows the bottom sediment distribution of Little Assawoman Bay, based on grain-size classification in Folk (1968). Bottom sediments in the eastern portion of the bay generally consist of medium- to fine-grained gray sand, grading to silty sand/muddy sand in a westerly direction. The deeper north-central and south-central portions of the bay are characterized by dark gray to black sandy clay and sandy muds. Little Bay, an embayment of the northern part of Little Assawoman Bay, is underlain by sand in the southeastern section, and sandy mud in the northern areas. The Narrows, a channel connecting Little Assawoman Bay with Little Bay, is underlain by muddy sand. Bottom sediments of the tidal tributaries, Dirickson Creek and Miller Creek, consist of dark gray sandy mud. A bottom sediment sample taken from

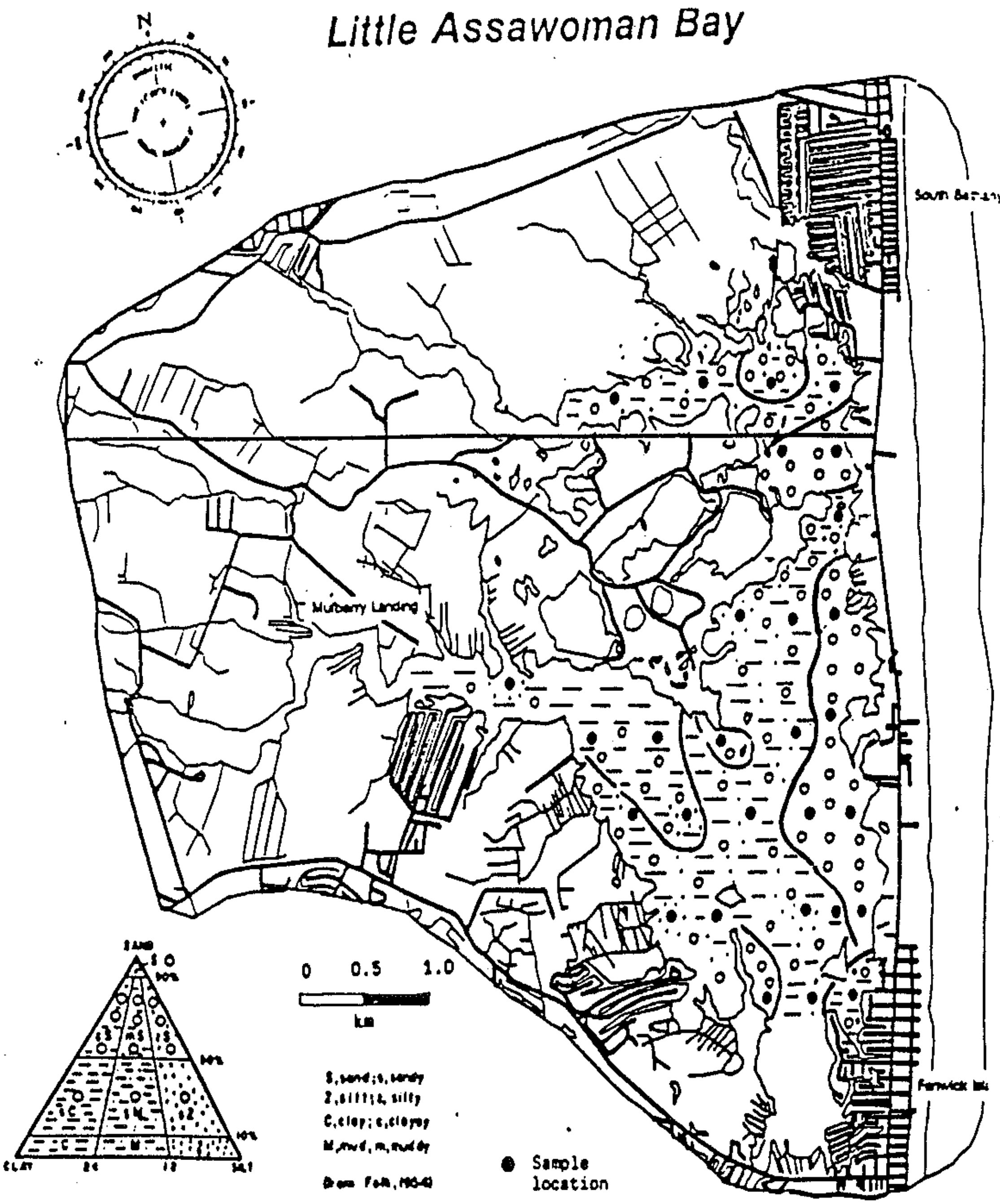


Figure 3.8. Bottom sediment characteristics and spatial distribution, Little Assawoman Bay, Delaware (Maurmeyer, 1991; DNREC, 1992).

Assawoman Canal, an artificial waterway flowing into Little Assawoman Bay, consists of silty sand. Bottom samples collected from two artificial lagoons in South Bethany consist of sand and muddy sand.

Dr. William Ullman, College of Marine Studies, University of Delaware, designed a comprehensive, integrated set of field studies to provide baseline data for characterization of Little Assawoman Bay. A one-day scientific survey of Little Assawoman Bay was conducted on June 12, 1991; Ullman (1991) compiled the results of studies by various field investigators.

Bock and others (1991) conducted a study of the benthos of Little Assawoman Bay and its northern embayment, Little Bay. Results of their sampling revealed that species abundances are relatively low. Polychaetes represent the dominant taxa; the only non-polychaete groups were Nematoda and Rhynchoceala. There appeared to be a general correlation with bottom sediment type, with few specimens found in the muddy area, and higher diversity in sandy areas. No arthropods nor live mollusks were found by Bock and others (1991). This observation was also documented by Tinsman (1991); no live mollusks were collected in a preliminary hard clam survey in Little Assawoman Bay. Tinsman speculated that the lack of hard clams (Mercenaria mercenaria) may be a result of seasonally low salinities (<20 ppt) within Little Assawoman Bay. A study by Price and Schneider (1991) indicates that Little Assawoman Bay appears to be a thriving nursery for blue crabs (Callinectes sapidus) and two finfish species, the spot (Leiostomus xanthurus) and the summer flounder (Paralichthys dentatus). Price and Schneider (1991) noted that muddy areas tend to support the mummichog (Fundulus heteroclitus) and the glass shrimp (Palaemonetes sp.); striped killifish were found in areas of sandy bottoms; and the striped mullet (Mugil cephalus) was found only in a dead-end artificial lagoon. Anderson (1991) conducted an epibenthic survey of Little Assawoman Bay, and found that the community is dominated by the blue crab (C. sapidus) and the glassy bubble shell gastropod (Haminoea solitaria). There appears to be a correlation between bottom sediment type and population density, with the blue crab most abundant in sandy sediments, and the gastropod in muddy and silty sandy sediments. Preliminary examination by Anderson (1991) of a sample from the muddy sediments of Dirickson Creek suggests that a dense and diverse infaunal community dominated by bivalves and polychaetes exists in the muddy areas of Little Assawoman Bay.

A direct comparison of the bottom sediment types depicted for Rehoboth and Indian River Bays with Little Assawoman Bay cannot be made, due to different sediment classification systems used in depicting the bottom material. For example, areas depicted as "sand" in Rehoboth and Indian River Bays contain >75% sand-sized particles, based on Shepard's (1954) classification; whereas areas depicted as "sand" in Little Assawoman Bay consist of >90% sand-sized particles, based on Folk (1968). classification. Thus, a bottom sample containing 80% sand-sized particles, 10% silt-sized particles, and 10% clay-sized particles would be depicted as "sand" in Rehoboth and Indian River Bays, but would be shown as "muddy sand" in Little Assawoman Bay. However, it is possible to compare sand-dominated (>50% sand) vs. mud-dominated (>50% mud [silt + clay]) areas, since these designations would be the same in both systems. Using this approach, Table 3.8 shows the percentages of bottom area dominated (>50%) by sandy sediments and muddy sediments. Proportionally, Little Assawoman Bay contains the largest percentage of sandy substrate (72%), whereas Indian River Bay contains the greatest percentage of mud-dominated bottom (49%). The dominance of sand in shallow coastal lagoons such as Little Assawoman Bay is due to a small sediment supply from landward sources, and an

	Bottom Sediments (by area):	
	Sand-Dominated	**Mud-Dominated**
Rehoboth Bay[1]	62%	38%
Indian River Bay[1]	50%	49%
Little Assawoman Bay[2]	72%	28%

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[1]From data by Chrzastowski, 1986
[2]From data by Maurmeyer, 1991; DNREC, 1992

Table 3.8 Comparison of Areal Extent of Sand-Dominated and Mud-Dominated Bottom Sediments, Rehoboth Bay, Indian River Bay, and Little Assawoman Bay

abundance of sand derived from barrier overwash, flood-tidal delta development, and the winnowing action of waves on the shallow bottom (Folger, 1972). Chrzastowski (1986) attributes the high proportion of muddy sediments in Indian River Bay to the large drainage area and discharge of Indian River.

3.3.2. Human Alterations of Subtidal Areas

Dredging

Dredging activities, conducted primarily for navigational access, have resulted in extensive modification of the Inland Bays and their tributaries. Since 1938, over 6.7 million cubic yards of material have been dredged from the Inland Bays and their tributaries for Federal (U.S. Army Corps of Engineers) and State (Delaware DNREC) navigational projects (Figure 3.9). Dredging projects in Indian River Bay account for 91.7% of the volume of material dredged; projects in Rehoboth Bay represent 7.7%; and Little Assawoman Bay, only 0.6% (Table 3.9).

Environmental effects of dredging in estuarine environments such as the Inland Bays include physical disruption of the bottom; destruction of benthic organisms; generation of suspended sediments and increased water turbidity; and changes in water flow. Kaplan and others (1979) classified the general effects of dredging on the fauna and substrate into three categories:

1. Immediate effects (during and after dredging):

   a. Suffocation of benthic animals by siltation;

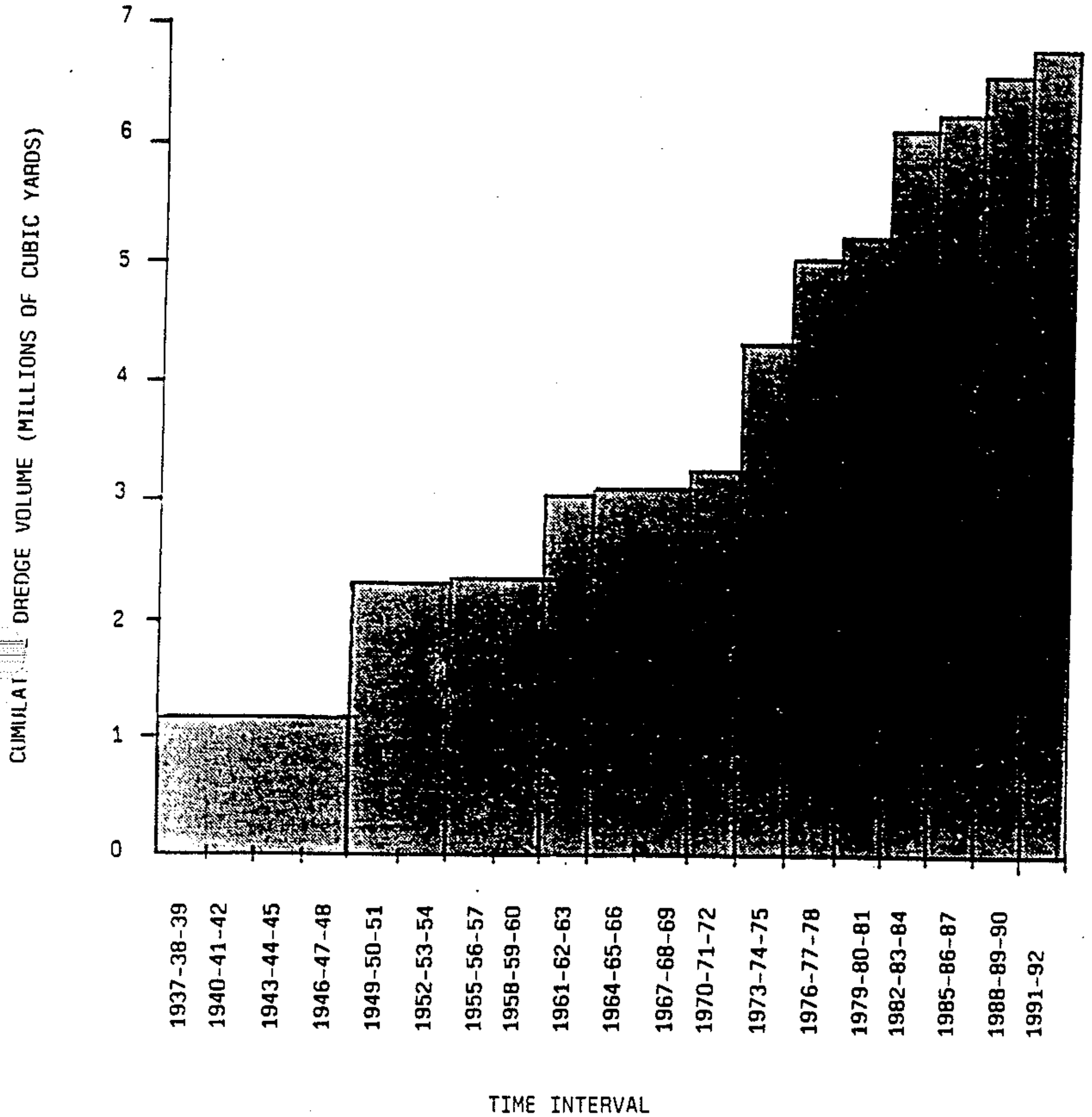

Figure 3.9. Cumulative dredge volume for U.S. Army Corps of Engineers and Delaware DNREC navigational dredging projects in Delaware's Inland Bays, 1937-1992 (data from U.S. Army Corps of Engineers and Delaware DNREC).

Waterway	Volume (Cubic Yards)	
Rehoboth Bay		
Lewes & Rehoboth Canal (including UD CMS Harbor, Henlopen Acres Marina, USCG)	111,646	
Love Creek	168,000	
Rehoboth Bay Sailing Assoc.	2,100	
Herring Creek	85,000	
Guinea Creek	75,450	
Wilson Creek	27,000	
Cozy Cove	17,745	
Massey's Ditch	32,000	
SUBTOTAL:	**518,941**	(7.7%)
Indian River Bay		
Indian River/Indian River Inlet	5,733,400	
Burton Island Marina	142,440	
South Shore Marina	3,000	
Pepper Creek	150,000	
White Creek	135,000	
Bethany Loop Canal	25,650	
SUBTOTAL:	**6,189,490**	(91.7%)
Little Assawoman Bay		
Jefferson Creek	38,820	
SUBTOTAL:	**38,820**	(0.6%)
TOTAL:	**6,747,251**	

Table 3.9 **Summary of Dredging Volumes for Federal and State (DNREC) Navigational Projects in Delaware's Inland Bays, 1938-1992 (Data from U.S. Army Corps of Engineers, Philadelphia District, and DNREC.)**

b. Flocculation and removal from the water column of planktonic organisms (which in turn affects filter feeders by removing their food source);

c. Changes in water chemistry as substances are released from the bottom material into the water column;

d. Increased turbidity through suspension of bottom material, which decreases light penetration for plants, and interferes with filter-feeding animals.

2. Transitory or semipermanent effects:

a. Mechanical removal of benthos from the dredged area;

b. Changes in the nature of the substrate.

3. Permanent changes:

a. Disruption of the ambient flow of water;

b. Changes in current distribution patterns.

An environmental assessment of potential impacts of dredging in Indian River Bay was prepared by Collier (1978). An analysis of the primary and secondary effects of dredging activities in Rehoboth and Indian River Bays, based on a review of studies conducted in similar estuarine settings, was conducted by Coastal & Estuarine Research, Inc. (1983). These reports summarize the general impacts of dredging on the benthic community, water quality, fish populations, and substrate.

Removal of bottom material during dredging results in immediate destruction of epifaunal and infaunal benthic organism community inhabiting the substrate as organisms are sucked up and transported through a pipeline (Collier, 1978). Recovery occurs over a period of weeks, months, or years, depending on the type of environment and the biology of the plants and animals affected (Hirsch and others, 1978). Resettlement occurs by active migration of the animals, and by hydrodynamic redistribution of juvenile and larval stages (Harrison, n.d.). However, permanent damage may occur if the new substrate does not resemble the original material or if other physical/chemical changes occur (Barnard and Reish, 1959). Several studies (Markey and Putnam, 1976; Cronin and others, 1970; Krantz and others, 1977) found no adverse effects of dredging on the biota of the dredged sites. Other studies (Kaplan and others, 1974; Pfitzenmeyer, 1981; 1982) report longer time periods for recovery, with indications that certain dredging activities may result in permanent damage to habitats. Pfitzenmeyer (1975) examined four shallow tidal creeks in the Chesapeake Bay area, and concluded that the effects of dredging can be minimized if (1) the ratio of total bottom area to dredged area is large; (2) flushing rates were enhanced and not reduced (the dredged channels did not lead to a dead end or trap water); and (3) the benthic populations were not removed from the euphotic zone by large dredging depths.

Increased turbidity due to resuspension of bottom sediments during dredging is frequently cited as an adverse effect of dredging. Most ecosystems experience varying ranges of natural turbidity (due to wind agitation, wave action, currents, increased river discharge, plankton blooms, etc.) to which resident flora and fauna are adapted (Hirsch and others, 1978). However, environmental problems result from excessively high concentrations of suspended sediments. These include (1) interference with filter feeding activities of invertebrates; (2) clogging of fish gills; and (3) interference with plant photosynthesis due to decreased light penetration. Studies measuring the duration and extent of the turbidity plumes associated with dredging generally reported that the increased turbidity due to dredging is of a short-term and localized nature, with no appreciable impact on the environment (Cronin and others, 1976 and 1981; Krantz and others, 1977). Increased turbidity caused by dredging in estuarine environments is in most cases transient, as material placed into suspension settles out of the water column rapidly. This is attributed to the high electrolyte content of estuarine waters, which causes flocculation, in which fine-grained materials such as clays to aggregate into larger particles with faster settling rates (Biggs, 1968).

Agitation and resuspension of bottom material in estuaries increases oxygen demand, and thereby temporarily lowers dissolved oxygen content of the water. The Delaware State Planning Office (1976) reported that suspended sediment can have up to eight times greater oxygen demand (BOD, COD) than undisturbed bottom material. Most investigators report that short-term dissolved oxygen depletion due to dredging is not a problem in estuarine areas. However, a study by Thornton (1975) of oxygen requirements of various species of juvenile fish in Rehoboth and Indian River Bays suggests that because of their higher metabolic rate, juveniles are more susceptible to oxygen deficiency than adults. The species most susceptible to low dissolved oxygen concentrations are the bay anchovy and Atlantic silverside.

Alteration of bottom topography by dredging may cause changes in salinity, due to salt water intrusion up tidal rivers and creeks (Daiber and others, 1975). This may be beneficial for some organisms, but detrimental to others.

BCM Eastern, Inc. (1986) prepared an Inland Bays dredging study in which goals and objectives, creek evaluations, and dredging criteria were developed. Table 3.10 lists the goals and objectives of Delaware's Inland Bays Dredging Program. On the basis of these goals, BCM

GOALS AND OBJECTIVES OF DELAWARE'S INLAND BAYS DREDGING PROGRAM

GOAL: Maintain the navigability of the Inland Bays channels for current and future recreational and commercial boating uses.

- Maintain the navigability of the Indian River inlet.
- Maintain proper depths in channels leading to marinas and to other waterfront activities requiring access by commercial boats.
- Maintain proper depths in channels used by recreation boats, when justified by significant public recreational boat traffic and when significant environmental impacts can be avoided.
- Keep the depth and width of new navigable channels to the minimums required to accommodate projected boat traffic.

GOAL: Encourage the development of a spatially concentrated, functionally efficient land use pattern that minimizes potential adverse impacts on the Inland Bays environmental resources and infrastructure needs.

- Extend navigation channels only to areas designated for future development under state, county, or local land use plans.
- Reinforce the existing land use patterns by encouraging additional growth in already-developed areas.
- Avoid the extension of navigation channels into creeks or creek segments where the waterfront land use being provided access is located more than one-half mile from the creek mouth.

GOAL: Create or enhance the supply and quality of recreational resources in the Inland Bays region.

- Encourage the beneficial use of dredge spoil, including beach nourishment and habitat creation.
- Improve or create habitat for popular sport fish species and for shellfish.
- Maintain or improve access channels leading to water areas intensively used for recreational activities (e.g., boating, sailing, fishing, waterskiing, etc.)
- Prohibit the extension of navigation channels into areas where subsequent private shorefront development would preclude public access to such areas.

GOAL: Use the state dredge to maximize the ratio of public benefits to costs.

- Use the dredge on projects whose benefits are equally accessible to the general public.
- Prohibit the use of the state dredge in projects where private benefits would comprise all or a substantial majority of the project benefits.
- The dredge shall not be used to provide or maintain, at the state's expense, navigational or access channels to economically important waterfront land uses such as marinas, restaurants, boat dealers, etc.
- Schedule dredging projects so as to minimize mobilization and de-mobilization costs.

GOAL: Maintain or improve the environmental quality of the Inland Bays region.

- Create, enhance, or restore Inland Bays' wetlands.
- Create or enhance aquatic or terrestrial habitat using dredged material.
- Specify limits (e.g., seasonal restrictions) and set performance standards for required dredging in environmentally sensitive areas; prohibit dredging where limits or performance standards will not sufficiently mitigate adverse environmental impacts.
- Avoid the extension of navigation or access channels into areas where the necessary infrastructure (e.g., roads, sewer, water, electricity, gas, etc.) does not exist to support new development or where growth is limited by local land use planning.
- Avoid extension of navigation or access channels into environmentally sensitive or unique areas that would experience significant adverse impacts from development.

GOAL: Improve the quality of the Inland Bays' surface water resources.

- Enhance water quality in poorly flushed canals and lagoons through use of uncontaminated dredged materials of appropriate composition to equalize depths in these areas to those of the adjacent open waters.
- Promulgate dredging regulations to reduce the short-term adverse impacts that can accompany dredging operations.
- When dredging, follow to the maximum extent possible the existing contours of channels.
- Develop specifications for dredged material disposal operations to minimize environmental impacts.

Table 3.10 Goals and Objectives of Delaware's Inland Bays Dredging Program Developed by BCM, Inc. (1986)

developed a dredging classification for creeks, based on environmental considerations, water use and dredging history, and navigational demand. This evaluation resulted in classification of the Inland Bays system into three categories: areas of restricted (but not prohibited) dredging; areas open to dredging; and areas requiring further analysis (Table 3.11).

Dredge Spoil Disposal

Dredging and filling activities prior to the 1970's impacted wetlands habitats as well as subaqueous environments; however, since passage of the State Wetlands Act, authorized and permitted dredging and filling activities in wetlands have been minimal. Most of the dredge spoil material excavated from post-1970's dredging projects was removed from the Inland Bays system, and pumped onto upland spoil disposal sites. Sandy material obtained from dredging projects conducted for the purpose of beach nourishment of the severely eroding beach north of Indian River Inlet was pumped directly onto the eroding oceanside beach to provide a supply of sand.

The spoil material from the early dredge projects was customarily disposed via overboard (sidecast) disposal; used to create spoil islands (e.g., Sand Island in Indian River Bay); or placed on wetlands. Collier (1978) summarized the potential environmental effects of open water spoil disposal of dredge spoil in Indian River Bay. Deposition of dredge spoil without proper control can destroy productive hard clam and fish habitats. Dredge spoil mounds can interrupt major circulation patterns within the bays. If dredge spoil material is placed in areas of strong currents, sediment may be moved back into the channel from which it was dredged. Water quality may be impaired at dredge spoil disposal sites by suspended sediments, lowered dissolved oxygen levels, and released toxins and plant nutrients from the sediment.

CLASSIFICATION SYSTEM

STEP ONE: ENVIRONMENTAL CLASSIFICATION

Objective: Classify, as areas where dredging should be restricted, creeks, creek segments, and open water areas with high environmental sensitivity.

Factor One: Bodies of water and associated shorelines which have been designated as state natural areas, or which are totally contained in or where more than 50% of the shoreline borders a wildlife refuge or state/federal parkland.

Factor Two: Creek segments whose shorelines are dominated by wetland vegetation and which have open water channels equal to or less than 40 feet in width.

Factor Three: Creek segments where the presence of rare and endangered species has been identified either in-stream or along the shoreline.

Factor Four: Creek segments where at least 30% of the land area within 1/4 mile of the water's edge is contained in designated wetlands and is less than 50% developed (as moderate density residential development).

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AREAS OF RESTRICTED DREDGING

Upstream reaches of:
Vines Ck.
Pepper Ck.
Herring Ck.
- Hopkins Prong
- Burton Prong
- Guinea Ck.
Wilson Ck.
White Oak Ck.
- Johnson Branch
Collins Ck.
- Joshua Prong (Simon Glade)
- Edgar Prong
White Ck.
Arnell Ck.
Dirickson Ck.
Emily Gut
Love Ck.

Lingo Ck.
Drum Ck.
Roy Ck.
Lee Joseph Ck.
Love Ck.
Blackwater Ck.
Miller Ck.

Segments of:
Drum Ck.
Dirickson Ck.
Love Ck.
- Dorman Branch
- Lingo Cove
Joshua Cove
Slougns Gut
Collins Ck.
- Joshua Prong
- Edgar Prong
Stump Ck.
Swan Ck.
Island Ck.
Warwick Gut
Emily Gut
Lingo Ck.
Several small unnamed creeks/guts

* May eventually list more creek segments here as the presence of both state and federally designated rare and endangered species is identified.

Footnote: Creeks less than 40 feet in width (headwaters and tributaries) and other areas not designated on the maps should not be considered for dredging by the State.

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STEP TWO: CLASSIFICATION BY WATER USE AND DREDGING HISTORY

Objective: To further segregate creeks into those which are characterized by intensive use and an recent dredging history and those which are less used and have not been previously dredged. Those areas which are both intensively used and have a recent dredging history will then be classified as being open to dredging.

Factor One: Does the water body, creek or creek segment consistently and intensively used as an access route to, or between, the following types of boating activities:

- Recreational boating, including sailing, pontooning or excursions.
- Recreational or commercial fishing, including shellfishing.
- Water skiing, jet skiing, etc.
- Commercial transportation (i.e., hauling of commodities).
- Access channel connecting major water use areas.

Factor Two: Has the water area, creek or creek segment been dredged by the state or federal government within the last 15 to 20 years?

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AREAS OPEN TO DREDGING

- Assawoman Canal (and approach channels) (to be dredged for navigation purposes only. Future development projects requiring access to Assawoman Canal. Structures that conflict with navigation, and projects which degrade water quality will be prohibited.)
- Indian River Navigation Channel
- Lewes & Rehoboth Canal
- Massey's Ditch
- Rehoboth Bay Navigation Channel

Footnote: As a general policy, the State should not dredge artificially constructed dead-end lagoons unless it is for environmental rehabilitation or there are overriding concerns. If dredging is requested by incorporated communities, cost/benefit analysis should be conducted.

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STEP THREE: GENERATORS AND ATTRACTORS OF BOAT TRAFFIC

Objective: To further segregate the group remaining after Step II into those areas with or without navigational demand. The criteria used to determine navigational demand is the presence of generators and/or attractors of boat traffic as defined below.

Factor One: The presence of a marina with one of the following characteristics:

- Publicly accessible marina with more than 25 slips.
- Significant proportion of vessels using marina have drafts exceeding 4' and lengths exceeding 25'.
- Publicly accessible boat launching ramp.
- Private marina with more than 100 slips.

Factor Two: The presence of a residential subdivision, campground or trailer park with more than 50 units and which has either an accompanying marina, or whose parcels front on boat channel.

Factor Three: The presence of waterfront recreational, industrial or commercial activities that are regularly visited by vessels with drafts exceeding 2'.

Factor Four: At least 50 percent of the land area located within 1/2 mile of the creek or creek segment is developed at a minimum as moderate density residential (i.e., at least one dwelling unit/acre).

If at least one of the factors is present, classify as Level I; if none of the factors are present, classify as Level II. Level I creeks are higher priority projects as they satisfy the navigational demand criteria. Level II creek exhibits little current demand or use.

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AREAS REQUIRING FURTHER ANALYSIS

Level I Creek Segments**

Love Creek (up to first bridge)
Arnell Creek (mouth only)
Guinea Creek (up to bridge)
Lingo Creek
Pepper Creek (up to Holland Pt)
Vine Creek (up to Ballast Pt)
Dirickson Creek
Roy Creek
Herring Creek
- Burton Prong
- Hopkins Prong
- Wilson Creek (mouth only)
- Lee Joseph Creek (mouth only)

Level II Creek Segments**

Bald Eagle Creek
White Oak Creek (mouth only)
Emily Gut (mouth only)
Beach Cove
Vines Creek (from Ballast Pt to first bridge)

* These requirements were developed for marinas near the creek mouths on the bays. The marina size and facility requirements increase the farther upstream it is located due to related dredging costs and environmental impacts.

** These are only portions of the creeks listed under each level as illustrated on the set of maps accompanying this report.

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PROJECT EVALUATION CRITERIA

Table 3.11 Classification System for Delaware's Inland Bays Dredging (from BCM, Inc., 1986)

Collier (1978) and BCM, Inc. (1986) present several recommendations for alternative uses for dredge spoil material. Creation of dredge spoil islands, with containment of the sediment, can provide nesting habitat for colonial breeding birds. The least tern, which nests in the Inland Bays area, would benefit from this type of habitat (BCM, Inc., 1986). Another alternative is use of dredged material as a substrate for creation of wetlands by planting salt meadow hay (Spartina patens) and smooth cordgrass (S. alterniflora). The benefits of this procedure include creation of new wetlands habitat and breeding grounds for terrestrial and aquatic wildlife, shore erosion control, storm dissipation, and absorption of nutrients and pollutants (BCM, Inc., 1986). Collier (1978) cautions that the location should be chosen carefully so that productive submerged land is not destroyed.

Filling for Residential Communities

Many of the residential developments along the Inland Bays were built on wetlands using fill material obtained from dredging the bay bottom. Hardisky and Klemas (1983) attribute much of the wetlands destruction prior to 1971 to filling for home construction. Information about these dredge and fill projects is difficult to obtain, since these activities were generally conducted prior to the 1970's, so that permitting documentation is not available. Swisher (1982) presents a partial accounting of dredging operations in Rehoboth Bay, based on verbal information provided by State and Federal personnel. In 1960-62, approximately 400,000 cubic yards of material was dredged from Rehoboth Bay, and placed on wetlands and a shallow lagoon to create the Rehoboth Beach Yacht and Country Club residential community. Bookhammer Landing (Joy Beach) and West Bay Trailer Park, built in the late 1960's and 1970's, required approximately

40,000 and 45,000 cubic yards, respectively, of fill material obtained from dredging Rehoboth Bay.

Artificial Lagoons

Artificial lagoons have been excavated/dredged in a number of residential communities along the Inland Bays in order to increase waterfront property and provide direct access to the waters of the bays. These dredged lagoons are generally linear, narrow, deep channels ending in a dead-end canal. Some of the lagoon sides are stabilized by timber bulkheads. Daiber and others (1972, 1974, 1975) and Brenum (1976) conducted extensive studies to document the environmental and ecological conditions of these lagoons (including comparisons to the natural open bay and tidal creek habitats). The results of these studies show that most artificial lagoons represent stressed environments characterized by poor water quality and associated adverse effects on fish and benthos. This conclusion is based on the following findings:

- The number of benthic invertebrates inhabiting artificial lagoons is significantly lower than natural areas.
- The biota in artificial lagoons consists almost entirely of polychaete annelids (worms), which comprise over 94% of the total yearly number of individuals per square meter.
- Numbers of fish (mummichog) collected in the artificial lagoon were significantly lower than in natural environments. The estimated mean population size of the mummichog in the natural area was repeatedly about three times that found in the artificial lagoon.
- When anoxic conditions existed at the lagoon bottom, this fish species died during a survivability study, whereas those in natural habitats survived.

- Thermal, salinity, and oxygen stratification are more pronounced in artificial lagoon systems than in natural embayments.

- Dissolved oxygen values in the artificial lagoons are lower than in natural habitats. All dissolved oxygen values below 2.0 ml/L occurred in artificial lagoons.

- Water circulation in dead-end lagoons is impeded by several factors, including the narrow width; closure on one end (limiting water exchange to the entrance of the lagoon); the sheltering effect of the houses, which reduce wind-generated turbulence and vertical mixing of the water column; and, in many cases, the presence of a narrow sill at the lagoon entrance, which permits only shallow surface exchange of water.

- Dye studies showed slower flushing rates and slower water circulation in artificial lagoons than in natural waterways. Dye was flushed out of Jefferson Creek, a natural waterway, within the first 24-hour period, and never exceeded 5% of the initial concentration thereafter. In contrast, 32.5% of the dye remained on the surface of a South Bethany artificial lagoon after five days. After eight days, 4% of the dye still remained at the point of injection.

- Sedimentation studies showed high rates of siltation in artificial lagoons, where low turbulence and slow circulation allow fine particles to settle to the bottom. Grinstead (1980) calculated that the sedimentation rate in artificial lagoons varies from 2.6 to 12.0 cm/yr, which is considerably higher than most natural fine-grained depositional environments in the Inland Bays. (By comparison, various investigators have documented mean sedimentation rates of 0.3-0.4 cm/yr in tidal marshes along the inland bays, and sediment accumulation rates of 0.26 to 1.07 cm/yr within Rehoboth Bay and Indian River Bay.)

Marina Construction

Numerous public and private wet-slip marinas have been constructed within the Inland Bays. Detailed published information concerning construction activities is sparse. Swisher (1982) reports that construction of several marinas (Rehoboth Marina, Pier Point Marina, and the Rehoboth Bay Sailing Association marina) in eastern Rehoboth Bay in the 1960's involved excavation of a total volume of 85,000 cubic yards of bottom material from Rehoboth Bay. Environmental impacts resulting from marina construction as described in the U.S. EPA Coastal Marinas Assessment Handbook (1985) and in the DNREC Marina Guidebook (1991) include loss of habitat due dredging and construction of artificial shoreline structures (as described in preceding sections), and changes in water quality resulting from stormwater runoff and discharge from boats. Degradation of water quality due to nutrient enrichment and low dissolved oxygen concentrations result from sewage and upland runoff; hydrocarbons from exhausts and fuel spills; and heavy metals from antifouling paints and other pollutants.

3.3.3. Trends: Sedimentation in the Bays

Analyses of bathymetric data and sedimentation rates indicate that many areas within Rehoboth Bay and Indian River Bay are shoaling over time. Rates of sediment accumulation in Rehoboth and Indian River Bays over the past century have been documented by several investigators (Gerstel, 1982; Mirecki, 1983; Chrzastowski, 1984, 1986; Beasley, 1987), utilizing a variety of analytical techniques. Table 3.12 presents sedimentation rates in the Inland Bays as determined by these investigators.

Gerstel (1982) conducted a reconnaissance analysis of pollen in a sediment core from

Waterbody	Investigator	Method	Sedimentation Rate cm/yr	in/yr
Rehoboth Bay	Gerstel, 1982	Pollen	0.83	0.33
Rehoboth Bay	Mirecki, 1983	Pollen	1.07	0.42
Rehoboth Bay	Chrzastowski, 1984; 1986	Lead 210; Cesium 137	0.26	0.10
Rehoboth Bay	Beasley, 1987	Lead 210; Cesium 237	0.30	0.12
Indian River Bay	Chrzastowski, 1984; 1986	Lead 210; Cesium 237	0.57	0.22
Little Assawoman Bay	N/A	N/A	N/A	N/A

Table 3.12 Sedimentation Rates in Delaware's Inland Bays

central Rehoboth Bay, and calculated a sedimentation rate of 0.83 cm/yr averaged over 241 years. Mirecki (1983) analyzed the oak:ragweed pollen ratios in a core from central Rehoboth Bay, and calculated a sedimentation rate of 1.07 cm/yr, averaged over 243 years. These rates are approximately double those of typical time-averaged sediment accumulation rates of Atlantic and Gulf coastal lagoons (0.4-0.5 cm/yr), and may be attributed to inclusion of a thick sediment accumulation representing a short-term depositional event associated with local deforestation in the mid to late 1700's (Chrzastowski, 1984).

Chrzastowski (1984, 1986) utilized lead-210 (^{210}Pb) and cesium-137 (^{1}3^{7}Cs) analyses to obtain sedimentation rates of lagoonal muds from two locations within the bays. Results show a sedimentation rate of 0.26 cm/yr in north-central Rehoboth Bay, and 0.57 cm/yr in west-central Indian River Bay, averaged over the past 125 years. The higher rate of accumulation in Indian River Bay is attributed to the greater drainage area and discharge of Indian River, as compared to the Rehoboth Bay drainage system. In addition, Indian River Bay receives fine-grained sediment through Indian River Inlet via flood tidal currents.

Beasley (1987) analyzed two sediment cores from central Rehoboth Bay to document sedimentation rates. Lead-210 and Cesium-137 analyses yielded a rate of 0.30 cm/yr, similar to Chrzastowski's results.

The lagoonal mud accumulation rates approximate present rate of local relative sea-level rise (0.33-0.39 cm/yr). This indicates that no significant net bathymetric changes occurred in the central bay areas over the past century. If sea-level continues to rise at the present rate, and lagoonal sedimentation keeps pace with sea-level, the trend will be no net bathymetric change. However, if sea-level should stabilize or drop, the bays will most likely fill in and become broad marsh areas and tidal flats. The time frame for this scenario depends on the relative rates of sea-level rise vs. sediment accumulation.

Chrzastowski (1986) also determined rates of sediment accumulation and loss based on comparison of 1847 and 1981 bathymetric data. The figures were adjusted to account for a 0.3 foot rise in local relative sea-level rise; however, no corrections were made for sediment compaction. Figure 3.10 shows that most areas within the bays shoaled during the 134-year period, with the eastern, sand-dominated areas of the bays exhibiting the highest rates of sediment accumulation. Chrzastowski attributes this in part to human activities, such as inlet stabilization and dredge-spoil disposal, but the importance of sediment supply from the seaward direction (which was a factor even prior to human modifications to this depositional system) is stressed. Tidal inlet (flood tidal delta) deposition and storm overwash of the coastal barrier provide major sources of sand to the eastern parts of the bays. Perlin and others (1983) developed a sediment budget for the Atlantic coast of Delaware, which included quantification of the annual contributions of the flood tidal delta and overwash to the sediment budget. The authors believe that the Indian River Inlet flood tidal shoal is in equilibrium with the 18 year average annual dredging, i.e., 75,000 cubic yards/year. The annualized overwash volume is estimated to be approximately 94,000 cubic yards. Storms during which the barrier is overwashed and sediment transported into the Inland Bays do not occur every year; an annualized average volume is presented for the purpose of sediment budget considerations. During the past 30 years, only the March, 1962 northeast storm ("Ash Wednesday" storm) contributed a major volume of overwash sand to the Inland Bays.

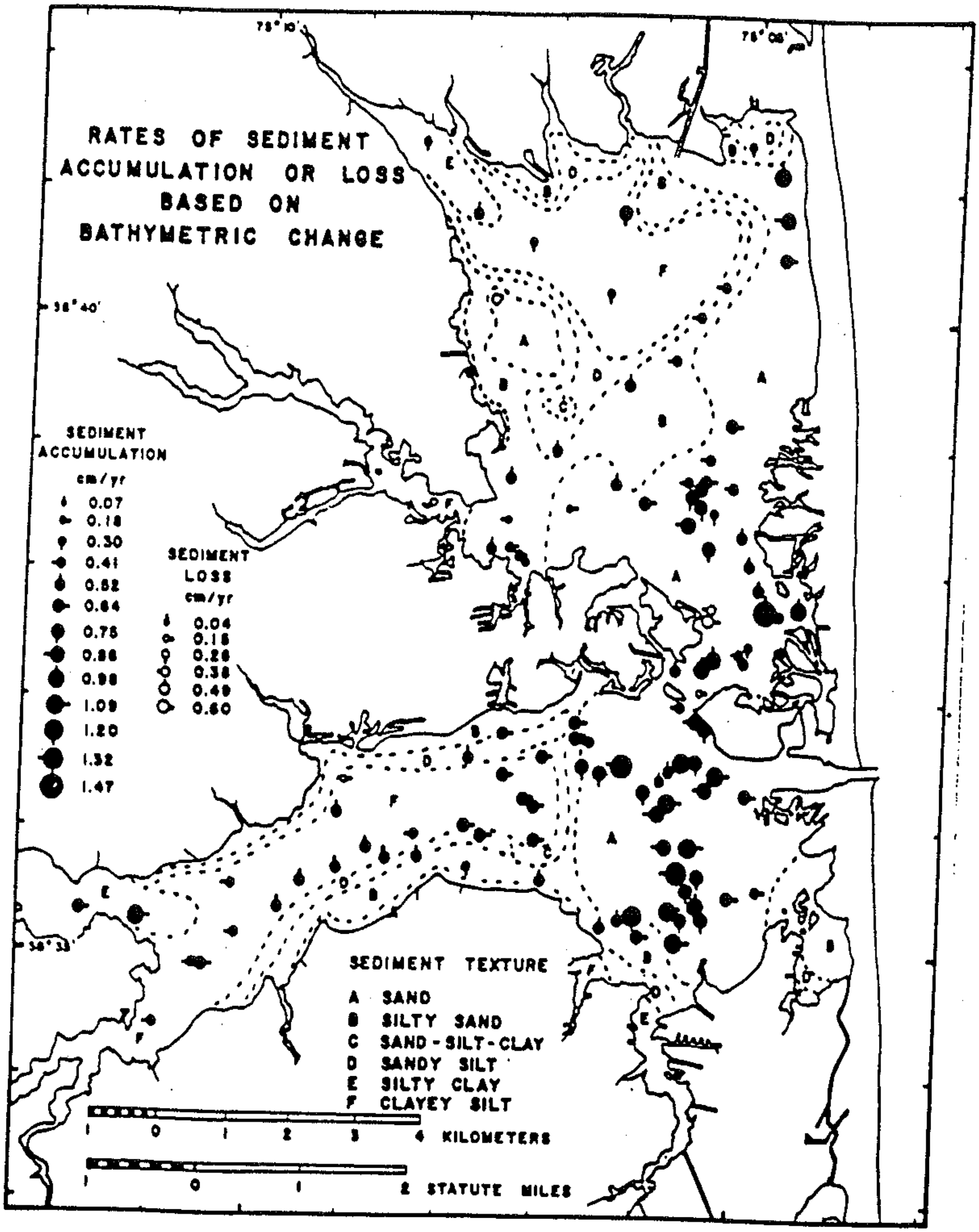

Figure 3.10. Average annual sediment accumulation rates, Rehoboth Bay and Indian River Bay, Delaware, 1847-1981, based on bathymetric changes (Chrzastowski, 1986).