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New Bedford Harbor

Historic Overview
Natural Resources
Uses Status Report

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Prepared for
New Bedford Harbor Trustee Council
Gloucester, Massachusetts

Prepared By
Vanasse Hangen Brustlin, Inc.
Watertown, Massachusetts
Providence, Rhode Island

July 1996

NEW BEDFORD HARBOR
HISTORIC OVERVIEW AND NATURAL RESOURCES AND USES
STATUS REPORT

Produced For The
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New Bedford Harbor
Superfund Site

Prepared for:

New Bedford Harbor Trustee Council

Prepared by:

Vanasse Hangen Brustlin, Inc.
Watertown, Massachusetts
and
Providence, Rhode Island

September 1996

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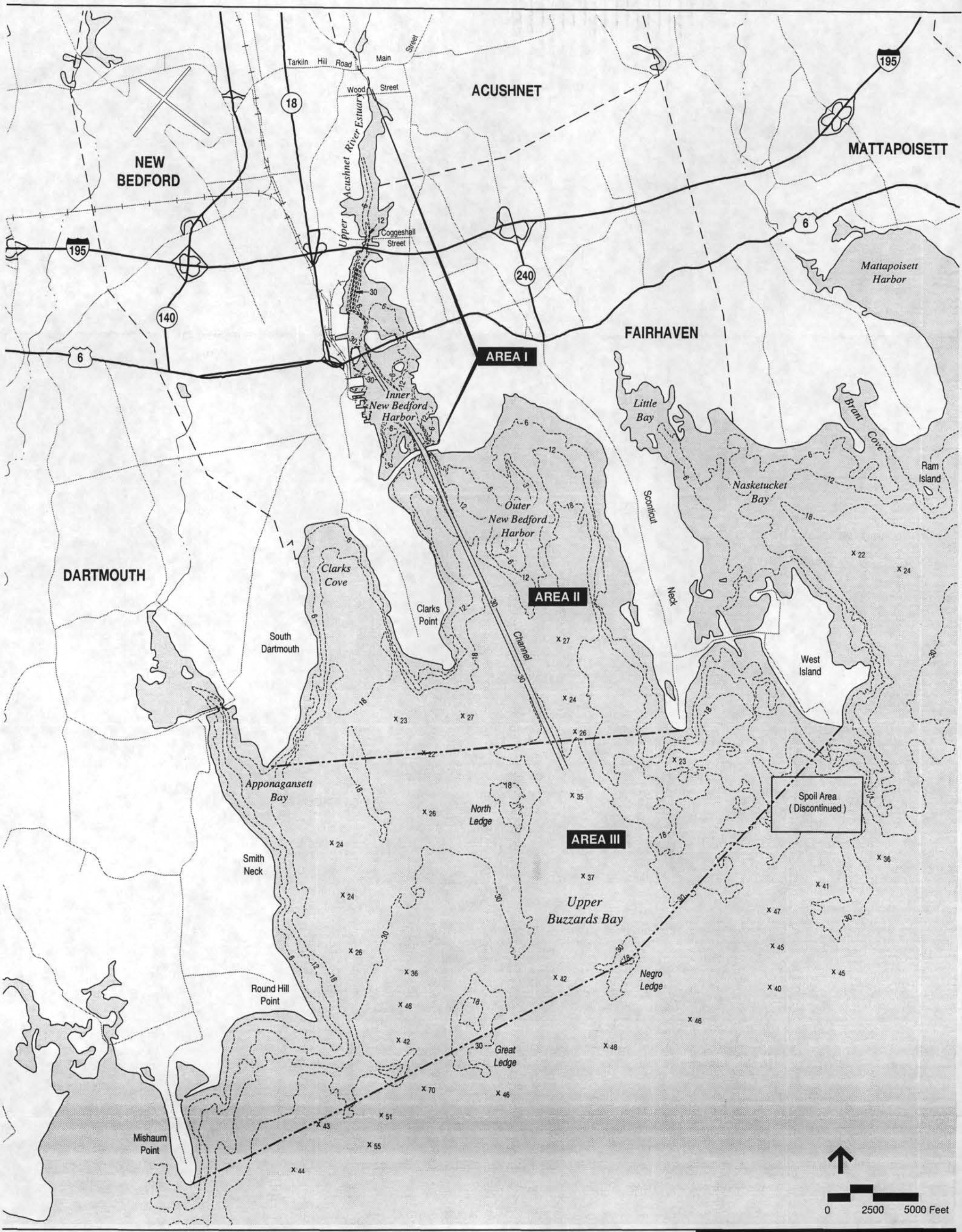
1.0 INTRODUCTION

1.1 PROJECT AREA DESCRIPTION

New Bedford Harbor, located in southeastern Massachusetts, is an important coastal resource area providing various recreational opportunities, and serving as an active port used by both commercial and recreational fishing vessels and merchant vessels importing goods for distribution throughout New England. New Bedford Harbor is also historically significant as being the largest whaling port in the United States from the late 1700s through the mid 1800s, and its significance sustains a valuable tourist attraction for the City of New Bedford. New Bedford Harbor, located at the mouth of the Acushnet River, is bordered by the City of New Bedford and the Towns of Fairhaven, Dartmouth, and Acushnet (Refer to Figure 1-1). These municipalities have served and continue to be important centers for marine-related industries including fishing, seafood processing, and shipping, as well as marine-related research and tourism. The Acushnet River, which includes valuable tidal and non-tidal waters and wetlands, discharges to the 210-square mile (mi^2) Buzzards Bay, an estuary with a watershed area of 425 mi^2 (1,104 square kilometers (km^2)). The Acushnet River Estuary, an area of 4.1 mi^2 (10.7 km^2) which includes New Bedford Harbor, is influenced by relatively minor but important freshwater inflows. The Acushnet River watershed encompasses an area of 16.5 mi^2 (43 km^2) (Refer to Figure 1-2), with an inferred base flow of 28.3 cubic feet per second (0.8 cubic meters per second) contributing 3.8 percent of the freshwater input to Buzzards Bay.

Reference to specific water resource areas relating to New Bedford Harbor is made throughout this report, and the geographical limits of these resources are introduced here to familiarize the reader for subsequent discussions. As previously mentioned, New Bedford Harbor is a part of the Acushnet River Estuary, and the "Upper Acushnet River Estuary" is defined as the tidal waters extending north from the I-195 Bridge to the limits of tide located where Tarkiln Hill Road crosses the river (Refer to Figure 1-1). The "Inner New Bedford Harbor" extends south from the I-195 Bridge to the Army Corps of Engineers' (ACOE) hurricane barrier. Tidal waters north of the hurricane barrier have also been designated as "Area I" as part of the U.S. Environmental Protection Agency's (US EPA) and the Commonwealth of Massachusetts' New Bedford Harbor contaminated site area. "Outer New Bedford Harbor" is defined as those waters between the ACOE hurricane barrier south to an imaginary line from Ricketsons Point in Dartmouth extending east to Wilbur Point in Fairhaven, and has also designated as "Area II". Waters seaward of the southern Outer Harbor boundary are part of "Upper Buzzards Bay", and for purposes of this report, continue southward to an imaginary line from Mishaum Point in Dartmouth extending northeast to Negro Ledge and continuing northeast to Rocky Point on West Island (Refer to Figure 1-1). This portion of Upper Buzzards Bay has also been



Note: Soundings are in Feet at Mean Low Water

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Figure 1-1

New Bedford Harbor and
Upper Buzzards Bay

Source: Mass GIS; USGS, 1977; NOAA, 1983

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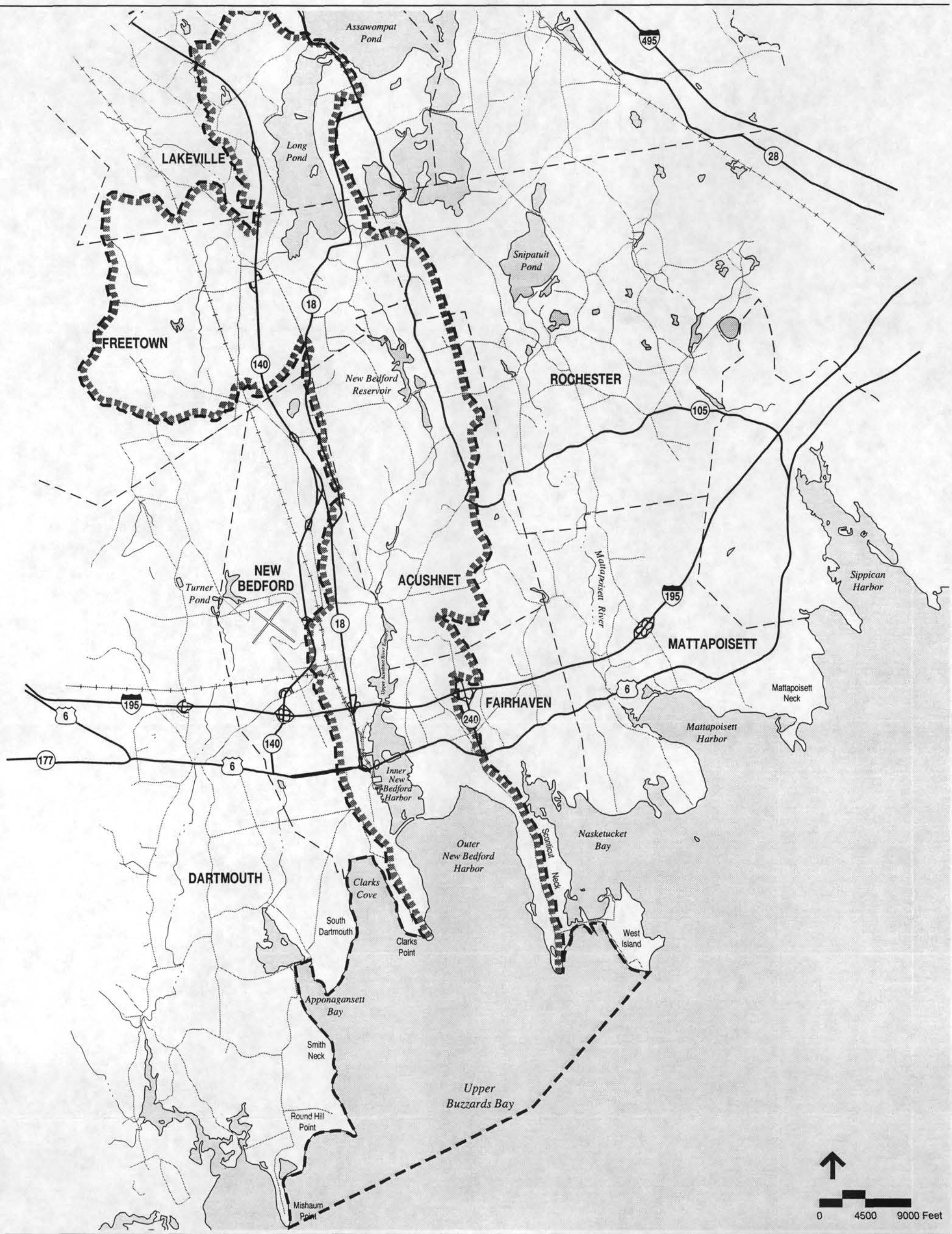

Acushnet River Watershed Boundary

New Bedford Environment

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Figure 1-2

Acushnet River Watershed
and New Bedford Environment

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designated as "Area III". Cumulatively, the Acushnet River watershed and all tidalwaters of Areas I, II, and III form the "New Bedford Environment".

New Bedford Harbor, the Upper Acushnet River Estuary, and a portion of Upper Buzzards Bay have been contaminated with high levels of hazardous polychlorinated biphenyls (PCBs), heavy metals, and polycyclic aromatic hydrocarbons (PAHs). Between the late 1940s and 1977, several electronics manufacturers discharged PCB-laden materials directly into the Upper Acushnet River Estuary and New Bedford Harbor, and indirectly into these waters and Upper Buzzards Bay as a result of releases from the City's wastewater treatment facility and numerous combined sewer-stormwater overflows. PCBs are known human carcinogens, and also have adverse effects on living marine resources including finfish, shellfish, birds and mammals. The high levels of metals, PAHs, and other contaminants that have been discharged to these waters have also been documented as having toxic effects on living marine resources. The presence of these high contaminant levels within the New Bedford Harbor site has required the closure of nearshore fisheries, restricted by regulation the use of these waters for recreation and other activities, and resulted in economic impacts to the region. Because of the high levels of hazardous materials in these coastal waters, the New Bedford Harbor site was placed on the US EPA's Superfund National Priorities List in 1984, and is the Commonwealth of Massachusetts' priority Superfund site.

1.2 SITE CLEANUP AND RESOURCE RESTORATION

In accordance with the Comprehensive Environmental Response, Compensation, and Liability Act regulations, federal and state natural resource agencies have been designated as Trustees for the New Bedford Harbor site restoration. For this site, the New Bedford Harbor Trustee Council (NBHTC), comprised of the U.S. Departments of Commerce (National Oceanic and Atmospheric Administration) and Interior (U.S. Fish and Wildlife Service) and the Commonwealth of Massachusetts (Executive Office of Environmental Affairs), is responsible for assessing damages associated with the release of hazardous materials; seeking the recovery of damages and restoration costs; and preparing and implementing a restoration plan which addresses resource injuries cause by the contaminant release. As a result of complaints filed by the Trustees in Federal District Court in 1983, a monetary settlement was agreed to by the electronic manufacturers, designated as the Responsible Party, to compensate for the US EPA harbor cleanup, the natural resource restoration efforts by the Trustees, and government expenditures. Settlement agreements also resulted in the formal designation of the NBHTC.

In preparing a restoration plan for New Bedford Harbor and nearby waters, the NBHTC will consider both near-term and long-term compensatory alternatives. To re-establish the uses and values of the New Bedford resources and minimize risk to human health and the living marine resources of these waters, removal and capping of contaminated sediments and other restoration activities will be required, some of which have been completed. The primary goal of restoration will be to return living resources and habitats to their baseline conditions prior to the contaminant release. Alternatively, resource replacement will be considered where restoration is not feasible, although substitute species populations or habitats which provide the same or similar functions and values as the affected resources will be established. Finally, the NBHTC will consider projects resulting in the "acquisition of the equivalent" resources that are comparable to the injured living resources and habitats. To determine how to best restore New Bedford Harbor resources, the

NBHTC has previously sought and will continue to seek public input throughout the restoration planning process.

1.3 PURPOSE OF THIS PROJECT

Prior to implementing the remediation plan for the New Bedford Harbor NPL site, the NBHTC must prepare a detailed plan and Environmental Impact Statement (EIS) that thoroughly discusses the site cleanup alternatives and measures to achieve each alternative, and describes how the existing and affected living marine resources and their habitats and functions and values will be restored. The purpose of this synopsis report is to serve as a base document and guide to the NBHTC in preparing the restoration plan and EIS. In completing this synthesis report, a thorough review of existing information was requisite. No new research was completed, nor was new data synthesized as part of this project. Much environmental data have been collected over time on New Bedford Harbor since the presence of contaminants was first noted in the mid-1970s. The database includes sampling and monitoring data for harbor sediments; contaminant concentrations and distribution in sediments and the water column; water quality and circulation; the presence and abundance of marine, estuarine, and riverine biota; and the levels of contaminants found in theliving marine resources inhabiting the harbor habitats.

Other information was collected on Acushnet River watershed resources, land use, and industrial development; and on Buzzards Bay resources and their uses and values. Some of the environmental data predates the PCB contamination of the harbor and adjacent waters, and provide information on habitat conditions prior to the release of these hazardous materials. Historical land use and population data help describe how harbor and watershed resources have been affected over time. In general, some of this information is available in published documents, while other unpublished data are maintained by federal, state and municipal agencies; universities and other academic institutions, and various organizations. Much information was obtained by a thorough review of documents from the US EPA's New Bedford Harbor Administrative Record and the New Bedford public libraries. Agency staff and academic researchers were contacted as additional informational sources. This information was then compiled and consolidated in preparing five report chapters addressing specific interrelated topics. The suceeding chapter topics within this report are described in the following section.

1.4 CONTENTS OF THIS REPORT

Chapter 2 presents a historical overview of the development of New Bedford Harbor and surrounding areas including the City of New Bedford and Towns of Fairhaven, Acushnet and Dartmouth. A brief description is also provided on the pre-historical conditions that were likely present in the area prior to European settlement. Specifically, this chapter chronicles population, land use, and industrial changes that have occurred over four distinct periods characterizing the New Bedford Harbor area. Discussion is also provided on the effects of the land uses throughout these periods on the New Bedford Harbor and Acushnet River watershed resources, using maps and data prepared by federal, state, and local agencies and other entities, as well as various qualitative and anecdotal information. This information serves a beneficial purpose in helping to define the

baseline ecological conditions of the harbor area, and describing man-induced habitat and living resource impacts, and the scale, spatial distribution, and severity of these coastal resource impacts over time. The results of this historical overview will be used to compare existing conditions with past ecological conditions and impacts to facilitate the decision making process for identifying restoration alternatives for New Bedford Harbor habitats and living marine resources.

Chapter 3 includes a characterization of the habitats within and the ecological processes affecting the Acushnet River watershed, including New Bedford Harbor, and Upper Buzzards Bay. Discussion of the processes influencing the ecology of the watershed include climate, freshwater inflows, tides, currents, and sedimentation rates. Descriptions of biological and physio-chemical conditions are provided. General areal descriptions and the degree of alteration of these habitats are also presented, and some reference is made to information presented in the previous chapter. An inventory of the fish, shellfish, and wildlife found in or using these waters is also provided, and seasonal abundance and distribution patterns are described. Special attention has been dedicated to fish and shellfish resources of commercial and recreational value.

Chapter 4 provides an overview of the major comtaminants present in New Bedford Harbor and Upper Buzzards Bay, identifying the distribution and concentrations of PCBs, heavy metals, and PAHs. Information is also provided on the vertical distribution of contaminants both in the sediments and the water column. The presence of these contaminants is then related to the distribution and health of fish, shellfish, and other estuarine resources previously described in Chapter 3. A general discussion of contaminant fate pathways, including chemical, physical, and biological pathways, is presented, and potential ecological and human health impacts associated with the contamination are discussed.

Chapter 5 presents an economic analysis discussing impacts resulting from harbor contamination as described in the previous chapters. A general overview of the natural resource damages assessment is described, followed by a discussion of the natural resource damages that have occurred as a result of restricted harbor uses, focusing particularly on those damages associated with commercial and recreational fisheries and other water-related forms of recreation. Present and potential future resource use constraints are discussed, while benefits resulting from alternative uses of harbor resources are suggested.

Chapter 6 provides a summary of the existing and ongoing monitoring programs occurring in New Bedford Harbor and Upper Buzzards Bay, many of which served as informational sources for this project. These include federal, state, and local agency programs addressing physical, chemical, and biological conditions; and contaminant concentrations and distribution in sediments, the water column, and living marine resources. When possible, information is provided on the parameters sampled; the general location and identification number of the monitoring or sampling stations; the frequency and duration of the monitoring; and the principal investigator of or contact for a program.

1.5 DATABASE MANAGEMENT

To facilitate the review and use of existing data and informational sources, relevant data have been compiled in a Geographical Information System (GIS) database, using the Massachusetts GIS

(MassGIS). Data from existing maps and reports have been entered into this database, following the Massachusetts Executive Office of Environmental Affiars procedures to produce mapping and matrix information on natural resource conditions and distribution; land and water resource uses; contaminant concentrations and distribution; and monitoring programs. The information generated in the MassGIS database conforms to national mapping accuracy standards for 1:25,000 scale digital mapping. Within pertinent sections of the report, reference is made to the availability of the data in the MassGIS database. An appendix to this document provides a list of each source file name and description.

2.0 HISTORICAL OVERVIEW OF NEW BEDFORD HARBOR AND COASTAL RESOURCE IMPACTS

2.1 INTRODUCTION

This chapter presents a general overview of the history of the New Bedford Harbor area; describes changes in population, land uses, and industries that have occurred in the area; and assesses coastal resource impacts that have resulted from land and resource uses. New Bedford, Fairhaven, Acushnet, and other area municipalities abound in history, dating far back to some of the earliest explorations of North America by Europeans. Fortunately, much of this historical account has been documented in books, manuscripts, maps, government reports and other sources that have been compiled in libraries and other research centers in the region. An ample supply of anecdotal information exists for the colonial, early industrial and pre-colonial periods, and detailed summaries of these chronicles are available and have been invaluable in preparing the early history of the New Bedford Harbor area. Published materials and maps, as well as historians helped in expanding the database for the earlier and more recent periods and were consulted when possible, to verify anecdotal information.

This information was then used to develop a chronology of the coastal resource impacts that have occurred such as the loss of habitats due to filling and dredging; habitat degradation attributed to pollutant discharges and the construction of wharves, bridges, dams and other structures; and the general effects of fishing, contaminant discharges, and other habitat alterations on living marine resource distribution and abunadance (Although long-term climatic changes, sea level rise, and catastrophic storm events also have a significant effect on coastal resources, an indepth discussion of these factors is beyond the scope of this document). By presenting this chronology, it is feasible to more accurately describe pre-disturbance, baseline ecological conditions of New Bedford Harbor; examine the coastal resource impacts in terms of spatial distribution, severity, and scale; and assess how harbor habitats and living marine resources have been affected by man over time.

Chapter 2 is divided into four primary sections, reflecting the major development periods of the New Bedford area including pre-colonial and early American history; the whaling era; the textiles era; and post-textiles era. Each section includes a historic synopsis and a section on population, land uses, industries, and land use impacts to coastal resources. The historical sections often describe land use changes and development that did not occur directly adjacent to the harbor, but are included because these activities occurred within the watershed discharging to New Bedford Harbor and adjacent coastal waters. The sections addressing the 19th and 20th centuries include a matrix table of and a graphic depicting the major industries (i.e., potential primary pollutant ssources) operating in the area during each period, as compiled from Beers Atlases, Sanborn Fire Insurance Maps of various periods, various maps, history books, and other sources. The list is not intended to be an exhaustive compilation of all industrial sites in the area, as such a list was beyond the scope of this project and would require an intensive review of changes in owners, operators,

manufacturing processes, and products for innumerable land parcels throughout the approximate 350-year period. Rather, this descriptive list presents a sample of industries, from readily available sources, to illustrate the types of uses and resource impacts occurring in the area during each period.

Lastly, a discussion is presented on the future directions of the New Bedford Harbor waterfront, examining the probable shifts in the fishing industry, manufacturing, and tourism. Much of this information has obtained from the City of New Bedford's Economic Development Plan and the published results of the HarborVisions! Environmental Design Charrette held in October 1995.

2.2 PRE-COLONIAL AND EARLY COLONIAL SETTLEMENT IN THE AREA

2.2.1 Historical Overview

Before Europeans arrived in what is now New England, it is estimated that approximately 60,000 to 75,000 Indians lived in hundreds of small villages throughout Southern New England. During the Woodland Period (between 3,000 and 1,500 years before present), the tribes of southeastern New England including the Wampanoags (or Pokanokets) were established with approximately 21,000 to 24,000 Wampanoags occupying southeastern Massachusetts and Eastern Rhode Island (Russel, 1980; Weinstein-Farson, 1988). Early historical records and archaeological investigations suggest that Native Americans used lands in the area for plant gathering, agriculture, and hunting and coastal waters for fishing and shellfishing. Champlain and other early explorers described the landscape as a patchwork of cleared hardwood and softwood forests and fields, or as partially deforested and planted with corn, squash, beans, and tobacco. The Wampanoags and other nearby tribes were generally seasonally transient, moving to the coast in the summer to fish, harvest seeds and roots, and raise crops, then returning inland into forestlands which afforded greater protection from the harsh winter climate.

The Wampanoags typically worked agricultural fields for eight to ten years and relocated their fields when they were no longer fertile. The Indians burned the understory of forests, to provide forage area for deer, a source of food, and to facilitate traveling and hunting in the woods. In spite of the transient nature of the Indians, the boundaries of tribal lands were well established, defined by such physical features as drainage basins, streams, and hills, although certain fishing places and oyster beds were considered common property resources (Russel, 1980; Weinstein-Farson, 1988; Cronon, 1983). Examples of Indian settlements in the New Bedford Harbor area were in vicinity of what is now Coggeshall Street in New Bedford and Sconticut Neck in Fairhaven (Boss and Thomas, 1983; McCabe, 1988).

In 1602, Bartholomew Gosnold and his crew landed in southeastern Massachusetts while visiting Buzzards Bay, the first recorded Europeans in the New Bedford area. There was little European activity in the area until 1652, when a group of 34 settlers purchased from Chief Wesamequen of the Wampanoags a large tract of land including the present towns of Dartmouth, New Bedford, Acushnet, Westport, Fairhaven, and parts of Rhode Island (This land tract was reportedly purchased for 30 yards of cloth, 8 moose skins, 22 pounds of wampum, an iron kettle, and several other miscellaneous items) (McMullin, 1976). Soonafter, the land was divided into plantations, creating a pattern of large-scale agricultural uses in the area (Boss and Thomas, 1983; Clayton and Whitley, 1979; Hutt, 1924). The land was first incorporated as the township of Dartmouth in 1664, with the

other municipalities being incorporated from Dartmouth, later. By 1690, most of the Village's population consisted of Quakers (McMullin, 1976). In the early 1700s, the New Bedford area had 11 families, all engaged in agriculture (Boss and Thomas, 1983). A mapped survey completed by Benjamin Crane in 1711 depicts approximately 30 land parcels comprising the New Bedford area (Worth, 1906) (Refer to the MassGIS database).

The early landings by explorers of the New England coast who sought to trade goods with the Native Americans inadvertently introduced European diseases to the continent, rapidly decimating many Indian populations. Pilgrim records note abandoned villages totaling thousands of casualties (Russel, 1980; Boss and Thomas, 1983). Early colonial settlement brought further problems for the Native Americans, as Europeans introduced property ownership, ultimately resulting in the expulsion of Native Americans from their farmlands and hunting and fishing grounds.

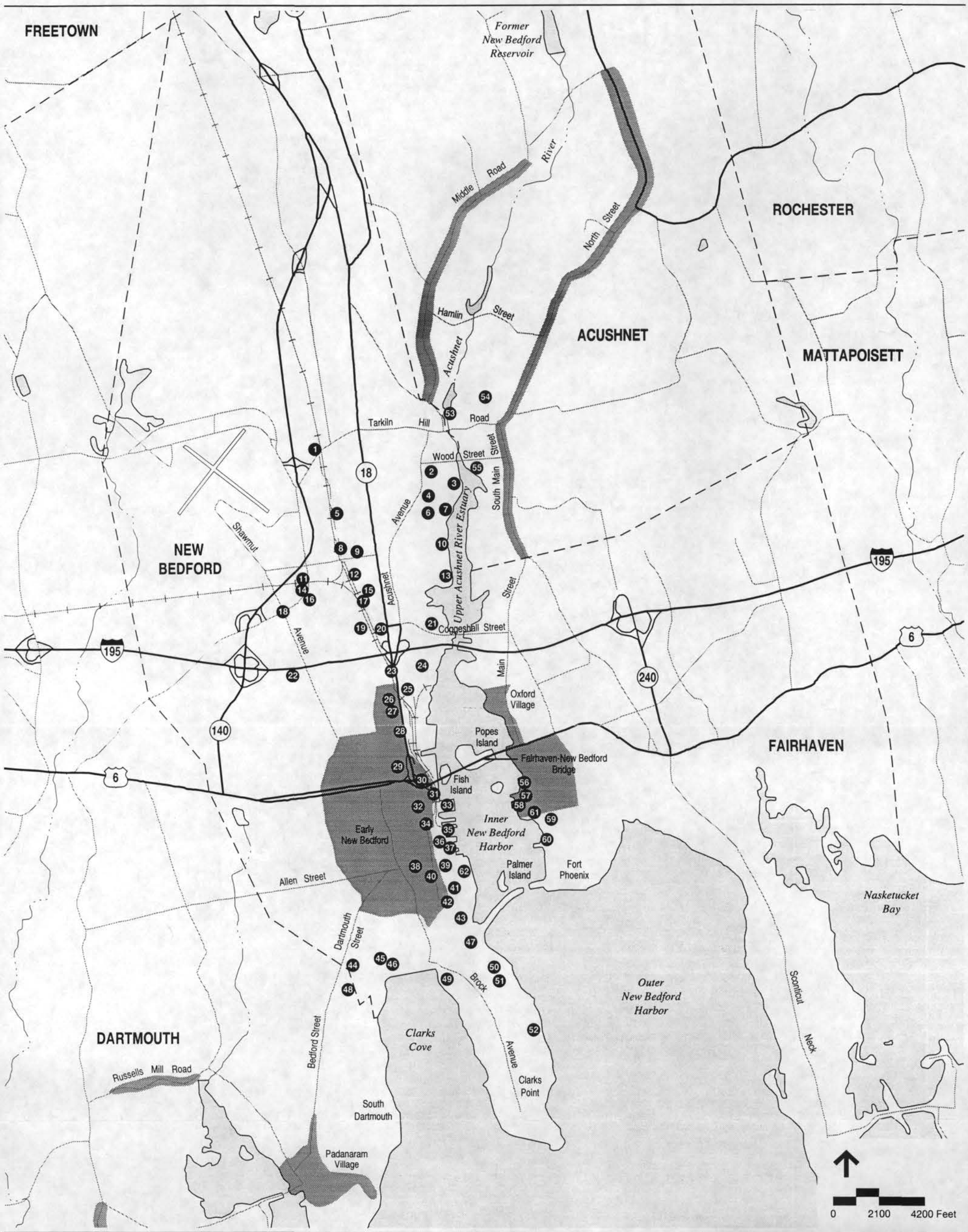
During the first 100 years of colonial settlement, Acushnet developed to a greater degree than any other area in old Dartmouth. The first settlement in the area was on the east side of the Acushnet River in what is now the Town of Acushnet, near the head of the Acushnet River, along what is currently Main Street. A grist mill was built on Sconticut Neck in Fairhaven by Thomas Pope in 1652 (MHC, 1981b). During the 1700s, several grist and saw mills located near the head of the Acushnet River, taking advantage of the river as a power source (See Figure 2-1, No. 53). In contrast, the first century of settlement and growth was slow elsewhere in Old Dartmouth, with scattered farms and dwellings along both the east and west shores of New Bedford Harbor (Boss and Thomas, 1983; McCabe, 1988).

2.2.2 Land Use Effects on Coastal Resources

Native American Land Uses

Aside from ecological changes due to catastrophic events (e.g., hurricanes, lightning-set fires) and climatic change over time, man has had an overriding influence on his environment from earliest human occupation. During the Woodland Period, the Wampanoags began to more intensively clear and cultivate lands along the Southern New England coast, settling into villages on a seasonal basis during the spring through fall, growing crops and harvesting fish and shellfish (Weinstein-Farson, 1989). The extent and magnitude of impacts to coastal resources, in vicinity of what is presently the New Bedford Harbor area, resulting during Pre-European settlement can be qualitatively described by considering archaeological study findings and historical documentation of the general land use practices by Native Americans.

Anecdotal historical accounts and archaeological studies present widely varying evidence of the extent of land clearing primarily for purposes of agriculture in this region. Giovanni de Verrazzano visited the southern New England coast in 1524, making brief excursions into the interior and describing his observations. During these excursions, he noted that continuous tracts of open lands created by the Wampanoags were extensive in this region (Wroth, 1970). Verrazzano further noted that many of the cleared areas were free of any trees, and the areas which remained forested were so open that "a large army could walk through without being impeded". In 1604, Sieur Samuel de Champlain noted during his explorations along the coast that "there is a great deal of land cleared up and planted with Indian corn".



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00 Approximate Location of Sites Referenced in Text and Table 2-1

Approximate Location of Settled Areas, circa 1875

Sources: Beers Atlas, Bristol County, Massachusetts; Sanborn Fire Insurance Maps New Bedford and Vicinity 1924, 1950, and 1960s; New Bedford Industrial Parcel Inventory-Plat Maps- 1960s-1970s; Inventory and Analysis of New Bedford's Economy (1993); McCabe (1988); and Boss and Thomas (1983).

Figure 2-1

Historic Land Uses
New Bedford Harbor Area

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Other early accounts tell of broad farm fields as large as several hundred acres that were cleared by Native Americans in southeastern Massachusetts, and may have been cultivated in common or consisted of many small, individual plots (Russel, 1980).

Conversely, material presented in Ellis (1892) on the original English deed for the purchase of Acushnet ("Acushena") from the Indians suggests more extensive forest cover in the Acushnet River watershed. In passage, it states:

> "to extend three miles to the eastward of the most easterly part of the bay or river called Coaksett...and to extend *eight miles into the woods*...with all marshes, rivers, waters, woods, timbers..." (emphasis ours).

The "Coaksett" River refers the Acushnet River, and the deed implies that broad forestlands were still present in the watershed, providing at least some harvestable resources. There is no reference as to the specific conditions of these forestlands nor how much had been cleared by the time of European settlement. Other evidence suggests that Native American deforestation practices were not extensive in the Acushnet River watershed. As recent as 1834, broad forestlands were still present throughout much of New Bedford, as depicted by a map of the township (Pendleton, 1834) which depicts prevalent forest cover. The map depicts most of the lands north of the area now aligned by Coggeshall Street as sustained by a forest cover, except for an approximate 2,000 to 3,000-foot wide swath along the western shore of the estuary and north to the vicinity of Tarkiln Hill Road.

It is highly probable that at least some lands in the Acushnet River watershed had been cleared for agriculture prior to European settlement. Native Americans employed slash-and-burn techniques (i.e., "swidden"), stoking fires around bases of living trees to kill and fell them with stone axes (Patterson and Sassaman, 1988; Salisbury, 1988). Once felled, the wood would be used for loghouses or burned for fuel, clearing the land for agriculture (in addition to making areas more favorable to grazing by deer) (Baker et al., 1994). Corn was the most important crop, while squash, beans and other vegetables were also grown. The earliest maize cultivation in southern New England has been dated at approximately 1,200 AD, with early agriculture centering near known fishing areas along rivers (Mulholland, 1988). As an example of the potential extent of land clearing needed for supporting Native Americans with crops, a Native American village population size of 400 (of the early Wabanaki groups in Maine) would have utilized between 330 and 580 acres of planting fields to assure subsistence maintenance for 50 years or more (Baker et al., 1994).

Soil disturbances and subsequent erosion and sedimentation impacts were likely at a relatively small scale in comparison to early European practices. Wampanoags used hand tools (a sharp or pointed stone or shell attached by rawhide thongs to a long wooden shaft or handle) to loosen soils for cultivation. Early colonists noted that Native Americans often selected the warmer, southfacing sides of hills, locating their planting fields on lighter (drier, sandy) soils where the trees were typically soft woods that could be easily burned, and less frequently oak and walnut. Corn crops were planted in small 1-foot high, 2 to 3-foot diameter mounds, typically spaced several feet apart. One 30-acre archaeological site in nearby Assonet, Massachusetts was estimated to contain at least 80,000 mounds.

Native American agricultural practices were transformed by early European settlement. Once the Indians observed the English plowing their fields with oxen and using iron tools, negotiations were

struck by the Native Americans who began to require their croplands to be plowed as partial payment for other lands purchased from them by the English (Russel, 1980).

In summary, the early prehistory of New England was characterized by low population density and relatively low land use. Farming practices by the Wampanoags prior to European settlement occurred on a relatively small scale using primitive tools in comparison to early colonial land use practices. Archaeological studies and historic records have identified several Indian occupational areas including Clarks Neck, the Coggeshall Street area, and a strip of land paralleling Acushnet Avenue in New Bedford (MHC, 1981a); an area east of the Acushnet River, both south and north of Main Street in Acushnet (possibly a settlement area during the fall and winter as suggested in MHC, 1981c); and in Fairhaven, at an area in the present day intersection of Route 6 and Mill Road, on Long Island, at the eastern part of West Island, and along the lower portion of Sconticut Neck (near the present day Seaview Avenue) (MHC, 1981b). Their land clearing and agricultural practices may have more likely created a scattered patchwork pattern of cleared lands within forested lands as suggested by Patterson and Sassaman (1988), and caused small-scale erosion and sedimentation to the Acushnet River and tributaries and estuarine waters. In a "worst case" situation, sedimentation impacts likely had only very localized impacts on nearshore shellfish beds caused by smothering. Deforestation may have also caused minor changes in watershed hydrology by increasing runoff from the land. Landing clearing and plant and animal harvesting practices undoubtedly had some effect on local endemic plant and animal species abundance and diversity in the region.

Native American Marine Resource Uses

Fishery resource use has been documented with discovery of several archaeological sites along the New England coastline which indicate Native Americans harvested Atlantic cod, sturgeon, striped bass, alewife, bluefish, pollack, tautog, monkfish and other species for food. In the spring, shad and alewife (migrating adults that used the upper Acushnet River as spawning habitat) were harvested (possibly using wooden-staked weir traps), and used both as a food source and for fertilizer (Russel, 1980). Contrary to common belief, at least one archaeological study suggests that Atlantic salmon were not a major component in the Indian fish catch, possibly because they were not extremely abundant and/or they were difficult to catch (Carlson, 1988). The Wampanoags also harvested oysters, scallops, soft-shelled crabs, quahogs, and surf clams as sought-after food sources, although lobsters were not eaten but used as fishing bait (Weinstein-Farson, 1989). In general, fish and shellfish were likely highly abundant, and normal harvesting practices by the small populations of Indians probably had negligible adverse effects on fishery resource populations.

Besides fishing and shellfishing, Native Americans also likely harvested birds (e.g., blackduck, brant) and mammals in the New Bedford area coastal waters for food and the production of clothing and other subsistence goods.

Early European Land Uses

Early European settlers often lacked axes for forest clearing and were typically unfamiliar with use of the tool. The colonists usually headed for lands cleared by Native Americans. The choicest farmlands were not easily relinquished by the Indians in the region, until increasing numbers of colonists fortified with firearms eventually overwhelmed the Native Americans (Russel, 1980). Increasing numbers of colonists farming the same parcels year after year with more effective

techniques and tools meant greater soil disturbances and an increasing potential for erosion and sedimentation during storm events.

Also, in contrast to the seasonal use of coastal areas by Southern New England Indians, early colonists used these areas throughout the year and on a more continuous basis. Early Europeans used high marsh habitats for cattle grazing or harvested salt meadow hay which made ideal fodder for cattle. Cattle often moved freely from marsh to marsh, and caused erosion of coastal marshes. Salt meadow hay was often cut in August and gathered in small piles ("straddles") to feed cattle later in the year. Smooth cordgrass was harvested for use as roof thatch. Continuous marsh cutting over time resulted in the loss of organic material to sustain peat accumulation. Destruction of natural mulch also caused increased soil surface exposure and a greater chance of marsh erosion, particularly in association with storm events. Still later, horse teams were brought onto the high marsh to draw plows in creating ditches to enhance drainage and provide firmer ground for mowing or crop growing (Teal and Teal, 1969). These high marsh uses further reduced marsh plant cover, increased erosion and sedimentation, altered hydrology, and introduced alternative plant species.

Deforestation for agriculture and as a source for building materials and fuel likely continued, although the lands now occupied by New Bedford were still largely forested in 1755 (Tower, 1907) and continued to be so at least through the 1830s (Congdon, 1834). Until the 1760s, colonial settlement in the New Bedford area was scattered between Tarkiln Hill Road to the north, the tip of Clarks Neck to the south, the estuarine shoreline to the east, and Acushnet Avenue and County Street to the west (MHC, 1981a). During the 1760s, rapid residential and commercial development occurred in New Bedford village centered along Water Street and the eastern third of Union Street. Increasing populations concentrated in this area resulted in sewage releases to small streams and ditches draining to the mid portion of New Bedford Harbor.

Along the eastern shore of the Acushnet River, increased residential and commercial development occurred in two locations: the Oxford Village area bounded by North, Adams, and Elm Streets; and Fairhaven Village bounded by Spring, Adams, and Church Streets (MHC, 1981b). Several marine-related businesses, tryworks, and taverns were established in these areas, and likely resulted in relatively minor quantities of sewage discharge and debris to the mid portion of New Bedford Harbor.

Construction of wharfs and shoreline structures began during the early to mid 18th century, affecting localized intertidal and subtidal habitats in New Bedford Harbor. In 1760, the Old South Wharf (now Kelley's Wharf) was constructed in Fairhaven (MHC, 1981b). By 1780, at least six wharves were present along the New Bedford Village shoreline, while at least three were constructed along the Fairhaven shoreline (DesBarres, 1780). Cumulatively, these wharves affected no more than 2 acres of intertidal and subtidal habitats.

The construction of several dams on the Acushnet River and tributary streams provided a source of power for grist, saw and other types of mills that served as effective blockages to anadromous fish migrating to upstream spawning grounds. In 1707, a mill was built near the crossing of the Acushnet River by Main Street in Acushnet (MHC, 1981c), and soonafter, a second mill was built slightly upstream of the first mill. In 1738, an iron forge was constructed by Steven West Jr. on Deep Brook, immediately north of its crossing by Middle Street (MHC, 1981c; McCabe, 1988). In 1746, a mill dam was also constructed across the Acushnet River off Hamlin Street. A fulling was also built on another Acushnet River tributary prior to 1750, directly north of its crossing by

Hathaway Street in Acushnet. Significant reductions in anadromous fish populations were noted soonafter dam construction, and in response, laws were passed in Southeastern Massachusetts, preventing grist and saw mills and other water-powered industries from interfering with the upstream migration by anadromous species (Fawcett, 1990).

Early European Marine Resource Uses

Cod was a resource highly sought by early explorers and colonists both as a subsistence fishery and for export to England. Virginians were the first fishermen to exploit the abundant stocks of codfish in New England's coastal waters, particularly off Cape Cod. It is uncertain whether nearshore areas like New Bedford Harbor were early European or colonial fishing sites. Between 1608 and 1614, the southern colonists appeared to have dominated the nearshore New England fishery. They depended on cod and other fishes primarily for subsistence, and not for profit or trade. Soonafter, more and more ships sailed from England to fish the bountiful New England waters. By 1624, at least 50 vessels were fishing New England waters with some returning catches to England (Baker et al., 1994). Once villages were established along the New Bedford and Fairhaven shorelines during the 18th century, harvesting of marine and estuarine fish and shellfish from New Bedford Harbor and anadromous fish from the Acushnet River likely became a common occurrence. Due to the relatively small population and relatively primitive fishing gear (hook and line), early European fishing likely had no significant effect on fish and shellfish populations in the area.

2.3 EIGHTEENTH AND NINETEENTH CENTURY WHALING/FISHING INDUSTRIES AND COMMERCIAL TRADE

2.3.1 Historical Overview

New Bedford and Fairhaven

By 1750, the village of Acushnet at the head of the Acushnet River was the largest settlement in Bristol County. Shipbuilding was established at the head of the river in 1780, before the industry developed at Oxford and Fairhaven Villages (McCabe, 1988). However, the start of the whaling industry during the mid eighteenth century brought about major changes to the settlement patterns of the area, which spurred rapid growth in New Bedford and Fairhaven.

New Englanders had engaged in nearshore whaling since about 1690, although whaling did not become a large-scale industry until after 1750. Joseph Russell III set up a tryworks for rendering whale blubber on the western shore of the Acushnet River. Small whaling vessels of approximately 40 to 60 tons sailed from the Acushnet River and stayed out a few weeks at a time, whaling relatively close to shore.

In 1760, Russell drew up a plan for Bedford village at the mouth of the Acushnet River, with Union Street as its base. At about the same time, a tryhouse was constructed and house lots were sold in Oxford Village in Fairhaven. Both New Bedford and Fairhaven villages grew with the whaling industry. Ship builders, carpenters, mechanics, and blacksmiths came to the area in support of the new industry. By 1765, all available land along Union Street had been sold. Joseph Rotch purchased 10 acres on the opposite side of the river, establishing Fairhaven Village, which

encompassed the current harbor in Fairhaven, Pleasant Street, William Street, and Walnut Street (See Figure 2-1). He established a ship-building business and provided considerable technical and financial support to the new industry (Boss and Thomas, 1983; McCabe, 1988).

Beginning in 1767, the New Bedford Harbor area experienced rapid growth. In 1767, Rotch launched the first locally built whaling vessel from Fairhaven Village, beginning a major ship building industry in Fairhaven. The ships manufactured in the New Bedford-Fairhaven area were substantially larger than early whaling vessels, allowing whalers to venture further offshore and remain at sea for long periods of time. Whaling-related industries developed in New Bedford and Fairhaven in support of the growing whaling industry, including shipyards, blacksmiths, rope works, cooperages, sail makers, and candle factories. By 1771, both sides of the Acushnet River comprised an active seaport, with 321 dwellings, 119 shops and warehouses, and over 30,000 feet of wharfage.[1] The Town of Bedford served as a home port for more than 50 whaling vessels and a number of merchant ships by 1774 (McMullin. 1976). Great Britain provided a substantial market for whale oil from the port.

The whaling industry suffered temporary setbacks during the Revolutionary War, the British embargoes of 1806, the War of 1812, and the Gale of 1815. However, the industry rebuilt and continued to grow in spite of the interruptions. The Fairhaven-New Bedford Bridge (what is now the Route 6 bridge) was constructed in 1792, and shipbuilding moved from Oxford Village in Fairhaven to central Fairhaven (See Figure 2-1). Banks and marine insurance companies were established in the early 1800s, in addition to whaling related industries. Local businessmen established saltworks on Ricketson's Point and elsewhere in Dartmouth to avoid dependence on Britain for salt during the British embargoes of 1806. In 1787, New Bedford was incorporated from Dartmouth and included the present City of New Bedford and Towns of Fairhaven and Acushnet.

During the early 1800s, the first textile mills were developed in the area, with Whelden Mill in Acushnet being the first cotton textile factory in Massachusetts, and White's Factory the first cotton mill on the Acushnet River. However, these mills closed down during the early to mid-19th century, and the cotton industry did not become well established until the late 1800s.

Following the War of 1812 and the Gale of 1815, the whaling industry grew rapidly. The first half of the nineteenth century was the "Golden Age" of whaling in New Bedford and Fairhaven. By 1823, New Bedford Harbor was the preeminent whaling port in New England, with 120 square rigged ships producing 41,144 barrels of sperm oil and 43,145 barrels of whale oil that year. At the time, the New Bedford area had ten spermaceti candle works (Boss and Thomas, 1983).

During the 1830s and 40s, new banks and insurance companies were established in New Bedford and Fairhaven. Town buildings included a custom house, court house, ten schools, four banks, and twenty manufacturers of oil and spermacetti candles (U.S. House of Representatives, 1846). A stage line was opened between New Bedford and Providence, and ferry service was established from New Bedford to Fairhaven. In 1840, a rail line was completed between Taunton and New Bedford, which allowed rail connection to Boston. In 1847 New Bedford was established as a city.

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[1] The pattern of development is described further in the Population, Land Use, and Industries Section.

In 1845, there were 249 ships and 2 brigs involved in the New Bedford whaling fleet (U.S. House of Representatives, 1846). During the 1850s, one-half of the American whaling fleet was based in New Bedford Harbor. More whaling vessels sailed out of New Bedford Harbor than from all other American ports combined. In 1850, New Bedford ranked third among U.S. ports for the tonnage of goods shipped (U.S. House of Representatives, 1851). Steamer service to New York City was established in 1853, providing direct shipping for whale oil to the New York City market. In the mid-1850s at the peak of the whaling industry, the combined New Bedford and Fairhaven fleets totalled 426 vessels, employing more than 10,000 seamen (Boss and Thomas, 1983).

Fairhaven was incorporated in 1812 and included the present Town of Acushnet. Although New Bedford was the home port for a greater number of whaling vessels, Fairhaven also was home port to a whaling fleet that ranged between 8 and 50 vessels. In 1840, there were 45 whaling ships, and in its peak year, 1857, 57 vessels sailed from the Fairhaven homeport. In addition to its small whaling fleet and related industries, Fairhaven became an important center of shipbuilding and repair, which complemented the New Bedford Harbor whaling industry. About 1840, a ship channel was dredged off Fairhaven Village. In 1858, the first of several wharves to include a marine railway was constructed along the Fairhaven waterfront, providing a means to haul out vessels for repairs. Wharves, marine railways, and shipyards became prominent features of the Fairhaven waterfront (Shipbuilding has remained important in Fairhaven since that time.) (McCabe, 1988; Town of Fairhaven, 1965; Harris, 1947).

During the mid 1800s, several events occurred that eventually led to the decline of the whaling industry. With such intensive whaling, whale stocks were being severely depleted, and whales were only being found further and further from the New England coast. In 1859, petroleum was discovered in Pennsylvania, and by 1860, two companies in New Bedford were refining and distilling petroleum (Boss and Thomas, 1983).[2] During the 1860s, many New Bedford waterfront businesses were devastated by a tremendous waterfront fire. The Civil War also resulted in a setback to the whaling industry with the enlistment of hundreds of seamen and the destruction of whaling vessels that were refitted for the war. In 1849, the Wamsutta textile mill was incorporated. It was the only continuously operating textile mill in New Bedford until 1871, but was very successful during the mid 1800s (Boss and Thomas, 1983, Clayton and Whitley, 1979).

The whaling industry declined steadily after the Civil War. Over 50 whalers had been destroyed during the Civil War. Insurance costs were rising as whalers ventured into the Arctic for whales. The New Bedford whaling industry faced competition both from west coast whalers and the development of petroleum products. In addition, other industries developed in New Bedford following the Civil War, competing for labor with the whaling industry, and offering a more stable income and safer working conditions. Ironically, while the growing industries increased demand for whale oil, the high demand and reduction in labor supply drove up whale oil prices, fueling the demand for cheaper substitutes and contributing to the decline of the industry. In 1871, 29 New Bedford whaling ships were abandoned in Arctic ice. The reduction of the fleet dealt a great blow to the whaling industry. In 1874, many remaining whalers moved to San Francisco, resulting in a major loss to the support industries along the New Bedford waterfront. By 1879, whaling was using steam powered whalers, but the industry continued to decline due to a scarcity of whales and

[2] Several petroleum companies are identified in Figure 2-1, and noted in the Population, Land Use, and Industries Section.

competition with petroleum and textile industries. By 1897, the whaling fleet was reduced to 32 vessels (Boss and Thomas, 1983), with the end of the industry occurring in 1905.

Acushnet

Acushnet village was originally the principal maritime port on the river. The first vessels were built in Acushnet village, before the shipbuilder moved to Belleville in the late 1700s. Manufacturing developed early in Acushnet,particularly in vicinity of the Main Street crossing of the Acushnet River which became the center of the early mill industry in Old Dartmouth because of the availability of water power (MHC, 1981c). Sawmills and an iron forge (on Deep Brook) were developed in Acushnet along the northern portion of the Acushnet River and its tributary streams during the 1700s (MHC, 1981c; McCabe, 1988). Around 1750, a fulling was constructed on a tributary to the Achushnet River, near Hathaway Road (MHC, 1981c). Some shipbuilding was occurring in the mid 1700s, directly south of the Main Street bridge. Cotton mills and factories were constructed on the river in the early 1800s. Wheldon, Swift and Company opened in 1814 and manufactured coarse cotton cloth that sold in Philadelphia and locally. In 1815, White's Factory, a two-story cotton mill, was built on Deep Brook (MHC, 1981c).

Acushnet supported a boat building industry during the 1850s, and many whaling masters of the period came from Acushnet. Acushnet had similar maritime support industries as New Bedford and Fairhaven, including storehouses, cooper shops, a candle factory, and other ship-building and whaling- related businesses. However, development in Acushnet remained relatively small-scaled as compared to New Bedford. When Acushnet was incorporated as a town in 1860, it was chiefly an agricultural community, with a good market in New Bedford (Boss and Thomas, 1983; Hutt, 1924).

Dartmouth

During this period, development in Dartmouth was concentrated in Padanaram Village and a small settlement along the most northwestern portion of Clarks Cove. Secondary settlements were found at Russel's Mills and Slocum Corner (Shipyard and town landing), Smith's Mills (North Dartmouth), Apponagansett, and scattered farmsteads along existing colonial roads (MHC, 1981d). Between 1810 and 1820, seven saltworks were developed along the inlet of the Apponagansett River in the vicinity of Padanaram Village. Most of Dartmouth's residents during this period were engaged in the New Bedford Harbor whale fishery or other fishing opportunities. Small vessels of all types were built and repaired in Dartmouth (Boss and Thomas, 1983; and McCabe, 1988.).

2.3.2 Population, Land Use, and Industries

Population

The population changes in the area reflected the growth of the whaling industry and related industry and commerce. Between 1775 and 1795, New Bedford's population doubled from 500 to 1,000 residents. By 1800, the population of the New Bedford Harbor area was 4,361. Between 1800 and 1840, the area's population had increased to 12,087, 16,000 in 1845, and by 1854, the area's population was 20,000 (Boss and Thomas, 1983; McCabe, 1988). In 1840, the population of Fairhaven was 3,951 (U.S. House of Representatives, 1846).

Land Use

Prior to the 1760s, colonial settlement was scattered in an area between Tarkiln Road in the north and the tip of Clark Neck in the south; and the west shore of the Acushnet River west to Acushnet Avenue and County Street (MHC, 1981a). During the whaling period, the area developed as harborside whaling industries and associated businesses grew rapidly. The center of activity shifted from Oxford Village (on the eastern shore), north of the present Route 6 Bridge, to downtown New Bedford and Fairhaven. Whaling-related industries and commerce were established along the waterfront, and business and residential districts developed somewhat inland, creating what is now the historic core of both communities. By 1778, development in Bedford Village was concentrated along eastern Union Street between County Street and the waterfront, and wharves and whaling-related businesses were concentrated along Water and Front Streets within one-quarter mile of Union Street. Some of the businesses were destroyed by the British during the Revolutionary War. By 1815, development in New Bedford had expanded to an area between Madison Street, Eighth Street, Maxfield Street, and the harbor. The first textile mill in New Bedford, Wamsutta mill, was built directly north of the whaling waterfront center (Figure 2-1, No. 25) (Boss and Thomas, 1983; City of New Bedford, 1979).

During the late 1700s, development in Fairhaven was concentrated in Oxford Village (Boss and Thomas, 1983). Two primary residential and commercial nodes emerged along the Fairhaven waterfront (MHC, 1981b). The first was located in an area bounded by North, Adams, and Elm Streets (i.e., Oxford Village), while the other growth area was centered in an area bounded by Spring, Adams, and Church Streets (i.e., Fairhaven Village). Following construction of the Fairhaven-New Bedford Bridge, the center of activity shifted south, and by 1815, the Fairhaven whaling village extended roughly between South Street and the bridge (See Figure 2-1) (Boss and Thomas, 1983; McCabe, 1988).

Dartmouth and Acushnet remained sparsely settled, except for the village of Acushnet on the river, Padanaram Village in southern Dartmouth, and settlement along major roads such as Bakerville and Russels Mills Road in Dartmouth, and North Street, Main Street, and Middle Street in Acushnet (Boss and Thomas, 1983; McCabe, 1988; Hutt, 1924; and the Town of Dartmouth, 1964).

Industries

Industries around the New Bedford Harbor during this period generally were related to whaling, including tryworks, spermacetti candle works, coopers, caulkers, riggers, rope works, sail lofts, turning mills, ship building and repair (chiefly in Fairhaven), and related commerce. The earliest shipyard in the village was established in 1760, while shipbuilding began in Oxford Village in 1781 and in Fairhaven Village in 1804 (MHC, 1981b). Although the New Bedford-Taunton Railroad was completed in 1840, most New Bedford industries remained strongly tied to the whaling industry. A grist mill was constructed by Joseph Russell at the junction of County and Union Streets in New Bedford prior to 1775 (MHC, 1981a). Several other industries located in the area by the mid-1800s including several saltworks, especially in Dartmouth; sawmills in Acushnet; and three cotton mills - two in Acushnet (e.g., William White's cotton mill built off Hamlin Street in 1799) and one in New Bedford. Industries in Fairhaven in 1855 included one brass foundry, one paper mill, manufacturers of chairs, cabinets, tin ware, boots/shoes, and tobacco (Boss and Thomas, 1983; McCabe, 1988). In 1854, the Fairhaven Branch Railroad was completed, providing a rail connection to the port towns of Marion and Mattapoisett and the Cape Cod Branch Railroad at Tremont (MHC, 1981b).

2.3.3 Land Use Effects on Coastal Resources

Agricultural Impacts

Early colonial agricultural practices which began in this region in the late 1600s continued into the early to mid 1700s. Extensive clearing and working of the lands likely resulted in significant erosion of soils and sedimentation of the Acushnet River and its tributaries, similar to other New England watersheds dominated by agriculture. Soils transported in runoff were eventually deposited in the upper Acushnet River estuary. Sedimentation of the estuary may have been significant due to poor land management practices, similar to conditions noted in other New England ports, as described by Cronon (1983). Teal and Teal (1969) also note the problems of harbor infilling experienced at various East Coast ports during this period, and use an example of the significant loss of water depths proximate to the Hanover Street Bridge crossing of Baltimore Harbor from a 17-foot depth in 1845, shallowing to 3.5 feet in 1897 and 0.5 feet by 1924.

Harbor Dredging

According to a U.S. Army Chief of Engineers report, New Bedford Harbor was first dredged in 1839, although no information was provided on the specific limits or area of dredging (House Document, 43rd Congress, 2nd Session, 1874). The dredging was limited to a 30-foot width, and excavation depth was no greater than 2 feet in creating a 12.5-foot channel depth and affected an area no greater than 5 to 10 acres. Federal funds were also approriated for a survey and dredging of the New Bedford shipping channel in 1852, although no dredging was completed during that year. A dredge channel to Fairhaven Village was completed in 1840.

Bridges, Wharves, Dams and Other Structures and Fills

It is difficult to assess the areal extent and rate of wetland loss that occurred in New Bedford Harbor as a result of land use during this period, although some historical information is available to identify wetlands that were present over time. The map of Buzzards Bay prepared by DesBarres (1780) is the earliest graphic depicting tidal marshes in New Bedford Harbor. This map depicts at least 18 broad wetland areas along both the western and eastern shores of New Bedford Harbor and northern Clarks Cove. Extensive salt marshes were more prevalent along the eastern shore, north of Crow Island (145± acres (59 hectares)), although a broad wetland area (35± acres (14 hectares)) was also located on the western shore, directly south of the present-day I-195 bridge crossing. Other large salt marshes and sandflats were located in New Bedford, directly west and southwest of Palmer Island (57± acres (23 hectares)), in vicinity of present-day East French Boulevard. At least one-half of the area of Popes and Fish Islands appeared to be wetlands, comprising approximately 4.8 acres of salt marsh. In total, it is estimated that at least 250 acres (101 hectares) were present in New Bedford Harbor and the Acushnet River estuary prior to extensive shoreline development in the area (Refer to Chapter 3 for current conditions). Wetland losses occurring during this period include impacts located:

- In New Bedford, east of the Purchase Street - Pearl Street intersection; Water Street - Howland Street intersection; and Water Street - South Street intersection;

- In Fairhaven, west of the Main Street - Elm Street and Washington Street - Middle Street intersections; and

- On Pope and Fish Islands.

A stone bridge was constructed at the head-of-the-river in Acushnet (i.e., the Tarkiln Hill Road Bridge) in 1828/1829, replacing a simple wooden structure that was originally constructed in 1664. This bridge had a span width of 32 feet and consisted of two arches of 14 feet, resulting in a minor loss of estuarine habitat due to construction of the bridge abutments and arch footing. Construction of this bridge did not adversely affect the migration of anadromous fish to and from upstream riverine habitat, as an early painting ("Head of the River") by Clement Swift (in McCabe, 1988) clearly depicts fishermen directly downstream of the bridge operating umbrella traps that were used to harvest alewife.

During this period, the New Bedford Harbor shoreline experienced rapid development, as well as Oxford Village (on the east shore of New Bedford Harbor) in vicinity of the whaling industry core. As early as 1760, the Old South Wharf was erected in Fairhaven at the site of the present Kelley Wharf (MHC, 1981b). By 1771, New Bedford had more than 30,000 feet of wharfage. An 1815 map by Russell (1815) of the New Bedford shoreline depicts at least 22 wharves and piers, while at least 32 wharves representing an estimated 9 acres (3.6 hectares) of fill or covering of intertidal and subtidal habitats is depicted by an 1834 map (Congdon, 1834) of the west shore of New Bedford Harbor. The construction of the first Fairhaven-New Bedford Bridge (about 4,300 feet (1,310 m) in length) in 1792, linking New Bedford and Fairhaven with Fish and Pope Islands resulted in the loss and alteration of approximately 3.7 acres (1.5 hectares) of subtidal habitat, caused changes in estuarine circulation and eliminated the use of Oxford Village's harbor (MHC, 1981b).

A 5-acre (2-hectare) tidal embayment ("Mill Pond") was originally located at the mouth of the Herring River, directly southeast of the intersection of present-day Route 6 and Main Street in Fairhaven. During the 1700s, Mill Pond served as a sheltered anchorage for ships, but in the late 1700s, Main Street was constructed over the creek, ending the use of the pond as a mooring area (McCabe, 1988). Due to the bridge construction, tidal circulation significantly decreased in Mill Pond, causing heavy siltation. In 1792, Abner Vincent installed tide gates under the bridge to power a mill, and in 1871, a dam was constructed across the pond's mouth, converting it to a non-tidal waterbody. In 1906, chronic sedimentation and shallowing of the pond led to the eventual filling of open water and emergent ("sedge grass") wetland habitat totaling 13 acres (5.3 hectares) to create uplands (This site is where Cushman Park is now located) (McCabe, 1988).

In nearby Dartmouth, saltworks were constructed along the shore of the Apponagansett River near Padanaran Village; these facilities likely resulted in the alteration of intertidal and/or coastal pond habitats. Although not documented, non-tidal wetlands in the Acushnet river watershed were likely cleared, ditched, and drained by farmers to create additional agricultural land.

In Acushnet, three saw and grist mills were constructed on the Acushnet River to take advantage of waterpower, and a total of at least 16 dams for generating power for various industries (besides saw mills and grist mills, tanneries and paper, cotton, and iron manufacturing) were constructed in

the Acushnet River watershed during this period (McCabe, 1988). Prior to 1834, a small dam was constructed on a stream in New Bedford, east of the intersection of Front Street and Linden Street, to power a grist mill (Congdon, 1834; Taber, 1851). In Fairhaven, a dam and saw mill was constructed on Lettice Jenney's farm on Naskatucket Brook in 1757, and a tide mill was constructed by Steven Nye on the Herring River in 1792 (McCabe, 1988). The construction of these dams not only altered river flows, but served as barriers to migrating anadromous fish and other species. It became apparent early during this period that the dams were adversely affecting the migration of alewives and other anadromous fish species, as a Herring Committee was established in 1790 to assure that passageways were provided around these obstructions (Belding, 1912). The Herring Committee was also responsible for setting gear and time restrictions in the Acushnet River.

Pollutant Discharges

With a rapid increase in the number of industries and population, significant wastes were generated and likely disposed of in New Bedford Harbor, the Acushnet River, and tributary streams. Discharges included sewage, household wastes, and industrial waste products. Tryworks, candle manufacturers, two brass foundries, sawmills, three cotton mills (e.g., Wamsutta Mills), and a paper mill established during this period undoubtedly released significant amounts of debris, oils, metals, organic wastes generating significant biological oxygen demand (BOD), dyes, nutrients, and other pollutants into the harbor. Discharges were most significant in proximity to the central business districts of New Bedford and Fairhaven, and from industries scattered along the upper Acushnet River. With the incorporation of New Bedford as a city in 1847, the installation of an underground sewer system began in 1850. This sewer system likely resulted in the piping and filling of smaller streams in the area or altered runoff discharging to these streams. Sewer installation also created larger volume point-source pollutant discharges to the harbor.

The presence of ships and the shipbuilding industry represented a source of contaminants to the harbor during this period. As a means of waterproofing, ship hulls were coated with pitch and metal sheathing. A sheet metal known as "muntz" or "yellow metal" that was comprised of 40 percent zinc and 60 percent copper was patented in 1832, and was commonly used on ships built and repaired in Fairhaven and New Bedford (Hall, 1982). A mixture of lead oxide and tallow was also used as an antifouling compound on ships during this period, and lead pastes were used for puttying ("paying") caulked seams of ships (Q. Snediker, pers. comm.). Copper and creosote were also likely used extensively at the shipyards along the harbor. Elevated heavy metal concentrations were probable during this period in vicinity of shipbuilding, repair and mooring locations, particularly in the Fairhaven and Oxford shipbuillding areas and along the New Bedford wharves.

2.3.4 Marine Resource Uses

From the mid 18th century through the early 19th century, residents of New Bedford, Oxford, Fairhaven, and other nearby communities undoubtedly continued to harvest fish and shellfish from New Bedford Harbor and Upper Buzzards Bay. Alewife, scup, tautog, bluefish, striped bass and other finfish were commonly caught within the harbor; quahogs, oysters, mussels, and other shellfish were harvested from nearshore beds. As the New Bedford and Fairhaven populations increased, greater fishing effort and improved gear likely had greater impact on fish and shellfish populations in the harbor. Additionally, significant increases in population and industrial

development during this period contributed to increasing pollutant loads to the harbor, adversely affecting the fisheries. With the decreasing resource abundance in the harbor, combined with improvements in ship and fishing gear design, fishing areas began to center in other portions of Buzzards Bay and offshore waters.

2.4 ERA OF INDUSTRIAL DEVELOPMENT - LATE NINETEENTH AND EARLY TWENTIETH CENTURIES

The New Bedford Harbor area underwent extensive development during the Industrial Revolution, transforming the small shipping port of New Bedford into a major manufacturing area. As a result of the industrial and residential development, severe degradation of harbor resources occurred. To facilitate the discussion of development along the harbor and related impacts, significant manufacturing sites and residential areas are shown in Figure 2-1, and accompanied by Table 2-1 which describes some of the industrial sites during this period and up to present conditions.

2.4.1 Historical Overview

New Bedford

Following the Civil War, the decline of the whaling industry and the development of the Industrial Revolution changed the landscape and economic base of the New Bedford area. Beginning in the 1870s, industrial development and associated residential and commercial growth transformed New Bedford from a relatively centralized whaling port to a major industrial center.

In 1871, Potomska Mills was established on South Water Street, expanding to a second building and 1,100 operatives by 1877 (See Figure 2-1, No. 42). In 1875, Wamsutta Mills built its fifth mill. The development of these and other mills resulted in substantial land use changes in New Bedford, as discussed in the Population, Land Use, and Industries section. Mills were established along the waterfront north of the commercial and whaling-oriented waterfront, and mill owners generally built workers' housing near the mills to help establish a stable labor force. Businesses and community buildings, such as schools and churches, developed near the new neighborhoods in support of the growing population (Boss and Thomas, 1983).

Additionally, Nantucket and Martha's Vineyard were becoming popular as summer resorts during this time, and steamer service was established from New Bedford with street trolleys being developed to connect the rail station with the steamers. In the 1860s and 1870s, Steamship Wharf was constructed, and the New Bedford railroad extended tracks to the wharf. This service was important to industry, as well as to the tourism trade, establishing a direct rail-shipping link. The steamers that had carried whale oil to New York City now carried fine textiles to the important New York City fashion/textiles market (Boss and Thomas, 1983).

TABLE 2-1
Selected Industrial Sites - New Bedford Harbor Area
Mid 1800s to Present*

Site No.**	Mid 1800s to Early 1900s	1920s	1950s	Early 1960s	1960s to 1970s	1980s to 1990s
1			John I. Paulding Mfg - Electrical Wiring Devices		Lambeth Rope, L&S Concrete Co., Roth Enterprises	Lambeth Rope
2					Aerovox Electronics Corp.	
3		Thomas Hersom & Co. Soapworks				Aerovox Electronics/Acushnet Processing Rubber Products
4			Acushnet Process Co. Rubber Processing; Aerovox Corp. Electronic Condensers			
5					Chamberlain mfg (shell casings for armored shells), formerly Firestone Cotton Mills	
6		Nashawena Mills Cotton & Silk	Nashawena Mills Cotton & Silk		Acushnet Co. Fibre Leather Co.; Bernco Co.; Realty Co.; New Bedford Gas and Edison Light	
7		Nonquitt Mills	Nashawena/Nonquitt Mills, various mfg		U.S. Storehouse	GSA Warehouse/Chamberlains
8			formerly Firestone Cotton Mills - not in operation			
9		Neild Mfg Cotton Mill	Soule Mill - cotton mill		Vacant	Knapp Shoes
10					Clifftex Clothing, Acushnet Co.	
11					Stanley Oil Company	
12		Whitman Mills				
13					Star Plating Co.; American Press, Inc.; development corp. - was Stokely Bros. Whitman Mills	
14					Continental Screw, Universal Roofing and Sheet Metal Co., Nauset Storage (warehouses)	
15			Cotton mill		Furniture Mart, clothing, Taber Mill, Hoosac Mills, Payne Cutlery Corp., Bread Products., New Bedford Gas and Electric (formerly National Silk Spinning Co.)	Clifftex Clothing
16			Continental Screw Co.			Buildling 19,Continental Screw

TABLE 2-1
Selected Industrial Sites - New Bedford Harbor Area
Mid 1800s to Present*

Site No.**	Mid 1800s to Early 1900s	1920s	1950s	Early 1960s	1960s to 1970s	1980s to 1990s
17	1870s - Morse Twist Dril	Taber Mill, Nat'l Spun Silk, Oneko Mill, Morse Cutting Tools	Grinnell and warehouse; Roy Paper; Alden Corrugated Container, Morse Cutting Tools		Laurans Bros., Gilt Edge Textile Mills, Alden Corrugated Container Corp., Roy Paper Corp., Morse Cutting Tools	Morse cutting tools out of business
18					American Flexible Conduit Co., Penn Central, Shawmut Liquid Petroleum Co. (formerly Home Gas Co.)	
19					Vacant,was Pierce Mills	Gentlemen's Wearhouse/U.S. Furniture/Dawson Brewery/Arlans
20					New Bedford Storage Warehouse	
21		Soule Mill	Sawyer Mills cotton weaving		Ernest Fournier Mill Buildings	Fairhaven Mills/Calvin Klein
22						
23				Union Street Eailroad Co.		
24	1875 - New Bedford Copper Works	Revere Copper and Brass;Palmer Scott boat building; plate mill.	Revere Copper and Brass;junk yard;former site of Bristol Mfg.	New Bedford Fish, realty		
25	Wamsutta Mills			Mill buildings-luggae mfg.		
26					Realty corp - was Wamsutta Mills	
27				Feed warehouse		
28				Waste mill; wool storehouses; small motor rebuilding; automobile washing; Dept. of Employment Security		
29				New Bedford Institute of Technology - carding, weaving, knitting, bleaching, dyeing		
30				Tidewater Oil Co.; small industries incl. iron foundry; water works repair shop; fish/poultry processing; fuel oil	Maritime terminals	

TABLE 2-1
Selected Industrial Sites - New Bedford Harbor Area
Mid 1800s to Present*

Site No.**	Mid 1800s to Early 1900s	1920s	1950s	Early 1960s	1960s to 1970s	1980s to 1990s
31		New Bedford Storage Warehouse (cotton); coal bins; coal sheds; Rhodes Co. Mfg (metal eyelets for shoes)		Small industries, incl. fishermen's supplies; belting facility; filleting, packing; marine supplies; tin shop; welding/machine shop; mfg metal eyelets	Socony Mobile Oil, various	
32		Fairhaven Iron Foundry				
33		New England Steamship Co. freight house, with filled chemical extinguishers		City Pier fish warehouses		
34	Philadelphia Coal and Iron; 1875 - Planing mill; 1895 - coal yards			Small industries incl: New Bedford Steel & Supply Warehouse; machine shop; plumbing/ship supplies; wholesale produce; ice plant; New Bedford Edison and Light - generator	Storage, etc. (formerly Babbitt Steam Specialty)	
35				Fish Companies; steamboat pier; cold storage	New Bedford Gas Dock, New Bedford Seafood Corp.	
36			Pocahontas Fuel Co. Coal; Tidewater Oil	New Bedford Gas and Edison Light		
37						Commonwealth Gas and Electric
38					Rolafre Mfr; formerly Van Norman; Morse Twist & Dye	
39				Container Corp. of America; Pairpoint Glass		
40				Bedford Realty - Quissett Mills Plant		
41				Metal Stamping		
42	1871 - Potomska Mills				Ottaway Newspapers/vacant - formerly Potomska Mills	
43			Former site of Acushnet Mills			Vacant land
44					Kaplan Realty - formerly Sharp Mfg	

TABLE 2-1
Selected Industrial Sites - New Bedford Harbor Area
Mid 1800s to Present*

Site No.**	Mid 1800s to Early 1900s	1920s	1950s	Early 1960s	1960s to 1970s	1980s to 1990s
45			Goodyear Fabric Corp.		Goodyear Tire and Rubber; New Bedford Gas and Edison Light; Bristol Industires; Bettencourt Furniture; Rochester Clothes	Vacant
46						Page Mill Complex
47	Naushon Mills				Berkshire Hathaway; realty; Intertational Dryer Corp - formerly Naushon Mills	Partially vacant - was Carol Cable
48			Sharp Mfg - cotton yarn Transformers on site.			
49					Realty/vacant - formerly Kilburn Mills	Furniture City Complex
50					Dikeview Industries, realty; was Marine Colloids and Seaplant Chemical Corp.	Cornell Dubilier Electronics/Dyrelite
51			Cornell Dubilier Electronics	Cornell Dubilier Electronics	Cornell Dubilier Electronics	Cornell Dubilier Electronics
52			Kilburn Mill - cotton yarn	Vacant		Rodney Metals/Brittany Print
53					New Bedford Storage Warehouse Company	
54					New Bedford Textile Co., Manhattan Bottling	
55					Continental Screw, Universal Roofing and Sheet Metal Co., Nauset Storage (Warehouses)	
56					Chamber Pain Mfg. (shell casings for weapon); formally Firestone Cotton Mills	
57			Small mfrs - junk reclamation, loom cranks, marine machinists			Norlantic Diesel
58	1868 - Atlas Tack on Fort Street		Beaconside boat building			
59		Atlas Tack, Gold Bond Powder			Atlas Tack and Gold Bond Powder out of business or relocated out of state in 1980s	

Site No.**	Mid 1800s to Early 1900s	1920s	1950s	Early 1960s	1960s to 1970s	1980s to 1990s
60	1850s - Oil factory; 1860s, carriage manufacturer					
61	1860s - Fairhaven Iron Works					
62					New Bedford Industrial Park: Plastic Co.; Cambridge Industries Storage; Servomation of SE New England, Alberox Corp. (bottling companies); PCI Group - eyelets; Borg-Warner - auto gear; Shaefer Marine Equipment; Epec Circuits; DeWalt Printing; Edson Corp.	

* This table is focuses primarily on approximate locations of example post-textile industries (1920s to present). Many of the industrial sites began as textile mills, which are noted under use designations for each period. A continuous history is not necessarily presented for each site and during each period. Site may have previously been undeveloped or farmland property.

** Refer to Figure 2-1 for site locations.

Sources:

1875 Beers Atlas, Bristol County

1895 Beers Atlas, Bristol County

1924 Sanborn Fire Insurance Maps - Vicinity of New Bedford

1950 Sanborn Fire Insurance Maps - Vicinity of New Bedford

1970s Industrial site inventory plat maps, New Bedford

1992 New Bedford Economic Development Plan - Industrial Site Inventory

Boss and Thomas (1983)

McCabe (1985)

During the closing decades of the 19th century, New Bedford was transformed into a booming industrial metropolis, with numerous massive brick mill buildings and mill housing. New Bedford enjoyed important advantages to the textile industry, with good transportation available by rail and sea, a favorable climate, and a steady market for fine textiles in New York City. Between 1880 and 1900, 14 cotton textile corporations were formed, and the city underwent considerable modernization with the establishment of telephones, electric company, and electric streetcars (Boss and Thomas, 1983).

The early 1900s were the height of the textile industry. From 1900 to 1925, New Bedford was one of the fastest growing cities in the United States, and third in the textile industry behind Fall River and Lowell, Massachusetts. From 1900 to 1910, 17 new textile corporations were founded, accompanied by considerable construction of new mills, housing, schools, churches, and businesses (Boss and Thomas, 1983). During the peak of the New Bedford textile industry, more than 35,000 laborers were engaged in the industry (Wolfbein, 1968).

In addition to manufacturing, New Bedford served as one of the major centers for receiving and distributing coal on the eastern seaboard, taking advantage of its superior shipping and rail facilities. With industrialization throughout the northeast, the demand for coal increased. In 1867, the City had six coal dealers; by 1890, there were 23 coal dealers in New Bedford. The same ships that would bring raw cotton and coal to the area would carry finished textiles back to New York (Boss and Thomas, 1983).

During the early 1900s, commercial fishing expanded with the advent of more efficent trawling gear began, harvesting groundfish from the Georges Bank, Nantucket Shoals, and other off-shore fishing grounds. The fishing industry grew slower than other industries due to the lack of a fish processing facilities capable of handling large catches. Although the fishing vessels did considerable business by selling fish in New York City or from small local markets, the City did not yet have the facilities to become a major fishing port (Boss and Thomas, 1983).

Competition with textile manufacturers in the Southeastern United States was apparent in the early 1900s and eventually led to the decline of the New Bedford textile industry. Originally, New Bedford focused on finer goods, serving the New York market and minimizing competition with southern manufacturers. The emerging auto industry generated a large demand for New Bedford tire fabrics, which New Bedford could manufacture more efficiently than southern factories, using similar processes to its fine textiles production (Boss and Thomas, 1983). World War I brought a large demand for coarse cotton goods for airplane cloth, bandages, gas masks, and uniforms. New Bedford industries switched from fine textiles to the coarser materials, reaping enormous profits but placing the City in direct competition with the southern textile centers (Boss and Thomas, 1983).

The New Bedford textile factories neglected to modernize following the war. Southern manufacturers were able to capture half of the tire fabric market by 1925. The New Bedford textiles industry peaked in 1923, then declined rapidly due to the combination of management problems - a prolonged strike in 1928, the Depression, and competition from the South which had easier access to raw materials, cheaper labor, and lower taxes. By 1925, the South exceeded New England in the number of active spindles, as many New Bedford mills closed down -- first the yarn, then tire fabric, and finally the cloth manufacturers. From 1917 to 1937, New Bedford lost 21,000 jobs as mills were moved, bought out, or abandoned. Some of the remaining mills switched to the production of rayon and silk, and the Delaware Rayon Company moved to New Bedford. By 1937, rayon comprised 60 percent of yardage produced in New Bedford, and silk 22 percent. The industry was hurt further when the Hurricane of 1938 damaged nearly all the mills, especially machinery and stock, placing approximately 10,000 workers temporarily out of work. World War II brought brief prosperity, but many mills closed or sold out after the war (Boss and Thomas, 1983).

Fairhaven

Following the Civil War, the whaling-related industries in Fairhaven declined as in New Bedford. Outside the seaport, the town remained largely agricultural (See Figure 2-1 for the locations of general development in 1875). During the late 19th and early 20th centuries, several industries were established in Fairhaven, some of which are listed in the Population, Land Use, and Industries Section. However, Fairhaven did not experience the rapid industrial growth that New Bedford did. Instead, Fairhaven town grew as a center of recreational boat racing, boat building, and repair for recreational boats, the local ferry, and later, fishing trawlers. Several manufacturers produced parts for boat building and repair. Fairhaven had several marine railways for hauling ships. In addition, the town became an important residential community for New Bedford factory workers. Oxford Village in northern Fairhaven grew considerably as a residential area during the late 1800s-early 1900s. In the late 1800s, Henry Rogers constructed numerous community facilities and churches throughout the center of Fairhaven and laid out and paved streets and sidewalks. Commercial and institutional areas were developed along with residential areas to serve the increasing number of residents (Boss and Thomas, 1983; McCabe, 1988; Town of Fairhaven, 1965; Harris, 1947; and Hutt, 1924).

Acushnet and Dartmouth

During this period, several manufacturers located in Acushnet and Dartmouth. However, these towns remained primarily rural and residential in nature. Padanaram Village in South Dartmouth and other scattered areas along the coast of Buzzards Bay became vacation resorts, with many cottages being constructed in the late 1800s (Boss and Thomas, 1983; McCabe, 1988; Hutt, 1924).

2.4.2 Population, Land Use, and Industries

Population

During the period of industrialization, New Bedford and Fairhaven grew rapidly with immigrants from Ireland, French Canada, the Azores, Portugal, and the Cape Verde Islands who came to the city to work in the mills (McMullin, 1976). New Bedford's population grew from 15,000 to 26,840 (56 percent) between 1870 and 1880, more than doubled by the turn of the century to 62,442, and more than doubled again to 118,159 by 1918 (Boss and Thomas, 1983).

Land Use

During this period, New Bedford and, to a lesser extent, Fairhaven central business districts expanded greatly (See Figure 2-1 for the extent of development in 1875). Land use changes during the industrial period reflected the rapid growth of textile mills, worker housing, and supporting establishments such as schools, churches, and businesses. New industries located primarily along the estuary north and south of the New Bedford whaling waterfront and included predominantly cotton mills, but also metals fabrication, and machinery industries, glassware, and rubber products. Extensive industrial development also occurred along Clarks Cove. In 1875, wharves extended roughly from Howland Street to Maxfield Street and included iron works, gas works, a planing company, a glass works, paraffin works, coal houses, and lumber yards (Beers Atlas, 1875).

By 1895, additional mills had been constructed along the waterfront north and south of the whaling center, including four textile mills constructed south of South Street (See Figure 2-1, No. 42) and several mills in the vicinity of Coggeshall Street (See Figure 2-1, Nos. 21, 24, and 25). Several wharves were served by

the New York, New Hampshire, and Hartford Railroad (i.e., Old Colony Railroad) (Beers Atlas, 1895). Much of New Bedford's central waterfront, Popes Island, Fish Island, and Palmer Island were used for coal and oil refining and importing, as the industrialization of New Bedford and the rest of the Northeast created a large demand for coal and oil. In 1900, the City of New Bedford covered an area of more than 19 square miles (49 square kilometers) (McMullin, 1976).

Middle and upper income residential areas characterized the central portion of the City well into the 20th century (MHC, 1981a). Between 1875 and 1895, residential areas continued to expand north to Sawyer Street between County Street and the waterfront; west to Rockdale Street between Union and Maxfield Streets; and south to Cove Street. Residential development followed trolley lines extending south to Clark's Point, southwest to the Dartmouth border, west as far as Rockdale south of Kempton, and north to Brooklawn and Pine Grove Cemetery (MHC, 1981a). Many mills provided worker housing near the mills, creating high density, 2 to 3-story tenements north, south, and west of the central business district. During the 1870s, 104 tenement apartments were next to Potomska Mills off Prospect Street. In 1889, Wamsutta Village was comprised of 300 high density tenements directly west of Wamsutta Mills near the intersection of Acushnet and Logan Avenues. Other residential areas were gradually developed throughout the City and in northern Fairhaven.

Commercial and institutional facilities developed in association with the residential areas and mills. Public and civic buildings were built downtown. During this period, New Bedford modernized its infrastructure with a linked rail-steamer service, electric company, electric trolley, public water supply, and telephones. During World War I, the State Wharf was constructed to aid shipments, providing a berthing space for large ships that previously had been unable to dock in New Bedford. (Boss and Thomas, 1983; Beers Atlases).

During the industrial expansion, New Bedford's historic core remained a mix of businesses and services, including the telephone company, banks, U.S. Customs House, and other services. During the 1920s and 1930s, there was some redevelopment in the historic core area to develop produce stores and warehouses. However, many of the structures in the central portion of the City's waterfront that had supported the whaling industry remained vacant (Boss and Thomas, 1983; City of New Bedford 1979). Small scattered settlements were located along Clark's Point, but the remainder of the Point was rural or institutional (e.g., City Farm and City Farm Hospital) (Beers Atlas, 1895).

During the late 1800s and early 1900s, the Fairhaven waterfront continued to develop with the growing boatbuilding and repair industry. Residential areas expanded north, south, and east of the historic whaling core, as mill workers from New Bedford moved into the town. Summer resort areas developed along Sconticut Neck and Fort Phoenix (McCabe, 1988).

Industries

During this period, textiles dominated the New Bedford industries, with over 50 textile mills concentrated along New Bedford's waterfront, (Figure 2-1 and noted in Table 2-1).[3] Other industries located in New Bedford and Fairhaven during the mid 1800s through the early 1900s; numerous coal dealers and

[3] This figure and table represent a sample of industries noted from local history books, Beers Atlases, and Sanborn Fire Insurance Maps. Many of the textile mills are not specifically referenced, but are the sites of subsequent industrial development, as noted in Table 2-1.

petroleum refining companies opened along the New Bedford waterfront and on Popes, Palmer, and Fish Islands.

During the 1860s, other New Bedford industries included the Taunton and New Bedford Copper Company,[4] Morse Twist Drill and Machine Company, Hathaway Soule and Harrington, and the New Bedford Glass Company, which was later incorporated into the Pairpoint Glass Company. The Brownell Carriage Manufactory was founded in early 1830s, and by the 1860s, was largest carriage manufacturer in New Bedford (Boss and Thomas, 1983). By 1924, New Bedford industries included, metal products manufacturers (e.g., Morse Twist Drill, Atlas Tack Corporation, Revere Copper and Brass, and Rhodes Company., a manufacturer of metal eyelets), Pairpoint Glass Company, and various small machine shops (Sanborn Fire Insurance Maps, 1924).

Several industries located to Fairhaven during late 1800s and early 1900s, in addition to shipbuilding and repair. An iron foundry was established in an abandoned cotton mill to manufacture mushroom anchors and remained in business until 1929. In 1894 the Thatcher Brothers Glass Company moved from New Bedford to Fairhaven, producing diamond-cut finished glass. The Atlas Tack Corp. located in Fairhaven in 1864 at a former spermacetti candle factory (Figure 2-1, No. 59) and grew throughout the late 1800s, expanding to new factories in Fairhaven and New Bedford. By 1891, Atlas Tack was Fairhaven's leading industry and one of the world's leading producers of small nails and related items such as cut tacks, furniture nails, grommets, washers, and rivets. Atlas Tack remained in operation until 1985. Gold Bond Powder was in Fairhaven (Figure 2-1, No. 59) during the 1900s, but relocated to Rhode Island in the 1980s. A lubricating oils refinery was established on Fish Island in Fairhaven, refining sperm oil, linseed oil, lard, and finally petroleum.

Industries in Acushnet during this period included a saw mill, box factory, wool carding, manufacture of nail kegs, a paper mill, and cotton mills. The Acushnet Process Company, a manufacturer of rubber products, was founded in 1910 along the waterfront in Acushnet (Figure 2-1, No. 55).

2.4.3 Land Use Effects on Coastal Resources

The development of textile and other various industries in New Bedford; the demand for coal and oil to support these industries and the workers and other residents in the area; and the use of New Bedford Harbor as a major shipping port during this period resulted in significant changes to the harbor. Many changes occurred along the waterfront, and in particular, development and redevelopment along portions of the existing New Bedford shoreline. The construction of wharves and other structures also occurred at various locations, and dredging was necessary to maintain important shipping lanes for waterborne commerce. Significant adverse impacts to marine resources during this period was attributed to large quantities of industrial pollutant discharges, as well as sewage and runoff from residential areas.

Harbor Dredging

An 1875 report by the U.S. Army Chief of Engineers includes a survey of the harbor, indicating the locations where dredging would take place to increase depths, faciliating use of the harbor by coal and steamer ships with deeper draughts (House Report, 43rd Congress, 2nd Session, 1875). The dredging

[4]New Bedford Copper Company produced finished copper and brass items. The company later merged with Grinnell Manufacturing, and finally Revere Copper and Brass.

occurred south of Popes Island and north and east of Palmer's Island, terminating approximately 3,000 feet northeast of Clark's Point. Dredging involved creation of a 200-foot wide swath to a depth of 18 feet and included a 33-acre (13-hectare) dredge area.

Dredging (including maintenance dredging) of a 200-foot wide, 18-foot deep channel extending south to Butler's Flat in Buzzards Bay was completed in 1887. Dredging of a 200-foot wide and 18-foot deep main harbor channel (approximately 10 acres (4 hectares) of dredging) and an anchorage off the north side of the main channel and south of Popes Island, with dimensions of 2,400 feet by 600 feet (33 acres (13 hectares)) and characterized by sand, gravel and mud was described in an 1892 federal report (U.S. House of Representatives, 1892) (Refer to the MassGIS database). Additional dredging of a 250-foot wide channel with a depth of 18 feet at mean low water between Popes and Fish Island was described in an 1896 Congressional Report (U.S. House of Representatives, 1897); the dredging involved and area of about 18 acres (7 hectares) and removal of 74,000 cubic yards (cy) of bottom materials from upriver of the Fairhaven-New Bedford Bridge, and 118,000 cy of materials seaward of the bridge (Refer to the MassGIS database). In 1920, the state maintenance dredged a channel approximately one mile in length from the Coggeshall Street Bridge south to the Fairhaven-New Bedford Bridge (ACOE, 1971), an area of about 35 acres (14 hectares).

Ships docking at and leaving the wharves in the harbor probably contributed to the altering of subtidal habitats as a result of prop-dredging.

Bridges, Wharves, Dams and Other Structures and Fills

Tidal exchange in New Bedford Harbor was undoubtedly reduced by the three bridges across the Acushnet River estuary and harbor. The Coggeshall Street bridge, a wooden structure, was completed in 1893, resulting in the loss of approximately 2 acres (0.8 hectares) of salt marsh and subtidal habitats and altering estuarine hydrology (Reconstruction of the bridge with fill during the early 1900s reduced the channel width from 900 feet to 160 feet (275 m to 50 m)). The Wood Street bridge, located approximately 1.5 miles (2.4 km) upstream of the Coggeshall Street bridge, was constructed in 1900. The wooden bridge was replaced in 1912 with a 487-foot (148-m) long concrete structure (0.5-acre (0.2-hectare)) fill of intertidal and subtidal habitat), further reducing tidal exchange in the upper estuary. An 1890 photograph of the Fairhaven-New Bedford Bridge depicts a well-fortified structure with numerous concrete abutments with narrow (<30-feet (<10-m) wide) openings (Boss and Thomas,1983), clearly altering tidal flushing in this portion of the harbor.
In 1869, the Ansel White Dam was built on the Acushnet River and a gravity conduit was constructed by the New Bedford Water Works to create a safe and continuous clean water supply for New Bedford (MHC, 1981c), affecting fish migration and altering freshwater inflows to New Bedford Harbor (This water supply was one of the principal factors permitting the establishment of the numerous textile mills during this era). After only 30 years of operation, the water withdrawls from New Bedford Reservoir ceased, as water was subsequently taken from Great and Little Quittacas Ponds (MHC, 1981a). In 1926, hydraulic changes were made, permitting withdrawals from Long, Assawompsett, and Pocksha Ponds.

Wharves continued to be built during this period, primarily in New Bedford, resulting in lost or altered nearshore habitats. In 1860, a 700-foot long stone jetty was constructed (1.2-acre (0.5-hectare) fill) on the east side of Clarks Point as part of Fort Taber (The area is now occupied by the New Bedford waste treatment plant). A new bridge from Fish Island to Fairhaven was completed in 1898 (U.S. House of Representatives, 1898), including bridge abutments in the river that resulted in subtidal habitat loss. By the early 1900s, wharves extended from Howland Street to Maxfield Street. New Bedford's State Wharf was constructed after World War I. The development of coal terminals and oil (whale and later petroleum)

refineries resulted in the filling of salt marsh and other intertidal and subtidal habitats on Popes, Fish and Palmer's Islands.

An 1892 U.S. House of Representatives report indicates that "Fort Clark" at Clarks Point was converted to a public park. The military fort was no longer in service, and improvements were completed including a 4-mile loop road at the shoreline, grading of lands proximate to the park, and tree plantings (U.S. House of Representatives, 1892). It is probable that fill of intertidal habitat likely resulted from this redevelopment, although no specific information on habitat impacts is available.

Much of the large wetland (50+ acres (20 hectares)) comprised of intertidal salt marsh and sand flats and non-tidal wetlands at the north end of Clarks Cove (in vicinity of Cove Road) was filled during this period. Most of the salt marshes east of Front Street - Gilford Street in New Bedford and Fort Street in Fairhaven were also filled during this period.

Pollutant Discharges

Although the first sewer system was installed in New Bedford during the 1850s, open sewers were still present in many areas. Streams such as Tripps Brook in the south-central portion of the City had become primary sewage waste conduits. The significant increase in population during the late 1800s, comprised mainly of mill workers, likely resulted in large quantities of sewage generated from a broad area from Tarkiln Hill Road south to the norhtern portion of Clarks Point and west to Rockdale Avenue. Much of New Bedford had been sewered by the late 1800s, and around 1910, a main north-south interceptor sewer was installed to pick up a major portion of the central business district sewers, carrying sewage and stormwater to the waste treatment plant constructed at Clarks Point in (B. Boucher, pers. comm.). The six fold increase in the population of New Bedford during this period generated significant loadings of nutrients and raw sewage to the harbor. In 1904, most of the Inner New Bedford Harbor and the northern portion of Clark's Cove were closed to shellfishing due to an outbreak of typhoid fever.

The development of the textile industry in the New Bedford Harbor area during this period also generated significant wastes to the harbor and required large quantities of water for production. Burford et al. (1953), Jones (1973), and Cooper (1978) present an overview of the textile processes that were used and wastes that were likely discharged to the harbor during this period. Desizing wastes containing large quantities of starch and sulfuric acid generated the highest biological oxygen demand (BOD), although kiering and mercerizing wastes were also high in BOD and alkalinity. The compounds resulting in high BOD included acetic acid, wheat starch, and corn starch. Dyeing processes generated phosphates, acid amides, amine condensates, long-chain alcohol sulfates, methyl oleyl aryl sulfonates, copper sulfate, potassium chromate, and organic solvents. An average waste discharge may have contained 1,000-1,600 parts per million (ppm) total solids, 200-600 ppm BOD, 300-900 total alkalinity, 1-3 ppm chromium, and 1-3 ppm sodium hydrosulfite. As more and more compounds were developed in the process, and synthetic fabrics (e.g., rayon) were introduced, the suite of contaminants discharged likely increased.

The quantity of pollutants generated by the textile industries during this time can be roughly estimated by compiling data from various sources. Masselli and Burford (1956) calculated that approximately 175 pounds of BOD were generated for every 1,000 pounds of cotton cloth produced, while Burford et al. (1953) calculated that 119 pounds of sodium hydroxide were released for every 1,000 pounds of cloth produced. Wamsutta Mills, the first cotton textile mill in New Bedford, produced approximately 25,000 yards of 39-inch sheeting (Crapo, 1937) or 8,930 pounds (Merrill et al., 1941) of cloth per week (464,000 pounds per year) during its first year of operation in 1849. Therefore, more than 80,000 pounds (40 tons)

of BOD and 55,000 pounds (28 tons) of sodium hydroxide may have been discharged into New Bedford Harbor in 1849 alone.

Using other information available from these reference sources, it is also possible to conservatively estimate that 60 pounds of cloth were produced annually per "spindle in place" in the New Bedford textile mills during this time. According to Wolfbein (1968), New Bedford textile production peaked around 1920 with 3.4 million spindles in place. Based on this value, the New Bedford textile mills may have cumulatively released as much as 100,000 tons of BOD-generating materials and 69,000 tons of sodium hydroxide annually into New Bedford Harbor. During the late 19th century, much of these wastes were discharged at numerous locations along the western shore of the harbor. Once public sewers were installed, much of the waste volume was then discharged to the Outer Harbor off Clarks Point after 1920. The release of great quantities of BOD materials undoubtedly resulted in hypoxia or anoxia on at least a seasonal basis in poorly flushed portions of the harbor.

Other industries established during this time were also sources of pollutants to the harbor. The New Bedford Copper Works founded in 1875 (later to become Revere Copper and Brass) on the western shore directly south of the present-day I-195 crossing was a significant source of copper, lead, and other metals to the upper Inner Harbor. Similarly, Atlas Tack Company founded on Fort Street along the Fairhaven shore was a source of heavy metals. Coal houses and bins along the waterfront and on Fish and Pope Islands were a source of coal dust, while the oil refineries on the islands were a source of hydrocarbons and other wastes. Tanneries were likely a source of suspended solids, high BOD, chromium, and sulfides (Nemerow, 1978). Boatbuilding and repair facilities along the Fairhaven waterfront were a source of metals, organic solvents, and hydrocarbons. The Acushnet Processing Company, a rubber manufacturer founded in 1910 near the head of the estuary was a probable source of suspended solids, oils, organic solvents, and high BOD (Sittig, 1975).

2.4.4 Marine Resource Uses

Although rapid development continued all along New Bedford Harbor and in portions of the upper Acushnet River watershed, fish and shellfish were still readily available from the harbor. Boss and Thomas (1983) and McCabe (1988) provide descriptions of the trapping of fish and crabs at the head of the Acushnet River bridge in the mid to late 1800s; scalloping and quahogging along the Fairhaven shore north of the Fairhaven-New Bedford Bridge in the 1880s; harvesting of quahogs in the late 1800s from the Coggeshall Street Bridge for depuration and sale; and the digging of soft-shelled clams along the Fairhaven shore in 1900. Commercial scalloping began in the New Bedford Harbor area about 1870. In 1880, New Bedford and Fairhaven inshore lobster landings were 50,000 and 44,000 pounds, respectively (Howes and Goehringer, In press). In 1860, a local newspaper article reported large catches of Atlantic menhaden in the Acushnet River during this time (P. Cyr, pers. comm.).

For this period, Belding (1908, 1912) provides qualitative descriptions of the Massachusetts shellfisheries rating the Achusnet River, Clarks Cove, and Priests Cove (located in the northeastern portion of the Outer Harbor) as "good" quahog production areas, the Outer Harbor as a "fair" production area, and the west shore of Sconticut Neck as an area providing only small quantities of quahogs. Chronic water quality impacts in New Bedford Harbor were evident during this period. Shellfish closure areas due to excessive bacterial contamination and typhoid fever outbreaks were first documented in New Bedford Harbor during the 1850s (P. Cyr, pers. comm), with many of these shellfish closures areas still present, today.

By the 1870s, offshore fishing on the Georges Bank had developed into the most important fishery in New England. After World War I, trawling for groundfish on the Georges Bank, Nantucket Shoals and other fishing grounds developed into one of the principal finfish harvesting methods.

Some anecdotal information is also available on marine recreational use during this period. Before Fort Phoenix was developed into a public recreational area, Higgins Wharf was a major swimming and amusement area (This site is now a commercial boating facility). A favorite spot for picnicking was located along the eastern shore of the harbor near the Acushnet-Fairhaven town line (McCabe, 1988). Marsh Island was also a favorite picnic locale. Sconticut Neck was a well known recreational area during this period.

2.5 POST TEXTILE INDUSTRIES (1930S-PRESENT)

2.5.1 Historic Overview

New Bedford

Since the decline of the textile industry, New Bedford has diversified its economic base and has remained the center for industry, retail trade, services, and other employment in the area. During the mid to late 20th century, three major industries developed in New Bedford: manufacturing, fishing, and tourism, each of which is described in the following sections.

Manufacturing. Since the late 1930s, New Bedford has been seeking new types of industry for its rapidly declining mills (Between 1930 and 1934, at least 12 New Bedford cotton textile companies stopped operating, some going out of business, while others moved to the South or attempted to reorganize (Wolfbein, 1968)).. The City has attracted a variety of manufacturers and other industrial concerns,

although these new employers generally have employed fewer people than the textile mills. A variety of industries are re-using the vacant mill buildings. In other locations, mills have been razed for housing or other projects, and industries are locating in new buildings. In 1927, the City of New Bedford Industrial Development Division was formed to promote industrial expansion, and in 1937 its name was changed to the Industrial Development Legion. At the time, New Bedford had 10 million square feet of floor space available due to the decline of the textile industry. The city's large, low-wage labor force helped encourage the garment industry and other manufacturers to move to New Bedford. In 1938, the Industrial Development Legion brought Aerovox Company, a leading producer of electronics capacitors, to the Nashawena Mill Building in New Bedford on the northern reaches of the harbor. The city set up special vocational classes to retrain textile workers, and a second electronics firm, Cornell-Dubilier Electronics, was attracted to the city. Acushnet Processing continued making rubber goods, producing gas masks and other materials for World War II, and returned to manufacturing golf balls, golf clubs, and hospital rubber goods afterward (Boss and Thomas, 1983; The Acushnet Company, 1980). Some of the industries that located in New Bedford during this period are listed in the Population, Land Use, and Industries section, Table 2-1, and Figure 2-1.

Following World War II, attracting industry to New Bedford again became a high priority for City leaders, and the non-profit Greater New Bedford Industrial Foundation was established to help. One of the early tasks of the foundation was to raise funds for construction of an industrial park in the northernmost portion of the City on Duchaine Road. The Industrial Park opened in 1961 and in 1982 was fully occupied at 1,300 acres with 18 companies employing 2500 people. In 1966, the Air Industrial Park Project included 111 acres adjacent to the Municipal Airport as a target for commercial and industrial projects. The Air Industrial Park was developed during the 1980s immediately east of the New Bedford Airport. In 1960, the New Bedford Redevelopment Authority was formed to implement four major urban revitalization projects, including the North and South Terminal projects. The terminal projects created new highways along the waterfront, including the John F. Kennedy Memorial Highway, and created new waterfront property and bulkheads for industry and fishing. During the 1960s, Route I-195 was completed, which bypassed downtown New Bedford and Fairhaven, but provided rapid direct trucking routes to Providence and Boston (Boss and Thomas, 1983).

Manufacturing has declined since 1984, when it represented 8,000 jobs, or 45 percent of the total employment base. The decline generally has been due to downsizing, rather than loss of industries, although five major employers discontinued operations since 1980, including: Chamberlain Manufacturing, Berkshire Hathaway textiles, Continental Screw, Morse Twist Screw, and Goodyear. Conversely, several segments of the manufacturing base increased during the mid-1980s, including instruments, primary metals, chemical and allied industries, and transportation equipment. The New Bedford Economic Development Plan indicates that as of 1994, New Bedford has a relatively high proportion of manufacturing jobs in Bristol County (27.8 percent), but that manufacturing companies represent only 6.7 percent of the total businesses in New Bedford (City of New Bedford, 1993).

Fishing. During the period that the textile industries were declining, New Bedford's fishing industry was becoming well established. By 1925, the city had 14 large fishing vessels (valued at more than $25,000 each) and numerous smaller vessels. The introduction of diesel powered vessels during the 1920s allowed more fishermen to harvest the Georges Banks more frequently. To meet the increasing demand, boat repair facilities expanded in both New Bedford and Fairhaven. Hathaway Machinery Company which started as an automobile repair shop became one of the best equipped marine engineering plants in the United States,

designing and repairing heavy vessel hoisting equipment.[5] In 1931, the first fish house was established in New Bedford with modern refrigeration, providing the ability to process and ship large quantities of fish. In 1936, the New Bedford commercial fishing industry brought in more than one million dollars. Additionally, more than 300 boats came into the harbor that year for repairs and fueling, 50 of which were scallopers. These larger boats were able to fish year-round for flounder, haddock, and cod. At the City's principal fish house on City Pier No. 3, located between the State Pier and the Fairhaven-New Bedford Bridge, fish and scallop daily auctions occur (Boss and Thomas, 1983; McCabe, 1988).

The fishing industry grew rapidly following World War II. By 1948, 1,400 fishermen were working 265 vessels, with 13 companies handling fish on the wharves along New Bedford's waterfront north and south of the Fairhaven-New Bedford Bridge. In addition to the fishing labor source, 27 filleting companies employed 550 people during this time. New Bedford's waterfront also had six refrigeration plants, three canneries, four ice plants, eight gear supply houses, five shipyards, and six machine shops (Boss and Thomas, 1983).

The fishing industry was severely damaged by both the Hurricane of 1938 and Hurricane Carol in 1954. Following Hurricane Carol, many of the fishing vessels left for safer harbors. In 1954, the fishing fleet went from 168 to 120 vessels due either to damage from the hurricane or the relocation of vessels (Boss and Thomas, 1983).

To protect the working waterfront, a 3,400-foot (1,035-m) long hurricane barrier was constructed across the harbor by the U.S. Army Corps of Engineers between 1962 and 1965. Terminal improvements (including fish packaging facilities) were also completed to upgrade the waterfront especially for the fishing industry, and these developments, together with the construction of the hurricane barrier, made New Bedford the premier fishing port on the East Coast. The South Terminal Project created 21 acres of waterfront real estate at South Terminal (See Figure 2-1), principally for fishing-related industries such as processing, fishing gear manufacturing, and ancillary services for the fleet. The project also created a 1,600- foot (485-m) long deep-water docking facility behind the hurricane barrier, where the majority of the fleet still unloads their catch. Wharves in the vicinity of the South Terminal provide berthing for fishing vessels.

Finfishing and scalloping grew rapidly during the 1970s and 1980s. New Bedford Harbor fishing industries have benefited greatly from the harbor's central location between Boston, Providence, and New York: All three major markets are within overnight trucking distance. In 1982, the New Bedford Harbor catch totalled $80 million, a 100 percent increase over the previous six years, and New Bedford had 17 large fish processing plants, mostly at the South Terminal. The fishing fleet increased from 120 vessels in the early 1970s to 200 vessels in 1982. The fishing industry was aided by the imposition of the federal 200-mile wide Fishery Conservation Zone (FCZ), which limited foreign fisheries competition. The greatest growth occurred in the scallop industry, increasing from 40 percent of the total catch value in 1976 to 64 percent of the catch in 1982. At least 65 fishing vessels were in the scallop fishery (Boss and Thomas, 1983; City of New Bedford, 1993), employing more than 1,000 fishermen and another 1,000 laborers in 20 processing plants (Doeringer et al., 1986).

In 1971, harvesting of quahogs, scallops, and oysters from inshore waters was severely impacted by contamination, adversely affecting the industry. Shellfishing areas in the Outer Harbor and Clarks Cove

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[5] Hathaway Machinery Company began on Pier 3 in New Bedford, between the State Pier and the New Bedford-Fairhaven Bridge. In 1936, Hathaway Machinery moved to Fairhaven and remained in business until 1985 (McCabe, 1988).

were closed because of high bacterial counts attributed to sewage releases from the New Bedford waste treatment plant and the numerous combined sewer-stormwater outfalls throughout the harbor. As many as 500,000 bushels of quahogs worth over $24 million may be present in these restricted waters, with the annual yield and indirect economic values of these shellfish potentially worth $6 million and $14 million, respectively (Conservation Law Foundation, 1988). Some of these shellfish are relayed to other town waters in the region for depuration purposes (Refer to Chapter 5 for a detailed discussion of these economic impacts).

Also during this time, the potential adverse effects of PCB discharges on New Bedford Harbor fishery resources and human health attributed to the consumption of seafood from this area were identified. In 1977, the Massachusetts Department of Public Health (MDPH) issued a health advisiory recommending the public not to eat bottom-feeding fish and lobsters caught in the area north of a line from Ricketson's Point in Dartmouth to Wibur Point in Fairhaven. Soonafter, area commercial lobstermen posed a voluntary ban on the taking of lobsters in the Inner Harbor (upriver of the hurricane barrier, and identified as "Area I") and within the area north of the line from Ricketson's Point to Wilbur Point (identified as "Area II"). In 1979, the MDPH prohibited the taking of all bottom-feeding fish and lobsters from Areas I and II, while no lobsters could be harvested from the area north of a line from Mishaum Point in Dartmouth, connecting to Negro Ledge, and extending to Rocky Point in Fairhaven (identified as "Area III"). This action was in response partially to the failure of lobstermen to abide by the 1977 voluntary ban. These restrictions on the lobster fishery closed an 18 square mile area. The lost value of the inshore lobster fishery landings (which included the ports of New Bedford, Fairhaven, and Dartmouth) that was attributed to these area closures was valued at $503,000 in 1983 (McConnell and Morrison, 1986).

The 1993 New Bedford Economic Development Plan reports that New Bedford Harbor has been one of the most important commercial fishing ports on the East Coast, recording the largest dollar value of commercial fishing for any U.S. port for seven of the ten years during the reporting period. During the late 1980s, the harbor supported a 300 boat commercial fleet, approximately 1,200 recreational slips and moorings (including those located in Fairhaven) ocean-going cargo and vessels, a Coast Guard facility with two 270-foot vessels, and two passenger ferries. The Economic Development Plan also lists 23 seafood product and fishing firms in the City, employing more than 1,500 workers (City of New Bedford, 1993).

Most recently, severe declines in ground fish populations due primarily to overharvesting led the National Marine Fisheries Service to close the fisheries on the Georges Bank and other federal waters, significantly affecting New Bedford's fishing industry. Many large trawlers remain idle in New Bedford, lacking alternative fisheries.

Tourism. During recent decades, tourism has been growing in importance in New Bedford. The New Bedford Whaling Museum has been an important tourist attraction since the 1960s. The ferry to Martha's Vineyard ceased operations in 1960, with ferry service being now provided from Woods Hole. However, the Cape Island Express Lines re-established ferry service to the Cape Cod Islands in 1972. In 1962, the Waterfront Historic Area LeaguE (WHALE) initiated serious efforts to preserve and designate important historic sections of New Bedford, and by 1984, the Bedford Landing Waterfront Historic District was completed as a working waterfront and historic district. Additional efforts to encourage historic district and waterfront tourism include walking tours, visitor centers in the historic districts, and the historic sloop, *Ernestina*. Several annual events, such as the Sea Fair, Portuguese Feast of the Blessed Sacrament, and the Whaling City Festival being thousands to New Bedford each year. In 1988, the downtown/waterfront area was selected for the development of a Heritage Park, and downtown New Bedford was designated as a "Main Street" district, a Massachusetts program with the purpose of encouraging economic development of an area through preservation and celebration of historic resources. The Heritage Park has not been

completed, pending funding. (Boss and Thomas, 1983; City of New Bedford, 1993; Clayton and Whitley, 1979; and City of New Bedford Waterfront Master Plan.)

Several local and state beaches were established in the New Bedford Harbor area. The City of New Bedford owns two urban beaches: East Town Beach and West Town Beach. East Beach is a one-quarter mile long strip of land on the east side of Clark's Point, while West Beach is a one-half mile long beach on the north west side of Clark's Point. Fort Phoenix, a 21-acre (8.5-hectare) state-owned beach in Fairhaven, offers a 2,400-foot (730-m) long beach southeast of the hurricane barrier. Public access to the shore is also provided at the Town of Fairhaven's West Beach (on the west side of Sconticut Neck) which offers a 0.75-mile (1.2-km) long beach and dunes. Several other small, narrow beaches (e.g., Shell Beach) and numerous jetties along the west side of Sconticut Neck offer public access for swimming, fishing, and other recreational (McConnell and Industrial Economics, 1986). Other local and state-owned beaches are located in Dartmouth (e.g., Jones Beach and Demarest Loyld State Park in Dartmouth and state-owned Horseneck Beach in Westport). The state beaches are used primarily by local citizens and summer residents, while the town beaches attract primarily neighborhood residents. Since the discovery of PCBs in the harbor and the state restrictions on coastal resources, studies have been completed to assess the effects on beach use and have determined that beach use has not been significantly affected in the New Bedford area (Refer to Chapter 5 for a detailed discussion).

Other New Bedford Harbor Communities

Since the 1920s, Acushnet and Dartmouth have remained relatively undeveloped, with scattered low density residential development, commercial strip and mall development along Route 6, and development of the University of Massachusetts at Dartmouth. The New Bedford Industrial Park expanded into Dartmouth.

While employment was declining in New Bedford during the mid-1900s, employment in Fairhaven remained stable. Fairhaven has remained an important center for boat building and repair, and has continued to provide support for recreational boating and the fishing industry. In 1937, Fairhaven was represented by four boatyards engaged in overhaul, repair, and refitting of pleasure craft (MHC, 1981b). Fairhaven manufactured and serviced recreational boats during the 1920s and 1930s, rumrunners during Prohibition, coasting (shipping) schooners during the 1930s, rescue boats during World War II, and fishing and recreational boats currently. The waterfront industries are still a major part of the Fairhaven economy, providing a strong emphasis on wharves, boat yards, and the marine service industries. The region's fishing industry has benefited greatly from such innovations as electronic navigation, improved facilities for shipboard fish packing and storage, large vessels able to travel offshore, and the imposition of the 200-mile wide FCZ.

In addition to boat building and repair, Fairhaven businesses continue to introduce and manufacture innovative fishing equipment, such as the beam trawler and other gear capable of towing nets and dredges. Other marine-related industries have continued to locate in Fairhaven throughout the mid and late twentieth century. Yacht building and repair also remains important in the Fairhaven economy. The 1965 Fairhaven Master Plan reports that 290 Fairhaven residents were fishermen. Outside the boat building and repair industries, many Fairhaven residents continue to rely on employment in New Bedford. Office development, such as the AT&T Data Processing Center and the Massachusetts State Lottery, have recently located in Fairhaven. Commercial continues to locate along Route 6 (McCabe, 1988; Town of Fairhaven, 1965).

2.5.2 Population, Land Use, and Industries

Population

As the textile industry declined, New Bedford's population from 130,000 in 1924 to 105,000 in 1955. From the 1950s to 1980, the population remained relatively stable at just under 100,000 residents (See Table 2-2). While many young people were leaving the City to seek employment elsewhere, immigrants were entering the city to work in the garment, construction, and fishing industries. While New Bedford's population declined, the population of the suburban towns doubled between the early 1900s and 1960. Fairhaven's 1965 Master Plan noted that population growth in Fairhaven was slowing due to out-migration. (Boss and Thomas, 1983; Town of Fairhaven 1965; Bureau of the Census, 1990). Presently, the City of New Bedford still accounts for the majority of the area's population, as shown in Table 2-2.

TABLE 2-2 1990 Population - New Bedford Harbor Communities

Community	1990 Population	% of Total Population
New Bedford	99,922	65.4
Fairhaven	16,132	10.6
Acushnet	9,554	6.2
Dartmouth	27,244	17.8
Total	***152,852***	***100.0***

Source: 1990 Census Transportation Planning Package

Land Use

During the early 1900s, residential development continued but at a much slower rate than previous periods. New Bedford residential areas extended to the Dartmouth border on the west and along Acushnet Avenue in the northern portion of the City (MHC, 1981a).

The period since the decline of the textiles industry has been characterized by:

- Re-use of historic buildings, both mills and commerce buildings;
- Development of residential areas at the outskirts of New Bedford and in Fairhaven and surrounding communities;
- Urban renewal in New Bedford;
- The transformation of the New Bedford waterfront through construction of highway and terminal projects;
- Continued development of urban waterfronts in New Bedford and Fairhaven for fishing and boat building/repair;
- Suburban residential development and schools on the outskirts of New Bedford and in surrounding communities;
- Development of a marine science center on Clarke's Point;

- Commercial development along Route 6 in Fairhaven and Dartmouth, both as commercial strips and shopping centers;
- Development of an industrial park in northern New Bedford and Dartmouth; and
- Development of the University of Massachusetts in Dartmouth.

The decline of the textile industry left millions of square feet of manufacturing space vacant in New Bedford. The greatest changes in the physical layout of New Bedford during this period were related to highway and urban revitalization projects, including construction of I-195, which bypassed much of New Bedford and Fairhaven; the JFK Memorial Highway, that was supposed to provide direct access to New Bedford's downtown; and the terminal projects. The North Terminal project opened up a large area of waterfront, most of which is used by fish processing plants. A portion of Popes Island has been converted to a marine park and marina, and some commercial uses have located on the island, in addition to the oil storage tanks. Fish Island is occupied by cold storage, oil storage, and parking. The possible construction of a casino by the Wampanoag tribe at the interchange of I-195 and Route 140 in New Bedford would introduce a new major land use at the outskirts of the downtown area (City of New Bedford, 1993; City of New Bedford Waterfront Master Plan; Boss and Thomas, 1983).

The emphasis on tourism and historic preservation is leading to additional land use changes. WHALE has been instrumental in attaining historic district designation for the downtown and waterfront historic districts and in historic preservation efforts. Efforts are underway to adaptively re-use historic buildings, exemplified by the Sheraton Whaler Hotel and the Old Colony Bank headquarters. The Whaling Museum has been an important tourist attraction since the 1960s. A national park is planned for the New Bedford Waterfront, pending funding. The City is also investigating other tourist attractions, such as an educational waterfront aquarium. (City of New Bedford Waterfront Master Plan; City of New Bedford, 1993; Clayton and Whitley, 1979).

Industries

A variety of industries have located around New Bedford Harbor since the 1930s, especially in New Bedford. The following presents a sample of industries, as noted in Boss and Thomas (1983), Sanborn Fire Insurance maps, plat maps, the Fairhaven Master Plan, and the 1994 New Bedford Economic Development Plan:

- New Bedford industries during the 1930s and 1940s included manufacturing of shoes; clothing; tire fabric; toys; electronic equipment; pocketbooks; finished metal products; rubber goods; and novelties. Calvin Clothing began operations in 1930 in one of the old Nashawena Mill buildings and has continued producing brand name clothing.

- During the 1950s, industries included paper and corrugated container companies; cotton mills; electronics; metals finishing and production such as Continental Screw, Atlas Tack, and Revere Copper and Brass; Pairpoint Glass; the Acushnet Process Rubber Company; Goodyear Tire Company; and machine shops. Fairhaven had boat building, cotton yarn production, and marine machinists.

- During the 1960s and 1970s, many of the mill buildings were subdivided for use by smaller industries. Industries in the area included paper and corrugated container companies; food processing and warehouses; luggage manufacturers; cotton mills; electronics; metals finishing and production such as Continental Screw Atlas Tack, Revere Copper and Brass, and a plating company; Pairpoint Glass; the Acushnet Process Rubber Company; Goodyear Tire Company;

furniture manufacturers; and small industries such as iron foundries, small motor rebuilding, welding, and machine shops. Companies located in the New Bedford Industrial Park include Polaroid; a plastic company; carbonated beverage bottlers; manufacturers of eyelets, automotive gear, marine equipment, electrical circuits, and a food packaging company.

- The 1965 Fairhaven Master Plan noted that electrical machinery represented the third highest employment sector in the New Bedford metropolitan area, employing 3,900 workers in 1960. The Fairhaven Master Plan also noted that the most important industry in the area was electronic components, with employment in 1960-1963 ranging from 2,900 to 3,900. Non-electrical machinery industries employed over 1,000 in the area, and manufacture of textile machinery was also important. The Fairhaven Master Plan further noted the importance of primary metals production, including Atlas Tack in Fairhaven, and several companies manufacturing tacks, eyelets, and venetian blinds, mostly located along the New Bedford waterfront.

- Since the 1980s, many of the mill buildings have been occupied by garment manufacturing shops, which employed approximately 8,000 workers in 1982. Other mills have been subdivided for a variety of industries, including and discount outlet shopping, cardboard manufacturing, print shops, and welding. The Acushnet Company still manufactures rubber goods in New Bedford, including golf balls, golf clubs, and household rubber goods. The Revere Brass Company continues to operate in New Bedford. Pairpoint Glass left New Bedford after the property was condemned for the South Terminal Project but has returned and occupies a historic mill building. Columbia Electronics moved to the old Dartmouth Manufacturing Company on Cove Road next to the hurricane barrier in 1970, and in 1982 employed 350 workers. The Wamsutta Mills complex was rehabilitated for subsidized housing in 1978 (Boss and Thomas, 1983; City of New Bedford, 1993).

The 1993 New Bedford Economic Inventory notes that New Bedford has 32 apparel manufacturers (50 percent of the apparel manufacturers in the county), 14 textile manufacturers, and three manufacturers of textile machinery. Other large manufacturing employers include food products, rubber and miscellaneous plastics, primary and fabricated metal industries, electronic products, instruments and related products, industrial machinery, printing and publishing, transportation equipment, and miscellaneous manufacturing. Five major employers discontinued operations since 1980, including: Chamberlain Manufacturing, Berkshire Hathaway textiles, Continental Screw, Morse Twist Screw, and Goodyear. Several sectors of the manufacturing base increased during the mid-1980s, including instruments, primary metals, chemicals and allied industries, and transportation equipment (City of New Bedford, 1993).

Industries in Fairhaven during this period have included Gold Bond Sanitizing Powder, marine service companies and related industries such as Acme Marine Hoist, Hathaway Machinery, which manufactured fishing fleet gear, and Norlantic Diesel. Gold Bond, Atlas Tack, and Hathaway Machinery ceased operations in the 1980s. Additional marine-related companies have continued to locate in Fairhaven. (McCabe, 1993)

2.5.3 Land Use Effects on Coastal Resources

Harbor Dredging

In 1952, the Army Corps of Engineers (ACOE) dredged (mostly maintenance dredging) the ship maneuvering area and portions of the main channel in and approaching the harbor to a depth of 30 feet (an

estimated area of 15 acres (6 hectares). The dredged materials (approximately 107,000 cubic yards (80,892 cubic meters) were disposed of in a designated offshore disposal area south of West Island (Malcolm Pirnie, 1982). Since 1952, two large anchorages and other smaller dredging activities along the Fairhaven waterfront have occurred (ACOE, 1971).

Bridges, Wharves, and Other Structures and Fills

Between 1962 and 1965, the 3,500-foot (1,070-m) long ACOE hurricane barrier with a 150-foot (45-m) wide opening (with floodgate) was constructed across the harbor, directly south of Palmer Island and west of Fort Phoenix State Beach to help protect the New Bedford and Fairhaven fleets. The project also included the construction of another 3,800 feet (1,160 m) of seawall and floodgates along the north/northeastern portion of Clarks Cove and 3,400 feet (1,035 m) of seawall along the northeast side of Clarks Point along East French Boulevard. The hurricane barrier resulted in the loss of an estimated 11.4 acres (4.6 hectares) of subtidal and intertidal habitats, while the Clarks Cove and peninsula seawalls resulted in the loss of approximately 23.1 acres (9.3 hectares) of primarily intertidal habitats. More importantly, the hurricane barrier significantly reduced tidal flushing of the harbor. The width of the harbor was reduced by 95 percent, thereby significantly altering flushing of the harbor and sequestering pollutants within the harbor. Although tidal currents are high in the immediate vicinity of the opening, overall Inner Harbor tidal current velocities are lower (Refer to Chapter 3 for a more detailed discussion).

New construction and redevelopment along New Bedford Harbor during this period likely resulted in further loss and/or alteration of nearshore habitats. The State Pier was constructed off Commercial Street filling approximately 7.3 acres (3.0 hectares) of subtidal habitats. In 1968, the South Terminal Project, a 1,600-foot (485-m) long ship unloading area, was completed in New Bedford off Hassey Street and directly north of the hurricane barrier, creating 19 acres (7.7 hectares) of new waterfront land, impacting primarily subtidal habitats. The North Terminal and extension completed in 1970 and located northwest of Fish Island, resulted in the filling of approximately 25 acres (10 hectares) of subtidal habitat (City of New Bedford, 1976). Bulkheaded and backfilled shoreline was also created during this period along the western shore, in vicinity of Wamsutta Mills and the Coggeshall Street bridge; and along the entire Fish Island shoreline and a portion of the Popes Island shoreline. In Fairhaven, shoreline bulkheading and/or filling occurred in the southern portion of Marsh Island (south of I-195) and along Fort Street and Middle Street areas. A dike was constructed across the Popes Beach wetland near Priests Cove (This is the reference wetland discussed in Chapter 3), altering the hydrology of this wetland.

During this period, numerous small groins were constructed along East and West French Boulevards on Clarks Point to control longshore drift and beach erosion. By 1977, at least five structures were constucted on the east side of the peninsula, and six were found on the west side of the peninsula. These groins resulted in the loss of relatively minor areas (less than 2 acres (0.8 hectares)) of intertidal and subtidal habitats.

In 1970, I-195 was constructed across the Acushnet River estuary directly south of the Coggeshall Street Bridge. This 4.7-acre (1.9-hectare) fill crossing reduced the width of the estuary from 1,150 feet (350 m) to 100 (30 m) feet, a loss of intertidal and subtidal habitats and reduction of the estuary width by 90 percent. Although the Coggeshall Bridge had been present long before, the I-195 bridge likely further reduced tidal flushing of the estuary.

During the late 1930s, the New Bedford Airport was constructed in the northern part of the City. It is assumed that this facility construction resulted in filling of non-tidal wetlands, as broad forested wetlands are located throughout much of the surrounding area.

Pollutant Discharges

The uncontrolled release of large quantities of sewage, industrial wastes, household debris, and other pollutants has been sustained in the 20th century, continuing to adversely affect harbor resources. Although an interceptor sewer was constructed in New Bedford in 1920 which transported sewage to waters off Clarks Point via a 3,300-foot (1,000-m) long pipe, many combined sewer outfalls (CSOs) were still present in the harbor area (CDM, 1990). In 1925, public health officials closed New Bedford Harbor and the Acushnet River to shellfishing because of typhoid fever outbreaks (Conservation Law Foundation, 1988).

The arrival of the Aerovox Company on the western shore of the Acushnet River estuary Incorporated (740 Belleville Avenue) in 1938 and Cornell-Dubilier Electronics in New Bedford at 1605 East Rodney French Boulevard, soonafter, led to the discharge of polychlorinated biphenyls (PCBs) and other contaminants to the harbor from the 1940s through 1977. PCBs were used widely during this time in manufacturing and were discharged at the various CSOs in the harbor area. Estimates suggest that 200 to 700 pounds of PCBs were being discharged annually during the late 1970s and early 1980s from the New Bedford waste treatment facility into New Bedford Harbor (Weaver, 1982). Between 1958 and 1977, an estimated 145 tons of PCBs were discharged to the harbor area (Howes and Goehringer, In press). As of 1982, Aerovox and Cornell Dubilier Electronics had discharges directly to the harbor and indirectly to the harbor via the waste treatment plant. A detailed discussion on the concentrations and distribution within New Bedford Harbor is provided in Chapter 4.

The adverse effects of PCBs on New Bedford Harbor fishery resources, and more specifically, on the potential adverse impacts on human health became evident in the 1970s. In 1977, the Massachusetts Department of Public Health (MDPH) released an advisory recommending that the public not eat bottom-feeding fish from an area north of an imaginary line from Ricketson's Point in Dartmouth to Wilbur Point in Fairhaven. In 1979, the MDPH prohibited the taking of all bottom-feeding fish and lobsters from both the area north of the hurricane barrier (Refer to the MassGIS database, identified as Area I) , and the area north of a line from Ricketson's Point to Wilbur Point (identifed as Area II) (Industrial Economics, 1985). Area I was later closed to all fishing activities. The MDPH also prohibited the harvest of lobsters from an area north of an imaginary line from Mishaum Point in Dartmouth, connecting to Negro Ledge, and extending northeast to Rocky Point on West Island in Fairhaven.

Other manufacturers and facilities (metals finishing, glass and rubber manufacturers, welding, iron foundries, plastics, fish processing, food packaging, and the few remaining textile mills) generated discharges, with effluents from some of these facilities discharged directly to the harbor, while discharges were carried to the New Bedford primary treatment wastewater facility after 1973. Summerhayes et al. (1985) suggest that metal enrichment in New Bedford Harbor has been occurring for approximately 100 years, with dischargers such as the Aerovox and Revere Brass and Copper, Inc. (western shore of the estuary near the Coggeshall Street bridge) more recently releasing as much as 200 pounds of copper to the harbor, daily (A detailed discussion of metal loadings are provided in Chapter 4).

Untreated pollutant discharges to the harbor have been common because of design flaws and the poor operation and maintenance of New Bedford's waste treatment plant (Conservation Law Foundation, 1988). Approximately 70 percent of the sewer systems in New Bedford are CSOs. Pollutants have been routinely discharged via at least 35 CSOs distributed throughout the harbor (approximately 25 outfalls) and Clarks Cove (approximately 10 outfalls) (Refer to the MassGIS database). Wet weather discharges to New Bedford Harbor from the CSOs have been estimated at 1.5 billion gallons (962 tons of nutrients) per year (Camp Dresser & McKee, Inc. , 1983), while dry weather discharges release of up to 1.7 billion gallons per

year to Clarks Cove (Camp Dresser McKee, 1987). The New Bedford wastewater discharges account for 80 percent of the total nutrients discharged to Buzzards Bay. With construction of the South and North Terminals in the late 1960s, separate sewer systems were built in this portion of the City (B. Boucher, pers. comm.). Prior to the construction of the Fairhaven wastewater treatment plant inthe late 1960s, raw sewage was discharged by outfalls off Beach and Huttleston Avenues; Taber, Union, Cherry, Pilgrim, Bridge and Streets; and Kilburn Wharf (Town of Fairhaven, 1965). Fairhaven's secondary wastewater treatment plant was upgraded in 1990 with a capacity of 5 mgd. These sewage releases represent significant BOD in the Inner and Outer Harbors.

New Bedford's wastewater treatment facility has been providing only primary treatment, and the plant was not generally meeting even the standards for primary treatment. High levels of fecal bacteria led to shellfish closures in 1971 (in Clarks Cove and the Outer Harbor), and additional closures in 1979. In 1983, Clarks Cove was again closed to shellfishing due to sewage contaminants (Conservation Law Foundation, 1988). By 1987, 3,478 acres of New Bedford shellfish beds, 2,256 acres of Fairhaven shellfish beds, and 1,593 acres of Dartmouth shellfish beds were closed due to sewage contamination (Germano, 1987).

The quantity of pollutants discharged to New Bedford Harbor will decrease as a result of plant upgrading. The improvements to New Bedford's wastewater treatment plant are scheduled to go into operation in June 1996. The new secondary treatment facility is designed for 30 million gallons per day (mgd) with a peaking capacity of 75 mgd for wet weather processing (R. LaBell, pers. comm.).

The advent and prolifieration of the commercial fishing industry during the early 1900s through the late 1980s led to the proliferation of numerous filleting, canning, and seafood processing companies generating significant fish wastes that were discharged to both the Inner and Outer Harbors. The release of these organic wastes greatly increased the BOD in these coastal waters, and has likely been responsible for hypoxic conditions and potential fishkills within the harbor. As an example of the loading, Jones (1974) suggests that 72 percent of flounder catch is waste, generating suspended solid loadings of 300 to 750 mg/l and an average of 74 pounds of BOD_5 per ton (192-1,726 mg BOD/l) of fish processed. In 1965, 80,400 tons of fish were landed in New Bedford, with some of the larger plants processing as much as 100,000 pounds of fish per day (Doeringer et al., 1986). This processing could have resulted in an annual release of as much as 2,975 tons of BOD_5 to the harbor, assuming no treatment plant removal. Although primary treatment by the New Bedford facility would have substantially reduced BOD releases, significant loadings were generated. Release of fish processing wastes directly to the Inner Harbor would have been particularly a problem following the completion of the ACOE's hurricane barrier in 1965.

Completion of I-195 in 1970 and JKF Memorial Highway in the 1975 resulted in water quality impacts to the Acushnet River estuary and New Bedford Harbor. The construction of these roads provided opportunity for new industrial development along New Bedford Harbor, and resulted in an increase of vehicles in the region, generating non-point source pollutants which are transported in runoff discharged to the harbor. Because nearly all of the development along New Bedford Harbor predates state and federal water quality statutes and regulations, most of the urban runoff in the area remains unmanaged and discharges directly to the harbor, releasing hydrocarbons, deicing salts, lead (between 1960 and EPA's required use of unleaded gasoline), zinc and other contaminants.

2.5.4 Marine Resource Uses

During the 1900s, finfishing harvesting in New Bedford Harbor has been limited to recreational fishing for bluefish, striped bass, scup and other species off piers, the hurricane barrier, and other shoreline features. Small skiffs are also used in the recreational fishery in the lower Inner Harbor and the Outer Harbor. As previously noted, shellfish beds were closed in portions of New Bedford Harbor and Clarks Cove because of bacterial contamination, and all commercial fishing in the Inner Harbor has been closed since 1977 because of elevated PCBs in the fish and shellfish resources.

Waters along Sconticut Neck on the eastern shore of Outer New Bedford Harbor were noted as "full of eel grass and scallops" during the 1930s. Quahogs were harvested from as far upriver as the coggeshall Street bridge aand transplanted to waters west of Sconticut Neck during the 1930s (Demanche, 1988). Data collected by the Massachusetts Division of Marine Fisheries on quahogs relayed from the Inner Harbor, Outer Harbor, and Clarks Cove to depuration waters suggest that significant densities of hard clams were present in the Acushnet River in the late 1930s and early 1940s, and in the Outer Harbor and Clark's Cove from the 1950s to the present (MDMF, unpub. data)(Refer to Chapter 3 for a more detailed description of the shellfish resources present in the study area waters).

Boss (1983) describes swordfishing taking place in nearshore waters using sailboats in the early 1900s, and then later using motorized vessels. Cod reportedly caught from local waters were brought in daily to Kelley Wharf in Fairhaven during the 1930s. By 1953, flounder and other groundfish resources on Georges Bank and other offshore fishing grounds had significantly dwindled. Scallop stocks were also severely overfished. During the 1970s, the 200-mile wide FCZ was established, restricting foreign competition for the dwindling fishery resources. This closure in association with other management practices, helped to rebuild stocks, and the New Bedford industry flourished. During the 1990s, off-shore fish stocks had become severly depleted, and fishing restrictions are now in effect.

As of 1965, five public boat launches were located in New Bedford, while another three were located in Fairhaven. Several commercial marinas were also found in Fairhaven (5) and New Bedfrod (2) at this time, and three of the Fairhaven marinas had hoist or railway facilities (Town of Fairhaven, 1965). Popes Island has a 190-slip marina owned by the HDC. East and West Beaches in New Bedford and Fort Phoenix in Fairhaven remain important public beaches in the harbor area. Public access opportunities are also available at the hurricane barrier, Palmer's Island, Tonnessen Park.

2.6 FUTURE DIRECTIONS - NEW BEDFORD'S WATERFRONT

2.6.1 Manufacturing

The City of New Bedford seeks to continue building on the city's strengths in manufacturing instruments and measuring devices, surgical supplies, photographic equipment, and ophthalmic supplies. In addition, New Bedford's economic future depends heavily on the waterfront and related facilities. Strategies cited in the Economic Development Plan related to manufacturing include: capitalizing on New Bedford's multi-modal transportation facilities, Free Trade Zone status, and excess industrial capacity; and capitalizing on the city's maritime assets wherever possible by focusing on marine related industrial activities. The development plan notes that factors for industrial development opportunities include: the potential re-use of vacant or under-utilized waterfront parcels and mill buildings; and the availability of a superior multi-

modal transportation network, including shipping, interstate highway access, and the airport (City of New Bedford, 1993).

2.6.2 Fishing

The 1993 Economic Inventory considers fishing one of the most important industries to foster for its future. The Economic Inventory notes the following advantages:

- The deep, broad navigation and maneuvering channels;
- A hurricane barrier creating a safe harbor;
- Refrigerated warehousing;
- Recent investment in waterfront marine infrastructure, including docks, piers, and terminals; and
- The multi-modal shipping facilities.

The Economic Inventory also notes that overall, the harbor has excess capacity for commercial and recreational vessels.

Conversely, the Economic Inventory notes the following factors as limitations to Harbor use and waterfront activities:

- Shallow areas in the harbor that may impede vessel traffic, including Palmers Cove area, just off the South Terminal, and north of Popes Island;
- Docking and berthing facilities for the commercial fishing fleet are severely congested (Steamship, Homer's, Fisherman's, and Leonard's Wharves), thus exceeding the capacity of the current waterfront facilities; and
- The State Pier appears to be at a height that is too high for fleet docking, limiting its capacity to serving only larger cargo vessels.

To provide for future growth of the New Bedford fishing, strategies recommended in the 1993 Economic Inventory include:

- Expansion of the bulkheads from South Terminal south onto the Standard Times parcel and at the North Terminal site, requiring fill behind the bulkhead, which may be available from harbor dredging of PCB-contaminated sediments;
- Addition of docking facilities at the south side of Fish Island; and
- Exploration of bringing a containerized feeder service into the harbor to encourage foreign trade.

The HarborVisions! charrette in October 1995 resulted in recommendations for use of the State Pier including a combined maritime/industrial and tourist-oriented functions including bulk cargo handling and storage, ferry and cruise ship accomodations, an international marketplace, and/or open-air seafood and produce markets. Measures are now being proposed to allocate funds to create Seaport facilities at several locations in the state of Massachusetts. According to a March 7, 1996 article in the *Standard-Times*, $18.7 million has been proposed for dredging New Bedford Harbor, and is supported by Governor Weld. These harbor improvements proposed for revitalizing the New Bedford economy are part of a state-wide proposal that must first be approved by the state legislature.

2.6.3 Tourism

The City is focusing on linking the historic waterfront with the downtown historic districts through walking tours, events, signage, and pedestrian walkways. The City seeks to continue bringing major events to the waterfront and historic districts. Potential measures for increasing the appeal of the waterfront such as the development of a Waterfront Heritage Park, a "Harbor Light" performing arts center, a hotel/conference center, an educational waterfront aquarium (The Cannon Street ComElectric generating plant was the recommended site identified in the HarborVisions! charrette) and other potential waterfront uses (WHALE, 1995; 1996). The HarborVisions! charrette also identifies Palmer's Island as a potential recreational area. The development of a gambling casino by the Wampanoags could bring numerous tourists to the outskirts of the city; through careful planning, marketing, and routing, these tourists could be directed to the historic and waterfront districts.

2.7 Summary of Land Use Changes

Following agricultural development by the Wampanoags and early European settlers, the history of the New Bedford Harbor area includes three periods of dominance and growth by a single industry beginning in the mid 1700s: whaling, textiles, and fishing. Although the most recent dependent period in New Bedford has been dominated by fishing, the area has seen a diversification in its economic base, ranging from electronics and clothing manufacturers to tourism and boating.

Land use changes in the harbor area have reflected the growth and focus of each period. New Bedford, Fairhaven, and Acushnet began in similar ways along the Acushnet River, beginning as small villages with saw mills, grist mills, and iron foundries. Boat building began in Acushnet. During the late 1700s to mid 1800s, all three communities were involved in whaling to some extent, with boat building, candle works, and maritime support industries. During the whaling period, development in New Bedford and Fairhaven was concentrated along the central waterfront of each community near the New Bedford-Fairhaven Bridge. Acushnet and Dartmouth remained largely rural, with scattered settlement along the roads. Dartmouth developed salt works, with a small community at Padanaram Village and a settlement northwest of Clarks Cove.

Following the whaling period, all four communities developed some industry, but New Bedford became the region's industrial center, with industrial and residential development, as well as support services, throughout the City and in Fairhaven. Fairhaven continued providing major support to maritime industries, becoming a center of yachting and boat building and repair. Industries such as Atlas Tack and glass manufacturers located in Fairhaven. Residential development intensified near Oxford Village, with New Bedford mill workers. Acushnet experienced mostly residential development, with the exception of a few industries such as Acushnet Processing. Fairhaven, New Bedford, and Dartmouth developed summer resort communities along Upper Buzzards Bay.

New Bedford and surrounding communities have experienced scattered growth since the mid to late 1900s, with residential development at the outskirts of New Bedford, and increased residential development south of Route 6 and scattered throughout the rural areas. Other development in the four communities has included the industrial park, University of Massachusetts, Dartmouth Mall, several highway projects, and the urban revitalization of downtown New Bedford. Industries that have operated in New Bedford since the decline of the textile industry include electronics, garment manufacturing, rubber products, brass and glass manufacturing, and miscellaneous smaller industries. Retail outlet stores are locating in some of the old mills, and others have been subdivided for smaller industries. New Bedford is focusing on increasing

tourism with revitalization of its historic buildings and linking the historic downtown with the working waterfront. The marina on Popes Island and the yachting facilities in Fairhaven provide opportunities for recreational boaters.

Presently, New Bedford Harbor is characterized by working urban waterfronts in New Bedford and Fairhaven with deep-water access and a protected harbor supporting major fishing, shipping, and boat building and repair industries. The most intense development is concentrated along the western shore of New Bedford Harbor and Route 140, primarily in New Bedford (See Figure 2-2). Industrial uses are concentrated in the old mills along the Acushnet River and Clark's Cove, and in newer industrial parks near the airport and in northern New Bedford. High density residential uses are concentrated in the central portion of New Bedford and along the Fairhaven and Acushnet waterfronts. Commercial development is concentrated along Routes 6 and 18. The New Bedford and Fairhaven downtown areas are mixed commercial and residential uses, small industries, and public offices. Rural and suburban residential development and undeveloped lands (primarily wetlands) extend east and west of the developed corridor encompassing the Acushnet River.

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Residential

Commercial, General Urban

Industrial

Transportation, Recreation, Public and Institutional Open Space

Source: Mass GIS

Figure 2-2

Existing Land Uses
New Bedford Harbor and Vicinity

70602ELU

TABLE 2-3 Chronology of Events - New Bedford Harbor Area

Period	Event	Population, Land Use, and Industries
Pre-European and Early European Settlement	Native Americans arrived in region 10,000 - 12,000 years ago	Farming occurred by burning and clearing large areas to grow corn, squash, and tobacco.
1600s to early 1700s	Gosnold landed in New Bedford (1602). Settlers purchased land including New Bedford and surrounding areas (1652). Dartmouth incorporated (1664).	Europeans arrived to mixed agricultural and wooded landscape. Sparse settlement - 11 European families in the area by the early 1700s
Mid 1700s	Grist mills, saw mills, iron forges built along head of Acushnet River and its tributaries.	
Whaling Era		
1750	Acushnet Village at head of Acushnet River largest settlement in Bristol County. Russel set up tryworks in present-day New Bedford. Small whaling vessels sailing from river.	Acushnet Village at head of Acushnet River
1760s	Russel drew up plan for Bedford Village. Tryhouse constructed, house lots sold in Oxford Village (Fairhaven). Rotch established Fairhaven Village (1765) and launched first locally built whaling vessel (1767).	Bedford Village along Union, Front Street, Water Street in New Bedford. Oxford Village in Fairhaven.
1771	Whaling industry is expansing.	Both sides of river busy whaling port with 321 dwellings, 119 shops and warehouses, and 30,000 feet of wharfage.
Late 1700s to mid 1800s	Prominence of whaling industry. Growth of seaport and commerce on both sides of river. Shipbuilding and repair industry established in Fairhaven. New Bedford incorporated (1787). New Bedford-Fairhaven Bridge constructed (1792). Fairhaven incorporated (1812). New Bedford becomes City (1847). Wamsutta Mill incorporated in New Bedford (1849).	Area's population grew from less than 5,000 in 1800 to 20,000 by 1854. New Bedford whaling village centered around bridge. Fairhaven village south of bridge. Whaling related industries along waterfront of New Bedford, Fairhaven, and Acushnet. Salt works in Dartmouth.
1850s to 1870s	Whaling declined, textile and other industries established. Petroleum discovered in Pennsylvania (1859). Oil distilling companies operating in New Bedford (1860). Whaling fleet of 29 vessels abandoned in Arctic ice (1871).	

TABLE 2-3 Chronology of Events - New Bedford Harbor Area (cont'd)

Period	Event	Population, Land Use, and Industries
Industrial Development		
1870s	Expansion of Wamsutta Mill, establishment of other mills.	
Late 1800s to early 1900s	New Bedford became industrial metropolis, with 31 textile corporations founded between 1880 and 1910. Mill housing, related commerce and services built north, south, and west of New Bedford whaling village. Fairhaven developed as center for shipbuilding and repair and recreational boating. Many New Bedford workers lived in Fairhaven.. Infrastructure established in New Bedford Harbor towns, including rail lines, gas lines, trolleys, telephones, water supply.	New Bedford's population grew from 15,000 in 1870 to 118,000 in 1918. Development in New Bedford and Fairhaven expanded outward from whaling villages, with textile mills and other industries concentrated along waterfront, oil and coal terminals on the Harbor's islands, residential and commercial development spreading inland. New Bedford industries included textiles, coal, oil, various manufacturers (metals, glass, rubber products). Fairhaven industries included shipbuilding and repair, related iron and machinery, and a few manufacturers. Acushnet and Dartmouth remained largely residential with few manufacturers.
Early 1900s	New Bedford third in textiles production in U.S. behind Fall River and Lowell, Massachusetts. Competition with South beginning. Commercial fishing fleet established but not major industry.	
Post World War I	Textiles industry declined due to competition from South, failure to modernize. Fishing industry becoming established, with diesel allowing fishing trips to Georges Banks.	
Post Textiles		
1930s	New Bedford had over 10,000,000 square feet of vacant mill space. New Bedford's Industrial Development Division formed, brought two electronics firms to New Bedford. Continued growth of fishing industry. First fish house established in New Bedford with modern refrigeration, allowing processing and shipping of large quantities of fish (1931). Three hundred vessels entered harbor for repairs and fueling (1931).	
1940s	Fishing industry grew rapidly. By 1948, 1,1400 fishermen working 265 vessels, with 13 companies handling fish on wharves. New Bedford seeking additional industries.	Variety of industries locating in New Bedford; including garment companies, paper goods, metals products

TABLE 2-3 Chronology of Events - New Bedford Harbor Area (cont'd)

Period	Event	Population, Land Use, and Industries
1960s to 1970s	New Bedford Industrial Park opened (1961). A variety of industries locate in New Bedford, using vacant mills, industrial park. Continued growth of fishing industry. Fishing fleet increased from 120 vessels in early 1970s to 200 vessels by 1982. Urban renewal in New Bedford created North and South terminals, highway projects. Construction of hurricane barrier created protected harbor (1962 to 1965). Construction of I-195 bypassed downtown areas and created direct trucking route to Boston, Rhode Island, eastern seaboard. Tourism growing industry. Establishment of Southeastern Massachusetts Technical Institute in Dartmouth.	New Bedford's population relatively stable at just under 100,000. Populations of surrounding communities growing. Subdivision and re-use of vacant mills, several mills burned or razed. Construction of I-195 through New Bedford and Fairhaven, bypassing downtown areas. Urban renewal in New Bedford, creating terminals and highways. Suburban residential and strip commercial development in outskirts of New Bedford and in other communities. Industries in New Bedford varied, including garment, electronics, rubber products, paper goods, metals, photoprocessing. Fairhaven important center for boat building, repair of fishing and recreational vessels. Recreational boating harbor.
1980s to present	Construction of New Bedford's Air Industrial Park (1980s). Decline of manufacturing, with several major manufacturers ceasing operations in New Bedford and Fairhaven. Growth in certain manufacturing sectors. Fishing and scalloping industries continued to grow, with New Bedford Harbor one of the largest commercial fishing ports on the eastern seaboard. Protected harbor, Fairhaven's boat yards, proximity to Boston, Cape Cod also contribute to New Bedford Harbor's importance as recreational boating center. Increased emphasis on tourism in New Bedford, with establishment of New Bedford's historic districts, major waterfront events, and potential maritime heritage park.	Re-use of vacant mills. Growth of several manufacturing sectors, including instruments, primary metals, chemicals and allied industries, and transportation equipment. Continued suburban residential and commercial development. Construction of offices in Fairhaven, including Massachusetts State Lottery and AT&T. Continued development of University of Massachusetts in Dartmouth (formerly Southeastern Massachusetts Institute of Technology, Southeastern Massachusetts University).

2.8 SUMMARY OF NEW BEDFORD HARBOR RESOURCE IMPACTS

The loss or alteration of intertidal and subtidal habitats of New Bedford Harbor and the riverine habitats of the Acushnet River by man have been qualitatively assessed, estimated, and in some cases, calculated, based on readily available historical data and archaeological information. Land use in the Acushnet River watershed by Native Americans prior to European settlement is speculative but supported by archaeological findings in Southern New England and anecdotal descriptions by early European explorers. Coastal resource impacts during the early colonial period are also inferred but based on more detailed information in the literature. Land use effects on New Bedford Harbor habitats and living marine resources during and following the Industrial Revolution have been more precisely assessed with the availability and cross-checking of numerous records, maps, and other documents. Ecological effects attributed to harbor dredging; the construction of piers, wharves, bridges, dams, and other development activities; and the release of sewage and indusrial discharges to the harbor and within the watershed have been identified and summarized (Refer to Table 2-4).

Although archaeological studies indicate that man first arrived in New England as early as 10,000-12,000 years ago, land use practices by Native Americans seasonally inhabiting the Southern New England coast have only been documented for the period after 1,200 AD. It is probable that the Wampanoags cleared lands along New Bedford Harbor and within the Acushnet River watershed from the 1200s through the mid 1600s, potentially causing incidental releases of sediments and changes in watershed hydrology. These practices likely had no greater effect on harbor habitats and living marine resources than the small-scale fishing and shellfishing practices that these scattered Indian bands employed during their seasonal forays along the coast.

Since the arrival of Europeans in the New Bedford Harbor area in the mid 1600s, more intensive land clearing and use occurred. Increasing numbers of colonists and the introduction of cattle and horses and more effective agricultural tools resulted in greater soil disturbances over a broader area, likely releasing increasing quantities of sediments to the harbor. Cattle grazing on tidal marshes as well as the harvesting and ditching of salt meadow hay caused localized salt marsh erosion, loss and conversion. Settlement along the harbor, principally in the Villages of New Bedford, Oxford and Fairhaven brought construction of scattered wharves and the release of sewage and debris to the harbor, causing minor impacts to nearshore habitats, submerged aquatic vegetation, and shellfish beds. The construction of dams on the Acushnet River and its tributaries during the early 1700s prohibited migrating anadromous fish from reaching upstream spawning habitats.

Distinct changes in habitats and living marine resource populations took place during the Whaling Period from about 1750 to 1860. The filling of salt marshes, mud and sandflats, and nearshore subtidal habitats resulted from wharve expansion at the head of the harbor in Acushnet and along N. Front Street in New Bedford and Main Street in Fairhaven Villages. Construction of the Fairhaven-New Bedford Bridge affected tidal flushing in the upper harbor. Substantial increases in village populations meant great increases in sewage discharge to small streams and the harbor, exerting a significant biological oxygen demand (BOD) and possibly causing localized hypoxia in the harbor. Metals and other pollutants were released and increased water column turbidity resulted from shipbuilding and repair facilities centered along the Fairhaven waterfront, while tryworks and other small-scale industries in New Bedford and Fairhaven also released BOD materials and metals to the harbor. Organic waste discharges also began with the founding of Wamsutta

TABLE 2-4 **Summary of Land Use Activities and Impacts, and Ecological Effects on New Bedford Harbor Resources**

Selected Time Period	Land Use Activity	Impact Type	Ecological Effects
1200s - 1650	agricultural development by Native Americans	localized erosion and sedimentation; minor changes in watershed hydrology	potentially minor releases of sediments to the Acushnet River and estuary; possible localized smothering of shellfish
1650 - 1750	deforestation and agricultural development by Early Europeans	increases in upland and marsh erosion; minor changes in watershed hydrology; cattle grazing, cutting, ditching in marshes	salt marsh loss,degradation, and hydrologic alteration; small-scale releases of sediments and smothering of shellfish
	scattered residential and commercial development in villages of New Bedford, Acushnet, Oxford and Fairhaven	relatively minor releases of sewage to local streams and New Bedford Harbor	localized increases in nutrients, Biological Oxygen Demand (BOD), resulting in loss of sensitive stream and/or harbor biota
	wharf development in New Bedford and Fairhaven villages	pier construction, minor fills	shading or loss of intertidal and subtidal habitats, potentially affecting submerged aquatic vegetation; loss of nearshore shellfish beds
	grist and sawmills, iron forge, fulling on upper Acushnet River and tributaries	dam construction	blockages to anadromous fish migration and access to spawning habitat
1750 - 1860	small-scale shipbuilding at the head of river	minor fills, pollutant discharges	minor loss of salt marsh and subtidal habitat for fish, shellfish, waterfowl, and wading birds; increased water column turbidity
	harbor development 1839, 1840	dredging of bottom sediments, increasing water depths in central part of harbor	alteration of benthic community; short-term increases in water turbidity; possible changes in tidal flushing patterns

TABLE 2-4 Summary of Land Use Activities and Impacts, and Ecological Effects on New Bedford Harbor Resources

Selected Time Period	Land Use Activity	Impact Type	Ecological Effects
1750-1860	shipbuilding and repair in Fairhaven and New Bedford	wharf construction; debris discharges; localized release of metals, hydrocarbons	loss or degradation of intertidal and nearshore subtidal habitats; minor changes in tidal flushing particularly along shorelines of mid portion of harbor where wharves concentrated; possible bioaccumulation of metals (Cu, Pb, Zn) in local shellfish
	tryworks and other whaling-related industries	organic waste discharges	increases in BOD in harbor; possible localized harbor areas experiencing hypoxia
	Wamsutta Textile Mill	organic waste and chemical discharges	increases in BOD in harbor in vicinity of N. Front Street-Wamsutta Street; possible localized hypoxia
	saw mills, grist mills, foundry	dam construction	conversion of riverine habitat to pond habitat in upper Acushnet River and tributaries (Acushnet) and Herring River (Fairhaven)
1860 - 1930	port development	dredging of channel, ship turn-around	alteration of 50-80 acres (20-33 hectares) of subtidal habitats; effects on tidal flushing; temporary increases in water column turbidity
	industrial, residential, and commercial development in New Bedford and Fairhaven	wharf and bridge construction	loss of salt marsh and intertidal flats along western harbor shore (40+ acres (16 hectares)), eastern shore (20+ acres (8 hectares), and Clarks Cove (40+ acres (16 hectares)); loss of intertidal and subtidal habitats (2+ acres (0.8 hectares)) for Coggeshall Street bridge, and 0.5 acres (0.2 hectares) for Wood Street

TABLE 2-4 Summary of Land Use Activities and Impacts, and Ecological Effects on New Bedford Harbor Resources

Selected Time Period	Land Use Activity	Impact Type	Ecological Effects
1860-1930	industrial, residential, and commercial development in New Bedford and Fairhaven	wharf and bridge construction	Bridge; alteration of tidal flushing in upper Acushnet River estuary and Inner New Bedford Harbor; new fill (4+ acres (1.6 hectares)) associated with Fairhaven-New Bedford bridge reconstruction
	water supply	dam construction and water withdrawals	alteration of habitat in upstream portion of Acushnet River; loss of flows to Acushnet River estuary
	coal terminals, oil refineries, and other industries	wharf construction, expansion, and infilling	loss of degraded intertidal and subtidal habitats, primarily along the western shore (10+ acres (4 hectares))
	textile mills and residential areas	exponential increase in organic wastes and chemical discharges	extensive water quality degradation in Inner and Outer New Bedford Harbor, algal blooms, hypoxic and/or anoxic conditions in poorly flushed areas; increased water column turbidity and loss of submerged aquatic vegetation; loss of shellfish and sensitive fish species; bioaccumulation of contaminants in fish, shellfish, and other fauna
	metal industries	waste discharges	bioaccumulation of metals (Cu, Pb, Zn, Cd, Cr); loss of sensitive species due to acute or chronic toxic effects
	boat building and repair industries	metal and chemical discharges	bioaccumulation of metals (Cu, Zn, Pb); toxic effects due to hydrocarbons and solvents

TABLE 2-4 Summary of Land Use Activities and Impacts, and Ecological Effects on New Bedford Harbor Resources

Selected Time Period	Land Use Activity	Impact Type	Ecological Effects
1930 - present	port access and shipping maintenance	maintenance dredging of channel and maneuvering area	alteration of 30 ± acres (12 ± hectares) of severely degraded benthic substrates
	port protection	hurricane barrier and seawalls	loss of 34.5 ± acres of intertidal and subtidal habitats; severe reduction in tidal flushing in Inner Harbor
	port development	large fills, bulkheading	loss of 51± acres of subtidal and intertidal habitats
	roadway development (I-195, Route 18)	fills, pollutant discharges	loss of 4.7 acres of intertidal habitats; severe reduction in tidal flushing in upper estuary
	industrial development	PCB, metals	bioaccumulation of contaminants in sediments/food web; toxic effects to marine organisms
	residential, commercial and industrial development	bacteria, BOD materials, nutrients	increase in hypoxic and/or anoxic conditions; loss of shellfish and finfish

Mill in New Bedford in 1849, adding a significant BOD to the harbor. Harbor dredging also began during this period, altering tidal flushing and deepening the harbor in vicinity of Popes and Fish Islands and the Fairhaven waterfront. Some riverine habitat in the Acushnet River was converted to pond and freshwater marshes during this period, caused by dam construction and sediment infilling of the impoundments.

Between 1860 and 1930, signifcant organic, chemical, and metals discharges were released to the harbor due primarily to the expansion of the textile industry, and to a lesser extent, the metals industries. Tons of organic and chemical processing wastes were discharged annually from cotton textile manufacturers along the New Bedford shoreline affecting much of the harbor. The installation of sewer systems carried a portion of these BOD wastes to the Outer Harbor off Clarks Point, causing wide-spread hypoxia or anoxia in the harbor. The flourishing mills meant a great increase in factory worker populations and sewage wastes generated mostly along the New Bedford waterfront but also from the western portion of New Bedford and the northern Fairhaven area, exacerbating harbor hypoxia and water column turbidity. Between 50 and 80 acres of the harbor were dredged during this period, causing temporary increases in water turbidity and altering tidal flushing. Industrial and residential development resulted in the loss of more than 80 acres of intertidal and nearshore habitats, while constuction of the Coggeshall and Wood Street Bridges and reconstruction of the Fairhaven-New Bedford Bridge eliminated 6.5 $\pm$ acres of tidal habitats and significantly decreased tidal flushing in the Acushnet River Estuary and Inner Harbor. A water supply dam constructed on the Acushnet River in 1869 reduced freshwater flows to the Acushnet River Estuary. Significant loss or stress of shellfish and finfish in New Bedford Harbor occurred during this period due to the cumulative effects of habitat loss, reduced freshwater inflows and tidal flushing, depressed oxygen levels, acute pollutant toxicity, and contaminant bioaccumulation.

Fishing port and industrial development and redevelopment has continued since 1930 up to the present. New industries meant the release of large quantities of PCBs, metals, and other organic and inorganic wastes and untreated sewage with toxic effects on harbor biota and sustaining wide-spread hypoxia/anoxia and other water quality problems. Construction of the hurricane barrier and seawalls between 1962 and 1965 caused a significant reduction in harbor flushing, exacerbating the water quality problem, and resulting in a loss of 34.5 $\pm$ acres of intertidal and subtidal habitats. Large industrial fills primarily along the New Bedford waterfront resulted in the loss of 51 $\pm$ acres of mostly subtidal habitats. In 1970, the I-195 Bridge was completed eliminating 4.7 acres of habitat, further reducing tidal exchange, and contributing to the water quality problem in the Acushnet River Estuary. Harbor and channel dredging occurred at various times during this period, altering 30 $\pm$ acres of habitats already dredged and severely impacted by poor water quality.

Cumulatively, it is estimated that at least 175 acres of salt marsh, mud- and sandflats, and subtidal habitats have been lost since early colonial timesby filling, ditching, or diking. Another 50 to 80 acres of primarily subtidal habitats have been altered by new or maintenance dredging. The ACOE has estimated that 3 to 4 million cubic yards of sand, silt, and rock have been removed from New Bedford Harbor with most of these materials disposed of in offshore waters of upper Buzzards Bay (ACOE, 1971). Large quantities of organic wastes, PCBs, metals, and other contaminants, combined with the reduced tidal flushing caused by construction of the hurricane barrier and four roadways across the harbor and estuary, have had substantial acute and chronic toxic effects on shellfish, finfish, and other living marine resources of New Bedford Harbor. These conditions continue to exist, representing resource restoration opportunities.

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3.0 NEW BEDFORD HARBOR, ACUSHNET RIVER, AND BUZZARDS BAY NATURAL RESOURCES AND VALUES

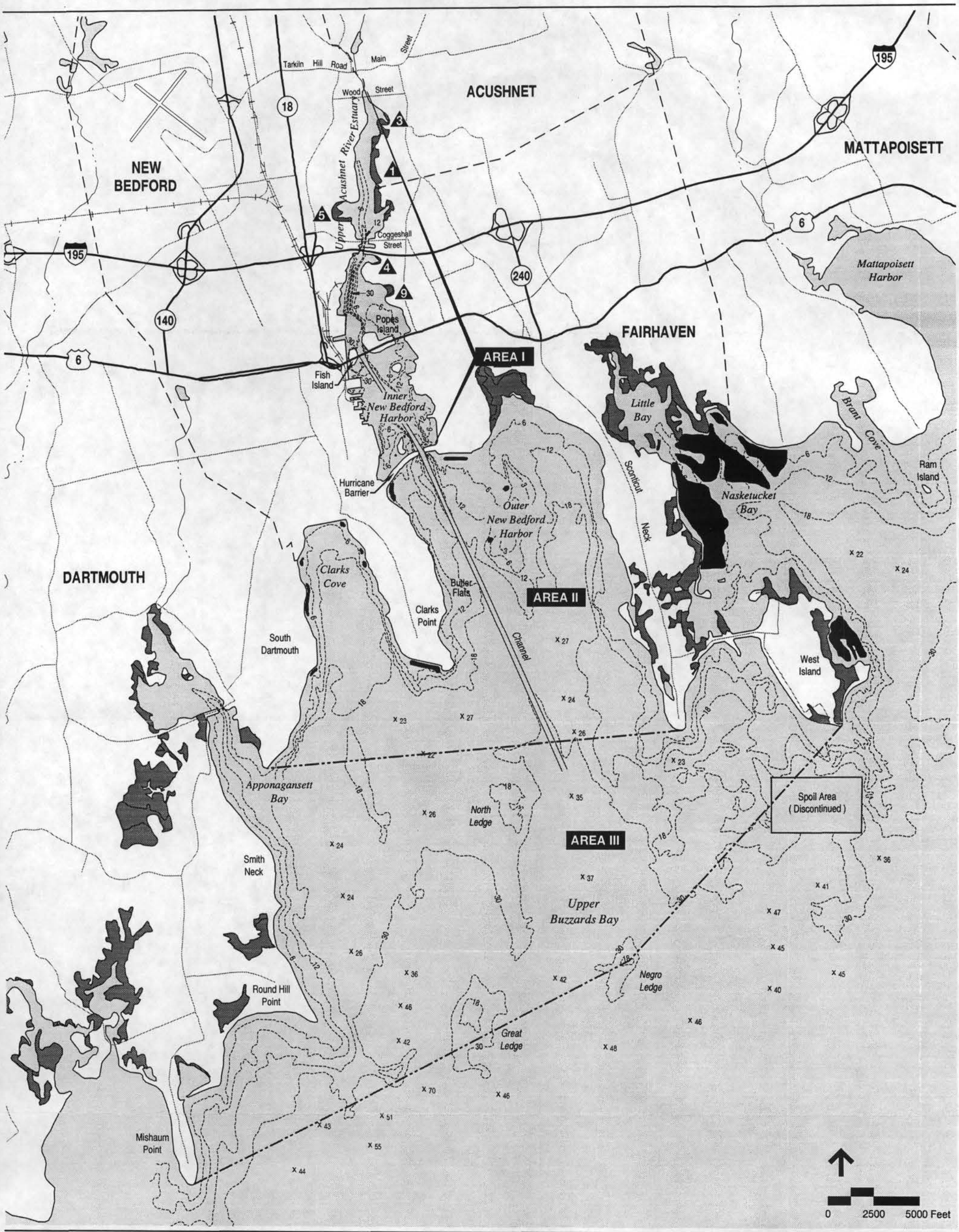
3.1 INTRODUCTION

Buzzards Bay, located in southeast Massachusetts, is a treasured resource providing habitat to fish, shellfish, marine mammals, turtles, birds and other marine and estuarine floral and fauna. The Bay also serves as an important setting for commercial and recreational fishing, recreational boating, swimming, vacationing, outdoor education, and research; provides a transit route for commercial shipping; and generates other economic, recreational, and aesthetic benefits. Buzzards Bay is unique in that it serves as transitional waters for many migrating marine arcadian and semi-tropical species, as it is proximate to the Atlantic Ocean to the south, Cape Cod Canal and Bay to the north, and Vineyard Sound to the east. New Bedford Harbor, located at the mouth of the Acushnet River, on the north Bay shore adjoining Upper Buzzards Bay, serves as important habitat for marine and estuarine species and is a major commercial fishing and shipping port.

This chapter focuses on the Acushnet River estuary, New Bedford Harbor and Upper Buzzards Bay (designated as Fishery Closure Areas I, II, and III) (Figure 3-1), describing the physical setting, bathymetry, habitats, living resources and uses of these marine and estuarine waters. For purposes of this document, the study area includes the entire Acushnet River watershed (Figure 3-2), estuary and portions of Buzzards Bay, and general descriptions are also provided for the watershed and its land uses, non-tidal wetland and upland habitats, living resources, and resource uses.

To prepare this chapter, numerous reference sources were obtained and reviewed to adequately describe the Buzzards Bay area, the Acushnet River watershed, the various habitats found in the estuary and watershed, the living resources found in these habitats, and the functions and values of these resources. The MassGIS database was accessed to extract existing land use information principally for the Acushnet River watershed, and to prepare figures to accompany the text. U.S. Geological Survey (USGS) map quadrangles (Assawompset Pond, Assonet, New Bedford North, New Bedford South quads) were used to identify general watershed land use conditions. The National Oceanic and Atmospheric Administration (NOAA) nautical chart for New Bedford Harbor and nearby waters was used in discussing and depicting the bathymetry of the study area tidal waters.

Colored aerial photographs at a scale of 1:48,000 and dated October 1994 were also reviewed to assess general land use conditions, compare with earlier aerial photographs and USGS maps, and identify any broad-scale changes in the watershed over time. Documents available in the U.S. Environmental Protection Agency's (US EPA) Administrative Record for New Bedford Harbor (and Hot Spot) were used to prepare many sections in this chapter. State and federal agency resource status reports were also reviewed, and agency personnel and scientists and resource managers from various organizations were contacted to obtain additional and current natural resource information.



Historical Submerged Aquatic Vegetation Beds (Costa, 1988)

Tidal Wetlands (MassGIS; 1994 NGS Aerial Photographs)

Wetland Number (Corresponds to Text Discussion)

Fishery Resource Closure Area (Areas I, II, III) Boundaries (MADPH)

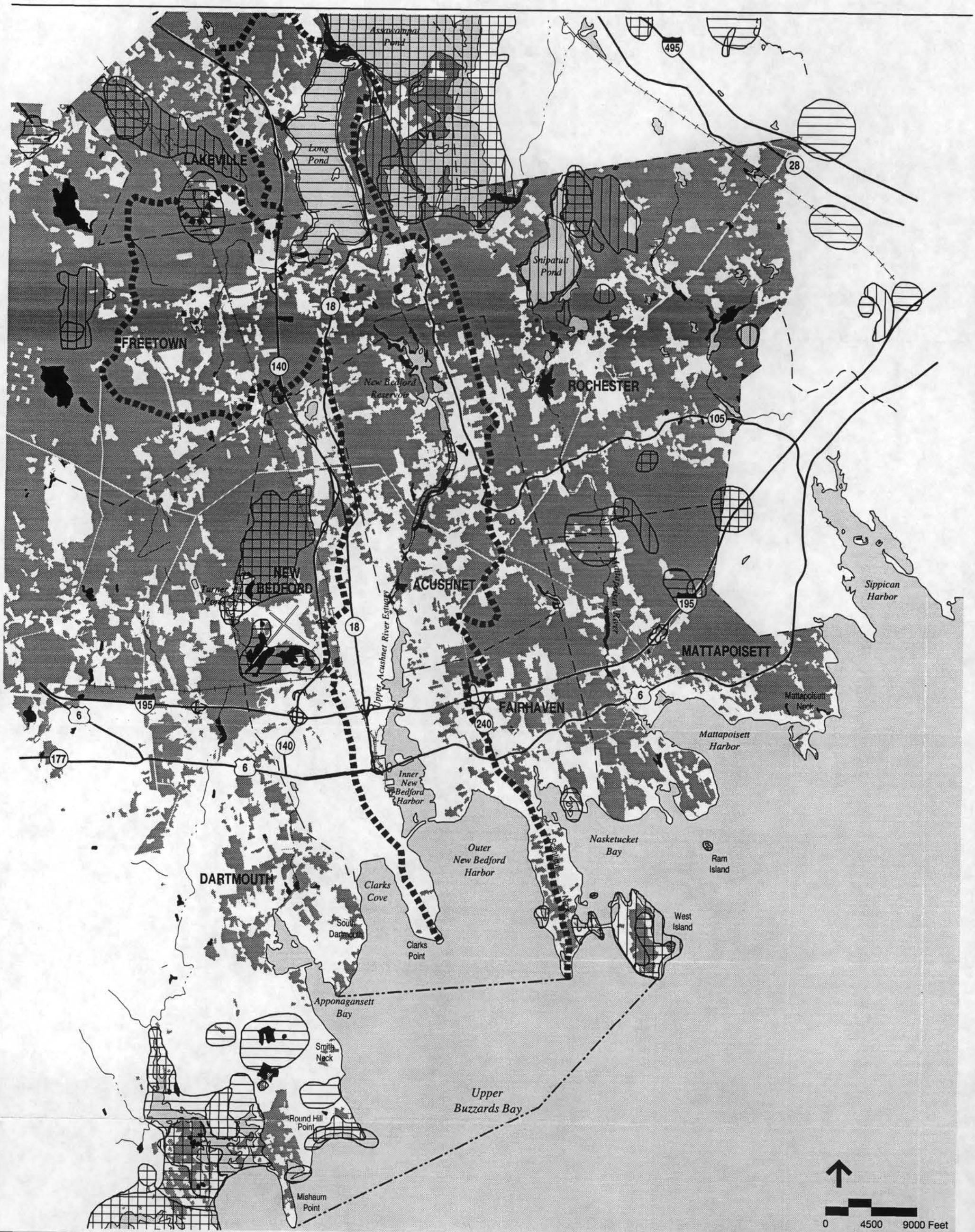
Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 3-1

New Bedford Harbor and Upper Buzzards Bay Habitats and Resources

70602NHR



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New Bedford Harbor Trustee Council

Watershed Boundary

Non-Forested, Non-Tidal Wetlands

Upland and Wetland Forests

High Priority Rare Habitats and Exemplary Natural Communities (Source: MNHP, 1995)

Habitats of Rare Wetlands, Wildlife, and Certified Vernal Pools (Source: MNHP, 1995)

X Known Fish Blockages

Area Closure Boundaries

Figure 3-2

Acushnet River Watershed
Habitats and Resources

70602AHR

3.2 PHYSICAL CONDITIONS

3.2.1 Buzzards Bay Setting and Physiography

Buzzards Bay is bounded by the Massachusetts mainland to the west, Cape Cod to the east and northeast, and the Elizabeth Islands to the southeast. The Bay is 28-miles (45-kilometers (km)) long with an average width of 8 miles (12 km) and an average depth of 36 feet (ft) (11 meters (m)). The total area of the Bay is 228 square miles (590 square km) with more than 280 miles (470 km) of shoreline. The drainage area of the Bay totals 425 square miles (1,104 square km). While the southwestern shoreline is physically regular, the northern and northwestern shores of Buzzards Bay are characterized by many drowned valleys and embayments, creating an irregular shaped shoreline. The northern portion of the Bay in proximity to New Bedford Harbor is referred to as "Upper Buzzards Bay", and for purposes of this overview, the southern limit of Upper Buzzards Bay project area is considered to be an imaginary line from Mishaum Point in Dartmouth, extending northeast to the southern point of West Island (Wilbur Point) in Fairhaven (Figure 3-1). The northern limit of Upper Buzzards Bay is an imaginary line extending southeast from Clarks Point in New Bedford to the southern point of Sconticut Neck in Fairhaven.

3.2.2 Acushnet River Watershed Physiography and Hydrography

The Acushnet River watershed covers an area of 18.5 square miles (46.3 square km), including lands within the towns of Lakeville, Rochester, Freetown, New Bedford, Acushnet, and Fairhaven. Long Pond and its immediate watershed, located in the towns of Lakeville and Freetown, is included as a portion of the Acushnet River watershed, although water supply withdrawals (for the City of New Bedford and other area municipalities) from nearby Little Quittacas Pond and Assawompset Pond alter the hydraulic gradient, causing waters to generally flow from Long Pond into the Nemasket River watershed. Based on 1984 MassGIS data, approximately 59 percent of the Acushnet River watershed is forested and includes both upland and wetland forest (US EPA, 1991) which dominate the upper watershed (Figure 3-2). Another 21.2 percent of the watershed is comprised of other non-tidal and tidal wetlands (1.9 percent), pasture and croplands (12.2 percent), open land (4.5 percent); and woody perennial areas (2.5 percent). In 1984, residential, commercial, and industrial development comprised 14.3, 0.1, and 0.02 percent of the watershed, respectively. These values suggest that the Acushnet River watershed remains relatively undeveloped, although the land use mapping clearly reveals the more intensive developed land uses in the lower watershed within the City of New Bedford.

Discharge rates for the Acushnet River have been measured by the USGS in the Town of Acushnet at the Leornard Street Bridge, approximately 3 miles (4.8 km) upstream of the Coggeshall Street Bridge in New Bedford. Flow volume data collected at this station between 1972 through 1974 ranged from 26 cubic ft per second (cfs) (0.73 cubic m per second (cms)) in October 1972 to an extreme low of 0.55 cfs (0.02 cms) in August 1974 (USGS data, as referenced in Malcolm Pirnie, 1982).

3.2.3 Climatology

Wind, precipitation and temperatures have a significant influence on Acushnet River freshwater inflows; circulation in the estuary, New Bedford Harbor and Buzzards Bay; and ecological processes. Ocean winds moderate both summer and winter temperatures in the New Bedford area. The mean annual air

temperature in New Bedford is 10°C (50°F). The highest average monthly temperature is 22 C (72 F) in July, while the lowest, -1°C (30°F), is in January (Battelle Memorial Institute, 1990).

Frequent but short periods of precipitation characterize the area. Average annual precipitation is 46 inches (114 cm), and precipitation is, in general, uniformly distributed throughout the year (approximately 4 inches (10 cm)/month).

During the winter, northwest winds prevail, while southwest winds are more frequent during the summer. The highest average monthly winds occur during March and April, while the lowest occur during August. The highest storm winds occur in August with velocities as high as 78 knots (90 mph, 40.3 m/s) recorded.

Brief, but severe thunderstorms with high winds occur in the area typically from May through August. Hurricanes may occur during the summer and fall (June through November); and coastal storms which produce the most severe weather effects at New Bedford may occur during the late fall through the spring. During storm events, winds up to 60 knots (70 mph, 31.3 m/s) are predominantly from the south, causing tides to reach 1 to 3 ft (0.3 to 0.9 m) above normal (Battelle Memorial Institute, 1990).

Wind data for the area are available from an U.S. Army Corps of Engineers' (ACOE) weather station on the hurricane barrier in New Bedford, and from a NOAA Data Center station on the Buzzards Bay Tower at the mouth of Buzzards Bay (Geyer and Dragos, 1990). Data collected from the ACOE station between August 20 and December 12, 1987 indicated that the prevalent winds during this time were from the southwest and northwest with an average speed of 11 knots (13 mph, 6 m/s). Wind monitoring during this same period at the NOAA station revealed that wind speed is slightly greater than the winds measured at the hurricane barrier, and there were slight directional variations. This wind directional and velocity data can be used to explain the influence of winds on tidal currents dominating the study area (Refer to the discussion on tidal currents in Section 3.2.5).

3.2.4 Acushnet River Estuary and Buzzards Bay Bathymetry

The Acushnet River estuary is a shallow embayment with a well-defined, narrow channel that extends from the upper estuary south/southeast to Outer New Bedford Harbor, approximately 6,500 feet (1,980 m) southwest of the southernmost point of Sconticut Neck (Figure 3-1). The harbor channel has been widened and deepened to 30+ ft (9 m) by occassional dredging activities since 1839 (Refer to Chapter 2), although no dredging has occurred for more than 30 years, and channel depths are now generally less than 30 feet (9 m). Water depths north of the Coggeshall Street Bridge are generally less than 6 feet (1.8 m) at mean low water (mlw), although maximum depths of 18 feet (5.4 m) mlw are present in this area within the main channel. South of the Coggeshall Street Bridge, the main channel has been deepened by dredging to 30+ feet (9 m) mlw and is situated along the west side of the estuary, extending approximately 4,000 feet (1,200 m) south to where it has been broadened to accomodate shipping activities directly north/northwest of Popes and Fish Islands. East of the channel and north of Popes Island, depths are less than 6 feet (1.8 m) mlw. Extensive shoals and intertidal flats are present throughout the upper estuary and New Bedford Harbor. Tidal flats are found at elevations from -1 ft (-0.3 m) to 1 ft (0.3 m) mlw (NUS, 1984).

The 30-ft (9-m)deep dredged channel continues southeasterly between Popes and Fish Islands, and extends through the 150-ft (45-m) wide hurricane barrier entrance. Numerous shoals with depths less than 6 ft (1.8 m) mlw are present in Inner New Bedford Harbor north of the hurricane barrier, although depths of 12 to 18+ ft (3.6 to 5.4 m) mlw are present along both the New Bedford and Fairhaven waterfronts.

South of the hurricane barrier, the Outer New Bedford Harbor remains a relatively shallow embayment with depths generally less than 18 ft (5.4 m) mlw, except within and proximate to the dredged channel. Naturally occurring depths of more than 30 ft (9 m) mlw occur approximately 4,500 ft (1,350 m) southeast of Clarks Point. South of Clarks Point where the discharges from New Bedford's waste treatment plant are released, depths are between 20 and 30 ft (6 and 9 m) mlw. In general, depths greater than 30 ft (9 m) mlw occur seaward of an imaginary line drawn from Round Hill Point northeast to Great Ledge and east/northeast to the southernmost point of Sconticut Neck. In several locations, shoals with depths of 18+ ft (5.4 m) mlw, including Negro Ledge and Great Ledge, are present in the deeper waters of Upper Buzzards Bay proximate to the harbor entrance.

3.2.5 Freshwater Inflows, Tides and Currents

It is estimated that the Acushnet River has a mean annual discharge rate of 30 cfs (0.85 cubic meters per second (cm/s)), which is less than 1 percent of the average tidal prism of the New Bedford Harbor (NUS, 1984). Because of these relatively small freshwater inflows contributed by the Acushnet River, the estuary is typically well-mixed vertically and relatively saline, although it is weakly stratified during periods of high freshwater inflow. The 100-year storm flow for the Acushnet River is estimated at 1,350 cfs (38.2 cm/s) (NUS, 1984).

Along the eastern shoreline of the estuary and New Bedford Harbor, numerous small streams discharge freshwater flows. The cumulative discharge of these streams has been estimated at 50,000 cubic ft (1,400 cubic m) per day which is approximately 2 percent of mean annual discharge rate of the river. These flows have minimal effect on the currents in the estuary and Inner Harbor. Also, stormwater runoff from impervious surfaces along the estuary and harbor and other portions of the watershed contributes periodic high flows, and high velocities occur at the numerous combined sewer overflow outlets distributed throughout much of the harbor area.

Tides in New Bedford Harbor are semi-durnal. Between July 1987 and June 1988, the ACOE collected tidal measurements in New Bedford Harbor (ACOE, 1990). The average tide range during this sampling period was 4.65 ft (1.42 m) with a low of 1.41 ft (0.43 m) and a high of 5.05 ft (1.54 m). South of the Coggeshall Street Bridge, the Inner Harbor has a mean tide range of 3.7 ft (1.1 m) and a spring tide range of 4.6 ft (1.4 m).

Based on tidal prism calculations, tidal flushing of the upper estuary north of the Coggeshall Street Bridge is estimated to occur approximately every 1.4 tidal cycles (18.2 hours), although detailed estimates based on net flux through the Coggeshall Street Bridge suggest a range of 2 days during the winter to 8 days during the summer (Bellmer, 1988). These data suggest that suspended materials, including certain pollutants, remain in the upper estuary for longer perods during the summer than during other times of the year.

The Eldridge Tide and Pilot Book (1994) presents a general overview of the tides affecting New Bedford Harbor. At the beginning of the flood (incoming) tide, the Outer Harbor experiences 0.2 to 0.3-knot currents moving in a northeasterly dircetion. The Inner Harbor experiences only weak tides at this time. One or two hours into the incoming tide, the 0.3-knot currents extend up into the Inner Harbor with water flowing faster through the hurricane barrier. By the third and fourth hours, the direction of the tide is northerly, straight into the estuary. Currents of 0.3 knots occur up to the I-195 bridge. By the fifth and sixth hours of the flood tide, the water level in the estuary is nearing its peak, and currents slacken. The 0.3-knot speeds are present only in the Outer Harbor, and by high tide, current speeds are minimal. As ebb

tide begins, 0.3 to 0.4-knot currents are present in the Outer Harbor, flowing to the southeast. Weak tides are present in the Inner Harbor. For the next four hours, the ebb tide strengthens with faster flows of up to 0.3 knots extending up to the I-195 bridge. These flows are oriented directly out of the mouth of the Inner Harbor (*i.e.*, south/southeast) and to the south in the Outer Harbor. As low tide approaches, currents diminish until the next flood tide begins.

Tidal currents are the principal force of circulation in the Acushnet River estuary. Flood current velocities in the harbor are generally higher than ebb current velocities (Summerhayes et al., 1977), and the maximum flood and ebb currents occur approximately 3 hours prior to the turn of each tide (Battelle Memorial Institute, 1990). Currents in the upper estuary are relatively low, generally less than 0.6 knots (1 ft/s, 0.3 m/s) and an average of 0.3 knots (0.5 ft/s, 0.15 m/s) (ACOE, 1986). Tidal currents are highest at three constriction locations: the Coggeshall Street Bridge, Popes Island, and the hurricane barrier. These constriction points create a series of eddies and geyers which move laterally from the openings (Bellmer, 1988). At the Coggeshall Street, tidal currents have been measured as high as 3.5 knots (6 ft/s, 1.83 m/s) during the maximum ebb flow (Battelle Memorial Institute, 1990). During July 1987 through June 1988, the currents at the bridge averaged 0.7 knots (1.12 ft/s, 0.34 m/s). North of the bridge, currents averaged 0.2 knots (0.3 ft/s, 0.09 m/s), with maximum ebb currents of 0.5 knots (0.9 ft/s, 0.26 m/s). Because of the relative weak currents in the upper estuary, the thickness of the well-mixed bottom boundary layer is typically only a small proportion of the total depth.

The Coggeshall Street Bridge and I-195 Bridge have significant effect on the instantaneous velocities and extent of currents in the upper estuary that influence the transport of tidal waters and suspended materials. Although high current velocities are generated in the narrow bridge openings which effectively flush these areas, suspended particulates are trapped in the lateral eddies and other areas incurring reduced currents. Suspended detritus, sediments, and contaminants are deposited in these areas and accumulate there until increased velocities ressuspend these materials during storm events. Also, reduced flushing in the areas upriver from the bridge structures may result in depressed disssolved oxygen levels, particularly in locations where organic matter is accumulating and biological oxygen demand (BOD) rates are high. As a consequence, the alteration of tidal currents in the upper estuary affects the presence, abundance, and diversity of organisms and ecological processes that typical occur there due to changes in the substrate, reduced dissolved oxygen levels, and accumulation of contaminants.

Currents vary within the Inner Harbor, with current velocities generally less than 0.4 knots (0.6 ft/s, 0.18 m/s). Within the lower Inner Harbor, bottom friction results in small-scale eddies that create a vertically well-mixed boundary layer in the deeper waters, thereby causing sediments and other materials to remain suspended in the water column. At the narrow (150-ft (45-m) wide) hurricane barrier opening, currents as high as 2.4 knots (4 ft/s, 1.22 ms) occur.) In the Outer Harbor, current velocities are generally less than 1 knot (1.6 ft/s, 0.50 m/s). Along the north side of the hurricane barrier, where the highest current velocites are present, eddies are created on either side of the incoming tidal flows.

Winds also affect currents within the Outer Harbor. Moderate southwesterly winds in the summer and strong northwesterly in the winter cause distinct seasonal current effects. A fetch of more than 8.7 miles (14 km) is present in the southwesterly direction, and the Outer Harbor is most vulnerable to waves generated by southwesterly winds. Waves reaching 6.5 ft (2 m) are generated by wind speeds of 78 knots (90 mph, 40 m/s) (Battelle Memorial Institute, 1990). The Inner Harbor is generally well protected from waves by the hurricane barrier. North of the Coggeshall Street Bridge, waves as high as 3 ft (0.92 m) have been estimated during a storm with winds as high as 26 knots (30 mph, 13 m/s) (Teeter, 1988 as referenced in Battelle Memorial Institute, 1990). Near-surface wind-driven current velocities are typically 3

percent of the wind speed in the down-wind direction. In shallow waters less than 20-ft (6-m) deep, wind-driven waves may contribute to the highest bottom velocities, particularly during storm events.

3.2.5 Salinities and Temperatures

Both horizontal and vertical salinity gradients are present in the estuary and harbor, and are greatest at the head of the estuary as affected by the Acushnet River inflows.
Salinities measured in the vicinity of the Coggeshall Street Bridge have ranged between 10 and 32 parts per thousand (ppt), while north of the bridge salinities between 7 and 31 ppt have been measured in the estuary (Bellmer, 1988). Salinity measured at the Coggeshall Street Bridge between July 1987 and June 1988 ranged between 24 and 33 ppt (ACOE, 1990). At the Coggeshall Street Bridge, vertical salinity gradients as great as 18 ppt have been measured (Battelle Memorial Institute, 1990). These higher vertical salinity gradients in the upper estuary affect the rate of transport of materials through the estuary by keeping suspended materials in the higher saline bottom waters or depositing areas with low tidal current velocities. The average horizontal gradient in the Inner Harbor is approximately 4 ppt over a 3.1-mile (5,000-m) distance (Bellmer, 1988). Vertical salinity gradients in the harbor vary little, with a range of 3 ppt during the spring and an average change of 1 ppt. Salinities were highest in the low marsh with fluctuations greatest near mean high water.

Water temperatures in New Bedford Harbor range between 33° F (0.5° C) in winter and 66° F (19° C) in summer. Higher temperatures during the summer reduce dissolved oxygen levels and increase biological activity and BOD levels; these conditions may increase stress in oxygen-sensitive organisms, potentially causing fishkills especially in poorly flushed estuarine areas.

3.2.6 Nutrients and Dissolved Oxygen

Ammonia levels were measured in the Acushnet River estuary by the Massachusetts Department of Environmental Quality and Engineering (MDEQE) in 1971, and were found to be as high as 0.4 ppm. Values in the Outer Harbor were found to be at similar levels, except in vicinity of the Clarks Point sewage outfall where levels as high as 22 ppm were measured (SES, 1988). Total Kjeldahl nitrogen (TKN) ranged from 0.03 to 3.1 mg/l in the Inner Harbor and from 0.1 to 1.4 mg/l in the Outer Harbor. Total phosphate levels in the Inner Harbor ranged from 0.07 to 0.29 ppm, while concentrations in the Outer Harbor ranged from 0.07 to 0.40 ppm. Phosphate concentrations as high as 17 ppm were measured in vicinity of the Clarks Point sewage outfall.

Excessive nutrient levels in the vicinity of the wastewater treatment plant have been a chronic problem since the facility was constructed in the early 1900s. These high nutrient levels lead to increased phytoplankton production, increased BOD rates, and decreased dissolved oxygen levels that eliminate oxygen-sensitive organisms from the area waters. The upgrading of New Bedford's wastewater treatment facility, which is expected to go on-line in June 1996, should reduce nutrient releases and result in improved water quality to the Outer Harbor.

Water quality was assessed by the MDEQE during October 14, 15, and 16, 1986 at two Inner Harbor sampling stations (one site at the hurricane barrier and one at the Coggeshall Street Bridge). Six other stations were located in non-tidal portions of the Achushnet River and its tributaries (MDEP, 1989). Highest ammonia concentrations were measured at the Coggershall Street Bridge where values averaged 0.44 mg/1. TKN measurements for the two tidal stations ranged from 0.56 to 2.0 mg/l with mean values

of 1.70 and 1.04 mg/l, respectively. Highest TKN measurements (6.10 mg/l) were again recorded at the Hamlin Street dam (Refer to Figure 3-2), suggesting a pollutant source directly upstream of the sampling station. Total phosphorus for the two tidal stations averaged 0.15 and 0.22 mg/l, respectively, while highest phosphorus measurements of the eight sampling stations were recorded at the Hamlin Street dam. In general, nutrient levels were not significanly elevated, although excessively high upstream inputs are clearly evident, potentially causing hypoxic conditions and stress in oxygen-sensitive organisms in these non-tidal waters.

During 1987-1988, nutrient data were collected in the vicinity of the New Bedford wastewater plant outfall and from an area 0.5 miles (0.8 km) south of Negro Ledge (Camp Dresser & McKee, 1990). Highest inorganic nutrient levels were found in the surfacewaters in the vicinity of the plant outfall, with orthophosphate levels 4 to 5 times higher and nitrogen levels 10 times higher than measurements from Upper Buzzards Bay. These high nutrient levels supported high primary production, based on the chlorophyll and productivity measurements. High levels of inorganic nutrients were also found directly above the sediment surface, indicating that nutrients in the effluents were being returned to the sediments. Results of the outfall study revealed that 85 percent of the organic nitrogen in the plant effluents were being remineralized in the Outer Harbor sediments, and nitrogen was continually being released from the sediments (Camp Dresser & McKee, 1990).

Dissolved oxygen (DO) measurements collected by Camp Dresser & McKee (CDM, 1990) for the improvements to the New Bedford wastewater plant indicate seasonal variation, as expected. Higher DO levels were measured during the winter due to the higher saturation levels, while lowest levels were identified for the summer samples when saturation is lowest. The DO levels also decreased with depth, particularly during the summer due to higher macrobenthic activity, greater sediment oxygen demand, and the potential for maximum stratification in the water column. In the vicinity of the outfall, the average difference between surface versus bottom DO measurements was 1.2 mg/l, and the lowest measurements were 3.5 mg/l (within the shipping channel east of the tip of Clarks Point). In many of the sampling locations, highest DO concentrations were measured at depths of 6.5 to 13 ft (2 to 4 m). The high values at these depths may be attributed to several processes occurring at the surface (*e.g.*, atmospheric release, photoinhibition) or directly below the surface (*e.g.*, high phytoplankton productivity).

Measurements of DO in the vicinity of the wastewater plant outfall indicated that materials released from the plant are relatively quickly dispersed throughout the surrounding waters, and do not cause significant decreases in water column DO levels (CDM, 1990).

3.2.7 Sediments and Sedimentation Rates

Subsurface profiles suggest that the granitic gneiss bedrock underlying the estuary is overlain with 8 to 9 ft (2.4 to 2.7 m) of glacial till or 6 to 9 ft (1.8 to 2.7 m) of gravelly sediments. Sands and silts also cover these materials. Unconsolidated sediments as much as 60 ft (18.2 m) thick have accumulated in the New Bedford Harbor (Summerhayes et al., 1977).

The estuarine environment is a dynamic system where exchanges of energy and mass occur between the land, sea, and atmosphere. The physiographic setting in which these processes now occur within Buzzards Bay and New Bedford Harbor reflect the influence of past geologic processes, especially the most recent Pleistocene glaciation.

Sedimentary History of Buzzards Bay

Prior to glaciation, the Cape Cod region consisted of a coastal plain formed from Tertiary and Cretaceous rocks extending out to the present day Nantucket Island, Martha's Vineyard, and Block Island (Howes and Goehringer, 1989). The bedrock within this region consisted mostly of gneisses and granites (Hough, 1940). Three lobes of the Laurentide Ice Sheet, which radiated from the Hudson Bay region, made their maximum southeastward advance into the Cape Cod/Buzzards Bay area during the late Wisconsin Stage of the Pleistocene Epoch. This was a terrestrial event in what is now the Buzzards Bay area, as sea levels were greatly depressed by water that was trapped in continental ice sheets. The retreat of the Buzzards Bay Lobe of this ice sheet has been estimated to have taken place 15,800 +/- 800 years ago (Kaye, 1964). The Buzzards Bay Moraine, which marks the furthest advance of this lobe of ice, occurs along the western shore of Cape Cod and includes the Elizabeth Islands which now form the southern limits of the Bay (Larson, 1980). This moraine feature reaches heights of 98 to 200 ft (30 to 61 m) mean sea level (msl) on Cape Cod. The Elizabeth Islands exhibit a lower relief with elevations generally below 40 ft (12.2 m) with a maximum of 120 ft (36.6 m) msl.

In addition to this end moraine, the glacier deposited till and outwash materials throughout the area which now forms Buzzards Bay. The topography of the uplands were modified by glacial activity into drumlin landforms (*e.g.*, Clarks Point, Sconticut Neck), rocky recessional moraines, and outwash plains which now form the watershed of the Bay. As the glacier retreated, meltwaters deposited coarse textured outwash south of the melting ice. Stream gradients were highest near the melting ice front where stratified gravels and sands were deposited. Finer sands were deposited a greater distance from the ice front. Silts and clays were carried even further to collect in low energy environments such as temporary glacial lakes and estuaries. The meltwaters also carved out distinct drainageways including the Acushnet River. The submerged Pleistocene channel of this river now forms the Upper Acushnet River estuary and New Bedford Harbor and extends out into Buzzards Bay.

The rapid warming which began approximately 14,000 years ago resulted in the break up and melting of the continental ice sheets (Howes and Goehringer, 1989) and caused sea level to rise significantly. Rising sea level flooded the area now occupied by Buzzards Bay 5,000 to 6,000 years ago. As this gradual rise in sea level took place, wave action reworked till deposits along the continuing northward shifting shoreline, washing out fines and leaving coarser lag deposits. Since flooded by the ocean, wave action has eroded headlands and island shores within the Bay, modifying the coastline. Biogenic and water transported deposits have also developed as sorting of the sediments continues to take place (Howes and Goehringer, 1989).

Geologic Setting of New Bedford Harbor

The seabed of New Bedford Harbor has been described by Summerhayes et al. (1977) as a drowned drainage system with steep-sided, rough-topped ridges and smooth-floored troughs. Bathymetric mapping of New Bedford Harbor and its approaches (NOAA, 1983) depicts the drowned channel of the Acushnet River through the harbor and into Buzzards Bay following the approximate line of the dredged entrance channel. A second channel located between Fairhaven Shoals and Sconticut Neck was formed by a former tributary to the Acushnet River. North of Clarks Point, the depth of the drowned Acushnet channel ranges from 20 to 30 ft (6 to 9 m) in both the Inner and Outer Harbors.

Depths within Buzzards Bay seldom exceed 45 ft (14 m) except in drowned glacial-derived river channels. The Bay opens to the southwest adjoining Rhode Island Sound. Approaches to New Bedford Harbor are

sheltered from the larger Bay by prominent peninsulas including Smith Neck, Clarks Point, and Sconticut Neck.

Bottom Sediments

Sediment thickness and textures vary with the bottom topography. Sediments are thinnest over the topographic highs and thickest in the drowned channels (Summerhayes et al., 1985). The shallower deposits typically consist of 8 to 9 ft (2.4 to 2.7 m) of glacial till or 6 to 9 feet (1.8 to 2.7 m) of gravelly outwash over bedrock. These deposits sometimes have a thin (less than 3 ft (1 m)) mantle of marine sands or silts capping the underlying deposits.

Corings of the buried channel of the Acushnet River estuary within the Inner Harbor revealed the presence of up to 60 ft (18 m) of unconsolidated sediments. Examination of core samples taken within the Acushnet River estuary channel revealed that the deepest sediments consisted of up to 20 ft (6 m) of silt and sandy silt. Above this layer, sandy sediments with layers of gravel and discontinuous lenses of silt are present which appear to have been deposited in an oxidizing environment. The uppermost layer is organic enriched silts, is darker in color, contains more shells, and is as much as 10 to 15 ft (3 to 5 m) thick (Summerhayes et al., 1985).

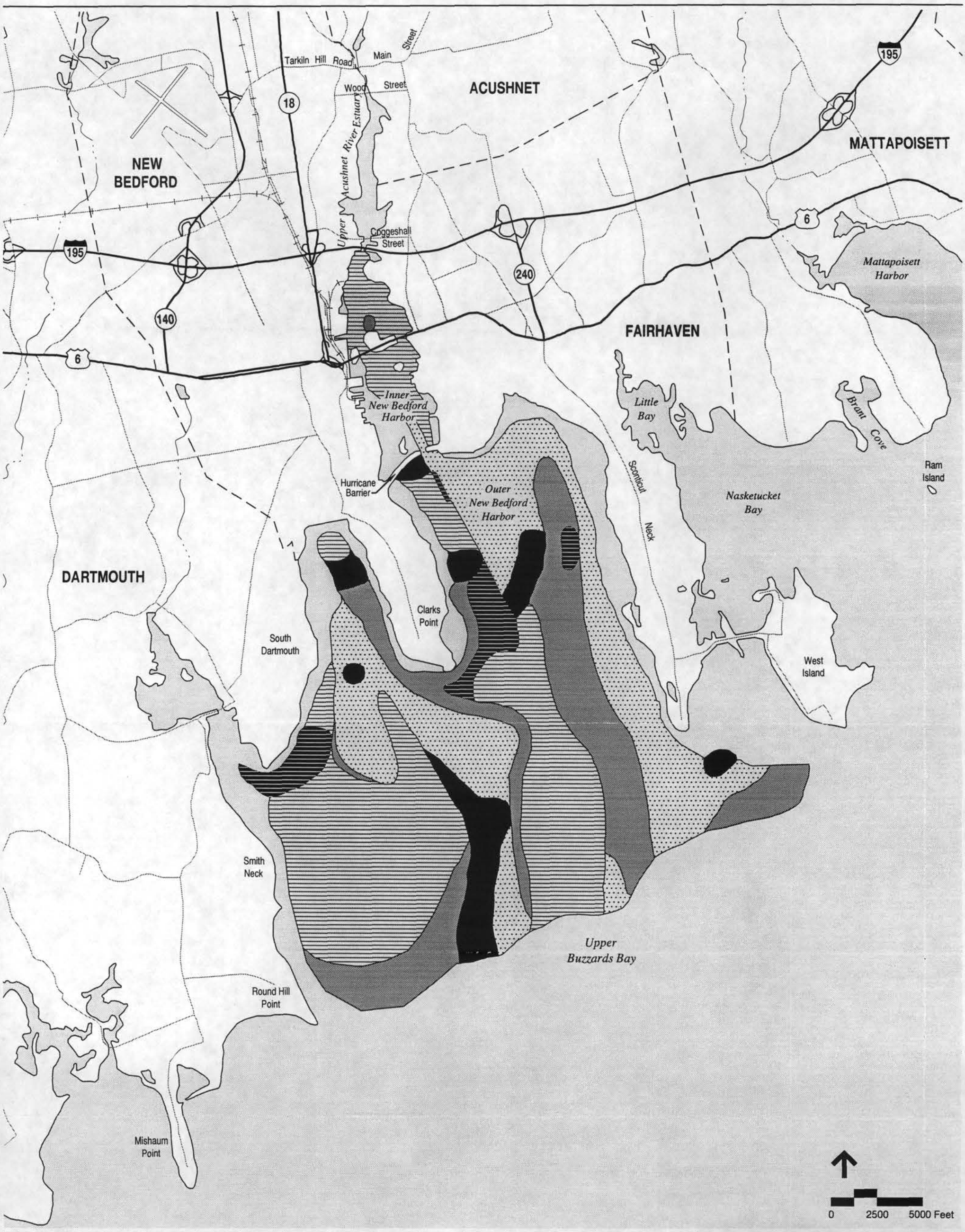
The textural characteristics of bottom sediments in New Bedford Harbor and its approaches have been characterized and mapped by Summerhayes et al., 1977. Fine textured muds, sandy muds, and gravelly and sandy muds accumulate in low-energy environments such as the leeward side of Smith Neck; inside of the hurricane barrier; and within deeper waters not exposed to strong currents (Figure 3-3). Gravelly sands and sands are found on shallow shoals exposed to turbulance such as the Fairhaven Shoals and within the harbor channel in vicinity of the hurricane barrier while sediments are subject to very strong tidal currents.

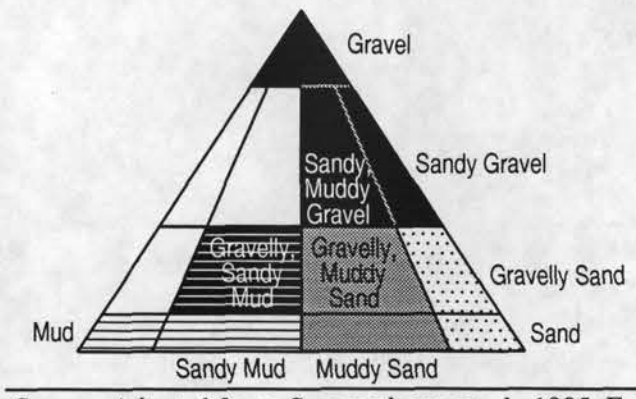
Sources and Mechanisms of Sedimentation

Buzzards Bay has been described as a low-energy microtidal estuary according to the classification provided by Hayes (1971). The sheltered configuration of the Bay provides a relatively low-energy environment by excluding long period oceanic waves from the basin (Moore, 1963). The completion of the hurricane barrier in 1965 enhanced these conditions by reducing tidal and wind-driven currents in the Inner Harbor. Tidal and wind-driven currents are the primary sources of sediment transport and sorting within Buzzards Bay.

Camp Dresser & McKee (1990) described the Bay as a net depositional area in terms of sediment transport. This is typical of many estuaries around the world which are being filled by the landward transport of ocean sediments (Summerhayes et al., 1985).

Sediments input to New Bedford Harbor from the Acushnet River has been considered minimal except when related to anomolous large storm events. Studies of New Bedford Harbor and its approaches have shown that the primary source of sediments to the harbor is the transport of near bottom suspensions of silt and clay carried in from Buzzards Bay by flood tide currents. Suspended particulate material within the Inner Harbor is approximately 1 to 4 mg/l which is similar to the levels found in Buzzards Bay (Farrington et al., 1985, as referenced in SES, 1988). Higher sediment levels (10 to 35 mg/l) are typically found in the bottom waters (*i.e.*, the lowest 2 to 3 m) of the harbor where tidal and wind-driven currents resuspend bottom sediments. The maximum suspended sediment concentrations occur approximately 1 hour after the velocity maximum of a decreasing flood tide (Battelle Memorial Institute, 1990).





Source: Adapted from :Summerhayes et al., 1985; Folk, 1968

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 3-3

New Bedford Harbor and
Upper Buzzards Bay
Bottom Sediment Textural Conditions

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The mechanism for sediment transport can be explained by the observation that the particle size and amount of sediments that can be carried in suspension in water is directly related to the energy (velocity and/or turbulance) of the water. Since tidal currents are stronger on the flood tide than on the ebb tide, incoming flows can transport greater suspended sediments then outgoing currents. Tidal currents are generally less than 1 knot (1.6 ft/s, 0.5 m/s) in Buzzards Bay and are generally less than 0.5 knots (0.8 ft/s, 0.25 m/s) in the outer approaches to New Bedford Harbor. As previously discussed, higher velocities have been recorded over shallow shoals and at the 150-ft (45-m) wide hurricane barrier entrance where tidal currents are forced through this narrow gap at velocities up to 2.4 knots (4 ft/s,1.22 m/s) (Summerhayes et al., 1985).

Sediments carried by the tidal currents tend to be fine-grained silts and clays (diameter less than 0.0625 millimeters) often occurring as irregularly shaped agglomerated masses of organic matter associated with dispersed mineral grains. Summerhayes et al. (1977) reported that the majority of these suspended sediments occur in a well developed turbid layer which extends 6.5 to 9.8 ft (2 to 3 m) above the seabed. The investigators reported a gradual transition between the lower water column and the seabed. The investigators reported a gradual transition between the lower water column and the seabed. The density of the turbid layer over the seabed increases exponentially with depth and the uppermost bottom sediments have been described as "soupy" and easily resuspended by turbulance. The uppermost sediments on the seabed have also been characterized as modified biologically into mineral and organic material agglomerations, much of which has been identified as fecal pellets produced by benthic organisms (Refer to Section 3.4.2).

The clay content of sediments sampled from the Inner Harbor was found to be less than that sampled in the deeper waters of the Bay. This may be explained by the fact that larger suspended particles of equivalent density settle faster than smaller ones. This would suggest that during particulate residence time within the harbor, more silt settles from the turbid waters brought into the harbor relative to clay. Clay that remains suspended in the water column during this residence period, or which is resuspended by turbulance, is then transported back out of the harbor on the ebb tide and into Buzzards Bay where it may settle in deeper, quieter waters. Summerhayes et al. (1985) reported sediment clay to mud (silt + clay) ratios of 0.34 in central Buzzards Bay; 0.28 at the seaward end of the drowned valley of the Acushnet River estuary (*i.e.*, the Outer Harbor); and 0.18 in New Bedford Harbor.

In sediment core samples analysed from the estuary, organic carbon content generally decreases with depth. In most of the estuary, organic carbon content in the upper 10 centimeters of sediment is between 1.0 and 2.0 percent (Summerhayes et al., 1985). The Inner Harbor contains surface sediments with an organic carbon content of 4 to 7 percent. Deep water sites within the drowned valley of the Acushnet River seaward of the hurricane barrier and an area associated with the Clarks Point waste treatment plant outfall had organic carbon percentages which reached 3.2 percent. The authors of the study concluded that the elevated organic carbon percentages could be attributed to urban sewage discharges, and organic wastes and oil residuals from shipping.

The Battelle Memorial Institute (1990) completed a modeling study of the Acushnet River estuary and Inner and Outer Harbors to determine mass balance for sediment transport. The net flux of sediments computed in the simulation was 980 pounds (446 kg)/tidal cycle at the Coggeshall Street Bridge and 3,400 pounds (1,546 kg)/tidal cycle at the hurricane barrier. Results of the study agreed with field measurements that the upper estuary and Inner Harbor are net sediment depositional areas. In the Outer Harbor, there is a net transport of sediments seaward to Buzzards Bay.

Sedimentation Rates

Studies conducted in Buzzards Bay suggest an average sedimentation rate of between 1 to 3 mm/year (Bowen et al., 1976). Comparable rates have been determined for Chesapeake Bay (2 to 3 mm/year; Schubel 1968) and Long Island Sound (Thompson et al., 1975). Sedimentation rates are highest in the low energy deep waters and protected areas within the Bay. Rates of sedimentation at the topographic highs (shoals) and channels scoured by tidal currents are relatively low.

By studying sedimentation cores in New Bedford Harbor north of the hurricane barrier using lead Pb^{210}, a rate of 2 mm/yr was determined below a sediment depth of 0.7 ft (0.2 m) and 17 mm/year above that depth. The change is attributed to the completion of the hurricane barrier in 1966, suggested that sedimentation rates in the Inner Harbor are more than eight times greater since barrier construction. Other sedimentation rate investigations completed using carbon dating of buried mollusc shells or sampling the depth of dredged materials with a known date of overboard disposal have determined similar rates (Summerhayes et al., 1977). Dark, fine grained highly organic sediments characterize the upper substrate stratigraphy of the Inner Harbor.

Sedimentation rates for the seabed adjacent to the Clarks Point waste treatment plant outfall were also determined to be higher than other areas within the Bay. Sedimentation rates of 30 mm/year directly beneath the sewer outfall and 3 mm/year at a distance of 0.3 miles (0.5 km) from the point of discharge have been estimated (Summerhayes et al., 1977). These results indicate that an organic-rich substrate is present in the vicinity to the outfall, and likely limits the diversity of macrobenthic organisms in this area.

3.3 HABITATS

3.3.1 Habitat Classification

Habitats are defined by the specific biotic and abiotic features which make them distinguishable from one another. For purposes of this report, the U.S. Fish and Wildlife Service's wetland and deepwater habitat classification system (Cowardin et al., 1979) is used to describe the habitats found in the Acushnet River estuary and watershed and Upper Buzzards Bay. Within the Acushnet River estuary, both estuarine (waters at least occasionally diluted by freshwater) and marine (stable salinities typically between 30 and 33 ppt) subtidal and intertidal habitats are present. Because the freshwater inflows from the Acushnet River are relatively small, estuarine habitat, by definition, is generally limited to the upper Acushnet River estuary, although diluted ocean waters extend further south in the estuary during the spring and other periods of high runoff. New Bedford Harbor and Upper Buzzards Bay are principally characterized by marine intertidal and subtidal habitats. Some of these habitats are colonized by submerged aquatic vegetation.

Upstream of tidal influence, the Acushnet River is characterized as riverine habitat, while palustrine forested, scrub-shrub, emergent wetlands comprise the vegetated non-tidal aquatic habitats in the watershed. Both natural and man-made ponds (palustrine open water habitats) and lakes (lacustrine habitats) are also found throughout the watershed. The following are descriptions of the more important habitats found in the study area.

3.3.2 Subtidal Habitats and Submerged Aquatic Beds

The subtidal habitats in the Acushnet River Estuary and Inner Harbor are characterized by depths generally less than 12 ft (4 m) mlw. Greater depths in the Inner Harbor are associated with the dredged channel where depths of approximately 30 ft (10 m) are present. In the Outer Harbor, depths greater than 20 ft (6 m) are more frequent, while depths of 20 to 40 ft (6 to 12 m) are common in Upper Buzzards Bay (*i.e.*, Area III).

Subtidal habitats include marine and estuarine waters where the substrate is continuously submerged, and the texture and organic matter composition of the substrate influences macrobenthic species diversity and abundance (Refer to Section 3.4.2), and contaminant concentrations (Refer to Chapter 4). As described in Section 3.2.7, subtidal substrates in the Upper Acushnet River estuary and Inner Harbor, where low-energy conditions exist, are predominantly unconsolidated organic-rich silts, fine-textured muds, and sandy muds. Sands and gravelly sands are prevalent on shoals in the Inner and Outer Harbor, Upper Buzzards Bay, and within and proximate to the harbor channel in vicinity of the hurricaane barrier. Marine subtidal substrates in Upper Buzzards Bay are generally highly variable and consist primarily of sands, gravels, and muds (Refer to Figure 3-3).

Eelgrass (*Zostera marina*) is the prevalent submerged aquatic vegetative species found in Buzzards Bay, serving as an important source of organic material to herbivores and detritivores. Eelgrass beds also serve as important cover and nursery habitat for shellfish (*e.g.*, bay scallops) and finfish (*e.g.*, winter flounder) (Thayer et al., 1985). Eelgrass is found in a variety of subtidal habitats with varying salinites and substrate types.

During the 1930s, eelgrass virtually disappeared from Buzzards Bay and other marine/estuarine waters along the Atlantic Coast due to "wasting disease" (USEPA, 1991), caused by *Labarynthula* spp., a saprobic or parasitic protozoan that is found on macroalgae and vascular aquatic plants. Eelgrass subsequently recovered in portions of Buzzards Bay, while more recent declines during the 1970s and 1980s have been attributed to other factors including excessive nitrogen loading (such as that associated with the New Bedford wastewater treatment facility), intensive boat traffic, and other anthropogenic disturbances.

Costa (1988) completed a detailed stuidy on the historical distribution of eelgrass (*Zostera* marina) in Buzzards Bay, based on historic aerial photographs. The easrliest aerial photographs used (from the 1940s) show few eelgrass beds in the New Bedford Harbor area (figure 3-1). The author concluded that two factors contributed to this scarcity: the wasting disease which killed 90 percent of all eelgrass in the northeast during 1930 and 1931; and the highly urbanized condition of the New Bedford waters prior to the wasting disease, which inhibited the return of eelgrass. More recent aerial photographs show only two areas of eelgrass beds, one south of Clarks Point, the other on the west shore only two areas of eelgrass beds, one south of Clarks Point, the other on the west shore of Clarks Cove (Figure 3-1). Eelgrass beds are now generally found at maximum depths of 3 ft to 10 ft (0.9 to 3.0 m) (Howes and Geohringer In Press).

The scarcity of eelgrass beds in the New Bedford Harbor area is anomolous in comparison to the waters along Clarks Point and other nearby portions of Buzzards Bay which characteristically have more extensive eelgrass beds. Most of Buzzard Bay, including areas in the vicinity of New Bedford Harbor, have experienced a steady re-colonization during the last five decades (Figure 3-1), while New Bedford Harbor has not. Costa (1988) cites historic and on-going causes. Major physical and chemical perturbations from industrial and urban sources are described as primary problems. The presence of PCBs, heavy metals, sewage and other pollutants (as documented in Chapter 4) and increased turbidity (rapidly eliminating light

penetration in the water column), combined with the filling of shallow water habitat for development, have reduced the suitability of the harbor for submerged aquatic vegetation (SAVs). Also, the construction of the hurricane barrier resulted in the loss of shallow water habitat and significantly reduced tidal flushing, exacerbating problems for SAV establishement. Due to reduced tidal flushing in the Inner Harbor, changes in bottom substrates from firmer silty and sandy substrates to highly-organic, oozy mucks have occurred which may also prevent SAV establishment. Due to the scarcity of quality shallow water habitat and continued chronic input of pollutants, it is expected that SAV distribution will not significantly increase in the harbor area.

The Massachusetts Wetlands Conservancy Program, in cooperation with the Massachusetts Office of Coastal Zone Management and the National Marine Fisheries Service, is presently conducting an inventory of SAVs within the state's waters. The program includes photointerpretation and field surveys to accurately delineate and classify state SAV and algal resources. The resources of Buzzards Bay, including the New Bedford Harbor area, are scheduled to be completed in late 1996 (C. Costello, pers. comm.).

3.3.3 Intertidal Habitats

Salt Marshes

In 1985, more than 5,100 acres (2,060 hectares) of salt marsh were present in Buzzards Bay (Hankin et al., as referenced in US EPA, 1991). In April 1985, a tidal marsh study was completed by the USEPA's Environmental Photographic Interpretation Center (Bellmer, 1988), identifying approximately 395 acres (160 ha) of tidal wetlands within the Acushnet River estuary (Bellmer, 1988). Detailed descriptions of the tidal wetland communities present in the Upper Acushnet River estuary, New Bedford Harbor and nearby Popes Beach (considered as an uncontaminated reference wetland) along Upper Buzzards Bay have been provided in reports prepared by Sanford Ecological Services (SES) (1988), IEP (1988), and Bellmer (1988).

As part of this study, 1992 black and white orthophotographs (at a 1:5,000 scale) obtained from the University of Massachusetts Cartographic Institute, and more recent (1994) aerial color photographs available at the Massachusetts Coastal Zone Management Program (at a 1:5,000 scale), were reviewed to identify any broad-scaledifferences in these wetlands versus conditions previously described. The five Acushnet River estuary wetlands and the Popes Beach reference wetland closely approximated the conditions previously depicted and described, and no discernable physical changes are evident during this period. Other tidal wetlands in the area were also identified using the aerial photographs, and these wetlands are depicted in Figure 3-1. This section presents a brief summary of the study results, describing the dominant wetland plant communities and environmental conditions influencing these wetland communities within the study area.

Vegetational Overview

The zonation of plant communities within tidal wetlands has been the subject of a number of classic studies in plant ecology (Johnson and York, 1915; Nichols, 1920). The frequency and duration of tidal inundation is one of the most easily identified factors leading to the development of distinct vegetational zones along topographic gradients in tidal wetlands. Three tidal wetland regimes, as described by the U.S. Fish and Wildlife Service classification system (Cowardin et al., 1979), have been identified within the study area:

- Irregularly exposed (land surface is exposed by tides less frequently than daily);

- Regularly flooded (tidal waters alternately flood and expose the surface at least once daily); and
- Irregularly flooded (tidal waters flood the land surface less often then daily)

Irregularly exposed wetland habitats include tidal waters such as tidal creeks and guts, mosquito ditches, rocky beaches, sandflats and mudflats, and are described in the following sections. A study prepared by SES (1988) identified sea lettuce (*Ulva lactuca*), filamentous algae, and rockweed (*Fucus* spp.) as some of the common plant species which occur in the study area wetlands belonging to this water regime class. Regularly and irregularly flooded habitats include the aggregation of plant communities commonly referred to as "salt marsh" in New England. With few exceptions, regularly flooded tidal wetland habitats within the study area are dominated by the tall form of smooth cordgrass (*Spartina alterniflora*). This community is often referred to as "low marsh", and the name is derived from the plant community's position in the landscape, not the height of the vegetative canopy which typically exceeds 3 ft (1 m). As indicated by the water regime class, these habitats occur within the zone inundated by tidal waters twice daily. The smooth cordgrass plant community of the low marsh typically exhibits relatively low species diversity and high primary productivity (Teal, 1984).

Irregularly flooded vegetated wetlands generally host a greater variety of plants. The areas, known regionally as "high marsh", are dominated by salt meadow grass (*Spartina patens*). The five principal vegetated tidal wetlands found in the upper portion of the Acushnet River, as described by Bellmer (1988), are dominated by high marsh vegetation. In some portions of the study area spikegrass (*Distichlis spicata*) and blackgrass (*Juncus gerardi*) have been found as co-dominants with or common associates of salt meadow grass (IEP, 1988). Sea lavender (*Limonium carolinianum*), sea orach (*Atriplex patula*), perennial glasswort (*Salicornia virginica*), seaside goldenrod (*Solidago sempervirens*), and slender-leaved aster (*Aster tenuifolius*) are some of the forbs in the study area high marsh communities (SES, 1988).

A distinct, short form of smooth cordgrass (*S. alterniflora*), generally less than 1 ft (30 cm.) in height often occurs in isolated flooded depressions within the irregularly flooded zone of marshes lacking drainage. The environmental conditions which lead to the development of the "stunted" form of saltwater cordgrass are characterized by higher salinity in the soil pore water (created by the lack of frequent water input and presence of high evaportranspiration rates) and low oxygen conditions in the substrate (due to the presence of stagnant water) (Teal, 1986; Neiring and Warren, 1980; Nixon, 1982).

Another plant community type recognized in the irregularly flooded zone are areas dominated by marsh elder (*Iva frutescens*). This community often occurs in transitional areas between tidal marshes and upland habitats. Within the study area, the community is most common along the landward edges of the high marshes and on refuse soil mounds associated with past mosquito ditching practices (IEP, 1988).

Common reed (*Phragmites australis*) also was noted in some irregularly flooded tidal wetland habitats, particularly in areas of recent disturbance such as the mounds of sidecast materials deposited during mosquito ditching practices. Common reed is an invasive species which quickly colonizes disturbed moist to wet soils, and frequently outcompetes slower growing species. Plant communities dominated by common reed are considered to be of limited wildlife habitat value because of the dense, impenetrable stands it forms, and it is not used as a food source by wildlife.

Study Area Wetland Vegetational Descriptions

A general description of each of the wetlands in the study area and its location is presented in the following sections, and these wetlands are depicted in Figure 3-1. The wetland identification numbering

scheme (as shown in Figure 3-1) follows the one originally described by the ACOE, New England Division (Bellmer, 1988) and followed by IEP (1988); the letters in parenthesis correspond to the identification scheme referenced in the Sanford Ecological Services (SES, 1988) report. Other tidal wetlands not described in the previously mentioned reports but found in the area have also been described, based on interpretation of 1992 UMass black and white orthophotographs.

Wetland 1 (Wetland B): This long (approximately 4,600 ft (1,400 m)), narrow (maximum width is 600 ft (200 m)) wetland is located along the eastern side of the Acushnet River estuary, about midway between the Coggeshall Street and Wood Street Bridges, occupying approximately 30 acres (12 ha). It has one major tidal creek, 10 to 15 ft (3 to 5 m) wide, and extensive lateral and longitudinal ditching (Bellmer, 1988). SES (1988) identified 21 separate plant communities within this wetland. The two dominant cover types are salt meadow grass and marsh elder, which together cover 80 percent of the vegetated wetland. The tall form of smooth cordgrass covers approximately 18 percent of the remaining vegetated wetland and is restricted to a narrow band less than 165 feet (50 m) wide along the Acushnet River. It has been suggested that the network of mosquito ditches in this wetland may have hydrologically altered habitat conditions such that salt meadow grass has extended its range into the regularly flooded zone. The increased drainage facilitated by the presence of these ditches shortens the period that the site is inundated with higher salinity waters, possibly lowering salinity of the soil pore water (IEP, 1988).

Wetland 2 (Wetlands E, G, F): This 121-acre (49 ha) wetland is located outside the Acushnet River estuary at Popes Beach in southeastern Fairhaven. It has been used as a reference wetland for the other wetlands within the harbor, as its sediments are characterized by relatively low PCB concentrations although the wetland sediments do contain several metals at concentrations significantly above background levels (due to discharges from the Atlas Tack Superfund site).

The hydrology of Wetland 2 has been altered by a roadway constructed on fill and a culvert and floodgate structure which divide the wetland into northern and southern parts. North of the roadway, Wetland 2 (Wetlands G and E) is comprised of seasonally flooded freshwater wetland (primarily woody species) habitats that cover approximately 50 acres (20 ha). Stands of common reed cover 23 percent of the vegetated wetland area primarily north of the floodgate (IEP, 1988). The 71 acres (29 ha) of wetlands south of this roadway (Wetland E) consists of estuarine wetland. Two major creeks, each with mouths at the Outer Harbor of 20 to 23 ft (6 to 7 m) across and 3 to 8 ft (1.0 to 2.5 m) deep, characterize this wetland. A narrow band of tall smooth cordgrass covers about 3 percent of the wetland area along the marsh by edge. Tall and short forms of smooth cordgrass also form minimal 3-ft (1 m) wide bands along mosquito ditches and tidal creeks within the wetland. The estuarine wetland is dominated by salt meadow grass which covers 55 percent of the wetland. Small pannes (flooded depressions) occur within this high marsh where the short form of smooth cordgrass is found. Blackgrass (*Juncus gerardi*) was also determined as a dominant species in this wetland.

Wetland 3 (Wetland A): Wetland 3, located directly north of Wetland 1, is the northernmost wetland studied in the Acushnet River Estuary and is approximately 7 acres (2.8 ha) in size. This wetland is characterized as forming a narrow fringe along the cove it is located in, and has a drainage ditch on its landward side. Three separate plant communities, including the tall form of smooth cordgrass, salt meadow grass, and common reed, each contribute approximately 30 percent of the wetland cover. The remaining area is dominated by marsh elder (6 percent cover).

Wetland 4 (Wetland C): This 9.5-acre (3.8-ha) wetland is located south of Interstate 195 on the east side of Acushnet River Estuary. This wetland has been significantly altered by scattered fills and consists primarily (84 percent) of dense stands of common reed. A narrow band of tall smooth cordgrass occurs

along the intertidal mudflat and occupies approximately 9 percent of the wetland area. Small isolated areas of short form smooth cordgrass and salt meadow grass make up the remaining vegetated wetland areas.

Wetland 5 (not included in SES study): This 3.5-acre (1.4-ha) wetland is located along the west side of the Acushnet River Estuary north of Interstate 195. Evidence of historic alteration of this wetland include abandoned foundations and various fill materials. A narrow (less than 16 ft (5 m wide)) fringe of tall form smooth cordgrass, landward of an intertidal mudflat, occupies approximately 68 percent of the vegetated wetland; salt meadow grass covers approximately 26 percent of the wetland while the remaining cover consists of marsh elder and common reed. Among the wetlands studied by Bellmer (1988), the tall cordgrass area of Wetland 5 exhibited the highest herbaceous biomass.

Wetland 9 (Wetland D): This small (1.7-acre (0.7-ha)) wetland is located south of Wetland 4 (Wetland C) on the east side of the Acushnet River Estuary, approximately 2,500 feet south of the Coggeshall Street Bridge. This wetland is associated with a gravel beach. The dominant plant community is high marsh consisting primarily of salt meadow grass and spikegrass; communities of both tall and short forms of smooth cordgrass also occur in patches. Stands of marsh elder and common reed are also present.

Other Area Wetlands (As depicted in Figure 3-1): Tidal wetlands comprised of both low marsh and high marsh are found along Apponagansett Bay in Dartmouth and South Dartmouth, and on Sconticut Neck and West Island and along Little Bay in Fairhaven. A 150+-acre (60-hectare) marsh and scrub shrub wetland is located on the southwest side of Apponagansett Bay (south of Gulf Road and west of Smith Neck Road), while smaller (between 5 and 20 acres; 2 and 8 hectares) marshes are located along the nothwest portion of Apponagansett Bay (east of Bakerville Road). Other tidal marshes along Apponagansett Bay in Dartmouth include a 16-acre (6.5-hectare) wetland on the northwest side of Ricketsons Point and a 15-acre (6-hectare) area at the intersection of Gulf and Smith Neck Roads. A 40+-acre (16-hectare) marsh is present on Smith Neck (east of Smith Neck Road and north of Green Street), while a 35+-acre (14-hectare) marsh is located approximately midway between Round Hill Point and Mishaum Point. West of Mishaum Point, significant tidal marshes are present in the Little River estuary; more than 110 acres (44 hectares) are located north of the Little River Road bridge (Plummer Memorial Bridge), while another 18+ acres (7 hectares) are situated directly south of Little River Road on the west shore of Mishaum Point. Tidal marshes are also present in the Slocums River estuary, particularly within Demarest-Lloyd Memorial State Park where more than 35 acres (14 hectares) are present east of Barneys Joy Road.

Numerous tidal wetlands (between 4 and 50 acres; 1.6 and 20 hectares) are also present in the southern and eastern portions of Sconticut Neck, while at least four marshes between 10 and 50 acres (4 and 20 hectares) in size are located along the eastern, northern and southern shores of West Island. Salt marsh dominates much of the intertidal habitat of Little Bay, totaling more than 160 acres (65 hectares). Many of these marshes have been altered by mosquito ditching, placement of excavated sidecast soils, micellaneous fills, tidal constrictions due to road construction, unmanaged urban runoff, and other development activities.

Intertidal Flats and Creeks

Shallow water areas which are subject to diurnal tides, exposing mud and sandy bottom substrates are another important type of habitat in Buzzards Bay. These habitats are characterized by a broad range of salinities, temperatures, and tidal and wind driven currents. According to the Buzzards Bay Comprehensive Management Plan, there are more than 5,200 acres (2,100 ha) of intertidal sand and mudflats in Buzzards Bay, with the largest areas found in Westport, Falmouth, Fairhaven, Mattapoisett, and Wareham (US EPA, 1991). Approximately 50 acres (20 ha) of intertidal flats are present in the Acushnet River estuary (Hankin et al., as referenced in US EPA, 1991). Most of these areas consist of fine grained muds and sandy muds

with shell fragments. Indepth studies have been completed, describing the composition of organic and inorganic particulate material in New England tidal flats (Table 3-1). The composition of these substrates is an important factor affecting both macrobenthic faunal and contaminant distribution.

For intertidal flats and nearshore sediments adjacent to the five previously discussed salt marshes within the Acushnet River estuary, Bellmer (1988) measured sediment grain size, determining that silt and clay are the dominant substrate particles. Substrates within the tidal creeks of Wetland 1 along the eastern shore of the estuary were comprised of 62 percent clay and silt, with peat comprising 7 percent. In a nearby reference wetland outside the estuary and next to Popes Beach, intertidal habitat within the tidal creek was coarser-grained, comprised of more than 50 percent sand and 3 percent peat. Peat was present in higher percentages in the intertidal mud banks than in the tidal creek substrates sampled from these salt marsh sites. At Wetland 1, peat comprised 16 percent of the mud banks, while sand comprised 33 percent of this intertidal habitat. The mud banks along the tidal creeks of the Popes Beach wetland were composed of 28 percent peat and 46 percent silty sand.

TABLE 3-1 **DIFFERENT TYPES AND RELATIVE ABUNDANCES OF ORGANIC AND INORGANIC PARTICULATES (IN PERCENT) FOUND IN SANDS AND MUDS OF SOME NEW ENGLAND TIDAL FLAT SEDIMENTS[1]**

Particle Type	Sands	Muds
Organic-mineral aggretates (detritus)	11.3	41.2
Organic-encrusted mineral grains (*e.g.*, bacterial films, diatoms, fungi)	28.2	16.7
Clean mineral grains	51.6	36.1
Vascular plant fragments (*e.g.*, *Zostera marina*, *Spartina alterniflora*)	0.2	1.5
Diatoms	3.1	2.6
Algal fragments	0.7	0.1
Fecal material (fragments and pellets)	3.8	0.8
Meiofauna (*e.g.* copepodes, nematodes)	0.1	0.1
Protozoans (*e.g.*, ciliates, foraminiferans)	0.1	
Molluscan shells and fragments	0.2	0.5
Chitinous molts and fragments	0.3	0.1
Polychaete setae and tubes	0.1	0.1
Pollen, spores, and seeds	0.1	0.1
Rods, spines and spicules	0.2	0.1

[1] Adapted from Whitlach, 1982

3.3.4 Riverine Habitat

The Acushnet River and its tributaries are classified as riverine habitats within the watershed. The river is relatively small, with widths of less than 30 ft (10 m) and depths less than 18 inches (0.45 m) during

average flow conditions. It widens in two impoundment locations: above the Mill Street Dam and above the Hamlin Street Dam in Acushnet (Refer to Figure 3-2). Much of the river is characterized by a sand, gravel, and cobble substrate, as high flows during spring and storm events create erosive conditions that transport sediments and detritus downstream. Behind the dams and in other riverine areas where flow velocities are relatively low, net sediment depositional areas are present and characterized by organic-rich mud and fine sand substrates. The riverine habitat includes intermittent streams with well-defined channels found throughout muxh of the upper, less urbanized watershed.

3.3.5 Non-tidal Wetlands

Although numerous, vegetated wetlands are found in the upper Acushnet River watershed, many of these systems have been adversely affected by clearing, fragmentation and ditching for residential development, roads and utilities; sand and gravel excavation; and the construction of cranberry bogs. Wetland fragmentation and conversion from one cover type to another often results in reduced effectiveness and/or opportunity for ecological functioning (*e.g.*, wildlife habitat, nutrient removal and/or transformation) and societal values (*e.g.*, flood impact abatement, water quality enhancement). Opportunities exist in the watershed to restore some wetlands (particularly wetlands affected by cranberry production and other agricultural practices) and/or create wetlands (by excavating lower value uplands or altering hydrology) near existing wetlands to improve ecological functioning and provide greater values (*e.g.*, wildlife habitat, pollutant removal, flood flow alteration). Identification of potential restoration and/or creation sites would require a more thorough review of appropriate scaled aerial photographs supported by limited field verification. The following is a general overview of the vegetated non-tidal wetlands present in the Acushnet River watershed.

Palustrine Forested Wetlands

Non-tidal wetlands dominated by trees greater than 20 ft (6 m) in height are classified as palustrine forested wetlands or swamps. Forested wetlands found in the Acushnet River watershed are primarily in the upper, less developed portion of the study area (Refer to Figure 3-2 which depicts the MassGIS database for combined upland and wetland forest cover). These wetlands include both broad-leaved deciduous and needle-leaved coniferous forested wetlands. Red maple (*Acer rubrum*) and green ash (*Fraxinus pennsylvanica*) are dominant tree species in many of the seasonally flooded and/or saturated, broad-leaved deciduous wetlands. A detailed ecological description of these wetlands is provided by Golet et al. (1993). White pine (*Pinus strobus*) and Atlantic white cedar (*Chamaecyparis thyoides*) are coniferous tree species that are common in the forested wetlands in the watershed. Often, white pine is a sub-dominant or co-dominant canopy species in seasonally flooded/saturated red maple swamps in the Acushnet River watershed. Atlantic white cedar sometimes occurs as a dominant species, particularly in semi-permanently flooded and permanently saturated sites underlain by thick organic mucks. Laderman (1989) presents a detailed overview of the Atlantic white cedar wetlands found in southeastern New England.

Black and white orthophotographs, date 1992 and at a scale of 1:5,000, were obtained from the Massachusetts Department of Environmental Protection (MADEP) to help in identifying major wetland systems located in the watershed. These orthophotos depict approximate wetland boundaries identified by the MADEP. Additionally, a limited window survey was also completed in February 1996 to verify approximate wetland limits and cover types. A large forested swamp, located along the southwestern shore of Long Pond and directly east of Route 140 that is dominated by red maple and white pine along its perimeter and Atlantic white cedar in the interior, is a classic example of the forested wetlands found in the watershed. Similar cover type forested wetlands include areas in the Fall Brook drainage in the western

portion of the Acushnet watershed; approximately 1,100 acres (445 ha) of floodplain swamp along the Acushnet River directly south of New Bedford Reservoir; the 600+- acre (245-ha) Bolton Swamp between Route 140 and Country Road in Freetown; and the 350-acre (140-ha) Hathaway Swamp which is a broad system located southeast of the Peckham Road-Acushnet Avenue intersection in Acushnet. The Acushnet Swamp, which is actually in the Paskamanset River watershed directly west of Acushnet River watershed, is an expansive Atlantic white cedar-dominated wetland.

Palustrine Scrub-shrub Wetlands

Wetlands dominated by shrubs or saplings less than 20 ft (6 m) in height, and/or which have a trunk diamter at breast height of less than 4 inches (10 cm) are classified as scrub-shrub wetlands or swamps. Scrub-shrub wetlands are prevalent in areas where the forest canopy has been cleared, and in semi-permanently and shallow permanently flooded areas where the hydrology inhibits tree establishment or growth. Scrub-shrub wetlands in the Achushnet River watershed are generally dominated by alders (*Alnus* spp.), highbush blueberry (*Vaccinium corymbosum*), buttonbush (*Cephalanthus occidentalis*), red maple saplings, and willows (*Salix* spp.). Examples of scrub-shrub wetlands in the watershed include a large buttonbush and willow-dominated swamp at the north end of Long Pond adjacent to Assawompset Pond in Lakeville, and a red maple sapling swamp near the impoundment above Hamlin Street in Acushnet.

Palustrine Emergent Wetlands

Palustrine emergent wetlands are freshwater marshes dominated by persistent and/or non-persistent herbaceous plants. These wetlands may include seasonally saturated meadows, pond and lake fringes, and semi-permanently flooded areas lacking woody species cover. Cattail (*Typha* spp.) and grasses are species commonly dominating the watershed emergent wetlands, while duck potato (*Sagittaria* spp.) and pickerelweed (*Pontederia cordata*) are typical non-persistent species. Examples of emergent wetlands occur as fringes along the impoundments off Mill Street and Hamlin Street in Acushnet.

Palustrine Open Water and Lacustrine Wetlands

Small, shallow (less than 6.6 ft (2 m)), freshwater (salinities less than 0.5 ppt) open water bodies lacking significant emergent vegetative cover are classified as palustrine open water. Lacustrine wetlands include those waterbodies larger than 20 acres (8 ha), although waterbodies less than 20 acres (8 ha) in which an active wave-formed or bedrock shoreline is present, or maximum depths exceed 6.6 ft (2 m) are also classified as lacustrine (Cowardin et al., 1979). Within the Acushnet River watershed, palustrine open water habitat includes small natural ponds with mud or mucky substrates and man-made basins created for cranberry production or stormwater management, or resulting from sand and gravel mining. Examples of palustrine open water habitat include the small impoundment north of the Hamlin Street Dam in Acushnet, and the numerous cranberry production and quarry ponds off Braley Road and Route 18 in the northern portion of Acushnet. Long Pond and New Bedford Reservoir are examples of lacustrine wetlands in the watershed.

3.4 DESCRIPTION AND DISTRIBUTION OF BIOTA

3.4.1 Plankton

Camp Dresser & McKee (1990) provided information on phytoplankton and zooplankton sampled from Outer New Bedford Harbor in the vicinity of the New Bedford wastewater treatment plant outfall. In August 1979, the dominant phytoplankton species was *Cyclotella michiganiana*, with small cryptophyte and crysophyte flagellates making up most of the remining populations. Additional sampling was completed by CDM in August and October, 1983, and 60 species of phytoplankton were identified in 40 samples. The total cell densities in the vicinity of the wastewater treatment outfall were similar or higher than densities measured in Narragansett Bay which is considered to have a high abundance of phytoplankton, as compared to most New England waters. These results suggest that excess nutrient releases from New Bedford's wastewater facility were causing at least seasonal phytoplankton blooms. Dominant species were *Skeltonema costatum Chaetocerus* spp., and flagellates.

Forty-eight species of zooplankton were also identified in the waters adjacent to the New Bedford wastewater treatment outfall during August 1979 sampling by CDM (CDM, 1990). Cpoepods (*Acartia* spp.) was the dominant species, followed by *Paracalanus crassirostris*.

Phytoplankton and zooplankton species representative of New Bedford Harbor were also identified in the baseline ecological risk assessment prepared by EBASCO (1990). Dominant phytoplantation species include *Skeletonema costatum*, *Leptocylindrum minimus*, and *Rhizosolenia* spp. (Howes and Geohringer, In Press). Primary phytoplankton production in Buzzards Bay is largely attributed to diatoms. Phytoplankton density typically ranges from 1-2 mg/m^3, although values of 10+ mg/m^3 have been measured in some nutrient-enriched embayments (Roman and Tenore, 1978). Phytoplankton are rincipal food item to many zooplankton, serving as a primary producer in the estuarine food web. Other higher-order grazing estuarine species (*e.g.*, Atlantic menhaden) also feed on phytoplankton.

Phytoplankton populations may seasonally explode in numbers when optimal conditions are present. Warm water temperatures combined with extended sunlight and a nutrient source are factors supporting phytoplankton growth. High nutrient releases such at the New Bedford wastewater treatment plant outfall may result in very high phytoplankton densities, causing increased rates in BOD and localized depressed dissolved oxygen levels.

The copepod, *Acartia tonsa* and two diatoms, *Rhizosolenia alata* and *Skeletonema costatum*, were plankton species considered representative of the study area. Opposum shrimp (*Neomysis americana*), an epibenthic species, was also considered in the ecological risk assessment for the New Bedford Harbor site as representative of the planktonic group because of its size and behavior, similar to zooplankton. Many zooplankton species use phytoplankton as a food source, while zooplankton are principal food items for many macroinvertebrates, larval fishes, and adult planktivores (*e.g.*, bay anchovy).

3.4.2 Benthic Macroinvertebrates

Sanders (1958, 1960) first described the benthic infaunal community of Buzzards Bay, finding shallow protected, nearshore and offshore muddy substrates to be dominated by (*Nephtys incisa)* (a burrowing worm) and *Yolida limatula* (a deposit-feeding pelecypod which re-works sediments, causing significant bioturbation), while sandy substrates in the open bay areas were dominated by *Ampelisca* sp (burrowing,

surface feeding amphipod). The offshore macrobenthic assemblage found in northwestern Buzzards Bay is dominated by *Nassarius trivittatus* (basket shell) and *Y. limatula* (a burrowing pelcypod detribivore) while the shallow, protected areas are dominated by *Crepidula fornicata* (slipper shell), *Nucula proxima* (infaunal mollusc), *Crepidula plana* (slipper shell), *Bittium alternatum*, and *Laevicardium mortoni* (tusk shell) (Howes and Goehringer, In press). Open bay areas are characterized by suspension feeders, carnivores, herbivores, or non-selective deposit feeders including *Nassarius trivittatus* (mud snail), *Chaetopleura apiculata*, (chiton) and *Anachis avara* (a snail). The benthic communities of the more stable, sandy open waters of Buzzards Bay are thought to be more diverse than less stable areas dominated by mud substrates (Sanders, 1958). Howes and Taylor (1989) suggest that the benthic communities found in the central bay are also present in the waters near New Bedford Harbor, and changes in the benthic assemblages in this area is most pronounced in the nearshore areas.

Physical and chemical conditions of bottom substrates are affected by the macrobenthos inhabiting these habitats. The redox state (presence of oxgen) of benthic sediments is due to several factors including the type of benthic community, the bioturbation rate, and the rate of delivery of organic material to the sediments (Howes and Goehringer, In press). Where organic matter input is low or deep-burrowing deposit-feeding communities are present, sediments are generally oxidized. Reduced environments occur in sites with high organic input (*e.g.*, substrates in the vicinity of the wastewater treatment plant outfall) or where shallow burrowing communities only are present. Benthic communities are affected by the input of organic matter or the secondary effects of water column hypoxia or anoxia. These factors can result in lower species diversity, a shallower depth of bioturbation, and an increase in the reduced (low or no oxygen) sulfidic zone within the bottom sediments. Uncertainty remains over to what extent natural changes versus anthropogenic organic inputs affect macrobenthic species diversity and abundance in Buzzards Bay.

Based on Whitlach (1982), a list of the infaunal invertebrates found in Buzzards Bay has been prepared, along with their specific habitats, living mode and feeding mode (Table 3-2). Habitats vary from muds and fine sands to eelgrass beds and wrack material. Of the 154 infaunal species identified, 66 percent are burrowers, while 23 percent are surface tube dwellers. The remaining 11 percent live at the surface, are subsurface tube dwellers, live in U-shaped burrows, or are combinations of the previous categories. Approximately 54 percent of the species are deposit feeders, particularly the annelid worms. Another 10 percent are suspension feeders, while the remaining species are carnivores, grazers, omnivores use some combination of these feeding mechanisms.

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Crustacea					
Cumacea	***Oxyurostylis smithi***	cumaceans	Estuarine muddy sands	B	DF
	Mancocuma stellifera		Sands	B	DF
	Almyracuma proximoculi		Especially muddy sands	B	DF
	Diastylis polita		Sands	B	DF
Isopoda	*Edotea triloba*	rock lice, sea slaters	Ubiquitous	B	DF
	Cyanthura polita		Ubiquitous	B	DF/C
	Chirodotea coeca		Primarily sands	B	DF/C
Amphipoda	*Gammarus mucronatus*	sand fleas, scuds,	Estuarine muds	B	DF/G
	Gammarus lawrencianus	skeleton shrimps	Sands, sandy muds	B	DF/G
	Gammarus palustris		Estuarine muds	B	DF/G
	Gammarus oceanicus		Estuarine muds	B	DF/G
	Monoculodes edwardsi		Sands	B	DF
	Ampelisca macroscephala		Sands	T-S	SF/DF (?)
	Ampelisca vadorum		Coarse sands	T-S	SF/DF (?)
	Microdeutopus gryllotalpa		Near eelgrass beds	T-S	DF
	Microdeutopus anomalus		Muds	T-S	DF
	Leptocheirus pinguis		Sands, sandy muds	T-S	DF
	Leptocheirus plumulosus		Estuarine muds	T-S	DF
	Corophium insidiosum		Sandy muds	T-S	DF/SF (?)
	Corophium tuberculatum		Sandy muds	T-S	DF/SF (?)
	Corophium acutum		Muds and sands	T-S	DF/SF (?)

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Amphipoda (Cont.)	*Haustorius canadensis*	sand fleas, scuds,	Common in sands	B	DF
	Acanthohaustorius millsi	skeleton shrimps	Sands	B	DF
	Pseudohaustorius caroliniensis		Sands and muds	B	DF
	Amphiporeia virginiana		Estuarine sands	B	DF
	Neohaustorius biarticulatus		Sands	B	DF
	Neohaustorius schmitzi		Sands, especially beaches	B	DF
	Phoxocephalus holbolli		Sands, sandy muds	B	DF
	Trichophoxus epistomus		Fine sands	B	DF
	Psammonyx nobilis		Sands	B	DF/SF
	Talorchestia megalophthalma		Sands	B	DF
	Talorchestia longicornis		Fine sands	B	DF
	Orchestia grillus		Commonly under wrack	B	DF
	Melita nitida		Estuarine muds		
	Amphithoe valida		Estuarine muds	T-S	G
	Amphithoe longimana		Estuarine muds	T-S	G
Tanaidacea	*Leptochelia savignyi*	tanaid	Muds, sandy muds	T-S	DF
Sipuncula	*Phascolopsis gouldii*	peanut worm	Primarily in sands	B	DF
Nemertea	*Micrura leidyi*	ribbon worms	Sands	B	C
	Cerebratulus lacteus		Sandy muds	B	C
	Amphiporus ochraceus		Sands and muds	B	C
	Amphiporus griseus		Sand and muds	B	C
	Lineus spp.		Muds and sands	B	DF
Bivalvia	*Mya arenaria*	softshell clam	Muddy sands, muds	S	SF

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Bivalvia (cont.)	*Macoma balthica*	Baltic macoma	Estuarine muds	S	DF
	Mercenaria mercenaria	hard clam, quahog	Sands, sandy muds	S	SF
	Gemma gemma	gem clam	Fine sands	S	SF
	Tellina agilis	northern dwarf tellin	Sands	S	DF
	Spisula solidissima	surf clam	Sands, mostly beaches	S	SF
	Lyonsia hyalina	glassy lyonsia	Fine sands, muddy sands	S	SF
	Solemya velum	Atlantic awning clam	Fine sands	S	SF
	Laevicardium mortoni	Morton egg cockle	Fine sands, muddy sands	S	SF
	Montacuta elevata	montacutid	Commensal with *Clymenella torquata*	S	SF
	Enis directus	Atlantic jacknife	Sands	S	SF
	Petricola pholadiformis	false angelwing	Common in peat	S	SF
	Mysella planulata	plate mysella	Sands, muddy sands	S	SF
Holothuroidea	*Lyptosynapta tenuis*	sea cucumber	Sands	B	DF
Annelida					
Capitellidae	*Capitella capitata*	capitellid threadworms	Ubiquitous	B	DF
	Heteromastus filiformis		Ubiquitous	B	DF
	Mediomastus ambiseta		Muds	B	DF
Orbiniidae	*Scoloplos robustus*	polychaete worms	Sands and muds	B	DF
	Scoloplos acutus		Sands and muds	B	DF
	Scoloplos fragilis		Sands and muds	B	DF
	Orbinia ornata		Sands and muds	B	DF

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Nereidae	*Nereis virens*	segmented worms	Estuarine muds	B	O
	Nereis acuminata		Sands and muds	B	O
	Nereis succinea		Estuarine muds	B	O
	Nereis pelagica		Ubiquitous	B	O
Chaetopteridae	*Spiochaetopterus oculatus*	U-shaped burrower	Sands	T-S	SF/DF (?)
Dorvilleidae	*Protodorvillea gaspeensis*	burrowing polychaetes	Muds and sands	B	O
	Schistomeringos caecus		Muds and sands	B	O
Eunicidae	*Marphysa sanguinea*	burrowing polychaete	Muddy sands, mud	B	DF/O
Opheliidae	*Ophelina bicornis*	segmented burrowing worm	Sands	B	DF
Ctenodrilidae	*Ctenodrilus serrata*	burrowing polychaete	Sands and sandy muds	B	DF
Polynoidae	*Harmothoe imbricata*	predatory polychaetes	Muddy sands, muds	S	C/S
	Lepidonotus squamatus		Muddy sands, muds	S	C/S
Maldanidae	*Clymenella torquata*	subsurface deposit-feeding polychaete	Sands	T-SS	DF
Lumbrineridae	*Lumbrineris impatiens*	scavenger polychaetes	Sands and muds	B	DF/SF
	Lumbrineris tenuis		Sands and muds	B	DF/SF
	Lumbrineris fragilis		Muddy sands, muds	B	DF/SF
	Ninoe nigripes		Sands and muds	B	DF/SF

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Phyllodocidae	*Eteone lactea*	burrowing polychaetes	Muddy sands	B	DF/O
	Eteone longa		Muddy sands	B	DF/O
	Eteone heteropoda		Ubiquitous	B	DF/O
	Phyllodoce mucosa		Muddy sands	B	DF/O
	Phyllodoce groenlandica		Sands	B	DF/O
	Phyllodoce arenae		Sands	B	DF/O
	Paranaitis speciosa		Ubiquitous	B	DF/O
	Eulalia viridis		Sands and muds	B	DF/O
	Eumida sanguinea	burrowing polychaete	Muds	B	DF/O
Paraonidae	*Paranonis fulgens*	burrowing polychaetes	Sands	B	DF
	Aricidea catherinae		Sands and muds	B	DF
Nephtyidae	*Nephtys picta*	burrowing predatory polychaetes	Sands	B	C
	Nephtys caeca		Sands	B	C
	Nephtys ciliata		Muds and sands	B	C
	Nephtys bucera		Sands, muddy sands	B	C
Glyceridae	*Glycera dibranchiata*	burrowing predatory polychaetes	Sands and muds	B	C/DF
	Glycera capitata		Sands and muds	B	C/DF
	Glycera americana		Sands and muds	B	C/DF
Hesionidae	*Microphthalmus sczelkowii*	burrowing grazing polychaetes	Sands and muds	B	DF/G
	Microphthalmus aberrans		Sands	B	DF/G
	Podarke obscura		Muddy sands	B	DF/G

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Pectinariidae	*Pectinaria gouldii*	ice-cream cone worm	Sandy muds	T-SS	DF
Sabellidae	*Sabella micropthalana*	feather-duster worms	Near Zostera beds	T-S	SF
	Potamilla neglecta		Near Zostera beds	T-S	SF
	Fabricia sabella		Near Zostera beds	T-S	SF
Arabellidae	*Drilonereis longa*	burrowing predatory polychaetes	Sands and muds	B	DF
	Drilonereis magna		Ubiquitous	B	DF(?)
	Arabella iricolor		Mostly sands, muddy sands	B	DF(?)
Arenicolidae	*Arenicola marina*	L-shaped burrowing pugworm	Sandy muds, muds	U-B	DF
	Diopatra cuprea	tube-dwelling polychaete	Sands and muds	T-S	C
Pilargiidae	*Sigambra tentaculata*	burrowing polychaete	Shelly muds	B	O(?)
Syllidae	*Parapionosyllis longicirrata*	burrowing polychaetes	Muddy sands	B	O
	Exogone hebes		Sands, muddy sands	B	O
	Exogone dispar		Sands	B	O
	Syllis cornuta		Ubiquitous	B	O
	Syllis gracilis		Ubiquitous	B	O
	Syllides longocirrata		Primarily sands	B	O
	Brania clavata		Sands and muds	B	O
	Brania wellfleetensis		Muddy sands	B	O

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Syllidae (cont.)	*Streptosyllis arenae*		Sands	B	O
	Streptosyllis varians		Sands	B	O
Cirratulidae	*Caulleriella* spp.	shallow-water detritivores	Sandy muds, muds	B	DF
	Tharyx spp.		Sands, muds with shell	B	DF
	Chaetonzone spp.		Sands	B	DF
	Cirriformia spp.		Muds	B	DF
Megelonidae	*Magelona rosea*	burrowing polychaete	Sands	B-S	DF
Ampharetidae	*Melinna cristata*	tube-dwelling polychaetes	Estuarine muds	T-S	DF
	Ampharete artica		Muds	T-S	DF
Spionidae	*Streblospio benedicti*	thin-bodied, soft	Ubiquitous	T-S	DF
	Polydora ligni	tube-dwelling polychaetes	Ubiquitous	T-S	DF
	Polydora caulleryi	(mud worms)	Muddy sands, muds	T-S	DF
	Polydora quadrilobata		Sandy muds	T-S	DF
	Polydora socialis	thin-bodied, soft tubes	Muds	T-S	DF
	Scolecolepides viridis	dwelling polychaetes	Estuarine muds	T-S	DF
	Spio setosa		Sands and muddy sands	T-S	DF
	Scolelepis squamata		Sands	T-S	DF
	Spiophanes bombyx		Sands	T-S	DF
	Prionospio heterobranchia		Sands, muddy sands	T-S	DF
	Prionospio steenstrupi		Muds	T-S	DF
	Pygospio elegans		Sands	T-S	DF
	Dispio uncinata		Sands	T-S	DF
	Boccardia hamata		Muds	T-S	DF

TABLE 3-2
COMMON INFAUNAL INVERTEBRATES ASSOCIATED WITH BUZZARDS BAY TIDAL FLATS[1]

Taxonomic Group	Scientific Name	Common Name	Habitat[2]	Living Mode[3]	Feeding Mode[4]
Terebellidae	*Polycirrus eximius*	polychaete with permanent	Muds	B-S	DF
	Amphitrite ornata	tubes	Muds	T-S	DF
	Pista maculata		Estuarine muds	T-S	DF
	Nicolea zostricola		Muds	T-S	DF
	Enoplobranchus sanguinea		Muds	T-S	DF
Oligochaeta	*Marionina spicula*	burrowing worms	Sands	B	DF
	Marionina achaeta		Sands	B	DF
	Marionina southerni		Sands	B	DF
	Marionina preclitellochaeta		Sands	B	DF
	Marionina subterranea		Sands	B	DF
	Peloscolex benedeni		Sands	B	DF
	Peloscolex gabriella		Sands and muds	B	DF
	Phallodrilus monospermathecus		Sands	B	DF
	Paranais litoralis		Sands	B	DF
	Enchytraeus capitatus		Sands	B	DF
	Monopylephorus irroratus		Sands	B	DF

[1] Adopted from Whitlach, 1982.
[2] Habitat: Sediment type where species are most commonly found.
[3] Living Mode: B = burrow; S = feeding on or slightly above sediment surface; T = tube dweller; SS = subsurface feeders;U-B = U-shaped burrow
[4] Feeding Mode: DF = deposit feeder; SF = suspension feeder; C = carnivore; G = grazer; O = omnivore

Howe and Geohringer (In Press) provide a discusion of the dominant macrofauna (and macroflora) found in three intertidal substrate types in Buzzards Bay. Polychaete species are most prevalent in soft-bottom substrates, polychaetes and crustaceans in hard-bottom substrates, and crustaceans and gastropods in rocky intertidal habitats (Table 3-3).

To determine the effects of pollution on benthic community structure in New Bedford Harbor, Bellmer (1988) collected 78 grab samples from 26 stations (triplicate sampling at each station) distributed throughout the upper estuary, Inner Harbor, and Outer Harbor in September 1986. A total 199 taxonomic groups were identified, with more than 40 percent of the taxa represented by polychaetes, 29 percent by molluscs, 11 percent by oligochaetes, and 10 percent by crusteceans. The number of species sampled from these stations ranged from 2 to 51 with a mean of 16 species.

Although no single species was caught at all sampling stations, several dominant species were identified including *Streblospio benedicti*, (an early colonizing mud worm of highly disturbed habitats), *Odostomis seminuda* (odostome pyramid shell), *Tharyx acutus* (a cerratulid worm), Tubificoides sp. (tubiferid worms), and *Mediomastus ambiseta* (a thread worm). In general, the upper estuary was dominated by *Streblospio benedicti* (and *Pectinaria gouldii* (trumpet worm) and *Nereis succinea* (common clam worm) according to SES, 1988); the Inner Harbor dominated by *Tharyx acutus*; and the Outer Harbor dominated by bivalves and gastropods (*e.g.*, *Odostomis seminuda*, *Tellina agilis*). In total, 19 dominant benthic species were identified (Table 3-4). The results of the sampling of benthic organisms and sediments for contaminant levels indicated that a decrease in benthic species diversity within the study area was most highly correlated with increased levels of PCBs, mercury, and arsenic in the sediments. No conclusions were drawn on the effects of physical conditions (*e.g.*, sediment grain size) or other chemical parameters (*e.g.*, sediment redox (oxygen) levels) on benthic species diversity or abundance. In general, benthic macroinvertebrate species diversity increased from the upper estuary south through the Outer Harbor.

During field investigations between 1985 and 1987, Bellmer (1988) observed abundant ribbed mussels (*Geukensia demissa*) in the salt marshes within the Acushnet River estuary. Within the salt marsh located on the eastern shore of the estuary, about midway between the Coggeshall and Wood Street Bridges (Wetland 1), dense aggregates of ribbed mussels were observed in the peat banks, approximately 6 to 12 inches (15 to 30 cm) above the intertidal flats, creeks and ditches. Abundant ribbed mussels were also observed within the regularly flooded *Spartina alterniflora* zone of the other Acushnet River estuary wetlands and the reference wetland located outside of the harbor. Soft-shelled clam (*Mya arenaria*) were also abundant in the sandy intertidal flats adjacent to Wetland 5 which is located in a cove on the west side of the estuary, approximately 2,500 ft (760 m) north of the Coggeshall Street Bridge. The presence of soft-shelled clams suggests that relatively high dissolved oxygen levels were present in these habitats.

During June and September 1987, Bellmer (1988) sampled (1 liter cores) mud bank and tidal creek habitats within a salt marsh on the eastern shore of the harbor (Wetland 1) and a nearby reference salt marsh outside the harbor, proximate to Popes Beach (Wetland 2) for the presence and abundance of macroinvertebrates. The results of these surveys were analyzed to determine if the two sites had significant differences in the abundance of annelids, oligochaetes, *Polydora ligni*, and *Mya arenaria*; taxa number; and biomass. Shellfish were also sampled from intertidal flats next to these two marsh sites.

TABLE 3-3
DOMINANT SOFT-BOTTOM, HARD-BOTTOM AND ROCKY INTERTIDAL COMMUNITIES IN BUZZARDS BAY[1]

Substrate Type	Scientific Name	Common Name	Class or Phylum[2]
Soft Bottom	*Nucula proxima*	Nut clam	Bivalvia
	Nephthys incisa	Red-lined worm	Polychaeta
	Ninoe nigripes	Lumbrinerid worm	Polychaeta
	Cylichna orzya	Minute bubbleshell	Gastropoda
	Callocardia morrhuana		Crustacea
	Hutchinsoniella	Cephalocarid	Crustacea
	Lumbrineris tenuis	Lumbrinerid thread worm	Polychaeta
	Turbonilla sp.	Turbonillid pyramid shell	Gastropoda
	Spio filicornis	Spionid mud worm	Polychaeta
	Retusa canaliculata	Channeled bubbleshell	Gastropoda
	Stauronereis caecus	Burrowing worm	Polychaeta
Hard Bottom	*Ampelisca spinipes*	Four-eyed amphipod	Crustacea
	Byblis serrata	Four-eyed amphipod	Crustacea
	Cerastoderma nulatum[3]	Little cockle	Bivalvia
	Ampelisca macrocephala	Four-eyed amphipod	Crustacea
	Glycera americana	Bloodworm	Polychaeta
	Nephthys bucera	Red-lined worm sp.	Polychaeta
	Tellina agilis	Fragile wedge clam	Bivalvia
	Ninoe nigripes	Lumbrinerid tread worm	Polychaeta
	Lumbrineris tenuis	Lumbrinerid tread worm	Polychaeta
	Nephys incisa	Red-lined worm	Polychaeta
	Molgula complanata	Sea grape	Tunicata
	Unicola irrorata	Tube-dwelling amphiod	Crustacea
Rocky Intertidal	*Semibalanus balanoides*	Acorn barnacle	Crustacea
	Balanus balanus	Large rock barnacle	Crustacea
	Carcinus maenas	Little green crab	Crustacea
	Cancer irroratus	Rock crab	Crustacea
	Pagurus longicarpus	Long-clawed hermit	Crustacea
	Littorina littorea	Common periwinkle	Gastropoda
	Littorina obtusata	Round (Obtuse) periwinkle	Gastropoda
	Littorina saxatilis	Rough periwinkle	Gastropoda
	Mytilus edulis	Blue mussel	Bivalvia
	Modiolus modiolus	Horse mussel	Bivalvia
	Crepidula fornicata	Slipper shell	Gastropoda
	Nereis virens	Clam worm	Polychaeta
	Ascophyllum nodosum	Knotted wrack	Phaeophyta
	Fucus vesiculosus	Rockweed	Phaeophyta
	Chondrus crispus	Irish moss	Rhodophyta

[1] Adapted from Howes and Geohringer (In Press).
[2] Phyla are listed for seaweeds, classes for other species.
[3] Because *Cerastoderma* populations are highly seasonal, it is not considered to be a good characterizing species for this community.

TABLE 3-4 DOMINANT BENTHIC MACROIVERTEBRATES SAMPLED FROM NEW BEDFORD HARBOR IN DECREASING ORDER OF ABUNDANCE[1]

Scientific Name	Common Name
Streblospio benedicti	Bar-gilled mud worm
Eteone heteropoda	Freckled paddle worm
Nassarius obsoletus	Eroded basketshell snail
Podarke obscura	Swift-footed worm
Tharyx acutus	Cerratulid worm
Polydora ligni	Whip mud worm
Mercenaria mercenaria	Hard clam or quahog
Mulinia lateralis	Dwarf surf clam
Mediomastus ambiseta	Thread worm
Tubificoides sp.	Annelid worms
Weteromastus filiformis	
Pectimaria gouldii	Trumpet worm
Lumbrinerus tenis	Lumbrinarid thread worm
Nereis succinea	Common clamworm
Odostomia seminuda	Odostone pyramid shell
Tellina agiluis	Fragile wedgeclam
Brania welfleectensis	Sylid worm
Capitella capitata	Capitellid thread worm
Eobrolgus spinosus	

[1] Adopted from Bellmer, 1988

Wetland 1 tidal creeks were dominated by opportunistic surface deposit feeders and shallow burrowing deposit feeders (oligochaetes and *Capitella* sp.). During September, *Streblospio benedicti*, a spionid, was also abundant in the tidal creek habitat. Species richness was three times higher in Wetland 2 than Wetland 1, and the most frequently observed taxa are typical estuarine surface and subsurface deposit feeders. In particular, the tidal creek stations inWetland 2 contained three to four times more species of polychaetes and bivalves than the creek stations sampled in Wetland 1 throughout the sampling period. Macroinvertebrate numbers often exceeded $100/m^2$ in Wetland 2, and soft-shelled clams were abundant in the tidal creeks of this wetland. Sediment grain size and the presence of macroalgae were factors influencing species abundance in the tidal creeks; *Mya arenaria*, *Scoloplos* sp., *Scolecolepides* sp., and syllidae were more abundant in stations dominated by gravel versus those stations characterized by medium sand. The presence of herbiverous benthic organisms (*e.g.*, *L. littorea*, *G. inucronatus*) was associated with the presence of macroalgae. In general, no patterns were observed in annelid biomass for any of the tidal creek sampling sites.

Thirty benthic species were recorded from the mud banks in Wetland 1; 10 of these were polychaetes and 7 were amphipod species. The mud banks sampled in Wetland 1 contained significantly more taxa than the tidal creek stations sampled in this wetland. Oligochaetes, *Fabricia sabella*, *Capitella* sp., and *S. benedicti* were the dominant species in Wetland 1 during both June and September sampling periods. Amphipods, bivalves, and gastropods were also moderately abundant during both sampling periods, except for

gastropods which decreased in abundance in September. Similarly, oligochaetes and *F. sabella* were the dominant organisms in the Wetland 2 mud bank stations sampled in June and September; *P. ligni* was also abundant. A total 61 species were recorded from Wetland 2 mud banks, comprised mainly of polychaetes, amphipods, and bivalves. Bellmer (1988) suggests that the higher benthic species diversity in Wetland 2 mud banks versus those in Wetland 1 may have been attributed to a higher proportion of organic matter and fine-grained sediments which enhance habitat for deposit feeders and detritivores.

In general, there were no significant differences between the mud bank habitats sampled in each of the two wetland sites, and all sampling stations were characterized by relatively few species (particularly annelids such as *F. sabella*) with high abundances and low abundance of the remaining species. The presence of patchy clusters of mussels was a factor increasing the number of benthic taxa sampled from the mud banks, as these mussel colonies provided microhabitat for other species such as *Neresis succinea*, *Petricola pholadiformis*, *Edotea triloba*, and *Hiatella* sp. A higher macroinvertebrate biomass was associated with the presence of large bivalves; biomass measured in theWetland 2 stations were more influenced by the abundance of *N. succinea* and *F. sabella*.

Ten species of molluscs and 13 other shellfish species were collected from Wetlands 1 and 2 during the 1987 sampling. Ribbed mussel was the only bivalve species sampled from Wetland 1 tidal creek habitat. Tidal creeks in Wetland 2 were characterized by abundant soft-shelled clam, hard clam (*Mercenaria mercenaria*), and Baltic macoma (*Macoma balthica*); the higher abundance in Wetland 2 sampling stations was attributed to the prevalence of large-sized substrate sediments. The marsh crab (*Sesarma reticulatum*) and fiddler crab (*Uca pugnax*) were collected from the mud banks of Wetland 1, while xanthid crabs (*Rhithropanopeus harrisii* and *Neopanope sayi*) were collected from Wetland 2. These results indicate that Wetland 2 is influenced more by tidal flushing than is Wetland 1. Tidal flushing increases the opportunity for transport of fine-grained sediments and organic matter to and from the site; input of well-oxygenated waters; and plankton and other food items for macrobenthos inhabiting this area.

Although limited quantitative data are available on the distribution and abundance of bivalves in the Inner Harbor, quahogs are known to occur in high densities, while oysters and bay scallops are present in lower numbers (B. Borque, pers. comm.). Quahogs, soft-shelled clams, and oysters have been sampled from waters near Palmers Island. High numbers of quahogs have also been noted in the vicinity of the Fort Rodman waste treatment plant, and the high densities in this area may be attributed to the fishery closure in this area or dense plankton populations associated with the elevated nutrient levels from the outfall. The abundance of quahogs in both the Inner and Outer Harbors was documented by Bellmer (1986); *Mercenaria mercenaria* was recorded as the seventh most abundant macroinvertebrate of the 199 taxa sampled from 22 stations throughout the Upper Acushnet River estuary and Inner and Outer Harbor during September 1987.

In 1987, SES (1988) identified epifaunal species present in the estuary and harbor area. Common periwinkle (*Littorina littorea*), slipper limpet (*Crepidula fornicata*), barnacles (*Balanus* sp.), and American oyster (*Crassostrea virginica*) were attached to rocks along the shoreline directly south of the Coggershell Street Bridge. Mudsnail (*Ilyanassa obsoleta*) were found in dense aggregations on the mud flats in the upper estuary. Fiddler crabs (*Uca pugnax*) were observed in all vegetated tidal wetlands except Wetland 1. Amphipods (*Orchestia* sp.), isopods (*Edotea* sp.) and salt marsh snail (*Melampus bidentatus*) were found in all of the Acushnet tidal wetlands.

In December 1972, three hauls of a small otter trawl were taken in the lower Inner Harbor between Popes Island and the hurricane barrier (Hoff et al., 1973). Twenty-seven epifaunal species were collected with the most abundant species including barnacle (*Balanus amphitrite nivenus*), slipper shell (*Crepidula fornicata*), slipper limpet (*C. plana*), serpulid tube worms (*Hydroides dianthus, Filograna implexa, Spirobis spirillum*), shipworm (*Toredo navalis*), mud crab (*Neopanope texana*), and blue crab (*Callinectes*

sapidus). The dominance of these species indicates that the substrate sampled was comprised of coarser-grained materials.

Camp Dresser & McKee (1990) reported the results of macrobenthic studies for the upgrading of New Bedford's wastewater outfall. Macrobenthos were sampled stations in the vicinity of the existing outfall, and other more southerly stations, extending as far south as a site in Upper Buzzards Bay (the 301 (h) Site), about 0.5 miles (0.8 km) south of Negro Ledge (Refer to Figure 3-1). As expected, opportunistic, pollutant-tolerant species were dominant in the stations closest to the outfall. During the 1988-1989 sampling, polychaete worms (*Mediomastus ambiseta, Carazziella hobsonae*) and surf clam (*Mulinea llateralis*) comprised 83 percent of the fauna sampled from the outfall area. The greatest macrobenthic species diversity was sampled from stations at an intermediate distance from the outfall, and was attributed to a settling of organic material that was high enough to attract benthic organisms but not at excessive concentrations that would cause organism stress.

In comparison to the outfall stations, the 301 (h) Site station was dominated by the nut clam (*Nucula annulata*) and two polychaetes (*Nepthys incisa, Levinsenia gracilis*), species common to soft-bottomed habitat of Buzzards Bay and previously reported by Sanders (1958). Camp Dresser & McKee (1990) suggested that the macrobenthos in this location was showing no sign of stress from the waste discharges coming from the New Bedford facility.

To complete the baseline ecological risk assessment for New Bedford Harbor, EBASCO (1990) identified representative ecological communities and species of concern which are subject to potential risk by PCB and metal contamination in five selected zones (as based generally on contaminant concentrations and the location of known man-made or natural features) of the Acushnet River estuary, the Inner Harbor, and the Outer Harbor. Five groups of organisms representative of the major ecotypes in the harbor were selected. For these groups, the habitat location (*i.e.*, benthic versus pelagic), organism lifestage, and feeding method (*e.g.*, filter feeder, deposit feeder, carnivore) of the typical taxa of each group were used to define the primary contaminant exposure route. The species of concern were selected based on their distribution within the study area, trophic level, the value of the species as a commercial or recreational resource, and the availability of information on the species. Of the five taxa groups, three were macroinvertebrate groups: crustaceans, molluscs, and annelids. A total of 19 representative macrobenthic species were selected from these groups.

Lobster (*Homarus americanus*) is one of the largest macroinvertebrates found in the study area, and was considered the top predator in the risk analysis using a three level food chain model for the New Bedford Harbor NPL site (Battelle Memorial Institute, 1990). Existing information from stomach content analyses were used in the simulation model study, indicating that the major prey items of lobster in the area include small crustaceans (primarily crabs), molluscs (particularly mussels), polychaetes, and echinoderms.

Data are lacking indicating the presence and abundance of lobster in New Bedford Harbor. Based on previous information on substrate types and other environmental conditions, it is probable that the abundance of lobsters increases from the Inner Harbor south to the Outer Harbor and Upper Buzzards Bay. Highest densities of adult and juvenile lobster are associated with sandy substrates with overlying flattened rocks (MacKenzie and Moring, 1985). Where rocky structures with crevices are unavailable, lobster create shelters by excavating under objects resting on the seafloor. Higher lobster densities are likely found in the vicinity of the hurricane barrier where habitat structure is available; within the navigational channel at the hurricane barrier opening where sands and gravelly sands are present (Refer to Figure 3-3); and in the Outer Harbor where sandy and gravelly substrates and rock outcrops are found.

Lobsters found in inshore waters tend to have limited home range. Mark-and-recapture studies reveal that most juvenile and adult lobsters move less than 5 miles (8 km) and generally less than 1.3 miles (2.2 km)

(MacKenzie and Moring, 1985). Lobsters inshore temporarily move to deeper waters (increased depths up to 33 ft (10 m)) when storms generate heavy seas.

The shallow, relatively warm waters of Buzzards Bay are a principal New England lobster spawning and nursery area, based on the results of a 3-year neuston sampling study completed by the Massachusetts Division of Marine Fisheries (MDMF). Eleven stations were sampled by the MDMF in Buzzards Bay between 1976 and 1978, with the mouth of Sippican Harbor being the closest station (Station "2") to New Bedford Harbor (Sippican Harbor is approximately 10 miles (16 km) northeast of New Bedford Harbor) (Collings et al., 1981). Results indicated that larvae were most abundant in Buzzards Bay in the surface water layer with average seasonal densities during this period ranging from 7.4 to 8.7 larvae per 1,000 m^3, while maximum densities ranged from 79 to 266 larvae per 1,000 m^3. Lobster larval hatching in much of Buzzards Bay commences in the third week of May; peak larval densities are present in the water column during late June; and larvae settle out of the water column by mid-August. The optimal temperature for Stage I lobster larvae in the Bay was determined to be 20°C. Winds influence the presence and density of lobster larvae found in the surface water layer. Although the MDMF study did not include sampling of the New Bedford Harbor area, it is probable that Outer New Bedford Harbor and nearby waters serving as lobster recruitment areas. The presence of the hurricane barrier likely severely restricts transport of lobster larvae into the Inner Harbor.

3.4.3 Finfish

According to the National Oceanic and Atmospheric Administration, at least 42 species of estuarine, marine, anadromous, and catadromous finfish inhabit Buzzards Bay and its estuaries (Table 3-5). Eighteen specied (43 percent) are considered
common, while 10 (24 percent) are categorized as rare, 8 (19 percent) considered abundant, and 6 (14 percent) considered highly abundant. The numbers of species present in Buzzzards Bay waters with normal seawater salinities (25 to 33 ppt) versus mixing zone waters (0.5 to 25.0 ppt) are very similar; only slightly fewer species during their larval stage are present in mixing zone waters (Stone et al., 1994).

Estuarine and Marine Fishes

Between February and May 1972, 71 ichthyoplankton net tows were completed by Giovani (1973) within and between the Acushnet River and Westport River estuaries. Larvae of nine taxa were collected including sand lance (*Ammodytes* americanus), sculpin species (*Myoxocephalus* spp.), winter flounder (*Pleuronectes americanus*), Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), pollack (*Pollachius virens*), tomcod (*Microgadus tomcod*), snakebelly gunnel (*Lumpenus lumpretaeformis*), sea snail (*Liparis atlanticus*), rock gunnel (*Pholis gunnellus*), and fourbeard rockling (*Enchelyopus cimbrius*). Sampling results also revealed eggs from ten species including fourbeard rockling, cunner (*Tautogolabrus adspersus*), tautog (*Tautoga onitis*), windowpane flounder (*Scophthalmus aquosa*), Atlantic cod, haddock (*Melanogrammus aeglefinus*), hake species (*Urophysis* sp.), and yellowtail flounder (*Limanda ferruginea*).

Trawl collections were also completed in the lower Inner Harbor during December 1972 and April and December 1973, and in the Outer Harbor during December 1972 (Hoff et al., 1973). In December 1972, windowpane and winter flounder were the most abundant species collected in both the Inner Harbor and Outer Harbor, with higher catches from the Inner Harbor. Eight species were collected from the Inner Harbor, while six species were collected from the Outer Harbor.

Other ichthyofaunal studies have been completed in Buzzards Bay, and may represent species distribution patterns in the vicinity of New Bedford Harbor. The MDMF completed surveys between 1976 and 1979, sampling finfish eggs, larvae, and juveniles from three stations in eastern Buzzards Bay (Collings et al., 1981). Egg densities peaked during the summer, with the highest number of eggs associated with Atlantic

menhaden (*Brevoortia tyrannus*), scup (*Stenotomus chrysops*), weakfish (*Cynoscion regalis*), cunner (*Tautogolabrus adspersus*), and yellowtail flounder (*Limanda ferruginea*). Larval densities peaked in June for all years sampled, with the highest numbers of larvae being cunner and tautog (*Tautoga onitis*). Examples of species that were captured in Buzzards Bay but not in the colder waters of Cape Cod Bay or the Cape Cod Canal include searobins (*Prionotus* sp.), sea bass (*Centropristis striata*), weakfish, butterfish (*Peprilus triacanthus*), and Atlantic menhaden.

During the summer of 1987, Bellmer (1988) sampled fish populations from the shallow water habitats proximate to salt marshes within the harbor. Seine and bait trapping techniques were used in capturing fish species, and the stomach contents of mummichog (*Fundulus heteroclitus*) and winter flounder were sampled to determine diet composition. Sixteen fish species were captured, with Atlantic silverside (*Menidia menidia*) and mummichog (*Fundulus heteroclitus* and *F. majalis*) the most abundant species found in the estuary.sampling sites. *Fundulus heteroclitus* were more abundant in the upper estuary, particularly in Wetland 1. *Fundulus majalis* were more abundant in the lower estuary (Wetlands 2 and 9). Winter flounder were only caught in Wetland 2.

TABLE 3-5 BUZZARDS BAY FISH AND MACROINVERTEBRATES AND THEIR RELATIVE ABUNDANCES[1]

Common Name	Scientific Name	Relative Abundance[2]
Blue mussel	*Mytilus edulis*	HA
Bay scallop	*Argopecten irradians*	A
American oyster	*Crassostrea virginica*	C
Northern quahog	*Mercenaria mercenaria*	HA
Softshell clam	*Mya arenaria*	A
Daggerblade grass shrimp	*Palaemonetes pugio*	HA
Sevenspine bay shrimp	*Crangon septemspinosa*	HA
American lobster	*Homarus americanus*	A
Blue crab	*Callinectes sapidus*	C
Skates	*Raja* species	A
Cownose ray	*Rhinoptera bonasus*	R
Atlantic sturgeon	*Acipenser oxyrhynchus*	R
American eel	*Anguilla rostrata*	A
Blueback herring	*Alosa aestivalis*	C
Alewife	*Alosa pseudoharengus*	C
American shad	*Alosa sapidissima*	R
Atlantic menhaden	*Brevoortia tyrannus*	HA
Atlantic herring	*Clupea harengus*	C
Bay anchovy	*Anchoa mitchilli*	A
Rainbow smelt	*Osmerus mordax*	C
Atlantic cod	*Gadus morhua*	C
Haddock	*Melanogrammus aeglefinus*	R
Atlantic tomcod	*Microgadus tomcod*	C
Pollock	*Pollachius virens*	R
Red hake	*Urophycis chuss*	C
Oyster toadfish	*Opsanus tau*	C
Sheepshead minnow	*Cyprinodon variegatus*	C
Killifishes	*Fundulus* species	A
Silversides	*Menidia* species	HA
Northern pipefish	*Syngnathus fuscus*	C
Northern searobin	*Priontus carolinus*	C
White perch	*Morone americana*	C
Striped bass	*Morone saxatilis*	C
Black sea bass	*Centropristis striata*	C
Yellow perch	*Perca flavescens*	R
Bluefish	*Pomatomus saltatrix*	A
Scup	*Stenotomus chrysops*	HA
Weakfish	*Cynoscion regalis*	C
Spot	*Leiostomus xanthurus*	R
Northern kingfish	*Menticirrhus saxatilis*	R
Mullets	*Mugil* species	R
Tautog	*Tautoga onitis*	A
Cunner	*Tautogolabrus adspersus*	HA
American sand lance	*Ammodytes americanus*	A
Gobies	*Gobiosoma* species	R
Atlantic mackerel	*Scomber scombrus*	C
Butterfish	*Peprilus triacanthus*	HA
Summer flounder	*Paralichthys dentatus*	C
Windowpane flounder	*Scophthalmus aquosus*	A
Winter flounder	*Pleuronectes americanus*	HA
Hogchoker	*Trinectes maculatus*	C

[1] Source: Stone et al., 1994

[2] Relative abundance represents highest abundance of adults or juveniles of species in any salinity zone and during any month. HA = Highly Abundant, A = Abundant, C = Common, R= Rare

Gut content analysis of mummichog and winter flounder revealed that molluscs were the principal forage item of *F. heteroclitus*, while fish and fish eggs, decapod crusteceans, and polychaetes were other important food items. Three taxa comprised the diets of 10 winter flounder sampled from Wetland 2: isopods and polychaetes were the primary food items, while amphipods served as a minor diet component.

An investigation on the population dynamics of winter flounder in the estuary, harbor and Buzzards Bay were previously completed as part of a sediment and pollutant transport model study of the New Bedford Harbor site (Battelle Memorial Institute, 1990). Age I and II winter flounder are found year-round throughout the Acushnet River estuary, the Inner and Outer Harbors, and Upper Buzzards Bay, suggesting that spawning occurs on the shoals throughout these areas. Larger winter flounder (Age IV and V) are more commonly found in the Outer Harbor and Upper Buzzards Bay, reflecting a general migration of adults from Nantucket Sound into Buzzards Bay.

As part of the ecological risk assessment for New Bedford Harbor (EBASCO, 1990) eight fish species were identified as representative of five zones in the upper estuary, Inner Harbor, and Outer Harbor. American eel (*Anguilla rostrata*), which frequently burrows in muddy and silty substrates, was considered representative of the Upper Acushnet River estuary and Inner Harbor, while scup, tautog, and Atlantic mackerel (*Scomber* Scombrus) were species identified as representative of the lower Inner Harbor and Outer Harbor. Four species (alewife, winter flounder, Atlantic silverside, and mummichog) were also considered as representative taxa of habitats throughout the study area.

Anadromous and Catadromous Fishes

Historically, significant anadromous fish populations utilized the Acushnet River as spawning and nursery habitat. In 1790, an alewife fishery, herring committee, and fishing restrictions were established for the river (Belding, 1916). More recently, anadromous species presence and abundance in the river has been severely reduced due to multiple factors, including loss of spawning habitat for dam construction, overfishing and pollution. The Massachusetts Division of Marine Fisheries (MDMF) has indicated that several anadromous fish species still utilize the Acushnet River for spawning. Alewife (and possibly blueback herring) are known to spawn in the river, although no published data are available suggesting the population size in the river (P. Brady, pers. comm.). Spawning herring adults enter the river during April or May, while young-of-the-year migrate from the river during the following fall.

Three structures on the river inhibit upstream migration by anadromous species. The Acushnet Sawmill off Mill Street in Acushnet is the first blockage encountered by migrating adults (Refer to Figure 3-2). In 1970, a fishway on the dam was reconstructed, although this facility is impassable to migrating adults during low water periods. Upstream, a second blockage is encountered at the Hamlin Street river crossing. This dam was reconstructed in 1920; the passage consists of two stone culverts. The wider culvert is partitioned into two channels (each approximately 6-ft (2-m) wide) with flash boards. The smaller culvert (10-ft (3-m) wide) also includes a flash board structure. Area residents have been known to adjust these flashboards to facilitate passage by the migrating alewives (P. Brady, pers. comm.). Further upstream, a 10-ft (3-m) high dam forming New Bedford Reservoir is a third blockage found on the Acushnet River, although it is uncertain whether migrating adults travel this far upstream. Suitable spawning habitat is present in the shallow water ponds directly upstream of the saw mill dam and Hamlin Street dam and most adults likely spawn in these waterbodies. The reservoir dam was constructed in 1869 (MDEM, unpublished report); some migrating alosids are believed to pass through the existing fishway, and enter the reservoir to spawn (P. Brady, pers. comm.).

According to the MDMF, other anadromous species may use the river as spawning habitat up to the sawmill dam, including rainbow smelt and white perch. Although no suitable spawning is available for striped bass in this drainage, they have been observed at the base of the sawmill dam, feeding on migrating alewives and other forage species (P. Brady, pers. comm.). In addition to these species, the Massachusetts

Coastal Zone Management (MCZM) Program has indicated that Atlantic menhaden, blueback herring, and Atlantic tomcod have been found in the Acushnet River watershed.

As previously discussed, American eel, a catadromous species, is commonly found in the Acushnet River and estuary and Inner Harbor, and is probably found throughout the watershed. American eel typically inhabit soft bottom muds of these waters, feeding on a variety of small macrobenthic organisms and fish species. American eel is the fish species that is in the greatest potential for exposure with the contaminated harbor sediments for the longest duration.

3.4.4 Wildlife

Waterfowl, Shorebirds, and Other Avifauna

During the summer of 1987, Bellmer (1988) conducted avian surveys within a tidal marsh on the east side of the harbor (Wetland 1) and a nearby salt marsh located outside of the harbor, proximate Popes Beach (Wetland 2). Three habitats (open water (including intertidal flats), tidal marsh, and salt marsh/upland edge habitats) were surveyed at each of these wetland sites. The surveys included point count and variable-strip methods.

For open water habitat, a total 16 bird species were observed in Wetland 1, while 24 species were present in Wetland 2. Five species were common to both open water sites: herring gull (*Larus argentatus*), double-crested cormorant (*Phalacrocorax auritus*), mallard duck (*Anas platyrhynchos*), great black-backed gull (*Larus marinus*), and rock dove (*Columbia livia*). Three of these avian species (herring and great black-backed gull and double-crested cormorant) commonly feed on fish and shellfish, while mallard duck frequently feed on macroinvertebrates (*e.g.*, amphipods and polychaetes) found in shallow intertidal habitiats; these prey items represent a potential tropphic level transfer of contaminants that bioaccumulate (*e.g.*, PCBs).

Least tern (*Sterna albifrons*), a state-designated Species of Special Concern, was observed in Wetland 1, and this species is known to nest on mainland beaches in the area, feeding on Atlantic silversides (*Menidia menidia*) in waters adjacent to Wetland 1 throughout August and early September. Osprey (*Pandion Haliaetus*) and common tern (*Sterna hirundo*), state-listed Species of Special Concern, were observed using Wetland 2 open water habitat. Herring gull was the most abundant and frequently observed species noted, and the greater number of herring gull observed at Wetland 2 reflected the greater size of the study site. Although species diversity was greater for Wetland 2, bird species density was nearly equal for Wetlands 1 and 2.

The numbers of shorebirds observed during the summer of 1987 was low, reflecting regional conditions when the majority of shorebirds are on their breeding grounds to the north. Avian data collected by the Lloyd Center (1986 as referenced in Bellmer, 1988) from a nearby monitoring site also suggest that few species are expected during the spring and summer in this area. Killdeer (*Charadrius vociferus*) was the only shorebird observed in Wetland 2 during the study period. Killdeer and spotted sandpiper (*Actitus macularia*) were observed at Wetland 2, and likely were early fall migrants. Bellmer (1988) suggests that the open water habitat of the Acushnet River estuary likely exhibits greater shorebird use as fall migration progresses. Many shorebirds stop in the estuarine area during their southerly migration to feed on macroinvertebrates found in the shallow intertidal waters.

Waterfowl were also observed using open water habitat during this study. Mallard Duck was commonly observed in both Wetlands 1 and 2, and was breeding at Wetland 2. Black Duck (*Anas rubripes*) were less common at these wetlands, although this species was more common in Wetland 3 where it was also observed breeding.

Wading birds using the intertidal waters were observed throughout the study period. Snowy egret (*Egretta thula*) was the most frequently observed wading species at Wetlands 1, 2, and 3. Least bittern (*Ixobrychus exilis*), a state-listed Threatened Species, was observed foraging along a common reed stand adjacent to Wetland 3. Passerine species observed at Wetlands 1 and 2 were using intertidal habitat for foraging.

The lower abundance of shorebirds and wading birds observed during the ACOE study (Bellmer, 1988) in comparison to avian data collected in this area (Tarkiln Hill Road to estuary mouth) by the Lloyd Center may be attributed to the more favorable location (*i.e.*, closer to tern breeding grounds) and conditions (*i.e.*, shallow lagoon with undeveloped shoreline) found in the Lloyd Center monitoring area. These factors likely contributed to the greater diversity and abundance of avifauna reported by the Lloyd Center. SES (1988) reported that the density of water birds observed in field investigations of the upper estuary wetlands during the winter and spring of 1985 was high in comparison to data obtained from other New England intertidal sites during these seasonal periods.

For salt marsh habitat, Bellmer (1988) recorded 12 and 18 bird species in Wetlands 1 and 2, respectively. Bird density was greater at Wetland 2 than Wetland 1. Passerine densities were very similar at the two wetland sites, but avian use differed. Wetland 1 was more frequently used by passerines nesting in nearby uplands as forage habitat Nesting passerine densities using the salt marsh were much higher in Wetland 2, reflecting the greater diversity and interspersion of plant cover types than Wetland 1 conditions. Both sites were regularly visited by mourning dove (*Zenaida macroura*) and insectivores (*e.g.*, chimney swift (*Chaetura pelagica)*, barn swallow (*Hirundo rustica*), tree swallow (*Tachycineta bicolor*)). sharp-tailed sparrow (*Ammodramus candacutus*), an obligate marsh nester, was commonly observed in Wetland 2.

Upland edge habitat proximate to Wetlands 1 and 2 were also monitored for avian use. Twenty-seven bird species were observed in the shrub transition zone (less than 245 ft (75 m) wide) of Wetland 1, while 32 species were observed using the common reed and sparse shrub transition zone (less than 165 ft (50 m) wide) landward of Wetland 2. Of the three habitat types studied, the transitional zone habitat exhibited the highest bird densities at both wetland sites. Many of the species observed in the Wetland 2 edge habitat were using to the nearby oak-hickory forest. Red-winged blackbird (*Agelaius phoeniceaus*), European starling (*Sturnus vulgaris*), northern mockingbird (*Mimus polyglottos*), song sparrow (*Melospiza melodia*), and American robin (*Turdus migratorius*) comprised 66 percent of the total species density of birds identified in Wetland 1. In comparison, red-winged blackbird, common yellowthroat (*Geothlypis trichas*), song sparrow, and European starling comprised 50 percent of the total species density of Wetland 2, reflecting a greater homogeneity of the edge habitat than Wetland 1.

Avian data have been collected along the Upper Acushnet River estuary and Inner and Outer Harbors during the summer and winter seasons for more than 10 years as part of an ongoing survey conducted by the National Audubon Society. Four specific monitoring areas have been established for the area, including the upper estuary (Area A is Slocum Street to the I-195 Bridge), upper Inner Harbor (Area B is I-195 Bridge south to Route 6 Bridge), lower Inner Harbor (Area C is Route 6 Bridge to hurricane barrier), and the Outer Harbor (Area D observations from Fort Phoenix and Popes Beach) (M. Boucher and D. Zimmberlind, unpub data). During the monitoring period 1986-1995, the highest number of species (58) were noted from the upper estuary (Area A), while fewer species were observed in the descending order of abundance: Outer Harbor (55), lower Inner Harbor (30), and upper Inner Harbor (25) (Table 3-6). The results also provide qualitative information on the relative species abundance in the New Bedford Harbor area. It is noted that these surveys do not take into account the presence and abundance of species during spring and fall migration periods when greater numbers of birds are expected stop over to rest and feed in the harbor area.

The diets of bird species influence their presence in the study area, their general behavior, and the potential for bioacumulating contaminants. The avian species found in the estuary and Inner and Outer Harbors represented seven feeding guilds including molluscivores, piscivores, carnivores, granivores, omnivores,

herbivores, and insectivores. Diving ducks and oystercatchers are representative of molluscivores, and molluscs comprise more than 60 percent of the food volume of winter sea ducks (Terres, 1980). Loons, grebes, and cormorants exemplify piscivores using the study area which feed on Atlantic silverside, snad lance, bay anchovy and other forage fishes. Osprey represent both the piscivore and carnivore feeding guilds; larger fish (*e.g.*, Atlantic menhaden), dabbling ducks (*e.g.*, black duck), and small mammals (*e.g.*, muskrat) are examples of food items of the osprey. Dabbling ducks, pigeons, and doves represent the gramnivore guild, while gulls and crows are omnivores. Canada goose is a primary herbivore (*e.g.*, diet items may include marsh grasses and forbs and submerged aquatic vegetation), while many of the passerine species using the intertidal habitats are insectivores (*e.g.*, tree swallow feeding on mosquitoes).

Roseate tern (*Sterna dougallii dougallii*), a federally-listed endangered species, are known to occassionally visit the New Bedford Harbor area to feed on resident prey fishes. Bird Island, located approximately 11 miles (18 km) east/northeast of New Bedford Harbor in Marion, is the largest known nesting colony of roseate tern in the Western Hemisphere (T. French, pers. comm.). This tern colony consists of approximately 1,500 breeding pairs of roseate tern as well as a greater number of breeding pairs of common tern (*Sterna hirundo hirundo*). Ram Island, which is a 2-acre (0.8-hectare) area located approximately 3 miles (4.9 km) northeast of New Bedford Harbor in Mattapoisett, also is inhabited by a nesting colony of approximately 300 pairs of roseate tern and 1,000 pairs of common tern. Roseate tern inhabiting these nesting islands feed primarily on sand lance, while common tern in the area feed on sand lance, menhaden, and alewife (B. Blogett, pers. comm.).

Peregrine falcon (*Falco peregrinus*), a federally-endangered species, occassionally pass through this area (In 1985, one was observed in vicinity of Wetland 1, as documented by Bellmer, 1988 and SES, 1988), and have been known to harass terns nesting at Bird Island. No known nesting sites are located in this area, and the nearest known nesting site of peregrine falcon is found on the Bracka Bridge in Fall River, more than 11 miles (18 km) west of New Bedford Harbor (T. French, pers. comm.).

TABLE 3-6 BIRD OBSERVATIONS IN NEW BEDFORD HARBOR AND UPPER BUZZARDS BAY, 1986-1995

SPECIES NAME		AREA*					
COMMON NAME	SCIENTIFIC NAME	A	B	C	D	SEASON**	ABUNDANCE**
Red-throated Loon	*Gavia stellata*				X	W	U
Common Loon	*Gavia immer*			X	X	W	C
Horned Grebe	*Podiceps auritus*	X	X	X	X	W	C
Red-necked Grebe	*Podiceps grisegena*	X				W	U
Great Cormorant	*Phalacrocorax carbo*	X	X	X	X	W	A
Double-crested Cormorant	*Phalacrocorax auritus*	X	X	X	X	S	A
Great Blue Heron	*Ardea herodias*	X	X	X	X	W, S	C
Great Egret	*Casmerodius albus*	X	X	X	X	S	C
Snowy Egret	*Egretta thula*	X	X	X	X	S	C
Green-backed Heron	*Butorides striatus*	X				S	C
Black-crowned Night-	*Nycticorax nycticorax*	X		X	X	S	C
Mute Swan	*Cygnus olor*	X	X	X	X	W, S	A
Great White-fronted	*Anser albifrons*	X				W	R
Snow Goose	*Chen caerulescens*	X				W	R
Brant	*Branta bernicla*			X	X	W	C
Canada Goose	*Branta canadensis*	X	X	X	X	W, S	A
Wood Duck	*Aix sponsa*	X				S	R
Green-winged Teal	*Anas crecca*	X				W, S	U
American Black Duck	*Anas rubripes*	X	X	X	X	W, S	A
Mallard	*Anas platyrhynchos*	X	X	X	X	W, S	A
Northern Pintail	*Anas acuta*	X				W	U
Blue-winged Teal	*Anas discors*	X				S	U
Northern Shoveler	*Anas clypeata*	X				W	U
Gadwall	*Anas strepera*	X				W, S	U
Eurasian Wigeon	*Anas penelope*	X				W	R
American Wigeon	*Anas americana*	X	X			W	C
Canvasback	*Aythya valisineria*	X				W	U
Redhead	*Aythya americana*	X				W	R
Ring-necked Duck	*Aythya collaris*	X				W	U
Greater Scaup	*Aythya marila*	X	X	X	X	W	C
Lesser Scaup	*Aythya affinis*	X	X	X	X	W	C
Common Eider	*Somateria mollissima*				X	W	C
Oldsquaw	*Clangula hyemalis*			X	X	W	C
Black Scoter	*Melanitta nigra*				X	W	U
Surf Scoter	*Melanitta perspicillata*				X	W	C
White-winged Scoter	*Melanitta deglandi*				X	W	C
Common Goldeneye	*Bucephala clangula*	X	X	X	X	W	C
Barrow's Goldeneye	*Bucephala islandica*	X			X	W	R
Bufflehead	*Bucephala albeola*	X	X	X	X	W	C
Hooded Merganser	*Lophodytes cucullatus*	X			X	W	U
Common Merganser	*Mergus merganser*	X				W	U
Red-breasted Merganser	*Mergus serrator*	X	X	X	X	W	C
Turkey Vulture	*Cathartes aura*	X				S	U
Osprey	*Pandion haliaetus*	X			X	S	C

TABLE 3-6 BIRD OBSERVATIONS IN NEW BEDFORD HARBOR AND UPPER BUZZARDS BAY, 1986-1995

SPECIES NAME		AREA*					
COMMON NAME	SCIENTIFIC NAME	A	B	C	D	SEASON**	ABUNDANCE**
Bald Eagle	*Haliactus leucocephalus*	X	X			W	R
Northern Harrier	*Circus syaneus*				X	W	U
Sharp-shinned Hawk	*Accipiter striatus*	X				W	U
Cooper's Hawk	*Accipiter cooperii*	X				W	U
Red-tailed Hawk	*Buteo jamaicensis*	X	X			W, S	C
American Kestrel	*falco sparverius*	X				W, S	U
Peregrine Falcon	*Falco peregrinus*	X		X		W	R
Clapper Rail	*Rallus longirostris*	X				S	U
Virginia Rail	*Rallus limicola*				X	S	U
American Coot	*Fulica americana*	X		X		W	C
Black-bellied Plover	*Pluvialis squatarola*				X	S	C
Semipalmated Plover	*Charadrius semipalmatus*				X	S	C
Killdeer	*Charadruis vociferus*	X			X	S	C
American Oystercatcher	*Haemotopus palliatus*			X	X	S	C
Greater Yellowlegs	*Tringa melanoleuca*				X	W, S	C
Lesser Yellowlegs	*Tringa flavipes*				X	S	C
Willet	*Catoptrophones*				X	S	C
Spotted Sandpiper	*Actitus macularia*				X	S	C
Ruddy Turnstone	*Arenaria interpres*				X	S	C
Sanderling	*Calidris alba*				X	W	U
Semipalmated Sandpiper	*Calidris pusilla*				X	S	C
Least Sandpiper	*Calidris minutilla*				X	S	C
Purple Sandpiper	*Calidris maritima*				X	W	U
Dunlin	*Calidris alpina*				X	W, S	C/U
Laughing Gull	*Larus atricilla*	X	X	X	X	W, S	C
Common Black-headed	*Larus ridibundus*	X				W	R
Bonaparte's Gull	*Larus philadelphia*	X	X	X	X	W	C
Ring-billed Gull	*Larus delawarensis*	X	X	X	X	W, S	A
Herring Gull	*Larus argentatus*	X	X	X	X	W, S	A
Iceland Gull	*Larus glaucoides*	X		X		W	R
Lesser Black-backed Gull	*Larus fuscus*	X				W	R
Glaucous Gull	*Larus hyperboreus*	X				W	R
Great Black-backed Gull	*Larus marinus*	X	X	X	X	W, S	A
Roseate Tern	*Sterna dougalli*				X	S	C
Common Tern	*Sterna hirundo*	X	X	X	X	S	C
Forster's Tern	*Sterna forsteri*				X	S	U
Least Tern	*Sterna albifrons*	X	X	X	X	S	C
Black Tern	*Chlidonias niger*				X	S	R
Snowy Owl	*Nyctea scandiaca*	X			X	W	U
Belted Kingfisher	*Ceryle alcyon*	X			X	W, S	C

Source: National Audubon Society (Christmas Count Data), M. Boucher, D. Zimmberlind (Unpublished Data)

Note: Data not collected during Spring and Autumn

* **Area A** = Wood Street Bridge to I-195 Bridge
Area B = I-195 Bridge to Route 6 Bridge
Area C = Route 6 Bridge to Hurricane Barrier
Area D = Hurricane Barrier South; all shorebird sitings in this area were from Fort Phoenix State Beach and Pope Beach

** **W** = Winter **S** = Summer
*** **A** = Abundance
C = Common **U** = Uncommon **R** = Rare

Mammals

During the winter and early spring, approximately 300 to 400 harbor seals (*Phoca vitulina*) are present in Buzzards Bay. Harbor seals are periodically observed in Buzzards Bay between mid-October and early May, and are found throughout the Elizabeth Island chain (US EPA, 1991). The largest single grouping is at Gull Island where 280 seals were recorded in 1988.

Gray seal (*Halichoerus grypus*) are occasionally seen in the Bay in very small numbers. Other marine mammals using the Gulf of Maine and Cape Cod Bay that may occasionally be found in Buzzards Bay include Atlantic bottlenose dolphin (*Tursiops truncatus*), harbor porpoise (*Phocoena phocoena*), and whales (*e.g.*, humpback whale (*Megaptera novaeangliae*), finback whale (*Balaenoptera physalus*)). Cetaceans are found seasonally near the entrance of Buzzards Bay, in the vicinity of Cuttyhunk (Howes and Goehringer, In Press).

Bellmer (1988) completed terrestrial mammal surveys of the vegetated tidal wetlands both within the harbor and a nearby reference wetland located outside of the harbor, proximate to Popes Beach. Sampling methods included observations of animals and/or signs (*e.g.*, tracks, scat, scrapes, nests, burrows), installation of scent posts, and routine monitoring of snap traps. Eleven mammals and/or their signs were identified in the Acushnet River estuary wetlands. Mammal use was documented in all habitat types within these wetlands. The trapping studies resulted in the capture of three mammal species: house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), and white-footed mouse (*Peromyscus leucopus*). Eastern cottontail (*Sylvilagus floridanus*) and its scat were frequently noted in Wetlands 1, 2, 3, and 9 high marsh habitat. Two active woodchuck (*Marmota monax*) burrows were observed in the Wetland 1 marsh elder habitat, while meadow vole (*Microtus pennsylvanicus*) and muskrat (*Ondatra zibethica*) sign were found in Wetland 1 high marsh habitat. Raccoon (*Procyon lotor*) tracks were observed at the intertidal flats of Wetland 1 and in the regularly flooded salt marsh of Wetland 9. Gray squirrel (*Sciurus carolinensis*) was observed foraging on the *S. patens* in the Wetland 9 high marsh In general, salt marshes bordered by broader transitional zones had the highest diversity and abundance of small and medium-sized mammals.

Herpetofauna

The leatherback turtle (*Dermochelys coriacea*) is the marine turtle most frequently observed in Buzzards Bay, generally between July through November (US EPA, 1991). The Atlantic ridley is found in Cape Cod Bay but has been occasionally observed in Buzzards Bay where juveniles and subadults were using the area for foraging during the late summer and early fall. No sitings of Atlantic ridleyshave been documented in Buzzards Bay since the 1930s (M. Payne, pers. comm.), and therefore, have not been affected by New Bedford Harbor contamination.

Very limited data are available on the presence of marine turtles in Upper Buzzards Bay. Typically, turtle strandings due to cold shock occur in Cape Cod Bay and areas of north facing estuaries where the turtles are geographically trapped as they migrate south (D. Beach, pers. comm.). Turtles have been observed along the north shore of Long Island (New York), foraging on green crabs in nearshore waters.

3.5 RESOURCE VALUES

3.5.1 Commercial Fishing

Finfisheries

A major U.S. whaling port in the early to mid 1800s, New Bedford has more recently been the highest-revenue fishing port on the East Coast. This high value of New Bedford's landings stems from both coastal and offshore catches, particularly from the Georges Bank, Nantucket Shoals, and Great South Channel fishing grounds (Doeringer et al., 1986). The rich off-shore fishing grounds have served as important harvesting areas for species such as sea scallop (*Placopecten magellanicus*), Atlantic cod, haddock, winter flounder, and mackerel (*Scomber* scombrus). More recently, overfishing, pollution and other factors have adversely affected many commercially valuable fish species, and a number of fish stocks in the North Atlantic have seriously declined in abundance. In 1995, the National Marine Fisheries promulgated new and more restrictive fishing regulations on harvesting in Northeast federal waters, severely affecting the New Bedford fishing industry and other New England fishing port communities.

More than 100 years ago, Buzzards Bay, including New Bedford Harbor, was closed to commercial fishing with nets, seines, and fish traps for purposes of aesthetics and resource allocation, and to serve as spawing sanctuary for finfish (Board of Commissioners on Fisheries and Game, 1916, as referenced in Cardin et al., 1995). Insight is provided on the value of Buzzards Bay and other nearby coastal and offshore waters important to commercially valuable fish species by reviewing existing data and obtaining information from state and federal agencies. Howes and Goehringer (In press) present a list of the region's ten most commercially valuable fishes and their abundance in Buzzards Bay (Table 3-7). Some of these species, including scup (*Stenotomus chrysops*), winter flounder, tautog, and bluefish (*Pomatomus saltatrix*), are common to New Bedford Harbor. Several other species (alewife, Atlantic menhaden, striped bass) are less abundant, but occassionally found seasonally in the Acushnet estuary or New Bedford Harbor. Striped bass are sought as a highly prized game fish, while alewife, Atlantic menhaden, and eel are typically harvested for fishing bait. Many of the prey items of these fishes (Table 3-7) are also inhabitants of the New Bedford Harbor NPL site.

Although not well documented, small-scale anadromous fisheries harvesting anadromous resources as the adults ascend upriver to spawn have existed in southeastern Massachusetts, including the Acushnet River, since colonial times.

TABLE 3-7 **DOMINANT COMMERCIALLY VALUABLE FISH SPECIES IN BUZZARDS BAY IN ORDER OF ABUNDANCE AND PREFERRED PREY ITEMS[1]**

Common Name	Scientific Name	Preferred Prey Items
Scup (porgy)	*Stenotomus chrysops*	Assorted benthos, occasionally small fish
Butterfish	*Peprilus triacanthus*	Copepods, small fish, jellyfish, worms
Winter flounder	*Pleuronectes americanus*	Worms, gastropods, bivalves
Alewife	*Alosa pseudoharengus*	Copepods, shrimp, eggs, and larvae
Blueback herring	*Alosa aestivalis*	Copepods, shrimp, eggs, and larvae
Atlantic menhaden	*Brevoortia tyrannus*	Phytoplankton
Black sea bass	*Centropristis striata*	Mysids and other benthic organisms
Tautog (blackfish)	*Tautoga onitis*	Mollusks, crabs, worms, lobster
Bluefish	*Pomatomus saltatrix*	Fish, worms, shrimp, lobster, squid, crab
Striped bass	*Morone saxatilis*	Fish, worms, shrimp, lobster, squid, crab

[1] Adopted from Howes and Geohringer (In Press)

Shellfisheries

As previously discussed in Chapter 2, New Bedford Harbor and nearby coastal waters have served as valuable sources of quahog, lobster, soft-shelled clams, and scallops since the early settlement of the region by Native Americans and European colonists, and these shellfisheries remain a valuable commodity, today.

Quahog or hard clam (*Mercenaria mercenaria*), including "chowder clams", "cherrystones" and "littlenecks", bay scallop (*Argopecten irradians*), soft-shelled clam (*Mya arenaria*), oyster (*Crassostrea virginica*), surf clam (*Spisula solidissima*) and blue mussel (*Mytilis edulis*) are the shellfish species of greatest commercial importance in the region. Other species such as razor clam (*Enis directus*), periwinkles, and conch are also harvested to a lesser extent as seafood species. Quahogs represent the most heavily harvested shellfish in Buzzards Bay. In 1990, more than 2.4 million pounds (1.1. million kg) were harvested in the Buzzards Bay commercial fishery and more than 695,000 pounds (316,000 kg) in the recreational fishery (Table 3-8). The total annual catch in pounds for the other five shellfish species have been substantially less, although these resource harvests also generate significant income to regional fisherman.

TABLE 3-8
RECREATIONAL AND COMMERCIAL SHELLFISH LANDINGS FOR BUZZARDS BAY BY YEAR (IN KILOGRAMS)[1]

	Quahogs (kg)		Soft-shelled clams (kg)		Oysters (kg)		Bay scallops (kg)		Surf clams (kg)		Mussels (kg)	
Year	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial	Recreational	Commercial
1977	517,08	358,888	198,814	0	30,046	35,562	179,444	1,244,134				
1978	530,458	531,801	204,084	726	57,662	26,490	48,858	1,701,326				
1979	564,460	490,251	199,439	2,830	6,260	15,422	320,350	1,022,378				
1980	593,998	637,108	224,224	75,334	71,233	19,414	37,848	91,409				
1981	607,316	1,352,381	232,570	29,684	70,326	38,683	34,619	153,825				
1982	570,266	2,671,160	247,230	45,578	81,212	64,774	550,053	573,641				
1983	290,259	2,309,659	61,182	12,481	28,658	14,098	17,908	90,482	0	7,348	2,859	
1984	125,479	2,209,204	85,585	43,524	13,608	92,453	5,906	69,466	1,497	44,144	2,722	
1985	1,444,135	1,723,616	112,647	31,968	38,320	42,811	315,787	1,384,791	4,627	0	6,396	
1986	476,089	2,044,956	119,315	83,771	30,945	42,947	10,777	29,393	0	0	4,491	
1987	570,447	2,138,111	122,758	106,768	32,221	52,282	0	6,559	1,497	0	0	
1988	438,749	1,474,046	96,445	75,660	17,609	45,233	0	816	163	0	136	
1989	404,647	1,566,907	92,553	59,189	10,435	11,009	272	6,341	327	0	218	
1990	316,114	1,079,268	55,069	109,675	3,388	0	0	1,959	272	0	272	

[1] Adopted from Howes and Geohringer, (In press)

No commercial shellfishing is allowed in the Inner Harbor because of contamination, although high densities of hard clams, soft shelled clams and other shellfish are present in these waters (B. Borque, pers. comm.). From the Outer Harbor, relay harvests are permitted by the MDMF, where shellfish are harvested and transplanted to "approved" waters by a number of local towns in the region. Between 1982 and 1995, twenty towns harvested quahogs from the Outer Harbor for relay purposes (B. Borque, City of New Bedford, unpublished data). In the Outer Harbor area, quahog densities have been sampled at ranges of 0.23 to 2.98/ft^2 within a 2,380-acre (965-ha) area (Hickey, 1983). The standing crop in this area was estimated at 249,599 bushels of legal sized quahogs in 1983. Highest densities have been recorded in areas between Butler Flats and Fort Rodman; south of the hurricane barrier; and on the east side of the Outer Harbor.

Germano (1987) calculated that 5,734.7 acres (2,322 ha) of New Bedford and Fairhaven waters in Areas 2 and 3 are "Restricted Areas" for shellfishing. An estimated 200,268 bushels (Conservation Law Foundation, 1988) of quahogs are present in the Outer Harbor area, open only for relay shellfishing. Between 1952 and 1994, an average of 3,854 bushels were removed annually from the Outer Harbor for relay purposes (D. Whittaker, MDMF, unpublished data).

Portions of Clarks Cove are presently open to commercial shellfishing. Clarks Cove includes both "Conditional" areas, which are closed to shellfishing by the MDMF for five days after any rainfall greater than one-half inch (storm events cause combined sewer stormdrain overflows), and "Approved" waters which are closed after storms with more than 2 inches of rainfall. An average five fisherman harvest quahogs from Clarks Cove daily, although as many as 15 fisherman may periodically be harvesting daily in Clarks Cove (B. Borque, pers. comm.).

Lobsters are a highly valuable commercial resource to the Buzzards Bay region, and the Bay serves as one of the major lobster spawning grounds along the East Coast. During the past several years, annual commercial lobster landings from Buzzards Bay have averaged more than 250,000 pounds (113,000 kg), which is approximately 3 percent of the state's total annual catch (Table 3-9). From 1991 through 1993, between 175 and 201 lobster fishermen used New Bedford to land their catch, while the number of lobstermen working out of Fairhaven totaled 60 in 1991, 35 in 1992, and 41 in 1993 (MDMF, 1993-1995). Annual commercial lobster landings from 1991 through 1993 from both territorial (state) and non-territorial waters for these two homeports have averaged 1.47 million pounds (668,000 kg) (Table 3-10). The combined territorial and non-territorial water lobster catch landed in Dartmouth during this period was substantially less than for New Bedford and Fairhaven; the annual landings for 9 to 15 Dartmouth fishermen ranged from 9,010 to 30,810 pounds (4,095 to 14,000 kg).

TABLE 3-9 COMMERCIAL LOBSTER LANDINGS FOR BUZZARDS BAY FROM 1981 TO 1991[1]

Year	Landings (pounds)	Landings (kg)
1981	214,079	97,088
1982	273,775	124,161
1983	317,593	144,033
1984	276,073	125,203
1985	237,374	107,653
1986	238,777	108,289
1987	249,822	113,298
1988	296,956	134,674
1989	316,199	143,401
1990	326,565	148,102
1991	290,769	131,868
1992	193,956	87,978
1993	268,719	121,891

[1] Adapted from Homes and Geohringer (In Press) and MDMF (1994, 1995)

TABLE 3-10 LOBSTER HARVEST BY NEW BEDFORD AND FAIRHAVEN FISHERMEN 1991 - 1993[1]

	1991		1992		1993	
Homeport	Territorial Waters	Non-Territorial Waters	Territorial Waters	Non-Territorial Waters	Territorial Waters	Non-Territorial Waters
New Bedford	152,367 (69,258)	541,266 (246,030)	103,067 (46,849)	583,344 (265,156)	102,647 (46,658)	655,683 (298,038)
Fairhaven	81,769 (37,168)	718,585 (326,630)	110,197 (50.090)	643,693 (292,588)	133,617 (60,735)	599,121 (272,328)
Total	234,136 (106,425)	1,259,581 (572,537)	213,254 (96.934)	1,227,037 (557,744)	236,264 (107,393)	1,254,804 (570,366)
Combined Total	**1,493,987 (679,085)**		**1,440,291 (654,678)**		**1,491,068 (677,758)**	

[1] Data from MDMF 1993, 1994, 1995; Values are in pounds and (kilograms)

3.5.2 Recreational Fishing

Recreational finfishing and shellfishing (for purposes of human consumption) in the Acushnet River estuary and New Bedford Harbor has been limited by the continuous, long-term presence of elevated fecal coliform levels within these waters, and by the ban on the taking of fishery resources from these waters because of elevated concentrations of PCBs found in sampled fish and shellfish. In September 1979, the Massachusetts Department of Public Health (MDPH) closed the Inner Harbor (*i.e.*, "Area I") to the taking of any finfish, shellfish, or lobsters (Refer to Figure 3-1). The Outer Harbor and portions of Upper Buzzards Bay were closed to the taking of bottom feeding finfish (*e.g.*, eels, scup, flounder and tautog) in

the area from the hurricane barrier south to an imaginary line drawn from Ricketsons Point in Dartmouth southeast to Wilbur Point in Fairhaven (*i.e.*, "Area II"). Lobsters cannot be harvested from any waters shoreward of line drawn from Mishaum Point in Dartmouth extending from Hursett Rock northeast to Rocky Point on West Island (*i.e.*, "Area III"). The prohibition against harvesting certain fish or shellfish resources from New Bedford Harbor is specified in the MDPH regulations (105 CMR 260.00). These closures remain in affect, restricting recreational fisheries in this area.

Conversely, catch-and-release recreational fishing remains an important activity in New Bedford Harbor and Buzzards Bay, although minimal quantitative data are available to describe these fisheries. According to the MDMF, sport fishing for striped bass, bluefish, tautog, and scup commonly occurs from shore along the hurricane barrier, jetties along Clarks Point, Fort Phoenix, and other areas both in the Inner Harbor and Outer Harbor (D. Kolek, pers. comm.). Fishermen are also known to fish for "schoolie" striped bass from or near the Route 6 bridge, and it is presumed that this remains a catch-and-release fishery. No data are available which indicate the MDPH bans are being violated. Recreational fishing by boat is limited in the harbor, although boat fishing commonly occurs in the Outer Harbor and throughout much of Buzzards Bay. Well-known recreational boat fishing locations include the waters around Little and Big Egg Islands and the Butler Flats Lighthouse, where striped bass, bluefish, and tautog are the species commonly sought.

Anadromous fish including alewife, blueback herring, and American shad were historically found in abundance in the Acushnet River, using upstream riverine habitat to spawn. Although no catch statistics are available, a small alewife fishery is maintained on the river, managed by the MDMF (P. Brady, pers. comm.). The alewife harvested in this fishery are presumed to be used primarily by local fishermen as bait for lobster, bluefish, and striped bass fishing.

Shellfishing continues to be an important recreational fishery in Buzzards Bay. Quahogs, soft-shelled clams, and bay scallops are the species most often sought (Table 3-8). Oysters, surf clams, mussels, and duck clams (*Pitar morrhuanus*) are other shellfish harvested recreationally.

In 1993, the MDMF issued 11,192 recreational lobster fishery licenses to potmen, divers, or those using both types of gear. The statewide recreational catch amounted to 384,270 pounds, approximately 2.7 percent of the total lobster commercial landings. Much of the lobster catch is harvested during the months of July through November when water temperatures are higher, allowing lobsters to grow faster and reach legal size. In 1993, 2.97 percent (268,719 pounds; 122,145 kg) of the coastal-license type recreational catch was harvested from Buzzards Bay (MDMF Area 14), while 8.11 percent (979 pounds; 445 kg) of the state-wide seasonal (student)-license type catch was harvested from Buzzards Bay (MDMF, 1995).

3.5.3 Natural Heritage Values

To identify important state-listed critical habitats and rare, threatened and endangered species in or near the Acushnet River watershed, maps from the Massachusetts Natural Heritage & Endangered Species Program Atlas (MNHESP, 1995) were reviewed, and MNHESP scientists and resource managers were contacted to verify habitat and species status. No high-priority rare habitats or exemplary natural communities are present in the watershed, although at least six sites have been designated within 2 miles (3.2 km) of the watershed (Figure 3-2). The Acushnet Cedar Swamp (in the Paskamanset River watershed), an exemplary southern New England coastal wetland, is directly west of the watershed and north of the New Bedford Airport. Six state-listed species have been identified in this wetland. Assawompset Pond, a large open water and wetland complex located adjacent to the northeast portion of the watershed, is inhabited by at least 15 state and federally-listed rare plant and animal species. Several other high-priority habitats are located in the general area.

Three known habitats of rare wetlands, wildlife, or certified vernal pools are found in the Acushnet River watershed (Figure 3-2). These sites are Long Pond in the northern portion of the watershed; a 1.9-mile

(3.1-km) segment of the Acushnet River and associated riparian wetlands directly south of New Bedford Reservoir; and an area of approximately 600 acres (242 ha) in the northwest portion of the watershed at the Freetown/Lakeville town line. Two state-listed threatened species have been identified within these areas including the marbled salamander (*Ambystoma opacum*) and water-willow stem borer (*Papaipema sulphurata*), while two state-listed Species of Special Concern, the eastern pond mussel (*Ligumia nasuta*) and spotted turtle (*Clemmys guttata*), are also known to inhabit these areas (NHESP, 1996).

As previously discussed, federally endangered peregrine falcon and roseate tern are known to occasionally use the New Bedford Harbor area for foraging on resident fishes. Although not thoroughly documented, other federally-listed species such as bald eagle (*Haliaeetus leucocephalus*), piping plover (*Charadrius melodus*), leatherback turtle (*Dermochelys coriacea*), Atlantic ridley turtle (*Lepidochelys kempii*), and loggerhead turtle (*Carietta caretta*) are transient species occasionally found in Buzzards Bay and possibly in the vicinity of New Bedford Harbor.

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4.0 NEW BEDFORD HARBOR, ACUSHNET RIVER AND BUZZARDS BAY CONTAMINATION AND ECOLOGICAL IMPACTS

4.1 INTRODUCTION

The presence of elevated levels of contaminants in the Upper Acushnet River Estuary, New Bedford Harbor, and Upper Buzzards Bay poses potentially significant human health and ecological risks. As previously discussed in Chapter 3, salt marshes and other intertidal and subtidal habitats are present in the study area. These habitats provide resting, foraging, spawning/breeding, and nursery habitats for numerous species of commercially and recreationally-valuable shellfish and other macrobenthic invertebrates serving as forage items to higher trophic level organisms; finfish of commercial and recreational importance and their prey species; waterfowl, shorebirds, and passerine birds including rare and endangered species; and occasionally marine mammals and federally-protected turtles. The societal values of the study area habitats and species inhabiting these habitats are also introduced in Chapter 2 and described in greater detail in Chapter 3, while the economic values associated with these resources are evaluated in Chapter 5.

The discovery of high levels of polychlorinated biphenyls (PCBs) in the Upper Acushnet River estuary and New Bedford Harbor during the mid 1970s led to fish and shellfish resource use restrictions within the study area in 1979. PCBs are acutely toxic to organisms in high concentrations, and prolonged exposure at relatively low concentrations has been determined to cause cancer in laboratory animals and humans. PCBs have a strong tendency to adsorb onto lipids or particulate material, giving the potential to accumulate in fatty tissues of organisms or within sediments. Bioaccumulation of PCBs has been documented in a number of laboratory and *in situ* experiments using aquatic organisms (*e.g.*, Jensen et al., 1969; Sipes et al., 1982; Metcalf & Eddy, 1983). Researchers have suggested that the adverse effects of bioaccumulated PCBs and other organohalogens include embryo mortality, edema, and deformities in marine birds; poor fertility and greater susceptibility to infections in marine mammals; and reduced psychomotor function, visual recognition, impaired memory abilities, and other developmental effects in humans (*e.g.*, Stone, 1992). Toxic effects of PCBs in organisms are well documented in published research (*e.g.*, Durfee et al., 1976; NAS, 1979; D'Itri and Kamrin, 1983; Grant, 1983; Safe, 1985). To protect human health from the adverse effects of PCBs, the U.S. Food and Drug Administration (FDA) Action Level for PCBs has been set at 2.0 parts per million (ppm) for the edible portions of fish and shellfish.

Sediment and water quality sampling of the Upper Acushnet River estuary, New Bedford Harbor, and Upper Buzzards Bay have also revealed that high levels of copper, chromium, cadmium, lead, zinc and other metals are present in the study area. Exposure to high levels of certain metals in sediments are known to cause both acute and chronic toxic effects in benthic organisms; and some metals are known to bioaccumulate in aquatic plants and animals (*e.g.*, Peterle, 1991; Nelson et al., 1995).

The following sections includes detailed descriptions of the principal contaminants and their sources and spatial distribution in the sediments, water column, and organisms of New Bedford Harbor and surrounding waters. Discussion is also provided on some of the toxic effects of PCBs, metals, and other contaminants on aquatic organisms; and the physical, chemical, and biological fate pathways that lead to adverse ecological and human health impacts. An overview and discussion of the previous ecological risk assessments completed for the New Bedford NPL site are then addressed, incorporating information provided in Chapter 3 describing biotic and abiotic conditions, habitats and estuarine and marine species, species interactions, and the ecological processes present in

the study area. The results of the previous human health risk assessment for the New Bedford Harbor area are also summarized and discussed.

To assist the reader in understanding the significance of the levels of contaminants discussed in the following sections, information is provided on current federal water criteria and sediment quality guidelines for protecting marine life. The U.S. Environmental Protection Agency (US EPA) has developed Ambient Water Quality Criteria (AWQC) for PCBs, metals, and other chemical constituents which are used in comparing with sampling results to determine if marine biota are exposed to contaminants that may cause adverse effects (Refer to Table 4-1). Both acute and chronic AWQC have been developed and may be periodically updated by the US EPA as refined analyses are completed. This report includes criteria for PCBs, eight metals, and polycyclic aromatic hydrocarbons (PAHs) which are the principal contaminants described hereinafter.

The National Oceanic and Atmospheric Administration (NOAA) has developed marine sediment quality guidelines for protecting aquatic biota, since the time that the Feasibility Study for the New Bedford Harbor Superfund site was completed. Two sets of sediment criteria for each of the previously mentioned constituents are presented here: a low effects range (ER-L) and a medium effects range (ER-M) criteria (Refer to Table 4-1). These values are based on the results of numerous toxicity tests using different marine organisms, and represent percentiles of the empirical distribution of the adverse effects data (Long et al., 1995). The ER-L represents the lower 10th percentile and is the range below which adverse effects would be rarely observed. Contaminant levels above the ER-L value but below the ER-M value (50th percentile) represent a possible-effects range in which adverse effects would occasionally occur, while probable effects would occur at concentrations above the ER-M. More detailed information on the methodology used in deriving these criteria can be found in Long and Morgan (1990) and Long et al. (1995).

TABLE 4-1
SURFACEWATER AND SEDIMENT CRITERIA
FOR PROTECTION OF MARINE LIFE[1]

	Surface Waters[2]		Sediments[3]	
Contaminant	**Acute**	**Chronic**	**Effects Range -Low (ER-L)**	**Effects Range -Medium (ER-M)**
Arsenic	69(III)	36(III)	8,200	70,000
Cadmium	43	9.3	1,200	9,600
Chromium	1,100(VI)	50(VI)	81,000	370,000
Copper	2.9	2.9	34,000	270,000
Lead	220	8.5	46,700	218,000
Mercury	2.1	0.025	150	710
Nickel	75	8.3	20,900	51,600
Zinc	95	86	150,000	410,000
PCBs	10	0.03	22.7	180
Total PAHs	300	--	4,022	44,792

1 All values are in parts per billion (ppb)
2 US EPA Ambient Water Quality Criteria, 1995
3 NOAA Sediment Screening Guidelines, 1994; Long et al., 1995

III = trivalent
VI = hexavalent

4.2 DESCRIPTION AND SOURCES OF CONTAMINANTS

The presence of contaminants in the sediments, surfacewaters, and biota of New Bedford Harbor has been well documented in various studies. In general, the investigations of environmental contamination have focused on PCBs, metals, PAHs, and in a few studies, total petroleum hydrocarbons (TPH) and pesticides. In this section, contaminants within each of the chemical groups are described and sources of contamination identified. The information presented in the following sections has been prepared using data primarily from EBASCO (1989; 1990a; 1990b) and U.S. Army Corps of Engineers (ACOE) documents (Bellmer, 1988), and other research studies (*e.g.*, Summerhayes et al., 1977; MDEQE 1978-1980; MDWPC, 1981; USCG, 1982; Malcolm Pirnie, 1982; Summerhayes et al., 1985) and existing data summary reports (Weaver, 1982).

4.2.1 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are stable, heat resistant materials that have been used as coolants; dielectric insulators; fire retardants and lubricants in capacitors, transformers, and hydraulic systems; machine tool cutting oils; and for numerous other industrial uses. They are composed of two connecting 6-carbon aromatic rings on which the hydrogen atoms have been substituted with two or more chlorine atoms. There are 209 possible structures arising from the substitution of one to ten chlorine atoms on the

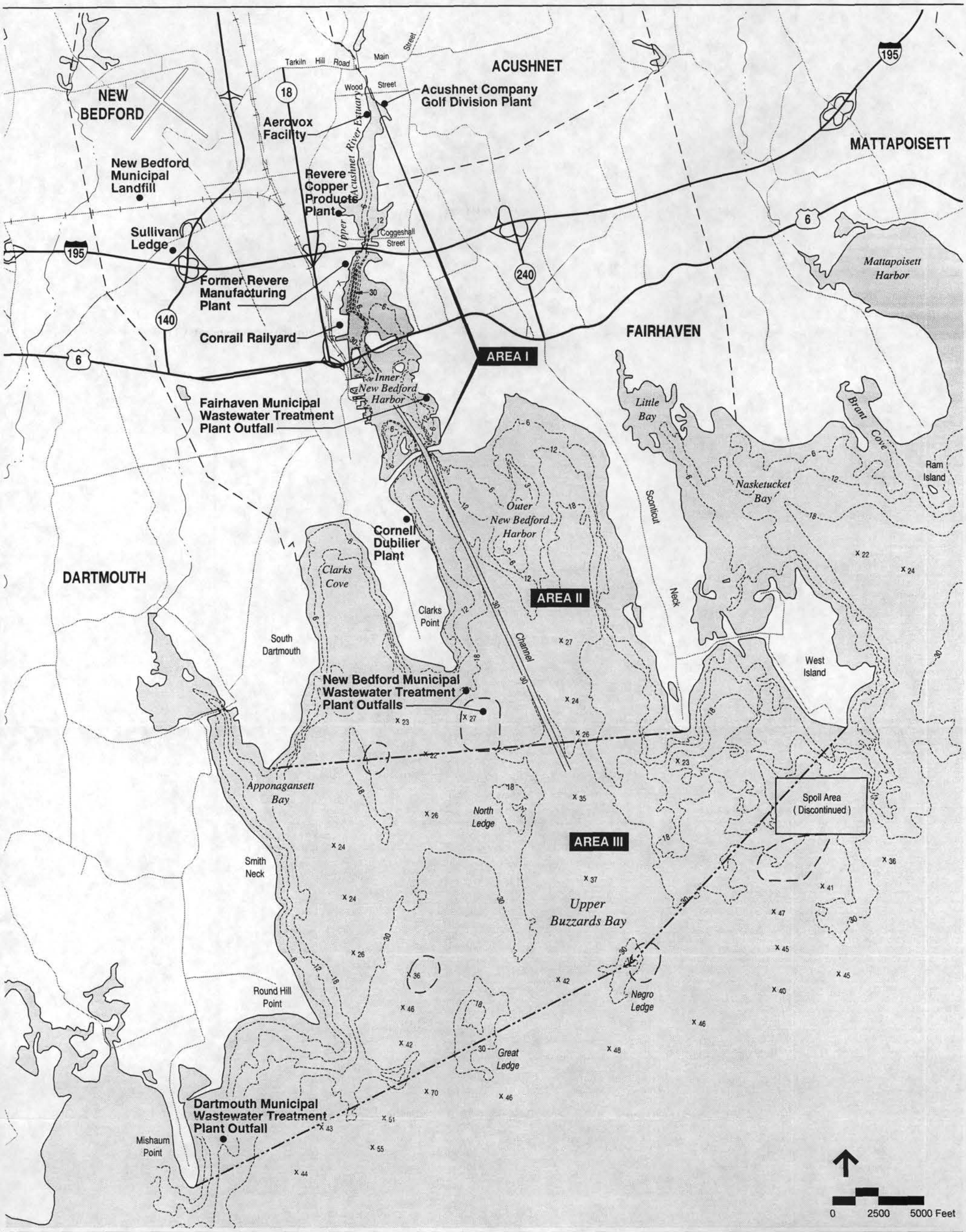
biphenyl nucleus (Hutzinger et al., 1974). PCBs were manufactured in the United States from 1929 to 1977 (USDHHS, 1993), and the Monsanto Chemical Company produced most of the PCBs used in the United States under the trade name "Aroclor". PCBs were produced as mixtures containing chlorinated biphenyl molecules with varying numbers and locations of chloride atoms. PCBs were marketed by Monsanto with the name Aroclor, followed by a varying four-digit number (*e.g.*, Aroclor 1254). The first two numbers indicate that there are twelve carbon atoms in the compound, whereas the latter two numbers indicate that the PCB mixture has an average chlorine content of 54 percent of the molecular weight. An exception to this standard nomenclature is Aroclor 1016, which has an average chlorine content of 41.5 percent of the molecular weight. In general, lower percentage chlorinated PCBs are viscous clear liquids, whereas higher chlorinated mixtures are clear to yellowish, sticky semi-solids.

Elevated levels of PCBs were first detected by the Woods Hole Oceanographic Institution in the Outer New Bedford Harbor in 1974, while the US EPA found high levels of PCBs in the harbor sediments and marine life in 1976 (Weaver, 1982). Two industrial facilities located on the western shore of the Acushnet River estuary in New Bedford used PCBs in the manufacture of capacitors from the early 1940s until 1977. These facilities were the Aerovox Corporation on Belleville Avenue along the Upper Acushnet River estaury; and Cornell-Dubilier on Rodney French Boulevard along the Outer Harbor (US EPA, 1990) (Refer to Figure 4-1). The Aerovox facility used Aroclors 1242, 1016, and in smaller quantities, Aroclors 1254 and 1252. Cornell-Dubilier used Aroclor 1242 and 1016. The use of PCBs by New Bedford's industries peaked at approximately 2 million pounds (0.91 million kilograms) per year during the years 1973 through 1975 (Santos, 1981, as referenced in Weaver, 1982).

Release of PCBs from these facilities to New Bedford Harbor occurred via several a pathways. The Aerovox facility discharged PCB-contaminated wastewater via two drainage troughs directly to the Acushnet River estuary and disposed of waste capacitors in the Acushnet River (US EPA, 1990). In 1984, capacitors containing high levels of PCBs were found along the harbor shoreline behind the Aerovox facility (Weaver, 1984) (None of these capacitors were found during the Hot Spot dredging). Tidal flats proximate to the Aerovox facility contained PCB concentrations in the thousands of ppm, and levels as high as 190,000 ppm have been measured in the harbor sediments (Weaver, 1982). The Cornell-Dubilier facility discharged PCB-contaminated wastewater into the City of New Bedford sewers with subsequent release to New Bedford Harbor via combined sewer-stormdrain overflows (CSOs); and to Upper Buzzards Bay via two outfalls from the municipal wastewater treatment plant at Clarks Point.

Another suspected source of PCB contamination to New Bedford Harbor is stormwater runoff from an area of known PCB contamination located opposite the Conrail Railyard (Refer to Figure 4-1). This area was used regularly to unload PCBs from railroad cars (US EPA, 1990), and as of the early fall of 1995, the site still contained a stockpile of contaminated materials covered by polyethylene sheeting.

More intensive investigations have been completed to determine the source of PCBs to New Bedford Harbor and Buzzards Bay. The locations of the City of New Bedford's sewer system was presented in a report by Begley (1982), which identified the locations of at least 13 combined CSOs discharging to New Bedford Harbor or Clarks Cove. The report also suggested that incineration of sewage sludge at the City's waste treatment plant was emitting ash laden with PCBs to nearby waters. More recent studies have indicated that at least 38 CSOs, with a combined sewer service area of 5.4 square miles (14 square km), discharge to New Bedford Harbor,



Fishing Resource Closure Area Boundaries (MADPH)

Elevated Surface Metal Concentrations (Summerhayes et al., 1985)
(Refer to Text and also Figures 4-2 through 4-5)

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 4-1

New Bedford Environment
Contaminant Information

Note: Soundings are in Feet at Mean Low Water
Sources: Mass GIS; USGS, 1977; NOAA, 1983; Weaver, 1982; Camp Dresser & McKee, Inc. 1990

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the Acushnet River, and Clarks Cove during wet weather events (Camp Dresser & McKee, 1990; US EPA, 1991).

The Towns of Fairhaven and Dartmouth have separate sewer and storm drain systems, so untreated wastewaters are not released by these municipalities to nearby coastal waters. Both of these towns have secondary waste treatment facilities; the Fairhaven outfall discharges to the Inner Harbor, while the Dartmouth outfall releases discharges to Upper Buzzards Bay approximately 3,000 feet (900 meters) south of Salters Point (Refer to Figure 4-1). Discharges from these facilities have been also considered as sources of PCBs to area coastal waters (Weaver, 1982). A portion of the Town of Acushnet is serviced by a public sewer system connected to the City of New Bedford system, and is treated by the City's wastewater treatment plant; the remainder of the Town is on septic systems.

In February and March 1981, PCBs in the City of New Bedford's sewers were measured downstream from the Aerovox and Cornell-Dubilier facilities and the wastewater treatment plant effluent to calculate PCB loadings to both the Inner and Outer Harbor (MDEQE, 1981). PCBs (measured as Aroclors 1016 and 1254) were detected in the samples downstream of the facilities at concentrations from 13.9 to 118.8 parts per billion (ppb), while concentrations in the wastewater treatment plant effluent were measured at 7.6 ppb for Aroclor 1254 and 1.28 ppb for Aroclor 1016. Assuming a treatment plant flow of 27 million gallons (102 million liters) of wastewater per day, corresponding PCB loadings of these two congeners is 1.8 and 0.3 pounds (0.8 and 0.1 kilograms) per day (Malcolm Pirnie, 1982).

The presence of airborne PCBs as a result of volitilization has also been considered as a source of the contaminant via dry and/or wet deposition to New Bedford Harbor (Exposure of the airborne contaminant to nearby residents has also been considered). In 1978, the US EPA indicated that atmospheric emissions of PCBs were the primary pathway release of the contaminant from the municipal landfill, located about 2 miles (3.2 km) west of the estuary (Weaver, 1982). Air sampling was conducted in 1977 and 1978 in proximity to the New Bedford municipal landfill, the New Bedford sewage sludge incinerator, and the Aerovox and Cornell-Dubilier facilities to measure PCB concentrations and mass emission rates. The conclusions of these studies indicated that the facilities were low level sources of airborne PCBs not significantly contributing PCBs to New Bedford Harbor and other nearby waters (Malcolm Pirnie, 1982). However, air sampling conducted at the municipal landfill in 1977 revealed PCB concentrations exceeding the federal 8-hour exposure limit (Weaver, 1982).

More recent air monitoring studies have revealed high levels of PCBs present in the north end of the Acushnet River estuary, particularly downwind of the US EPA's designated Hot Spot Area (EBASCO, 1990) where readings as high as 471 ng/m^3 were recorded east of the Hot Spot; these values significantly exceed the state ambient air standard of 0.5 ng/m^3. Results of the pilot dredging project indicated that PCB air levels were generally below existing ambient levels , and the background levels were influenced by meteorological conditions (EBASCO, 1990c).

During the Hot Spot dredging, air monitoring was completed at 16 stations along the Upper Acushnet River estuary, including six stations near the Confined Disposal Facility (CDF) off Sawyer Street on the west shore of the estuary. The highest average levels of PCBs (187 ng/m^3) were measured at Station 3 which was located at the northeast corner of the CDF (US EPA, unpublished data provided by P. Craffrey, MDEP). High average PCB concentrations were also measured at Station 11 (174 ng/m^3), which was located directly west of the dredge area. A single day maximum value of 2886 ng/m^3 was measured at the Station 11 during the initial days of dredging, although suprisingly, PCB levels were not detected at the other six stations along the estuary. This anomolous reading may have been attributed to calibration error or equipment failure. Excluding this value, between April and November 1994, four samples (all at Station 3) exceeded the 1,000 ng/m^3 shutdown level, while another 15 samples (eight at Station 3, four at Station 11, and three at Station 13 northeast of the Hot Spot) exceeded the 500 ng/m^3 action level.

The 40-acre (16-hectare) City of New Bedford landfill, located north of I-195 and west of Route 140, has also been considered a source of PCB contamination of the regional aquifer and nearby coastal waters (Refer to Figure 4-1). At least one-half million pounds (226 metric tons) of PCBs were disposed of at the landfill by the two capacitor manufacturing plants previously mentioned (Most of the PCBs were associated with reject capacitors), and in the waste products from the City of New Bedford's wastewater treatment plant (*e.g.*, rags, debris, and residual ash resulting from solid waste incineration) prior to 1976 (Weaver, 1982). Studies conducted on the landfill site indicated that PCBs were present in a localized portion of the shallow aquifer northwest of the site (US EPA, 1978). Bottom sediments of the nearby Paskamanset River, directly north of the landfill, were also found to contain PCBs. Other historic landfill sites in the area (*e.g.*, the City-owned 10-acre (4-hectare) Sullivan's Ledge off Hathaway Road (This site is not within the Acushnet River watershed), which is a former quarry filled in with contaminated wastes; and at least 10 sites in the area (specific locations were not presented) where harbor dredged materials were disposed) have also been considered as potential sources of PCBs to New Bedford Harbor. Lastly, residual PCBs in roadway runoff have also been considered a contaminant source, as it was once a common practice in this area to spray municipal streets with PCB-contaminated waste oils to control fugitive dust (Weaver, 1982).

4.2.2 Metals

Low (*i.e.*, background) concentrations of heavy metals occur naturally in the sediments of the Achusnet River estuary and Buzzards Bay. In portions of Buzzards Bay, including New Bedford Harbor, high concentrations of metals are associated with clay sediments and sediments containing organic material (Moore, 1963). Metal-rich industrial wastes have been discharged to New Bedford Harbor for more than 100 years (Summerhayes et al., 1985), resulting in an accumulation of heavy metals in New Bedford Harbor at concentrations of 6 to 400 times greater than natural background levels. Sediment cores previously collected by the ACOE (As referenced in Summerhayes et al., 1977) from a sampling station approximately 800 ft (240 m) north of the New Bedford-Fairhaven Bridge (Refer to the MassGIS database for sampling locations) revealed some of the highest concentrations of the following contaminants: copper, 2,027 ppm; zinc, 790 ppm; lead, 492 ppm; cadmium, 18 ppm; chromium, 744 ppm; arsenic, 45 ppm; and nickel, 69 ppm. These concentrations were measured at sediment depths of 12 to 14 inches (30 to 35 cm), except for the highest cadmium concentration that was obtained from the uppermost inch (3 cm) of the sediment sample. The highest copper concentration of 8,054 ppm was collected directly south the Coggeshall Street Bridge (Summerhayes et al., 1977).

The Massachusetts Division of Water Pollution Control (1971, 1975) also collected sediment samples from the Acushnet River, New Bedford Harbor, and Upper Buzzards Bay. Sampling was completed at one sampling station within New Bedford Reservoir; nine stations upriver of the New Bedford-Fairhaven Bridge; three stations in the Inner Harbor between the New Bedford-Fairhaven Bridge and the hurricane barrier; and five stations in the Outer Harbor (Refer to the MassGIS database). The highest metal concentrations were found in sediments sampled from two areas: one station approximately 0.5 miles (0.3 km) north of the Coggeshall Street Bridge, and a second station 0.5 miles (0.3 km) south of the bridge. Sediments from the sampling station located 0.5 miles (0.3 km) south of the Coggeshall Street Bridge contained a cumulative metal content of 1.17 percent copper, chromium, and zinc, with concentrations of these constituents in this sample measured at 7,250 ppm, 3,200 ppm, and 1,200 ppm, respectively.

Sediments were also collected from three sampling stations in an east-west transect across New Bedford Harbor, approximately 0.5 miles (0.3 km) south of the Coggeshall Street Bridge. Results indicated that the highest metal concentrations were associated with the western shore of the harbor, and it was deduced that a contaminant point source was present in this area (Summerhayes et al., 1977). Compared with sediments from central Buzzards Bay, the sediments in the Upper Acushnet River estuary and New Bedford Harbor are enriched by factors of up to 500 for copper, 100 for chromium, 40 for cadmium, 30 for zinc, 25 for nickel, 20 for lead, 13 for mercury, and 7 for arsenic.

Shine et al. (1995) applied multiple regression and principal component analysis to suggest sources of metal contamination in New Bedford Harbor. For their study, 13 sediment cores were collected throughout the upper estuary, harbor and Upper Buzzards Bay, and metal concentrations were measured in discrete sections of each core sample. Several conclusions were drawn as a result of their study. First, metal concentrations generally decreased in the sediments from the Coggeshall Street Bridge south to Upper Buzzards Bay, as similarly concluded in other previously discussed studies. Second, the harbor samples showed the presence of distinct subsurface maxima in metal concentrations, suggesting that the loadings of these metals to the harbor and their subsequent accumulation in the sediments have decreased in recent years. The depth of the metal concentration maxima were generally greater for sediments in the northern portion of the harbor than for sediments from the southern portion of the harbor. Thirdly, the distinct enrichment with a subsurface maxima for certain metals including chromium, cadmium, and copper suggests that point source discharges have been responsible for elevated metals in New Bedford Harbor. Lastly, lead and zinc were more uniformly distributed throughout the layers of the sediment cores, and the rates of decrease for lead and zinc towards the sediment surface were less than the rates of decrease for chromium, cadmium, and copper. This suggests that non-point sources such as atmospheric deposition and/or stormwater runoff began prior to the major point source inputs of metals, and the input of lead and zinc has remained relatively constant.

Summerhayes et al. (1985) identified the Aerovox Corporation and Revere Brass and Copper, Inc. as industries that discharged as much as 200 pounds (90 kg) of copper a day to the harbor from the late 1800s to the mid-1900s (Refer to Chapter 2). Study results indicated that copper, chromium, zinc and are the most abundant metal contaminants in the clay fraction of harbor sediments. Other investigations (US EPA, 1990) have revealed that cadmium, copper, chromium, nickel, lead, and zinc are the principal metal contaminants in the harbor. The sources of the metal contamination have been attributed to various industrial processes such as metal plating, manufacturing, and textile dye operations (US EPA, 1990). It has been suggested that the metal contamination was attributed to the release of either fine solids or solutions from which metals are then scavenged onto fine mineral or organic matter, or are precipitated (Summerhayes et al., 1977). Aerial fallout has also been suggested as a potentially significant contaminant pathway to the harbor (Summerhayes et al., 1985).

Camp Dresser & McKee (CDM.1990) completed subsurface field investigations to determine the significance of the City of New Bedford's waste treatment facility outfall in releasing metals to the Outer Harbor. Discharges from the Fort Rodman plant occur via two outfalls: the main outfall, a 60-inch (152-centimeter) diameter, 3,300-foot (1,000-meter) long pipe aligned southeast from the tip of Clarks Point; and a 72-inch (183-centimeter) diameter auxillary pipe, extending 1,000 feet (330 meters) from the tip of Clarks Point and paralleling the longer main pipe. Sediments were sampled from each of the two outfalls to identify metals concentrations at these sites. In general, metal concentrations in the outfall pipes were similar to concentrations in the ocean floor sediments, although cadmium and nickel were significantly higher in the pipe deposits, while lead concentrations in the discharge pipe samples were lower than ocean floor deposits (Camp Dresser & McKee, 1990).

The CDM study also identified two other industrial discharges releasing metals to New Bedford Harbor . The Acushnet Rubber Company's Golf Division, which releases wastewater from a blasting operation and non-contact cooling water (less than 0.5 million gallons (1,900 cubic meters) per day), is a source of copper and zinc, although the mass loadings of these metals are only 3 and 1 percent of New Bedford's wastewater treatment plant loadings, respectively. The Revere Copper Products plant which releases more than 0.46 million gallons (1,740 cubic meters) of non-contact cooling water, stormwater, and treated process wastewater per day, was also identified as a source of metals to the harbor (Camp Dresser & McKee, 1990).

To determine the chemical state that contaminants were released to New Bedford Harbor and nearby waters, Summerhayes et al. (1977) sampled sediments from New Bedford Harbor and chemically treated

them to identify the types of phases inwhich metals are concentrated in the sediments. Nearly 40 percent of the copper and zinc are present as insoluable mineral phases; another 20 percent of copper and zinc are in an authigenic mineral phase (*e.g.*, pyrite, hydrotroilite); 20 percent are sorbed (*i.e.*, attached) onto organic and inorganic particulates; and 20 percent form organo-metallic complexes. Results differed for chromium, as 85 percent of the metal was found in the authigenic phase (*i.e.*, minerals formed in place); 8 percent in insoluable mineral phase; and and 6 percent in organo-metallic complexes. The researchers concluded that more of the chromium versus copper or zinc was discharged to the harbor in a dissolved state.

As part of the pilot dredging and disposal project, air quality was monitored for the presence of metals released by the study activities. The results indicated that ambient levels of metals ranged from non-detection to only trace amounts (EBASCO, 1990c). Lead was measured at the highest frequency level particularly with prevailing southwest winds, but was measured at levels below the existing standard.

4.2.3 Polycyclic Aromatic Hydrocarbons

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of semi-volatile organic compounds composed of at least three 6-carbon aromatic rings produced by the incomplete combustion of organic material. These compounds are found in crude oil, cigarette smoke, exhaust of gasoline and diesel-burning vehicles, soot, and the residue from the burning of other organic materials such as wood and garbage. High concentrations of PAHs are also present in coal, asphalt mixtures, and coal tar. As previously dicussed in Chapter 2, numerous coal terminals were established and operated throughout New Bedford Harbor in the late 1800s and 1900s, and the burning of coal as a source of energy for industries and homes was a common practice during this period. Elevated levels of PAHs have been measured in New Bedford Harbor, and these contaminants may be adversely affect ing biota present in the estuary. It has been suggested that PAHs in New Bedford Harbor may be primarily the result of urban runoff (US EPA, 1990), although a significant portion of the PAHs may be due to aerial fallout (Farrington, as referenced in Summerhayes et al., 1977) and drainage from nearby railroads and other urban areas. PAHs have been detected in the tissues of marine benthic invertebrates, particularly molluscs (*e.g.*, Neff, 1979), although most macrobenthic organisms are unable to metabolize polycyclic aromatic hydrocarbons (Vandermuelen and Penrose, 1978). Studies have linked PAHs to carcinogenesis in certain animals (*e.g.*, Heidelberger, 1976).

4.2.4 Other Contaminants

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) have been reported in New Bedford Harbor sediments. The discrete source of these contaminants is not known, although it has been suggested that these compounds are present as impurities in the Aroclor mixtures; derived from atmospheric fallout from the incineration of sewage sludge at the New Bedford municipal waste treatment plant; and/or associated with long-distance atmospheric transport from other sources (US EPA, 1990). In a study of the City of New Bedford's wastewater treatment plant outfall, Camp Dresser & McKee (1990) identified relatively low concentrations of benzene ($\leq$ 0.25 ppm), 1,4-dichlorobenzene ($\leq$ 1.4 ppm), ethylbenzene ($\leq$ 0.19 ppm), methylene chloride ($\leq$ 2.3 ppm), and toluene ($\leq$ 0.14 ppm) in sediments sampled from within the facility's two outfalls. None of these contaminant concentrations exceed the US EPA's Ambient Water Quality Criteria for chronic marine life.

The Upper Acushnet River estuary and the New Bedford Inner Harbor have been contaminated by excessive levels of coliform bacteria and untreated sewage since at least the early 1900s (Conservation Law Foundation, 1988). The closure of the shellfishing in the Inner Harbor since the early 1900s due to "gross pollution" (*e.g.*, an outbreak of typhoid fever and high bacterial levels) is indicative of the long-term water quality problems that have characterized New Bedford Harbor. Additionally, high coliform pollution also

led to a ban on shellfishing in the Outer Harbor and Clarks Cove in 1971. Much of this area remains closed to shellfishing due to excessive coliform bacteria levels, and not due to high levels of PCBs (Conservation Law Foundation, 1988).

Contaminants released to the harbor are also attributed to other potential sources. Besides the discharges of pollutants from the City of New Bedford's waste treatment plant and combined sewer overflows, the Town of Fairhaven's waste treatment plant, and the Aerovox, Cornell-Dubilier, Conrail, Acushnet Rubber, and and Revere facilities, other known wastewater dischargers are present. A review of the National Pollution Discharge Elimination System (NPDES) permits for this region indicates that there are at least five other industrial wastewater sources to New Bedford Harbor and one permitted discharge to Clarks Cove (US EPA, 1991). Also, although pumpout facilities are available at marinas in the region, recreational and commercial vessels are also potential sources of sanitary wastes to the marine waters in this area.

According to the Buzzards Bay Comprehensive Management Plan, waste treatment facilities and CSOs are the principal source of nitrogen to the Bay, contributing 62 percent of the total annual loading of 2,470 tons (2,246 metric tons) (US EPA, 1991). The largest inputs are associated with New Bedford Harbor, although it has been suggested that the impacts of New Bedford nutrient discharges are limited only to the immediate coastal waters. These excessive nutrient inputs have an adverse effect on marine waters, causing rapid growth of phytoplankton, macroalgae and other plants which alter marine food webs; increase water column turbidity; increase organic matter accumulation in the sediments and reduce dissolved oxygen levels that, in turn, results in fish kills and other problems.

4.3 CONTAMINANT DISTRIBUTION AND CONCENTRATIONS IN SEDIMENTS

A summary of the distribution of PCBs, heavy metals, and PAHs in the sediments of the Upper Acushnet River estuary, New Bedford Harbor, and Buzzards Bay was developed from information primarily provided in the US EPA Feasibility Study of Remedial Alternatives for the Estuary and Lower Harbor and Bay (hereafter, referred to as the "Feasibility Study") (EBASCO, 1990a). The study was a compilation of information and databases from numerous studies including the U.S. Coast Guard Sediment Sampling Program (1982); NUS/Goldberg-Zoino Associates Harbor Grid Sampling Program (1986); ACOE Field Investigation Team Sampling Program (1988); and the ACOE Hot Spot Sediment Sampling Program (1988). Other studies referenced in this summary include results of investigations conducted by Camp Dresser & McKee (1979, 1990), Bellmer (1988), and Summerhayes et al. (1977 and 1985). Information on earlier sediment sampling for PCBs in the Acushnet River and Inner and Outer Harbor was obtained from documents prepared by Malcolm Pirnie (1982) and Weaver (1982).

4.3.1 Polychlorinated Biphenyls

As previously discussed, NOAA has developed contaminant threshold criteria for PCBs and other sediment-sorbed contaminants in marine sediments (Long and Morgan, 1990) since the completion of the Feasibility Study. NOAA's lowest ecological effects level for PCBs in sediments is 22.7 ppb, while the medium effects level is 180 ppb. These concentrations should be used as a reference value in reviewing the following information.

The levels of PCBs in the Acushnet River and New Bedford Harbor sediments were first determined via a number of sampling programs during the late 1970s and early 1980s. The sampling programs included:

- Commonwealth of Massachusetts Department of Environmental Quality Engineering (MDEQE) sampling in May 1978; August 1979; and September 1980 at 24 stations with sediment sampling depths of 2 to 14 inches (5 to 36 cm). Deeper cores were analyzed as composite sections, while

surface samples were tested as a single composite. Samples were measured for Aroclors 1016 and 1254, while Aroclor 1254 was used as an analysis standard.

- Commonwealth of Massachusetts Division of Water Pollution Control (MDWPC) sampling conducted in July and October 1981, collected along 19 transects from the Upper Acushnet River estuary south to the Outer Harbor in the vicinity of the wastewater treatment plant. Many of the MDWPC samples from the upper estuary were cores collected at depths of 8 to 22 inches (20 to 56 cm), while the Inner and Outer Harbor samples were collected from 0 to 4 inch (0 to 10 cm) sediment depths. The surface samples were collected as a single composite sample, while deeper cores were analyzed as composite sections. Samples were tested for Aroclors 1248, 1242, 1260, and 1254 with Aroclor 1254 as a standard; results showed that Aroclors 1248 and 1254 were prevalent in the Upper Acushnet River estuary, while various Aroclor mixtures were detected in the Inner and Outer Harbor samples.

- U.S. Coast Guard (USCG) sampling in June 1982. This sampling included 10 sediment cores along 2 transects approximately 1,800 ft (550 m) north of the Coggeshall Street Bridge. Sediments were collected to a depth of 12 inches (30 cm), and PCB concentrations were measured in the top one-inch (0 to 2.5 cm); between 5.5 and 6.5 inches (14 to 16.5 cm); and the bottom inch (27.5 to 30 cm). Samples were analyzed with Aroclor 1254 as a standard.

- USCG sampling in April 1982 at the northern Acushnet River estuary adjacent to the Aerovox facility. Sediment cores were collected at 33 sampling stations, and individual sample depths varied between 6.5 and 26 inches (16.5 and 66 cm) (Refer to the MassGIS database). Three composite samples were analyzed for each station and layers from 0 to 1 inch (0 to 2.5 cm); 5.5 to 6.5 inches (14 to 16.5 cm); and the deepest one-inch in each sample. PCB concentrations were determined using an Aroclor 1254 standard.

Results of these earliest sampling programs indicated that PCB concentrations north of the Coggeshall Street Bridge were generally greater than 500 ppm, and in some locations within this area, sediment concentrations exceeded 10,000 ppm (Malcolm Pirnie, 1982). PCB concentrations greater than 50 ppm were generally found in the Inner Harbor as far south as Popes Island; and in the Outer Harbor in the vicinity of the wastewater treatment plant outfalls. Concentrations between 10 and 50 ppm were found in samples from the nearshore perimeter of the estuary north of the Coggeshall Street Bridge; and an area along the western shore of the Outer Harbor, directly north of the Cornell-Dubilier plant. Lower concentrations were measured in samples from the dredged channel. Overall, Farrington et al. (1983) estimated that at least 100 tons (90 metric tons) of PCBs were present in the upper 20 inches (50 cm) of sediments in the Upper Acushnet River estuary and New Bedford Harbor.

The PCB concentrations are a measurement of the various congeners present. Prior to 1980, much of the sampling and analyses of PCBs in New Bedford Harbor were completed only for Aroclor 1254 (Boehm, 1983b), and Aroclors that were difficult to distinguish were reported as sum concentrations (*e.g.*, Aroclor 1016/1242) (Battelle Ocean Sciences, 1987). The PCB concentrations measured in these studies were associated with varying analytical methods, with varying congeners used as standards for analysis. Researchers from the Woods Hole Oceanographic Institution (WHOI) have suggested that most of the PCBs in New Bedford Harbor sediments are in the form of Aroclors 1016 or 1242, with lesser amounts of Aroclor 1254 (Farrington, 1981). The higher chlorinated compounds, including the tetrachloro- through heptachloro-isomers, apparently make up a greater proportion of the total PCBs in sediments with increasing distance from the Inner Harbor (Boehm, 1983a). As determined by WHOI, actual PCB concentrations in the sediments may be as much as three times higher than the those values reported for some of the areas, and therefore, these earlier data may have limited value in accurately defining the distribution of total PCBs.

The distribution of PCBs within the study area is provided as concentration contours for three geographical areas assessed in the Feasibility Study (US EPA, 1990). These areas include the Upper Acushnet River estuary between the Wood Street and the Coggeshall Street Bridges; Inner New Bedford Harbor between the Coggeshall Street Bridge and the hurricane barrier; and the Outer New Bedford Harbor. Individual sediment samples were collected from discrete depths of 0 to 6 inches (0 to 15 cm) (for the Inner and Outer Harbors), 0 to 12 inches (0 to 30 cm) (north of the Coggeshall Street Bridge); 12 to 24 (30 to 60 cm) inches; and 24 to 36 inches (60 to 90 cm).

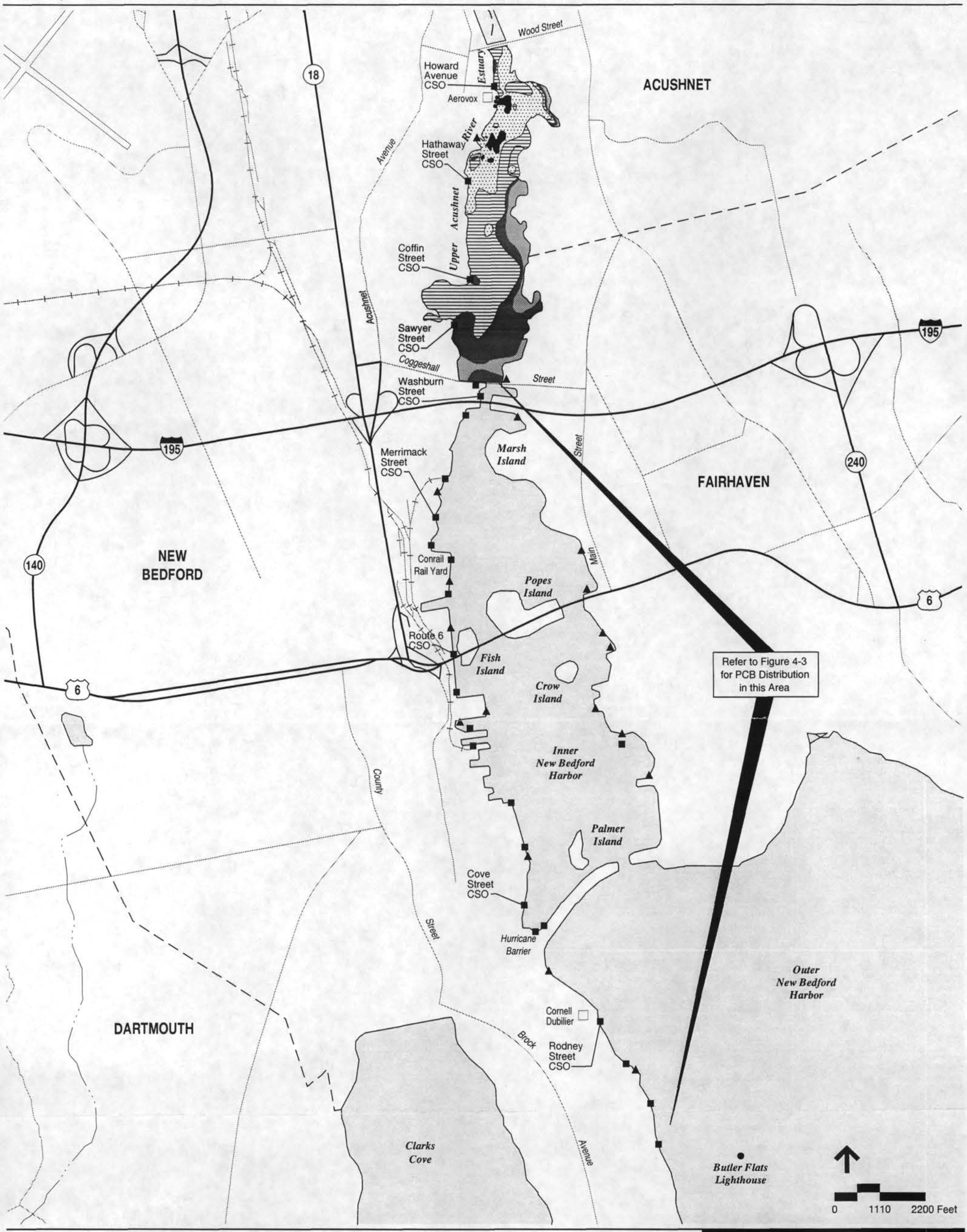
The highest PCB concentrations detected in the study area were found in sediments sampled from the Upper Acushnet River estuary between the Wood Street Bridge and the Coggeshall Street Bridge (Figure 4-2). Concentrations greater than 4,000 ppm were detected in two principal areas along the western shore of the river near the trench and outfall discharge points from the Aerovox facility. These high sediment concentrations were detected from the sediment surface to a depth of 36 inches (90 cm). No data from depths greater than 36 inches (90 cm) were presented in the Feasibility Study. The areal extent of surficial contamination with concentrations greater than 4,000 ppm was approximately 5 acres (2 hectares), although the areal extent of PCB concentrations greater than 4,000 ppm significantly decreased in size with increasing sediment depth. In 1989, this 5-acre Hot Spot Area was designated by the US EPA as a separate operable unit; and approximately 12,000 cubic yards (7,640 cubic meters) of highly contaminated sediments was removed as part of the site remediation. The removal of these highly contaminated sediments was completed in September 1995.

PCB concentrations in sediments generally decreased with distance from the Aerovox Corporation discharge points and with greater depth within the sediments. Between the Wood Street and Coggeshall Street Bridges, the upper 12 inches (30 cm) of sediments were contaminated with PCBs greater than 50 ppm. PCB concentrations less than 50 ppm were generally sampled from the eastern edge of the estuary; in wetland areas (Wetlands 1 and 3, as described in Chapter 3); and the southern portion of the upper estuary between 1,000 and 2,000 feet (300 to 600 m) south of the Coggeshall Street Bridge (Figure 4-2).

In contrast to the wide distribution of PCBs greater than 50 ppm at the sediment surface within the Acushnet River, PCB concentrations in the sediments at depths of 12 to 36 inches (30 to 90 cm) were below 10 ppm. Areas where PCB concentrations exceeded 10 ppm at sediment depths of 12 to 24 inches (30 to 60 cm) were the west side of the estuary adjacent to and south of the Aerovox facility discharge trenches, and along the east side of the river within a tidal marsh. Four other isolated areas with PCB concentrations greater than 10 ppm at sediment depths of 12 to 24 inches (30 to 60 cm) were identified. These sites included: one area located approximately 2,200 feet (660 m) south of the Aerovox facility; an intertidal area bordering a marsh (Wetland 1) on the east side of the river; an area approximately 4,000 feet (1,200 m) south of the Aerovox facility in the center of the river; and one area approximately 400 feet (120 m) north of the Coggeshall Street Bridge, slightly east of the center of the river (Refer to the MassGIS database for these locations).

Two relatively small areas within the Acushnet River sediments had PCB concentrations above 10 ppm at depths of 24 to 36 inches (60 to 90 cm). One area was directly adjacent to the three trench discharge points of the Aerovox facility and contained concentrations greater than 4,000 ppm. The second area, containing concentrations of PCBs ranging from 500 ppm to 4,000 ppm, was near the Hathaway Street CSO discharge on the west bank of the River, approximately midpoint between the Wood Street and Coggeshall Street Bridges (EBASCO, 1990a) (PCB concentration contours in the area between Wood Street and Coggeshall Street Bridges at sediment depths of 12 to 24 inches (30 to 60 cm) and 24 to 36 inches (60 to 90 cm) are presented in the Mass GIS database).

PCB contamination in the Upper Acushnet River tidal marshes is several orders of magnitude greater than that present in tidal marshes in other nearby portions of Buzzards Bay. To obtain a measurement from a marsh site located outside of New Bedford Harbor, the ACOE (Bellmer, 1988) collected tidal marsh



Total PCB Concentrations

- 0-10 ppm
- 10-50 ppm
- 50-500 ppm
- 500-4,000 ppm
- > 4,000 ppm (Hot Spot Area Remediated in 1994-1995)

ppm= parts per million

- ■ Approximate CSO Location
- ▲ Approximate Storm Drain Outfall Location
- • Aerovox Trench

Source: EBASCO, 1990

Vanasse Hangen Brustlin, Inc.

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Figure 4-2

Acushnet River Estuary
Total PCB Concentrations
0-12 Inch Sediment Depth

70602P12

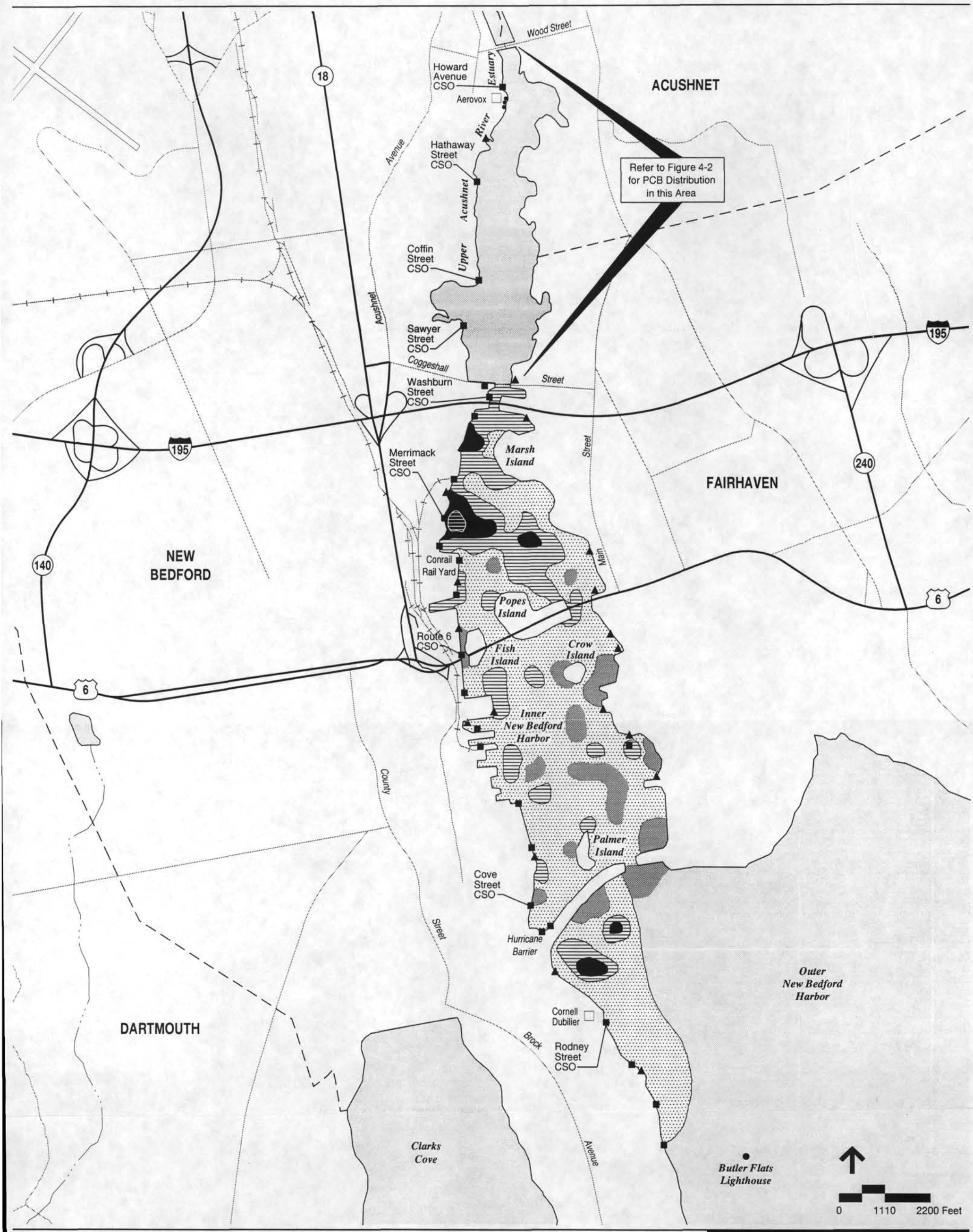
substrate samples at sediment depths of 0 to 15 cm (0 to 6 inches) from the Popes Beach wetland along Upper Buzzards Bay, located at the the end of Egypt Street in Fairhaven (Refer to Chapter 3, Figure 3-1). This reference wetland is a salt marsh of similar vegetative community types as that of the Acushnet River wetland (Refer to Chapter 3). The highest PCB concentration in the surficial sediments of the Popes Beach marsh was 4.1 ppm, as compared to a maximum concentration of 1,400 ppm in the surficial sediments of the Acushnet River salt marsh (Wetland 1, as described in Chapter 3).

PCB concentrations in Inner New Bedford Harbor were lower than those reported in the Upper Acushnet River estuary. In most of the harbor, PCB concentrations were below 50 ppm at sediment depths of 0 to 6 inches (0 to 15 cm), with most of the samples at this depth range in concentrations less than 10 ppm (Refer to Figure 4-3). Near surface sediments with concentrations generally greater than 50 ppm included an area directly south of the Washburn Street CSO along the New Bedford shore; and an area adjacent to the Conrail Railyard.

Sediments sampled from Outer New Bedford Harbor in the vicinity of the Cornell-Dubilier manufacturing facility had PCB concentrations greater than 50 ppm in the near surface sediments (0 to 6 inches (0 to 15 cm)) (Refer to Figure 4-3). PCB concentrations generally less than 10 ppm were present along the western portion of the Outer Harbor to just north of the Butler Flats Lighthouse (EBASCO, 1990a). The remainder of the sediments sampled from and south of the Outer Harbor were below 3 ppm, except for the sample collected at the New Bedford wastewater treatment plant outfall where 49 ppm of PCBs was measured in the near surface sediments.

Camp Dresser & McKee (1990) summarized the results of previous sampling that had been conducted on PCBs in the sediments of New Bedford Harbor and Upper Buzzards Bay. In general, results indicated that PCB concentrations are elevated in the Outer Harbor sediments, but concentrations decrease rapidly beyond the underwater ledges at the mouth of the harbor. One sediment sample (identified as station BT16) taken near the New Bedford Harbor waste treatment plant outfall (Location identified in the MassGIS database) revealed a PCB concentration of 226 ppm, which is above the threshold level defining PCB as a hazardous waste. The only other sediment sample in the Outer Harbor with PCB concentrations greater than 50 ppm was collected from a station (identified as station BT11) near the Cornell-Dubilier manufacturing plant (Location depicted in the MassGIS database).

The U.S. Army Corps of Engineers (ACOE) has estimated that approximately 415,000 cubic yards of sediment in the Upper Acushnet River estuary, an area of about 128 acres (52 hectares), contain PCBs at concentrations greater than 10 ppm (ACOE, 1995). Approximately 14,000 cubic yards (300 tons of PCBs) of sediment were dredged from the Hot Spot Superfund site in 1994 aand 1995. Within the Inner Harbor, an area of 35 acres (14 hectares) and an estimated 31,000 cubic yards of sediment contain PCBs in concentrations greater than 50 ppm. Approximately 28,000 cubic yards of sediment with PCB concentrations in excess of 50 ppm are present in two subtidal locations near the Cornell-Dubilier facility on the west shore of the Outer Harbor.



Total PCB Concentrations

- < 1 ppm
- 1-10 ppm
- 10-50 ppm
- 50-100 ppm
- > 100 ppm

ppm= parts per million

- ■ Approximate CSO Location
- ▲ Approximate Storm Drain Outfall Location
- • Aerovox Trench

Source: EBASCO, 1990

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 4-3

New Bedford Harbor
Total PCB Concentrations
0-6 Inch Sediment Depth

70602P6

4.3.2 Metals

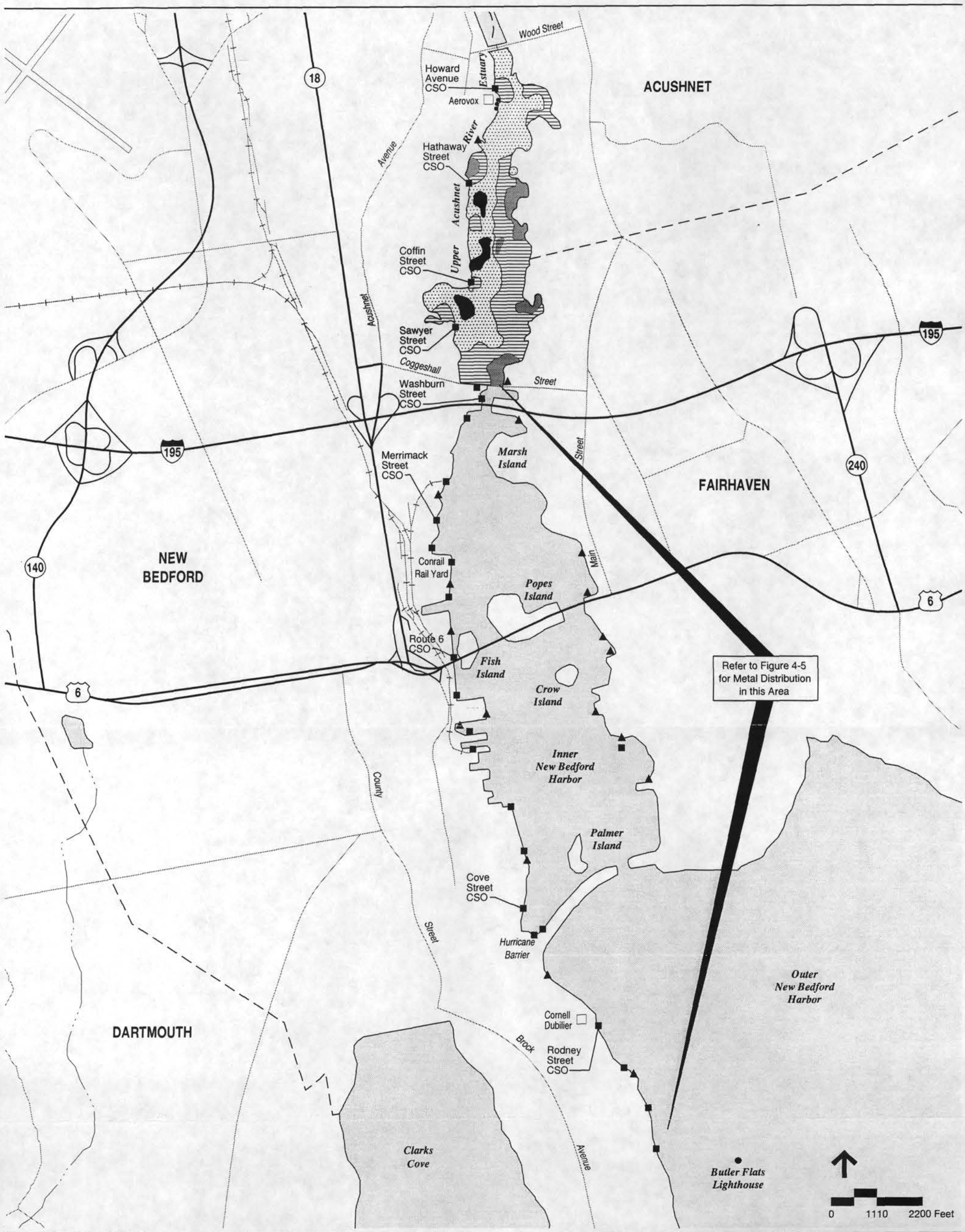
The Feasibility Study provides a summary of the concentrations and distribution of total cadmium, chromium, copper, and lead in the study area. These four metals were selected for a focus of discussion in the Feasibility Study based on previous studies identifying their frequency of occurrence, significantly elevated concentrations, physical mobility, and toxicity to aquatic organisms (EBASCO, 1990). In general, the Feasibility Study reported that the highest metal concentrations in the sediments were typically associated with industrial discharges and CSOs. Because the primary locations of metal discharges differed from the PCB discharge points, the distribution of metals in the harbor area was dissimilar in comparison to the PCB distribution.

Results provided in the Feasibility Study on metal concentrations in the Upper Acushnet River estuarine sediments between the Wood and Coggeshall Street Bridges was based on samples collected at 1-foot (0.3-m) sediment intervals to a depth of three ft (1 m). The highest metal concentrations were detected in the uppermost interval sediment layer (0 to 12 inches (0 to 30 cm)). Concentrations at the sediment-water interface for cadmium, chromium, copper, and lead in the this portion of the estuary generally ranged from 1,000 to 4,000 ppm (Refer to Figure 4-4). Concentrations greater than 5,000 ppm were recorded in the surfacial sediments sampled from three areas on the west side of the Acushnet River. One area was directly south of the Hathaway CSO, while the two others are located south of this point by approximately 1,200 ft (360 m) and 2,500 ft (750 m), respectively. Metal concentrations less than 100 ppm were reported for surfacial sediments sampled from three sites along the east side of the estuary including a tidal marsh located between 3,600 and 4,800 ft (1,080 and 1,440 m) north of the Coggeshall Street Bridge and approximately 2,000 ft (600 m) north of the bridge; and a subtidal area immediately north of the bridge.

Metal concentrations north the Coggeshall Street Bridge at sediment depths of 12 to 24 inches (30 to 60 cm) were generally greater than 100 ppm in the northern and western portions of the estuary, and lower than 100 ppm in the remaining areas. An exception to this pattern was observed in sediments from a discrete area immediately north of the Coggeshall Street Bridge and in the west central portion of the river, where metal concentrations ranged up to 1,000 ppm.

Concentrations of metals in the 24 to 36-inch (60 to 90 cm) sediment layer depth were generally less than 100 ppm, although several areas containing higher concentrations were present. These areas contained metal concentrations between 100 and 1,000 ppm. The highest concentrations, ranging from 1,000 to 5,000 ppm, were found along the western shore of the estuary, approximately midway between the two bridges.

The Feasibility Study also presented total concentration data for the four metals sampled in sediments from the uppermost 6 inches (0 to 15 cm) within the Inner Harbor and Outer Harbor. The highest concentrations of the four metals, which exceeded 1,000 ppm, were primarily north of Popes and Fish Islands (Refer to Figure 4-5). Sediment concentrations between Popes and Palmer Islands ranged from 500 to 1,000 ppm in the mid portion of the estuary with lower concentrations to the east and west. One exception is an area approximately 600 ft (185 m) southwest of Popes Island and 300 ft (90 m) northeast of the State Pier where concentrations exceeded 1,000 ppm. South of Palmer Island and the hurricane barrier, total metal concentrations in the uppermost six inches (0 to 15 cm) of sediment were below 500 ppm. Deeper sediment samples were collected from this area, but due to the lack of sufficient data, contours were not presented in the study. Total cadmium, chromium, copper, and lead concentrations in sediments collected in this area at depths to 36 inches (90 cm) were as high as 2,400 ppm. Authors of the Feasibility Study suggested that the sources of elevated metals in this area were multiple discharges from various industries along the New Bedford shoreline.



Total Metal(Cadmium, Chromium, Copper, Lead) Concentrations

- 0-100 ppm
- 100-1,000 ppm
- 1,000-5,000 ppm
- > 5,000 ppm

- ■ Approximate CSO Location
- ▲ Approximate Storm Drain Outfall Location
- • Aerovox Trench

ppm= parts per million

Source: EBASCO, 1990

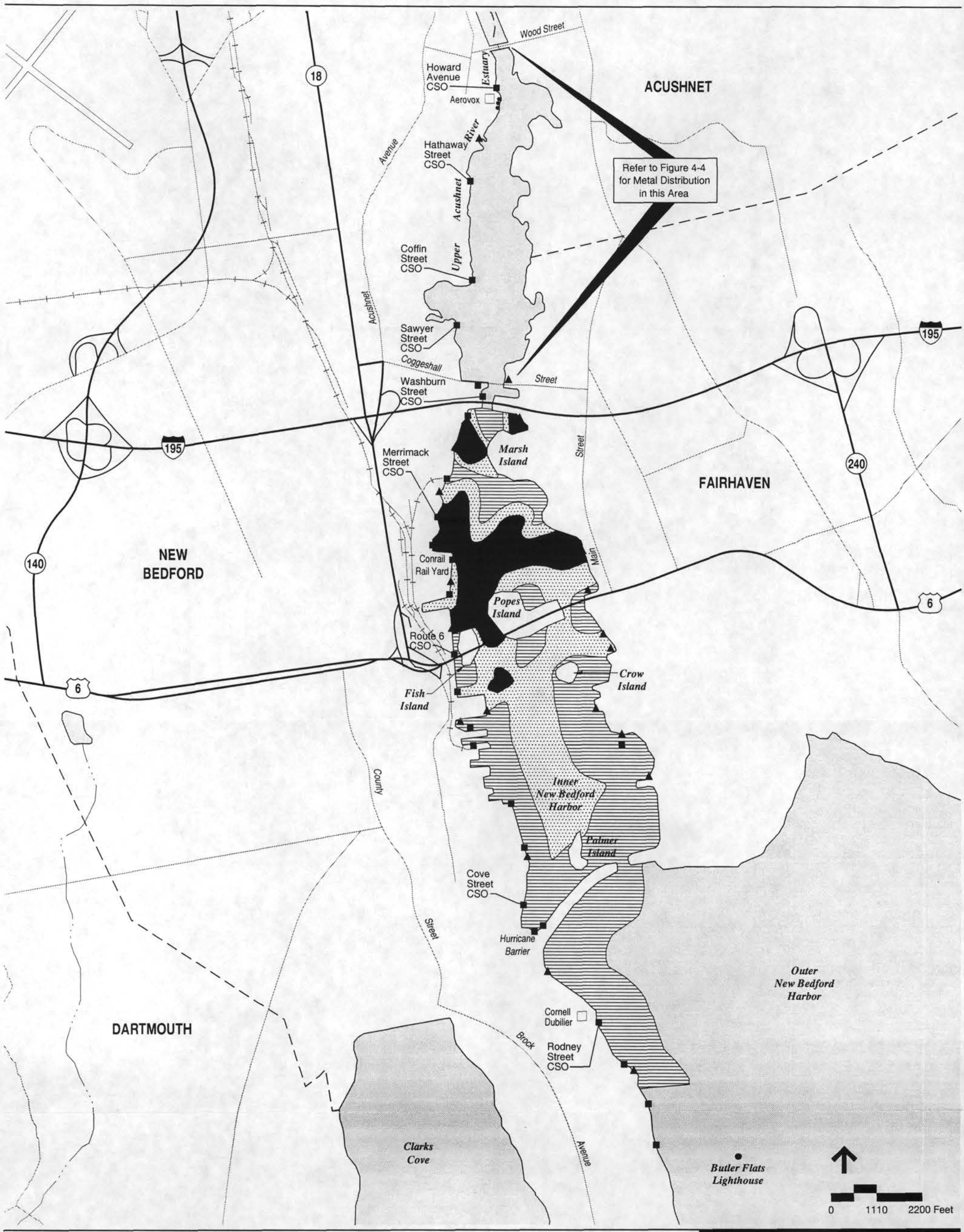
Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 4-4

Acushnet River Estuary
Total Metal Concentrations
0-12 Inch Sediment Depth

70602M12



Total Metal (Cadmium, Chromium, Copper, Lead) Concentrations

- 0-500 ppm
- 500-1,000 ppm
- > 1,000 ppm

- ■ Approximate CSO Location
- ▲ Approximate Storm Drain Outfall Location
- • Aerovox Trench

ppm= parts per million

Source: EBASCO, 1990

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 4-5

New Bedford Harbor
Total Metal Concentrations
0-6 Inch Sediment Depth

70602M6

In a study by Summerhayes et al. (1977), the metal concentrations in New Bedford Harbor sediments were compared to concentrations in Buzzards Bay sediments. They found that metal concentrations were similar for the sand fractions (*i.e.*, the portion of sediments based on size of particle) of sediment samples, but that silt and clay fractions of the harbor sediments had higher metal concentrations as compared to the Bay sediments. Fine clay fractions of the harbor sediments were the most metal enriched, with enrichment factors of 300 for copper; 150 for chromium; and 25 to 30 for cadmium, lead, and zinc. A more recent report by Summerhayes et al. (1985) presented updated study results, indicating enrichment factors of 400 for silver; 250 for cadmium; 140 for copper; 90 for zinc; and 45 to 6 for lead (45), mercury (40), chromium (32), arsenic (7), and nickel (6) in the clay fraction of the harbor sediments. They reported that copper was the most common metal found in the sediments, and that the enrichment of each of the remaining metals was highly correlated with the copper enrichment (Summerhayes et al., 1977).

The highest concentrations of copper found in the clays of harbor sediments were found near the Coggeshall Street Bridge. As a general pattern, copper concentrations decreased in New Bedford Harbor in a southerly direction and into Upper Buzzards Bay. Some localized areas of high copper levels in clay fractions were found inthe Outer Harbor, and the presence of these elevated metals is due to the City's wastewater treatment plant outfall. These metal concentrations are also partially attributed the functioning of the Inner Harbor as a "leaky sink" where contaminants are gradually transported through the hurricane barrier opening (Stoffers et al., 1977). High levels were also found south/southwest of the spoil disposal area south of West Island, where dredged harbor muds had been dumped; and several isolated locations in Upper Buzzards Bay (Summerhayes et al., 1977) (Refer to Figure 4-1). These anomolous elevated metal concentrations may be attributed to past dredge material disposal activities.

Sediment copper concentrations tended to decrease with increased sediment depth, and the thickest deposits of elevated copper concentrations were associated with the deeper waters of the harbor and Upper Buzzards Bay (Summerhayes et al., 1977). The copper rich layer thins towards the perimeters of the harbor, and decreases exponentially in thickness, progressing southward into Buzzards Bay. The authors of the study hypothesized that this exponential decrease was attributed to lateral harbor mixing due to horizontal eddy diffusion caused by near-bottom turbulence. The bottom currents transport the contaminants from the central portion of the harbor towards the harbor shores, although as the bottom current velocities decrease near shore, lower metal concentrations are expected in these areas.

Metals found in highest concentrations in the bulk sediment samples from New Bedford Harbor were copper, chromium, zinc and lead (Summerhayes et al., 1977), and most of the samples contained concentrations well above the acute AWQC for marine life in sediments. Other metals found at lower concentrations but at levels above background values included silver, arsenic, cadmium and mercury; the cumulative total concentration of these four metals was generally approximately 100 ppm. Metals were found in highest concentrations in sediments sampled along the western shore near the head of the harbor. For this area, it was reported that more than one percent of the dry weight of the sediments was comprised of copper, chromium and zinc (Summerhayes et al., 1977).

According to Summerhayes et al. (1977), chromium distribution differed from copper distribution, due to a geochemical front which inhibited seaward transport of chromium south of Clarks Point. Seaward of this area, chromium concentrations correlated with iron and manganese which are highest in sandy sediments on the topographic ridges.

It has been suggested that due to the metal levels in the fine clay fraction of sediment samples, industrial waste metals were likely discharged as very fine particles or in solution, and that about 60 percent of the copper and zinc and 90 percent of the chromium entered the harbor in solution (Summerhayes et al, 1977; 1985) . Another 25 percent of the waste metals in Buzzards Bay was attributed to atmospheric fallout.

Sediment metal concentrations measured in the Inner and Outer Harbors were also compiled in a 1979 wastewater waiver application report (Camp Dresser & McKee, 1979). One set of samples collected in 1972 indicated that highest metal concentrations were associated with the near surface sediments versus deeper (8 to 10 inches (20 to 25 cm)) sediments. An exception to this was sediment core samples collected from two stations (identified as Stations 5 and 6) in the dredge channel within the Outer Harbor, including an area approximately 1,000 ft (300 m) and another area 5,000 ft (1,500 m) south of the hurricane barrier (Refer to the MassGIS database for location). At these locations, higher elevated concentrations of several metals (*i.e.*, arsenic, lead, mercury, zinc) were found in the deeper sediment samples.

In a 1988 ACOE report, data were presented to compare levels of metal contamination in sediments in Acushnet River tidal wetlands with metal concentrations from sediments of a reference wetland near Popes Beach along Upper Buzzards Bay (Bellmer, 1988). Chromium was found in sediments at the Popes Beach wetland in concentrations ranging from 3 to 180 ppm, while in the Acushnet River tidal marsh, chromium concentrations were between 3.3 and 227 ppm. Some of the values measured at each site are above NOAA's low effects range (ER-L) of 81 ppm. Copper in the Popes Beach wetland sediments were found at concentrations of 8 to 1,400 ppm, as compared to concentrations of 3.2 to 557 ppm in the Acushnet River marsh (compare to the ER-L of 34 ppm). The range of lead concentrations in the sediments were similar for the two sites, with values ranging from 5 to 430 ppm at the Popes Beach marsh as compared to concentrations of 4.8 to 400 ppm for the Acushnet River marsh (compare to the ER-L of 46.7 ppm). Sediments of the Acushnet River marsh contained zinc in concentrations of 16 to 2,820 ppm, while the Popes Beach wetland sediments had zinc concentrations of 26 to 800 ppm (compare to the ER-L of 150 ppm). In contast to the distribution of PCBs, it was concluded that elevated levels of heavy metals were detected in both wetland sites, suggesting metal contamination is quite widespread, and not limited to the the harbor or upper estuary.

4.3.3 Petroleum Hydrocarbons and Polycyclic Aromatic Hydrocarbons

Summerhayes et al. (1977) provides an overview of the results of sediment sampling for PAHs both within New Bedford Harbor and seaward of the hurricane barrier by the ACOE. Six core samples were collected from within the harbor, while another nine samples were collected from stations within the navigational channel over a distance of approximately 3.8 miles (2.4 km). Harbor silts were found to contain between 10 and 80 times more oil and grease than Buzzards Bay sediments. In core samples collected at the head of the harbor, oil and grease formed more than 1 percent of the dry weight of the sediments. The highest oil and grease concentrations (17,000 ppm) were associated with three samples from the Inner Harbor; one sample was collected from an area approximately 800 ft (240 m) north of Route 6 Bridge, while the other two core samples were collected approximately 1,200 and 2,700 ft (360 and 810 m) south of the bridge, respectively.

Based on the results of the Feasibility Study (EBASCOa, 1990), concentrations of PAHs in the Upper Acushnet River estuary north of the Coggeshall Street Bridge ranged from a maximum of 930 ppm from a sample within the Hot spot area to values below the analytical method limit of detection. PAH concentrations averaged 70 ppm which is above NOAA's ER-L of 4.0 ppm. However, it was suggested in the Feasibility Study that this range of concentrations is similar to the sediment PAH concentrations detected in other urbanized estuaries in the Northeast (EBASCOa, 1990).

The Feasibility Study reported that sediments were sampled for PAHs and concentration trends were noted. The distribution pattern for PAHs in sediments was similar to the PCB sediment contamination, although the the range of PAH concentrations was less than that of PCBs (EBASCOa, 1990). The area with the highest PAH concentrations generally corresponded to the area where PCBs were found at concentrations greater than 4,000 ppm. Conclusions of the Feasibility Study indicate that the distribution pattern of PAH contamination and concentrations in the Acushnet River estuary was most likely attributed to non-point

source runoff and aerial fallout, unlike the PCB contamination which resulted from point source discharges. Combined sewer overflows were not cited in the study as point sources of PAHs. The study also determined that the majority of the environmental and health risk resulting from exposure to New Bedford Harbor estuarine sediments would be from PCBs, rather than PAHs.

4.4 CONTAMINANT DISTRIBUTION AND CONCENTRATIONS IN SURFACEWATERS

A summary of sampling data for PCBs and metals in surfacewaters draws primarily from the Feasibility Study of Remedial Alternatives for the Estuary and Lower Harbor/Bay (EBASCO, 1990a); the New Bedford Harbor Superfund Project Wetlands Assessment (Bellmer, 1988); the New Bedford Harbor Superfund Dredging Pilot Study (ACOE, 1990); the City of New Bedford Phase 2 Facilities Plan (Camp Dresser & McKee, 1990); and unpublished data collected by the US EPA (as provided by P. Caffrey, MDEP) during the Hot Spot dredging.

4.4.1 Polychlorinated Biphenyls

As previously mentioned, the solubility of hydrophobic PCBs in water is extremely low, and its solubility decreases with increasing chlorination. The solubility of PCBs in water ranges from 0.0027 ppm (for Aroclor 1260) to 15.0 ppm (for Aroclor 1221) (Metcalf & Eddy, 1983). In general, solubilities are less than 1 ppm for most Aroclors.

The concentrations of PCBs in surfacewaters was presented for 18 sampling stations within the Acushnet River estuary, New Bedford Harbor and Upper Buzzards Bay by Battelle Ocean Sciences in 1987 (EBASCO, 1990a). Three of the stations were located between the Wood Street and Coggeshall Street Bridges; eight stations were between the Coggeshall Street Bridge and the hurricane barrier; and the remaining seven stations were sited south of the hurricane barrier and located along Clarks Point. Data results represented the sum of the geometric mean values for particulate and dissolved samples from each of the sampling stations.

The highest PCB concentrations in surfacewaters, as presented in the Feasibility Study, were detected in the northernmost sections of the estuary, with surfacewater concentrations generally decreasing in a southerly direction. The highest concentration detected was 7.6 ppb in a sample collected directly south of the Wood Street Bridge, near the discharge points from the Aerovox Corporation facility. Between the Coggeshall Street Bridge and the hurricane barrier, concentrations measured in the seven samples collected ranged from 0.318 ppb to 0.091 ppb. South of the hurricane barrier, concentrations in the nine sampling locations ranged from 0.111 ppb to 0.005 ppb.

Continuous water quality monitoring was completed during the Hot Spot remediation to document net PCB transport in the water column from the upper estuary to New Bedford Harbor, and water column samples were collected daily from the Coggeshall Street Bridge throughout dredging period. Samples were analyzed for 5 congeners in both dissolved and particulate phases and transformed to Aroclor concentrations; ebb and flood tide volumes were calculated from measured tide heights at this sampling station. During the 260-day monitoring period, ebb concentrations ranged from 0.35 to 2.23 ppb, while PCBs in the flood tides ranged from 0.21 to 1.25 ppb. Cumulatively, 57.7 kilograms (kg) of PCBs were transported from the upper estuary into New Bedford Harbor over the 260-day period (US EPA, unpublished data), which was substantially less than the 240 kg threshold selected to prevent more than an average of 1 ppm increase in PCB sediment concentrations within the Inner Harbor.

The lack of consistent sampling protocols for contaminant monitoring affected some of the PCB concentrations measured in the water column. Sanford Ecological Services (SES) presented information

from a NUS report and from a personal communication with Battelle (SES, 1988). The report indicated Aroclors 1248/1254 were detected in the water column within the Acushnet River estuary at concentrations up to 6.1 ppm. This value is three orders of magnitude greater than other surfacewaters concentrations presented in the Feasibility Study. It is possible that this result represents total PCBs in an unfiltered water sample, as this concentration is significantly higher than the solubility limit for most PCBs, and may include PCBs adsorbed to sediments in the sample. Based on two other sampling studies, the SES indicated that concentrations of 1 to 10 ppb of total PCBs were detected along the northwest shore of the estuary near the Aerovox facility. It was reported that no significant differences in concentrations were measured during the tidal cycle or between surface and bottom water samples (SES, 1988). However, a review of the study results indicate that concentrations in the Outer Harbor were 5 to 10 times lower than those in the Inner Harbor. In general, nearly all of the measurements exceeded the chronic level AWQC of 0.03 ppb for PCBs.

Between July 1987 and June 1988, the ACOE sampled PCBs from the water column at two stations south of the Coggeshall Street Bridge ("Station 2") and another in the Inner Harbor, directly upriver of the hurricane barrier ("Station 4") (ACOE, 1990) (Refer to the MassGIS database). Composite water column samples from these stations were then analyzed for whole water (*i.e.*, total) PCBs. The average PCB concentration was 0.607 ug/l (0.6 ppb) for Station 2 during the ebb tide, while an average concentration of 0.114 ug/l (0.1 ppb) was measured at Station 4 during the ebb tide. These values exceed the chronic level AWQC for PCBs.

A study completed by Camp Dresser & McKee (1990) on the City of New Bedford waste treatment facility outfall presented data for PCBs in the mid-water column at stations throughout the Inner and Outer Harbors during the flood tide in January 1989, referencing data collected for the US EPA Superfund project. The data covered four sampling periods, and each sample station included various tide conditions. Mean values of the sum of the dissolved and particulate concentrations across all sampling periods ranged from 154 to 1.8 ppm. These values reported seem extremely high, and suggest the presence of significant suspended solids in the water column. It is assumed that these results actually represent samples with resuspended solids forming the "soupy" sediment-laden water that transitions into the bottom substrate (Refer to the Sedimentation section in Chapter 3 of this report). The highest measurement was associated with a station located approximately 1,000 ft (300 m) north of the hurricane barrier (Refer to the MassGIS database). Mean concentrations for samples from Upper Buzzards Bay south of Sconticut Neck in Fairhaven and Round Hill Point in Dartmouth were much lower (1.8-8.2 ppm) than the Inner Harbor mean concentration. Data from the Superfund project were also used to determine the background level for PCBs in Buzzards Bay. The total PCB value was determined by totaling the concentrations of the individual congeners quantified in each sample. A value of 0.18 ppb was determined as the ambient total PCB baseline concentration for Buzzards Bay, and it should be noted that this value exceeds the present chronic AWQC for PCBs.

As previously mentioned, some of the PCB concentrations reported for New Bedford Harbor were very high and beyond the solubility limit. The release of PCBs to surfacewaters is affected by several factors. PCBs are transported from the highly contaminated bottom sediments into the overlying water column as a result of erosion and resuspension by wind and tidal-driven currents at the boundary layer; bioturbation by benthic organisms; desorption from fine-grained sediment particles and upward diffusion into interstitial pore water; and upward convection with gases produced in anaerobic sediments (Battelle Memorial Institute, 1990). Storm events causing erosion and transport of PCB-laden sediments are likely the primary cause of PCBs in the water column; storms with wind speeds in excess of 34 miles per hour (15 m/s) typically occur on a monthly basis for a 1 to 2-day duration during October through April (ASA, 1987).

Conversely, PCBs are removed from the water column via several pathways. Dissolved PCBs in the water column are readsorbed to "clean" fine-grained sediment particles transported to the harbor from Buzzards Bay and neaby upland sources, thereby potentially decreasing water column levels (Refer to the Physical

and Biological Pathways section later in this chapter). PCBs are also uptaken and bioaccumulated by estuarine and marine organisms (Refer to the Biological Fate Pathway section later in this chapter). Lastly, PCBs in the water column are volatilized in significant amounts in the shallow areas of the estuary and harbor, thereby decreasing water column concentrations.

4.4.2 Metals

Total copper concentrations between 800 and 5,000 ppb and lead concentrations between 300 and 1,000 ppb were reported for surfacewaters sampled from the Upper Acushnet River estuary in 1985 and 1986 (SES, 1988). Dissolved copper (2.3 - 2.9 ppb) and lead (0.29 - 0.46 ppb) were significant lower; although one of the dissolved copper measurements reached the acute level AWQC of 2.9 ppb. Particulate cadmium concentrations up to 13 ppb were also reported with dissolved concentrations (0.11 - 0.31 ppb) significantly lower. Dissolved cadmium concentrations did not exceed the chronic level AWQC. In general, more than 97 percent of these three metals in the water column were associated with particulates.

Concentrations of copper, cadmium, and lead (the sum of triplicate samples of seawater with both dissolved and particulate metals included) in the mid-water column for samples from the lower Inner Harbor and Outer Harbor during the flood tide in January 1989 were presented by Camp Dresser & McKee (1990). Highest mean metal concentrations (copper, 2,910 ppm; cadmium, 195 ppm; and lead, 924 ppm) were measured at a station approximately 1,000 ft (300 m) north of the hurricane barrier, while concentrations in Upper Buzzards Bay were significantly lower. These elevated water column concentrations suggest samples with extremely high suspended solids. Baseline metal concentrations were also determined for Buzzards Bay, based on one sampling station determined to best reflect "pristine conditions". The mean baseline concentrations of copper, cadmium, and lead at the station were 0.436 ppb, 0.029 ppb, and 0.126 ppb, respectively. These background levels are similar to baseline levels that have been previously measured for Buzzards Bay and Rhode Island Sound.

4.4.3 Polycyclic Aromatic Hydrocarbons

No data on the concentrations of PAHs in the surfacewaters of New Bedford Harbor or the Upper Acushnet River estuary were found in previous reports. Background concentrations of PAHs were measured for Buzzards Bay by sampling the mid-water column during a flood tide in January 1989 at a station considered as a baseline site (located just north of Nashawena Island) for the Superfund project (Camp Dresser & McKee, 1990). No volatile organic compounds were detected, and of the semivolatile organics targeted, only very low mean concentrations (triplicate samples of seawater and particulates) of flouranthene (6 parts per trillion (ppt)), phenanthrene (7 ppt), and pyrene (1 ppt) were detected.

4.5 CONTAMINANTS IN BIOTA

The following sections provide brief summaries of the levels of contaminants found in biota within Areas I, II, and III and within portions of Upper Buzzards Bay seaward of Area III. Following these summaries, an overview is then presented on the physical, chemical and biological processes and factors that influence the bioaccumulation of contaminants in marine biota.

4.5.1 Polychlorinated Biphenyls

Kolek and Ceurvels (1981) discussed the levels of PCBs in the edible portions of New Bedford Harbor fish for the years 1976 through 1980. American eel (*Anguilla rostrata*) were found to contain the highest PCB

concentrations (11-730 ppm), as they spend much of their lives partially buried in sediments and have relatively high amounts (26 percent) of body fat in which PCBs are principally stored. Winter flounder were also found to contain relatively high PCB levels (0.2-13 ppm). In 1976, the highest mean concentrations (9.5 ppm) were associated with flounder from Area I, and progressively declined in Area II (8.3 ppm) and Area III (4.1). Also, PCB concentrations in winter flounder generally decreased in each of these areas between 1976 and 1980. Other finfish species were sampled and found to sometimes contain PCBs at levels above the 2 ppm standard set by the U.S. Food and Drug Administration for human consumption of fish.

Shellfish were also sampled by Kolek and Ceurvels (1981), and relatively high PCB concentrations were found in soft-shelled clam (*Mya arenaria*) (14.6-53.0 ppm), while significantly lower levels were found in quahog (*Mercenaria mercenaria*) (0.1-3.3 ppm). Blue crab (*Callinectes sapidus*) that were sampled only from Areas I and II contained PCB levels between 1.0 and 4.2 ppm. American lobster (*Homarus americanus*) sampled from Areas II and III as well as waters seaward of Area III (considered Area IV) contained PCBs concentrations between 1.0 and 68.2 ppm. The highest concentrations were generally associated with lobster from Area II and successively declined in Areas III and IV.

Concentrations of PCBs in the edible portion of New Bedford lobster, winter flounder, and hard clam were also collected by Battelle Ocean Sciences in 1987 and included in the New Bedford Harbor Feasibility Study. Highest PCB concentrations were found in winter flounder caught from Area (Refer to Table 4-2). The lower than expected PCB concentrations in lobster in comparison to winter flounder values were due to the exclusion of the tomalley in the analyzed samples; the tomalley is an organ in which PCBs bioaccumulation is excentuated in lobster. Hard clam harvested from Area I were the only other biota sampled that had levels above the FDA acceptable level of 2 ppm for human consumption.

Camp Dresser & McKee (CDM, 1990) reported on the bioburden of PCBs in American lobster, blue mussel, hard-shelled clam, and winter inhabiting New Bedford Harbor and Upper Buzzards Bay. Hard-shelled clams demonstrated a distinct bioaccumulation gradient, and highest measurements for total PCBs (2.3 ppm) were identified in the Inner Harbor with decreasing values towards and into Upper Buzzards Bay. The other species did not demonstrate this concentration gradient; PCB levels in whole tissue of lobster ranged from 0.04 to 1.6 ppm with no correlation with distance from the Inner Harbor. Very high PCB concentrations were measured in samples of lobster hepatopancreas, with values as high as 44 ppm from the Inner Harbor and values as high as 7 ppm for lobster caught from central Buzzards Bay.

The ecological risk assessment completed by EBASCO (1990) incorporated whole-body concentrations of total PCBs in lobster, winter flounder, blue mussel, quahog, green crabs, and mutliple polychaete worms collected from Areas I, II, and III of the New Bedford Environment and from waters seaward of Area III (Refer to Table 4-3). These samples were collected by Battelle Ocean Sciences between 1984 through 1986. In general, the tissue residue levels of PCBs correlated with the concentrations found in the sediments and water column. Highest concentrations were typically found in Area I and successively decreased in Areas II and III and waters seaward of Area III (defined as Area IV). The highest concentrations were associated with polychaete worms, species which are typically found living within and in direct and continuous contact with the contaminated sediments. Some of these polychaete species are pollutant-tolerant, and are therefore, more likely to bioaccumulate PCBs. Winter flounder were also found to have high PCB whole-body levels in comparison to the other species sampled, and these high levels reflect the species affinity for lying partially covered with sediments and its relatively high body fat content.

TABLE 4-2
CONCENTRATIONS OF TOTAL PCBS (ppm) IN EDIBLE TISSUE OF BIOTA COLLECTED FROM THE NEW BEDFORD HARBOR AREA, 1987

Species	Area I	Area II	Area III	Seaward of Closure Areas
American Lobster[1]				
Mean	0.906	0.568	0.213	0.064
Maximum	1.248	1.234	0.351	0.176
Winter Flounder[2]				
Mean	1.439	0.512	0.384	0.139
Maximum	3.628	1.446	1.138	0.469
Hard Clam				
Mean	0.689	0.231	0.156	0.039
Maximum	2.121	1.181	0.478	0.137

[1] Lobster concentrations do not include tomalley.
[2] The edible tissue concentration was estimated using a whole body/edible tissue ratio of 0.18

Data collected by Battelle Ocean Sciences, 1987
Adopted from: EBASCO (1990b)

Biota were also collected from the tidal marshes within New Bedford Harbor and a nearby reference wetland located outside the harbor near Popes Beach (Refer to Chapter 3 for detailed descriptions of these wetlands). Mummichog (*Fundulus heteroclitus*) and winter flounder were collected from tidal guts and other shallow water habitat within these marshes; grass shrimp (*Palaeomonetes pugio*) were collected from the salt marsh sediments; and ribbed mussel (*Geukensia demissa*) were collected from areas within the salt marsh zone (IEP, 1988). Highest mean PCB concentrations in grass shrimp were associated with those sampled from Wetland 3 which is the northernmost wetland locateed in the Upper Acushnet River estuary (Refer to Table 4-4). PCB levels in grass shrimp sampled from other harbor wetlands were found to be decreasing in the following order: Wetlands 1, 5, 4, and 9. Wetland 9 is the southernmost marsh, located in the Inner Harbor. The lowest levels were measured in shrimp sampled from the Popes Beach reference wetland.

Mean PCB concentrations in ribbed mussel and mummichog followed a similar pattern. The highest PCB concentrations in ribbed mussel were those sampled from Wetland 1 which is also located in the Upper Acushnet River estuary. Average PCB levels in mussels sampled from other wetlands were documented in the following decreasing concentrations: Wetlands 3, 5, 4, and 9. The lowest levels were measured in shrimp from the reference wetland. Mummichog were sampled from only three of the wetlands, and PCB levels in this species were identified for the wetlands in the following decreasing order: Wetlands 5, 9 and 2. The spatial pattern of PCBs in the harbor biota correlates with the spatial pattern of PCBs found in the sediments and water column that were described earlier in this chapter.

TABLE 4-3
WHOLE-BODY CONCENTRATIONS OF TOTAL PCBS (PPM) IN NEW BEDFORD HARBOR BIOTA USED IN NEW BEDFORD HARBOR ECOLOGICAL RISK ASSESSMENT

	Location[1]			
Species	**Area I**	**Area II**	**Area III**	**Area IV**
American Lobster				
Minimum	---	0.195	0.042	0.017
Mean	1.131[2]	0.568	0.213	0.064
Maximum	---	1.235	0.351	0.176
Winter Flounder				
Minimum	3.138	0.926	0.515	0.123
Mean	7.992	2.853	2.138	0.777
Maximum	20.230	8.067	6.349	2.616
Blue Mussel				
Minimum	1.467	1.461	0.254	0.008
Mean	2.262	3.874	0.266	0.023
Maximum	2.962	6.204	0.278	0.039
Quahog				
Minimum	0.200	0.010	0.026	0.200
Mean	2.121	1.182	0.478	0.137
Maximum	5.300	1.777	1.200	0.300
Green Crab				
Minimum	0.071	0.067	0.624	0.020
Mean	0.398	0.184	0.976	0.048
Maximum	0.725	0.301	1.329	0.077
Polychaetes				
Minimum	---	---	0.096	0.182
Mean	12.972[2]	1.654[2]	0.392	0.486
Maximum	---	---	0.689	0.790

Notes:

[1]Locations correspond to Fishery Closure Areas. Area IV is seaward of Area III.
[2]Only one value available

Adopted from: EBASCO (1990b)

TABLE 4-4
MEAN VALUES OF METALS AND PCBs (ppm) SAMPLED FROM NEW BEDFORD AREA WETLANDS, 1986[1]

Wetland Number/ Species	Cd[2]	Cr[2]	Cu[2]	Pb[2]	Hg[2]	Zn[2]	PCBs
Wetland 1							
Ribbed Mussel	--	--	--	--	--	--	39
Grass Shrimp	ND	0.97	44	0.90	ND	20.3	7.63
Mummichog	ND	0.88	4.3	1.1	0.0099	34	--
Wetland 2[3]							
Ribbed Mussel	0.32	0.57	5.5	0.56	0.0086	7.2	0.64
Grass Shrimp	ND	ND	33	0.85	ND	20	0.33
Mummichog	ND	ND	2.5	ND	0.018	30	3.0
Winter Flounder	ND	ND	1.7	0.32	0.0056	31	1.4
Wetland 3							
Ribbed Mussel	--	--	--	--	--	--	27
Grass Shrimp	ND	0.36	40	0.83	ND	20	25.3
Wetland 4							
Ribbed Mussel	0.26	0.62	4.8	0.87	ND	9.4	10.3
Grass Shrimp	ND	0.50	35	0.66	ND	15.3	2.4
Mummichog	ND	ND	2.9	0.35	0.016	37	--
Wetland 5							
Ribbed Mussel	0.33	0.67	2.8	0.79	ND	9.9	14
Grass Shrimp	ND	0.81	36.3	1.17	ND	20	3.6
Mummichog	--	--	--	--	--	--	44
Wetland 9							
Ribbed Mussel	1.04	0.82	2.1	0.92	0.0089	6.6	2.2
Grass Shrimp	ND	ND	38.7	0.61	ND	17.3	1.7
Mummichog	--	--	--	--	--	--	8.1

[1] Adapted from: IEP, Inc. (1988); Bellmer (1988)
[2] Cd=cadmium, Cr=chromium, Cu=copper, Pb=lead, Hg=mercury, Zn=zinc
[3] Wetland 2 is reference site at Popes Beach
ND = Not Detected

A general temporal trend in PCB levels in biota can be noted by reviewing data compiled by the Massachusetts Division of Marine fisheries (DMF) over a 15-year period for samples of lobster caught from eleven stations within Area III (Refer to Table 4-5). The DMF mean annual data for the edible portion of lobsters suggest a general decrease in the PCB concentrations over the 15-year period; mean values as high as 5.4 ppb (in 1984) were calculated for samples during the 1980s, while average

TABLE 4-5
MEAN ANNUAL PCB CONCENTRATIONS IN EDIBLE PORTION OF LOBSTER SAMPLED BY THE MASSACHUSETTS DIVISION OF MARINE FISHERIES FROM AREA III OF THE NEW BEDFORD ENVIRONMENT, 1980-1995[1]

Year	PCB Concentration[2] (in ppb)
1980	3.0
1981	2.3
1982	4.5
1983	3.8
1984	5.4
1985	4.5
1986	2.7
1987	4.1
1988	ND
1989	2.3
1990	2.4
1991	2.6
1992	0.95
1993	1.1
1994	0.63
1995	1.3

1 Data provided by J. Schwartz, DMF Cat Cove Laboratory, May 1996

2 Data include 11 sampling stations, with most values derived from composite samples of 2-3 individuals. Values for 1980-1981 represent averages of individual analyses or single analyses. Aroclor 1254 was standard for years 1980-1990; Data for 1991-1995 determined using US EPA 18-congener standard.

ND = No Data

concentrations have been no more than 2.6 ppb since 1989. Although this general decline in PCB concentrations may be attributed to the elimination of direct releases of the contaminant to the harbor, inconsistent sampling protocols need to be considered in this assessment. Most of the average annual concentrations are based on composite samples from 2 to 3 lobsters sampled from each of the eleven Area III stations, while values for 1980, 1981, the Spring sampling in 1986, and Station YY in the autumn of 1985 represent average concentrations of individual analyses or single analyses.

Also, concentrations determined for the years 1980 through 1990 were based on an Aroclor 1254 standard, as compared to values for the 1991 through 1995 samples that have been based on analyses using 18 PCB congeners (*i.e.*, protocol now used by the US EPA and NOAA). The more recent analyses using the 18-congener method indicates that there may be an even more significant decrease in PCB concentrations in lobster during this 15-year monitoring period, as earlier analyses using the Aroclor 1254 standard may have underestimated total PCB concentrations (Based on this downward trend in PCB levels in lobster, the DMF is presently petitioning the Massachusetts Department of Public Health to open Area III to lobster harvesting (D. Pierce, pers. comm.)).

Sanford Ecological Services (SES, 1988) also measured PCB levels in the tissue of selected aquatic biota and white-footed mice caught within the New Bedford Environment. PCBs (Aroclors 1242 and 1254) were detected in all samples. The highest PCB level (measured as wet weight), was identified in a subcutaneous fat sample (5,042 ppm) from a single black duck, although levels were lower in the black duck liver (425 ppm) from breast muscle (100 ppm). Other relatively high levels were measured in fat tissues of ring-billed gulls (33-340 ppm), while gull muscle tissue had lower PCB concentrations (0.96 - 38.00 ppm). Maximum PCB concentrations found in small numbers of other species sampled were as follows: white-footed mouse (56 ppm), Orchestia amphipods (47 ppm), ribbed mussel (92 ppm), *Melampus* sp. snail (5.6 ppm), and sea lettuce (*Ulva* sp.) (48.8 ppm). Higher levels of Aroclor 1242 were typically associated with the lower trophic level biota (*e.g.*, mussel, sea lettuce), while higher concentrations of Aroclor 1254 were found in the gulls, black duck, and white-footed mice. The results suggest biomagnification of PCBs within the food chain organisms tested.

4.5.2 Metals

Concentrations of metals in harbor biota did not follow the pattern of PCB levels identified in the biota. Cadmium, copper, and lead concentrations were measured in lobster, winter flounder, blue mussel, quahog, green crab, and multiple species of polychaetes, and results were included in the New Bedford Harbor ecological risk assessment prepared by EBASCO (1990b). For cadmium, the highest levels (0.703 ppm) were found in lobster caught in Area II (Refer to Table 4-6), while the highest cadmium concentrations (0.397 ppm) in winter flounder were fish collected from Area III. The highest cadmium measured in quahogs was in a sample from Area IV.

Copper concentrations in the harbor biota ranged from a low of 0.11 ppm in a lobster sampled from Area I to a high of 262.5 ppm in a green crab collected from Area I. Some of the highest copper concnetrations were found in the green crab, although relatively high levels were also found in lobster and winter flounder. The higher levels in green crab and lobster are attributed to crustacean physiology, and not necessarily bioaccumulation. The relatively high levels in winter flounder are attributed to the fishes' ability to metabolize and bioaccumulate copper.

Lead concentrations in the biota ranged from a low of 0.089 ppm in winter flounder from Area IV to a high level of 30.6 ppm in green crab collected from Area III. Concentrations varied widely in all species and from all four Areas sampled. These results are likely influenced by non-point source pollution (*i.e.*, runoff and aerosols) which is contributing lead to the harbor.

Camp Dresser & McKee (CDM, 1990) reported on the bioburden of contaminants in American lobster, blue mussel, hard-shelled clam, and winter flounder inhabiting New Bedford Harbor and Upper Buzzards Bay, and the organisms were sampled for copper, cadmium, and lead. Hard-shelled clams demonstrated a distinct bioaccumulation gradient, with highest measurements (7 ppm for copper; 2.5 ppm for lead; and 0.48 ppm for cadmium) in the Inner Harbor and decreasing values towards and into Upper Buzzards Bay.

Metal concentrations were also measured in biota collected from the harbor tidal marshes and the nearby Popes Beach reference marsh. Six metals (cadmium, chromium, copper, lead, mercury, and zinc) were measured in ribbed mussel, grass shrimp, mummichog, and flounder sampled from five harbor salt marshes and the Popes Beach wetland in 1986 (Refer to Table 4-4). Mean concentrations varied amongst species, wetlands, and the metals. The highest cadmium concentrations were found in ribbed mussel collected from Wetland 9, the southernmost harbor salt marsh. The highest chromium concentrations were measured in grass shrimp and mummichog from Wetland 1. Grass shrimp contained the highest copper levels that were more likely influenced by their chemical physiology than bioaccumulation. The highest lead concentrations were measured in ribbed mussel from Wetland 5; highest mercury levels were identified in mummichog from Wetland 4; and highest zinc levels from mummichog from Wetland 1 and winter flounder and mummichog collected from reference Wetland 2.

Metals were also sampled in higher trophic level organisms from the New Bedford Environment by Sanford Ecological Services (SES,1988). Muscle and fat tissue of ring-billed gulls contained maximum (wet weight) chromium, copper, lead, and zinc levels of 4.0 ppm, 6.7 ppb, 5.0 ppm and 130 ppm, respectively. Maximum levels of chromium, copper, lead, and zinc in black duck muscle and liver tissue were measured at 0.2 ppm, 5.7 ppm, <0.9 ppm (*i.e.*, below the detection limit), and 15 ppm, respectively. Maximum levels of chromium, copper, lead, and zinc in white-footed mice were measured at 3.7 ppm, 8.4 ppm, 3.9 ppm, and 91 ppm, respectively. Although some of these metals may be concentrated in several of the test organisms, the data do not suggest transfer within the food chain or biomagnification when compared to the metal concentrations in food items of these species and other trophic level organisms.

TABLE 4-6
RANGE OF TOTAL WHOLE-BODY METALS (PPM) IN NEW BEDFORD HARBOR BIOTA USED IN NEW BEDFORD HARBOR ECOLOGICAL RISK ASSESSMENT[1]

Organism	Area[2]	Cadmium	N[3]	Copper	N[3]	Lead	N[3]
American Lobster	I	0.002NC	2	0.11-24.9	2	0.223-1.29	2
	II	0.002-0.703	16	20.778-46.814	16	0.106-3.034	16
	III	0.001-0.538	14	17.997-50.945	14	0.021-1.124	14
	IV	0.002-0.588	21	15.788-62.663	21	0.029-0.842	21
Winter Flounder	I	0.004-0.014	23	0.692-11.247	23	0.215-3.36	22
	II	0.002-0.019	27	0.618-19.847	27	0.154-4.523	27
	III	0.002-0.012	17	0.691-51.642	17	0.099-2.728	17
	IV	0.003-0.099	22	0.480-43.9	22	0.089-6.84	22
Blue Mussel	I	0.242-0.326	9	1.948-2.49	9	0.293-1.41	9
	II	0.229-0.271	9	1.895-2.779	9	0.237-1.17	9
	III	0.326-0.397	6	0.726-0.841	6	0.367-0.647	6
	IV	0.145-0.209	6	0.727-1.081	6	0.134-0.308	6
Quahog	I	0.087-0.356	18	3.727-8.302	18	0.58-1.901	18
	II	0.209-0.329	18	1.47-4.055	18	0.488-0.981	18
	III	0.12-0.381	18	1.302-2.713	18	0.208-3.463	18
	IV	0.119-0.495	10	1.225-2.239	10	0.098-1.720	10
Green Crab	I	0.075-0.105	5	53.418-262.475	5	4.292-29.768	5
	II	0.027-0.095	4	12.1-52.897	4	1.45-6.908	4
	III	0.081[4]	1	201[4]	1	30.6[4]	1
	IV	0.057[4]	3	180.231[4]	3	13.824[4]	3
Polychaetes	I	NA		NA		NA	
	II	NA		NA		NA	
	III	0.065-0.188	6	2.36-6.37	6	0.467-3.979	6
	IV	0.111[4]	3	7.708[4]	3	1.076[4]	3

[1]Each value represents the mean of several organisms within one size class
[2]Areas correspond to Fishery Closure Areas; Area IV is seaward of Area III
[3]Total number of organisms sampled in each area
[4]Only one value available
NA = Not available
Adopted from: EBASCO (1990b)

4.6 CONTAMINANT FATE PATHWAYS

A thorough understanding of site-specific contaminant fate pathways is central to the assessment of risk from the exposure of living resources at the New Bedford Superfund Site. A multitude of complex, dynamic, and interactive physical, chemical, and biological processes collectively contribute to the fate of chemical contaminants in the marine and estuarine environment. Physical and chemical properties of contaminants and their fate pathways determine the chemical form and distribution of contaminants associated with the water column, suspended particulates, sediment particles, sediment pore water, and the air above the water surface. The bioavailability of contaminants is also a complex process influenced by many factors including contaminant chemical form, duration of exposure, organism feeding strategy, organism position in the food web, life history and habitat preference of the species, tissue lipid content, and detoxification mechanisms and rate.

Knowledge of site-specific contaminant fate pathways is necessary to estimate the cumulative exposure of biological receptors and the resultant risk to species, communities, and ecosystems. The principal known fate processes that result in the movement of pollutants from the active ecological compartments have been summarized by the US EPA (1993a) and include burial, degradation, volatilization (taken up in a gaseous phase), and advection (movement from one medium to another). Chemical processes that determine contaminant form, fate, and bioavailablility in sediments has also been recently reviewed (USEPA, 1994a).

Published studies on the sources and types of chemical contaminants at the New Bedford Superfund Site Study Area were previously described in Section 4.2 of this report, and Section 4.3 summarizes the literature on contaminant distribution and concentrations in New Bedford Harbor sediments, including concentrations at various sediment depths. To complement this information, The following sections are reviews of site-specific or site-relevant literature on the chemical, physical, and biological fate pathways of PCB and metal contaminants. Existing literature on the associated risk of potential adeverse ecological impacts in New Bedford Harbor resulting from exposure is then presented in Section 4.7.

4.6.1 Chemical and Physical Pathways

A thorough understanding of the chemical interactions and physical contaminant pathways is essential to effective decisionmaking for cost-efficient comparative risk management. Chemical pathway analysis requires contaminant monitoring, an understanding of site-specific chemical transformations, and fate modeling of the contaminant. Contaminants in the New Bedford Harbor area interact with the physico-chemical environment and are physically transported throughout the system. As these processes occur, biological receptors undergo varying degrees of exposure and effects, depending on a multitude of factors affecting a species' ecological niche and the habitats of the organism throughout its life cycle.

Within each of the general classes of chemicals addressed in this report are many congeners that form numerous compounds with varying physical, chemical, and biological properties. Some of the contaminants interact with biota and chemicals in the environment -- with profound effects on their chemical form and solubility, physical transport, and bioavailability to biota. Properties of the contaminants have a significant effect on the probability of significant exposure and harm, availability for uptake by biota, manifestation of toxic effects, transfer through the food web, and likelihood of biological transport both within and out of the estuary.

Polychlorinated Biphenyls

The chemical structure of PCBs is a major factor in their physical, chemical, and biological pathways and environmental persistence. The structure of PCBs is very different from the other site-specific contaminants

of concern (*i.e.*, heavy metals and PAHs). The properties that lead to their persistence and transfer through pathways has recently been thoroughly reviewed by Ericson (1991). As previously discussed, PCBs are variously chlorine-substituted biphenyls, and there are 209 different synthetic classes of PCB congeners, consisting of one or any combination of up to ten chlorine atoms attached to the biphenyl molecule. The chemical stability of PCBs is a key factor in their resistance to environmental degradation. To better understand the chemical pathways of PCBs in New Bedford Harbor, it is essential to identify and be familiar with the following key properties of PCBs that contribute significantly to their persistent availability in fate pathways and continuing exposure to estuarine organisms:

- PCBs readily adsorb to organic matter, clay, other fine-grained particulates, and phytoplankton;
- PCBs have a very low solubility in water;
- The resonance structure of PCB molecules contributes to their stability;
- Higher sediment adsorption is directly related to increasing PCB molecular weight and chlorine content;
- They are refractory to photochemical degradation from sunlight;
- Concentrations of PCBs in the environment reach an equilibrium or may be subject to a dynamic equilibrium affected by continuous exchange of PCBs between the sediments and the water column; and
- PCBs are very soluable in the lipid (fatty) tissues of many organisms and readily concentrate in aquatic organisms exposed to PCBs inhabiting contaminated habitats.

Due to these factors, PCBs have many properties that result in their widespread persistence in both abiotic and biotic pathways; exposure to biota at all trophic levels; accumulation in tissues; and subsequent transfer and concentration through food webs. By consuming contaminated seafood, man can also be exposed to PCBs, and for this reason, the MDPH has restricted the taking of fin- and shellfish from the New Bedford Harbor area since 1979.

Studies have been completed on the fate of PCB contaminant pathways in contaminated sites which are applicable to the New Bedford Environment. Balsam Environmental Consultants (1989) emphasized similarities between the New Bedford Harbor Superfund Site and the Waukegan Harbor, Michigan site including the type of setting and PCB-impacted fisheries. Based on the PCB monitoring in Lake Michigan since 1970, the US EPA (1993a) concluded "... the rate of decline is slowing and may be leveling off, resulting in concentrations continuing well above water quality criteria. Studies on biodegradation indicate that the most highly chlorinated (least toxic) forms of PCBs are degrading first, leaving the most toxic forms behind..." The US EPA also referenced research that "Laboratory experiments designed to provide optimal conditions for microbial activity have not been able to achieve complete PCB dechlorination, suggesting that the remaining forms of PCB may persist indefinitely...".

The distribution and fate of PCBs in the New Bedford Harbor study area was previously modeled by Battelle Memorial Institute (1990) and summarized by EBASCO (1990a; 1990b). PCB transport and fate was estimated using a three-dimensional hydrodynamic and sediment/contaminant transport model to simulate various conditions in the New Bedford Harbor System. The modeling study included an assessment of PCB movement, distribution and fate and a determination of the sources of PCBs and metals in study area biota. An analysis was also completed on contaminant bioaccumulation/biomagnification and trophic level transfer, and the effects of various remedial alternatives, storm events, and dredging. In turn the modeling results were used in assessing ecological risk to organisms in two representative New Bedford Harbor food chains (Discussed in more detail in Section 4.7.3 of this document).

To complete the study, a combination of current meter and drogue studies was used to establish seasonal current flows in the study area. The flow study results were then combined with field monitoring chemistry programs that included 25 stations in New Bedford Harbor, Upper Buzzards Bay, and the Upper Acushnet River estuary. Samples of sediment, water, and biota were analyzed for PCBs, copper, lead, and cadmium

concentrations during all four seasons of the year. Chemical analyses for the fate and effects modeling program included analysis of sediment and biotic samples, as well as bioconcentration, adsorption/desorption (Kd), and laboratory partitioning studies to determine rates at which selected study area biota take up and excrete the waterborne contaminants. Supplemental laboratory experiments included the feeding of chemically exposed polychaete worms and clams to lobster and winter flounder (EBASCO, 1990b).

The transport modeling indicated that PCBs are strongly bound to sediments. Storm events are the major mechanism for sediment transport and mixing in New Bedford Harbor, and the Inner Harbor is forced by tidal currents from the Outer Harbor and Upper Buzzards Bay under all conditions studied (EBASCO, 1990b). The results also indicated that time-varying distribution of PCBs in New Bedford Harbor depends on multiple interactive processes including PCB affinity for sediments; sediment resuspension; and transport by circulation patterns. Modeling of PCB migration from the source area in the Upper Acushnet River estuary to Buzzards Bay and the atmosphere resulted in the following conclusions:

- Erosion and resuspension by boundary layer currents and benthic organisms are responsible for most of the PCB transport;
- Dissolved water column PCBs reabsorb to clean fine-grained sediment particles imported to the harbor from Buzzards Bay and nearby upland sources; and
- Particle-bound PCBs in the Harbor are gained and lost by erosion and deposition, as well as advective and diffusive transport.

The simulations revealed that bed-to-water column transfer by direct desorption is the most important transport process. PCBs are then volatilized in shallow water areas, or transported by tidal-driven currents out of the New Bedford Harbor to Upper Buzzards Bay.

Balsam Evironmental Consultants (1989) also completed a report on the specific transport mechanisms that occur across the sediment-water interface in New Bedford Harbor that occur in the following sequence of events:

- PCB molecules desorb from sediment bed particles;
- The molecules then migrate vertically principally by bioturbation but also by molecular diffusion;
- At the sediment-water interface, PCBs in solution move through a water side layer (a benthic boundary); and
- PCBs are then transported through the water column.

The authors note several factors that slow these PCB transport mechanisms. Depositional fallout of new, relatively clean sediments to the substrate may retard PCB transport from the sediments, and bioturbation may result in the availability of fresh sorption sites for PCBs along with lower concentrations due to dilution and a lengthened transport pathway distance. Natural covering of the PCB-laden sediments shifts the bioturbation zone upward and reduces the flux rate which is the rate-limiting process.

Equilibrium concentrations (*i.e.*, state when a chemical balance is achieved) and the desorption rate (*i.e.*, the release of a PCB molecule from a sediment particle) of PCBs from particles to interstitial pore water (*i.e.*, water molecules located in between sediment grains) are determined by the PCB concentration, sediment organic content, particle grain size, and particle charge (Balsam Environmental Consultants, 1989). Particles with higher organic carbon and surface area (*e.g.*, silts and clays) will desorb fewer PCBs

as compared to inorganic, coarser-grained sediments. However, the low solubility of PCBs in sea water is the limiting variable for the molecular diffusion process.

Prior to the Hot Spot cleanup in 1994 and 1995, approximately 90 percent of all PCBs in the New Bedford Harbor Site were found in the Upper Acushnet River estuary. Sediment samples collected in the upper estuary in the vicinity of the Hot Spot were compared to sediment sampling of a depositional area with relatively low PCB sediment concentrations. High PCB sediment concentrations were measured within the deepest layer of estuary sample sediments, with decreasing concentrations near the sediment-water interface. This observation is indicative of the historically high pollutant loadings followed by depositional capping, contaminant transport, and release to the overlying water column. The upper estuary sampling also revealed vertical sediment mixing (*i.e.*, within the sediment stratigraphy), indicative of bioturbation or lateral PCB migration from adjacent source areas. The depositional area site may also have received PCBs from the upper estuary or the Inner Harbor, suggesting input from high-concentration source areas or water column desorption. Classical sediment bed "diffusion tails" from a depth of 6 inches (15 cm) and deeper were measured for each of the Aroclor congeners analyzed at each site, which also suggests that diffusion is one of the principal mechanisms affecting PCB transport.

Based on the transport models used in assessing the New Bedford Harbor site , the rate of PCBs removed from the Upper Acushnet River estuary sediments ranged from 1,100 to 13,200 pounds (500 to 6,000 kg)/yr. Without the capping of these sediments, approximately 41 percent of the PCBs would be lost through volatilization, while another 660 to 7,700 pounds (300 to 3,500 kg)/yr would be transported southward through the estuary by tidal-driven currents. Monitoring studies completed during the Hot Spot dredging indicate that PCB water column transfer from the upper estuary to the harbor is significantly less than the earlier predictions. During the 260-day monitoring period, ebb tide PCB concentrations in the water column ranged from 0.35 to 2.23 ppb, while PCBs in the flood tides ranged from 0.21 to 1.25 ppb. Cumulatively, 57.7 kilograms of PCBs were transported from the upper estuary into New Bedford Harbor over the 260-day period (US EPA, unpublished data), significantly less than the modeling results.

On a broad spatial scale, Kolek and Ceurvals (1981) suggested that the New Bedford Harbor hurricane barrier has acted as an effective barrier to the physical distribution and concommitant dilution of PCBs from their primary source in the Upper Acushnet River estuary and the Inner Harbor. High concentrations of PCBs and other contaminants remain in the sediments and biota found in the estuary and Inner Harbor, as the hurricane barrier creates a "leaky sink" effect, slowly releasing contaminats to the Outer Harbor (Refer to Chapter 3, Sediment Transport Section).

Metals

Metals present in New Bedford Harbor occur as finely divided solids, in adsorbed phases, and in organometallic complexes which are primarily associated with clays (Summerhayes et al., 1985). Because of these conditions, metals tend to be distributed similar to clay distribution. Summerhayes et al. (1977) determined that copper, chromium, zinc are being slowly released from the Inner Harbor to the Outer Harbor and Upper Buzzards Bay in the very fine silt and clay fractions of the sediments. They suggested that metal transport out of the harbor occurs via horizontal eddy diffusion in the near-bottom turbulent waters.

The chemical behavior and pathways of metals in sediments, interstitial pore water and the water column are affected by a number of factors including:

- the exchange sites on sediment particles as determined by grain size and charge;
- the presence and chemical availability of carbonates, manganese, and iron oxides or hydroxy-oxides in the sediments;
- the abundance of organic matter;

- the presence of oxygen;
- the presence of sulfides and sulfide-reducing bacteria that are influenced by seasonal and other climatic conditions; and
- the distribution and solubility coefficients and concentrations of the individual metals present.

Although previous studies have thoroughly documented high metal concentrations in the sediments of New Bedford Harbor, bulk metal sediment concentration data are now recognized as having limitations that were not readily understood when these earlier studies were completed. Scientists are now conducting research and developing sediment quality criteria that consider the effects of physico-chemical properties of sediments on contaminant bioavailability, including conditions when multiple metal elements are simultaneously present. Boothman (1992) summarized the relationship of sediment metal concentrations, acid-volatile sulfides (AVS), and metal bioavailability. He reported that, in general, the correlation between the concentration of total metals in sediments and the bioaccumulation by sediment-dwelling organisms is poor. This is due to the significant influence by the physical conditions and chemical forms in which metals are present that influence metal bioaccumulation and toxicity.

Boothman (1992) attributes competitive adsorption by various sediment components as a key factor in metal bioavailability. He described the US EPA's use of the Equilibrium Partitioning Approach in developing Sediment Quality Criteria ("SQC"). In anoxic (oxygen deficient) estuarine sediments, AVS are important in controlling the bioavailability of heavy metals. The AVS are formed principally by the reaction of iron with dissolved sulfides in sediment interstitial pore water. Sulfides are generated primarily from the anaerobic microbial reduction of sulfate during the oxidation of sediment organic matter. Metals forming sulfides which are less soluble than iron may serve as a solid phase sink, removing dissolved metals from pore waters and releasing iron, as is illustrated in the following chemical equation:

$$FeS\ (solid) + M^{+2}(aqueous) \rightarrow Fe^{+2}(aqueous) + MS\ (solid)$$

Microbial processes and organic matter in the environment directly and indirectly affect the fate of specific metals. Direct effects include the biodegradation by microorganisms, while indirect processes include the modification of the physico-chemical state of pore water with the formation of insoluble, biologically unavailable sulfides.

The bioavailability of many toxic metals in estuarine sediments is dominated by physico-chemical phenomena, bioturbation, sediment chemical compounds, microbial activity, and the presence of organic matter. In a briefing document to the US EPA Science Advisory Board, the US EPA (1994a) summarized these processes as they affect the bioavailability of sediment metals to benthic organisms. The document explains that AVS can be a key factor influencing interstitial water concentrations and bioavailability of metals in sediments. By quantifying the bioavailability of metals in pore water of anaerobic sediments, an evaluation can be made on the differences in relative organism sensitivity, thereby enabling the identification of biotic species at risk. Dissolved metals released in the presence of AVS (termed "Simultaneously Extracted Metals" or "SEM") are now being compared to AVS values in ratios as a means of assessing the toxicity of metals to both marine and freshwater organisms (See, for example, Allen et al., 1993). Lower-bound physico-chemical criteria are presented in the US EPA document where no adverse effects to aquatic life are expected if the criteria are satisfied.

The solid phase criteria are based on the concept that bioavailability of a chemical in sediment is related to the chemical activity of the sediment-interstitial water system, and called the "equilibrium partitioning model of bioavailability". For cadmium, copper, zinc, nickel, and lead, it has been shown that biological effects correlate with free metal activity in either water-only exposure or in sediment-interstitial water exposure. Thus, the SQC being developed for these metals are based on a state where the free metal activity is below levels that can cause adverse ecological effects (Casas and Crecelius, 1994; US EPA, 1994a). These initial solid phase criteria are based on the strongest metal binding phase when AVS are

present. If sufficient AVS are present in the harbor sediments, then no adverse biological effect will occur because the insoluable metals are unavailable for biological uptake. The availability of organic carbon is another factor on metal transport and bioavailability, and a partitioning model has been suggested for developing biological-effects based criteria (US EPA, 1994a).

The Feasibility Study of the New Bedford Superfund Site (EBASCO, 1990) revealed that cadmium, lead, chromium and copper were metals of concern because of their elevated concentrations and potential mobility and toxicity. Bulk chemical analysis revealed that the harbor sediments are rich in metals (Refer to Section 4.3.2). These data suggest that additional sampling and analysis of highly-reduced and organic-rich sediments may be required, based on the emerging understanding of the chemical fate of these metals in sediments. A research program is now being developed by the US EPA (Nelson, 1996) to evaluate sediment metal data from the New Bedford Harbor Superfund site.

4.6.2 Biological Pathways

Polychlorinated Biphenyls

Biological pathways also affect contaminant transport in marine and estuarine environments. Processes that affect the accumulation and transfer of PCBs in organisms include ingestion of contaminated food, sediments, and water; adsorption of PCBs in the gut, through respiratory surfaces, or into the body wall or exoskeleton; metabolism; excretion; desorption; and in some cases, release of PCBs in reproduction. PCB uptake by marine biota varies depending on the specific organism and the contaminant congener. Different marine species caught from the same area have been determined to have widely varying levels of certain PCB congeners (McDowell-Capuzzo et al., undated), and PCB bioaccumulation also varies widely in the different tissues of an individual organism (Metcalf & Eddy, 1983), as suggested by data presented by Sanford Ecological Services (1988) in Section 4.5.1. The US EPA has developed bioconcentration factors for numerous contaminants which are based on the tissue to water ratio with a 3 percent lipid concentration; the current bioconcentration factor for PCBs is 31,200 (US EPA, 1995b).

To better understand the biological pathways associated with PCBs, it is important to define the basic terms used in the principal contaminant exposure routes in New Bedford Harbor. "Bioconcentration" is defined as the net uptake of dissolved chemicals into organisms from water, and the "bioconcentration factor" is a ratio of contaminant concentrations in the tissue of an organism compared to the concentration in the water column in which the organism was exposed (EBASCO, 1990b). The net uptake of a contaminant by an organism from all sources (*i.e.*, ingestion or contact with water, food, and sediment) is defined as "bioaccumulation". The bioconcentration and bioaccumulation of PCBs in marine organisms are affected by many factors including the following:

- PCBs are very soluble in the lipid (fatty) tissues of many organisms at various trophic levels of estuarine food webs;
- The duration of exposure of PCBs to an organism affects bioaccumulation; for example, migratory, pelagic species may be only briefly exposed in comparison to infaunal, permanent resident species;
- Species with higher lipid content more readily bioaccumulate PCBs;
- PCBs are only very slowly degraded by microorganisms in sediments, particularly in oxygen-poor sediments; and bacteria are not able to metabolize PCB compounds with more than three chlorine atoms per ring;
- Rates of biodegradation of PCBs by bacteria decrease where relatively low concentrations of PCBs are present in the sediments;
- Aquatic macroinvertebrates are able to only slowly metabolize PCB compounds with 3 or 4 chlorine atoms per ring;

- Higher-level organisms can not readily degrade PCBs, but can more readily metabolize higher-chlorinated PCB compounds;
- The bioavailability of PCBs is greater for organisms in direct contact with organic-rich sediments (*i.e.*, grossly polluted environments);
- Higher PCB concentrations are generally associated with larger body weights;
  Older organisms retain higher body burdens of PCBs due to reduced excretion rates;
- For many marine and estuarine species, females tend to be larger and have a higher lipid content than males, thereby bioaccumulating higher burdens of PCBs;
- Concentrations of PCBs rapidly decrease in shellfish (*e.g.*, quahogs and oysters) that release the contaminants in their gametes during reproduction;
- Organisms subject to higher temperatures, higher metabolisms and faster growth rates accumulate PCBs at a faster rate, at least during the initial exposure;
- Bioaccumulation of PCBs may reach an equilibrium with the steady state concentration in the medium in which the organism is inhabiting, and the time to equilibrium occurs fastest via the ingestion of water than through other processes;
- When the time period to equilibrium increases, there is greater chance for an organism's physiological state to change, and the true equilibrium may never be reached;
- Depuratiion of PCBs occurs in organisms moving to less contaminated habitats, and is influenced by tissue in which the contaminant is found and the equilibrium state of PCBs in the medium inhabited by the organism;
- Trophic-level transfer of PCBs is dependent upon the prey items selected by an organism, and variation in diet affects trophic-level biomagnification; and
- Biodegradation of PCBs may result in the formation of chlorinated dibenzofurans which are compounds toxic to aquatic organisms.

The Battelle Memorial Institute (1990) fate and transport modeling study, as previously described in Section 4.6.1, provided an overview of the site-specific physical and chemical pathways of contaminants in the New Bedford Harbor site. The model was then linked to an empirical food-chain model to describe the uptake and loss of chemicals by selected biota representing major predator-prey interactions occurring within the New Bedford study area waters (Refer to Chapter 3 for a discussion on the trophic levels and food chains in New Bedford Harbor).

Results of the computer model as well as field-sampling of whole body PCB concentrations revealed concentrations higher in winter flounder than in lobster, because of the higher lipid content in flounder and differences in food chain dynamics for each of these top predator species. The authors then presented estimates of the long-term fate and trophic-level consequences for two harbor conditions: a "No-Action" alternative and a "Remedial Action" alternative. The results indicate that the Hot Spot area cleanup benefits would be localized, and both the no-action and cleanup of the Hot Spot would result in no significant reductions in the water column and sediment concentrations in the Inner and Outer Harbors (Battelle Memorial Institute, 1990).

IEP (1988) obtained similar results using an alternative assessment. The "No Action" alternative resulted in minimal change in PCB concentrations in harbor biota over time. The Hot Spot area had accounted for approximately 48 percent of the total PCBs in the estuary, and 45 percent of the PCBs throughout the entire Superfund site. The primary pathways transporting PCBs out of the Hot Spot area were determined to be: volatilization into the air; sediment transport and redeposition to Areas II and III sediments; or food chain transfer.

A deficiency in the early analyses of biological pathways and exposure of PCBs to harbor biota and human seafood consumption was the methodology used in measuring PCBs in New Bedford Harbor. Aroclor 1242 was the primary PCB congener used in New Bedford area, until the early 1970s when Aroclor 1016 began to be used to manufacture electronic capacitors. Much of the pre-1980 PCB sampling was

completed using packed column gas chromatography (McDowell-Capuzzo et al., undated), and only Aroclor 1254.was used as a standard (Weaver, 1982). Both Aroclor 1242 and 1016 are less chlorinated than the Aroclor 1254 monitored, and any microbial biodegradation occurring in the sediments would reduce the chlorination even further. Thus, an inaccurate analysis was used in many of the monitoring studies which had the potential to significantly underestimate the amount of total PCBs found in the study area. Conversely, it is highly probable that concentrations were high even with the use of the Aroclor 1254 standard for analysis, and significant ecological and health risks were and continue to be present.

Metals

The food-chain model prepared for the New Bedford Harbor Superfund site (Battelle Memorial Institute, 1990) did not evaluate metal bioaccumulation, as the physical/chemical model portion of the two-component model addressed only PCB fate and transport. The authors of the Feasibility study concluded that harbor biota were at risk due to exposure to metals, although these risks were negligible in comparison to risks due to PCBs (EBASCO, 1990b).

Sanford Ecological Services (1988) and Bellmer (1988) collected and analyzed aquatic and terrestrial biota from tidal wetlands and adjacent habitats within the New Bedford Environment to determine levels of metals present in these test organisms and trophic levels. The result were unable to document that biomagnification of metals is occurring. These results may be affected by the ubiquitous and long-term chronic problem of metals in the New Bedfrod area, causing widespread metal contamination in water and sediment; widely varying uptake rates by the biota sampled; and the lack of data to conduct a statistically powerful analysis (Bellmer, 1988).

Bellmer (1988) suggested that marsh vegetation plays a significant role in the retention of various metals including cadmium, copper, lead, manganese, nickel, iron, and zinc, and maximum uptaake occurs during the growing season prior to peak above ground biomass. Metals remain in the stems and leaves of salt marsh plants during the seasonal dormant period. Roots have higher metal concentrations that other plant parts, and older tissue typically contains higher metal concentrations than young shoots. Salinity, pH, Eh and other physico-chemical conditions have a significant role in metal availability to salt marsh macrophytes. Because of the eutrophic (*i.e.*, excess nutrients) nature of the Acushnet River estuar wetland sediments are more oxidized due to increased growth, increasing metal solubility in sedime water. Metal retention in the harbor marshes is likely poor.

Polycyclic Aromatic Hydrocarbons

Like PCBs, PAHs consist of an extremely complex mixture of different chemical compounds with very different physical-chemical properties leading to different toxicities, solubilities, and persistence in the environment. Unlike PBCs which are a series of chlorine substituted congeners of the same biphenyl molecule, PAHs consist of a wide variety of diverse compounds, many of them structurally unrelated. PAHs are naturally occurring in nature and are relatively less persistent in marine environments.Although many PAHs are oxidized by microorganisms and sunlight in surface waters, they generally degrade very slowly in anoxic sediments. With prolonged surface exposure, PAHs characteristically induce enzymes that degrade them.

McFarland (1995) reviewed the Theoretical Bioacumulation Potential (TBP) test that is widely used to evaluate potential adverse ecological effects of contaminated sediment. The TBP test is based on sediment chemistry and organism lipid content, and applies a universal accumulation factor (AF) to estimate the body burden of all neutral organic chemicals such as PAHs. It was concluded that the practice may be excessively conservative and not as predictive as was previously assumed (McFarland, 1995). Field-collected benthic invertebrates and sediments from San Francisco Bay have been used to predict

bioaccumulation potential, and it was determined that field-generated AF predictions improve the test for PAH compounds, as well as other bioaccumulating organic chemicals.

4.7 ECOLOGICAL IMPACTS

4.7.1 Introduction

The US EPA method for determining adverse ecological impacts at Superfund sites focuses on the use of an ecological risk assessment, and agency guidance is based on the process as described in "Framework for Ecological Risk Assessment" (US EPA, 1992a). Other relevant examples of ecological risk assessment background papers have been prepared by the US EPA (US EPA, 1993a; 1994a; 1994b), and information is periodically updated in a supplemental publication series entitled "ECO Update"(US EPA, 1991). The US EPA is also planning to release an updated risk assessment framework document which is scheduled for publication in late summer 1996 (Renner, 1996).

The US EPA ecological risk assessment process includes three principal phases: problem formulation, analysis, and risk characterization. "Problem formulation" establishes the goals, breadth and focus of the assessment and results in a conceptual model of the ecosystem affected. "Analysis" profiles the contaminant stressor exposure and effects on biota, while "characterization" integrates exposure and effects, and qualitatively and quantitatively estimates risk. The ecological risk assessment framework is conceptually similar to the human risk assessment process, although it is distinctive from the human risk assessment in that:

- Ecological risk assessment includes the effects beyond individuals of a single species and may include examination of a population, community, or ecosystem;
- There is no single set of ecological functions or values requring protection that can be generally applied to all ecological risk assessments; and
- There is a need to consider non-chemical (*e.g.*, biological stressors) as well as chemical stressors.

"Endpoint"is a term used in toxicology and risk assessment that refers to a particular measure of an effect (*e.g.*, death, illness, impaired behavior, inhibition of the photosynthesis, reproductive effects, change in species abundance)of a stressor on plant or animal species. Endpoints in aquatic toxicology usually involve the laboratory testing of adverse effects of single chemicals on selected endpoints of single species of organism, rather than the assessment of the complex mixtures of pollutants that characteristically exists in contaminated natural environments. Criteria and standards for contaminants in water, sediment, and air are largely based on bioassay tests.

The limitations of risk assessment are complicated by the narrow interpretation of the effects of pollutant mixtures and the physical and physiological ways in which one chemical interacts with another. For example, the mutagenic potential of hydrocarbons is due to more than one class of compounds in the mixture, even though selected single-indicator compounds are used to predict endpoint effects. Further, the various classes of compounds are known to have different half lives in the environment due to their resistance to biodegradation, sorption, volatility and other factors. As a result, some pollutants persist longer than others; some are transformed into other chemicals; and some interact by enhancing or diminishing toxic effects.

Application of endpoints for ecological effects assessment is obviously far more complex than single species testing. Suter (1990) wrote that ecological risk assessment endpoints should be (1) clearly defined

by social and biological relevance; (2) accessible to prediction and measurement; and (3) susceptible to the hazard(s) being measured. Population-level assessment endpoints such as species abundance and range are most generally useful. He suggested that landscape descriptions, material export and other "regional-scale" indicators can be used for broad-level (ecosystem and regions) assessments, although data are generally not available, and the validity of models has not been demonstrated.

In regards to the administration of risk assessment, the March 1992 issue of the US EPA's ECO Update helps to explain the role of the natural resource trustees in the Superfund process where "... the natural resource damage assessment process is the responsibility of the trustee agencies, not EPA". Conversely, the US EPA coordinates with natural resource trustees to "assist the site manager in determining the technical adequacy of ecological investigations." The US EPA New England (Region I, Boston) has responsibility for the cleanup of the New Bedford Harbor Site under the authority of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) as amended by the Superfund Act Reauthorization Amendments (SARA), and the human health and environmental risk assessment processes are central to the risk management of the New Bedford Superfund Site.

Information on the impacts of PCB and heavy metal contamination to the New Bedford Harbor ecosystem is presented in the following three sections. Section 4.7.2 discusses the results of several studies that were completed, discussing the effects of contamination on the species and community structure and function. Contaminant effects on the structure of the community may include altering the presence and abundance of an individual species or the overall number or species (*i.e.*, species diversity or richness) and the comparative species abundance (*i.e.*, evenness). Changes in community function relate to species interactions; information is provided on how contaminant effects on one species may alter the physiology and behavior of another species. Section 4.7.3 then provides a summary of the ecological risk assessment that was completed for the New Bedford Harbor Superfund site, applying the proces and concepts previously described. Section 4.7.4 provides information on other on-going studies that will be applicable to the decision making for remediation of the New Bedford Harbor Superfund site.

4.7.2 Contaminant Effects on Estuarine Species and Community Structure and Function

To identify any adverse physiological effects of contaminants in New Bedford Harbor biota, the MADMF collected fish, shellfish, and crustaceans from Areas I, II, and III between 1976 and 1980 (Kolek and Ceurvels, 1981). Gross inspection revealed no abnormalities or indications of disease symptoms, and seasonal development of the finfish reproductive organs appeared to be normal. Bellmer (1988) collected and visually examined the livers of winter flounder (*Pleuronectes americanus*) sampled from the harbor wetland areas for the presence of neoplasms; none were observed. Moore (1990) collected mummichog (*Fundulus heteroclitus*) from nearshore waters in the vicinity of the Aerovox plant and from a site directly south of the I-195 bridge (Moore, 1990). No visible lesions were evident on the fish specimen livers, and histological studies revealed no evidence of neoplastic foci. Moore contrasted these results with the results of mummichog sampled from the Elizabeth River in Virginia which exhibited a very high incidence of abnormal livers and high incidence of hepatocellular neoplasms; he suggested that mummichog are more readily affected by genotoxic PAHs (as was found in the Elizabeth River) than by PCBs. In contrast, Moore (1995) indicated that winter flounder caught from Inner New Bedford Harbor during that period were found to have a high incidence of liver neoplasia.

The pilot study for the harbor dredging included bioassay tests using samples collected from the Coggeshall Street Bridge and a control site near the hurricane barrier. US EPA protocols were used for these studies: sea urchin (*Arbacia punctulata*) sperm cell fertilization; red alga (*Champia parvula*) number of cystocarps developed; sheepshead minnow (*Cyprinodon variegatus*) larval survival and growth; mysid shrimp (*Mysidopsis bahia*) survivial and growth; and blue mussel (*Mytilus edulis*) scope for growth and increased shell length (US ACOE, 1990). The concentrations of particulate PCBs measured in these samples ranged

from 0.1 to 19.2 ppm, with an average of 6.4 ppm. No toxicological effects were noted for any of the test organisms, although decreased shell growth in blue mussel was found to be inversely related to PCB tissue concentrations after 28 days.

Bioassays were routinely completed by the US EPA during the Hot Spot remediation to determine the effects of dredging on test organisms including red alga (*Champia parvula*) survival and reproduction; sea urchin (*Arbacia punctulata*) sperm cell fertilization; mysid shrimp (*Mysidopsis bahia*) survival and growth; and blue mussel (*Mytilus edulis*) bioaccumulation after 7 and 28-day deployments. Although mortality and growth changes were detected in the Coggeshall Street Bridge (NBH-2) test organisms, these results were not significantly different from the values obtained for organisms in the West Island reference station (NHB-5).

Applying regression analysis, Bellmer (1988) compared concentrations of PCBs, eight metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc) and oil and grease in sediments sampled from New Bedford Harbor with infaunal species diversity, community diversity, and community evenness (*i.e.*, a comparison of the numbers of individuals of each species) determined for these contaminated sediment sites. Macroinvertebrates were found inhabiting sediments containing PCB concentrations as high 8,370 ppm, and PCB concentrations were found to be inversely related to decreasing species abundance, and community diversity and eveness. The statistically significant inverse relationship between PCB concentrations and community evenness may result as the number of individuals of the remaining pollutant-tolerant species decreases and become more equable with the increasing PCB levels. At the same time, organism density increases, and may be attributed to reduced species competition or loss of microhabitat which induce crowding. Of the remaining nine pollutants analyzed, statistically significant inverse relationships were identified between species richness and mercury and arsenic sediment concentrations. Only arsenic concentrations were found statisitcally significant in affecting infaunal community diversity and evenness.

Aquatic and terrestrial species were sampled from the New Bedford Environment in 1986 and 1987 by Sanford Ecological Services (SES, 1988), revealing lower numbers of species were correlated with the more highly contaminated sediments of the upper estuary. However, more detailed analyses were not completed to determine if the lower species diversity was attributed to high contaminant concentrations or one or a combination of factors such as high biological or chemical oxygen demand or low dissolved oxygen levels. High PCB or metal concentrations in organisms may cause stress which alters an organism's physiology, increasing susceptibility to parasites, pathogens, and predators.

The authors of the SES wetlands assessment (SES, 1988) mentioned the abundance of *Streblospio benedicti,* a pollution-tolerant polychaete worm species, but did not speculate on the significance of the presence of certain classes of species or the species diversity. For example, the presence and diversity of species of biota would be expected to vary depending on the organisms location in relation to a pollutant source, such as the municipal sewage outfall. A few pollutant-resistant "pioneer" colonizing species would predominate in and near the zone of initial dilution, then gradually be replaced by "equilibrium" species and a greater diversity with increasing distance from the discharge point. Other factors, such as the presence of another nearby pollutant "hot spot" or varying hydrographic conditions could also affect species presence, abundance and diversity. Shifts in composition and increasing abundance of more pollutant-tolerant benthic species in the harbor may also alter the prey resource for bottom-feeding fish and other species, causing behavioral shifts in predator species.

Avian species diversity and abundance was also determined by SES (1988) and Bellmer (1988) for the upper estuary and the harbor, and compared to a control site in the vicinity of Popes Beach. There was no significant difference in species abundance or diversity between the PCB-contaminated sites versus the control site. Avian species abundance and diversity were high at both the contaminated and uncontaminated sites (Bellmer, 1988). Birds that are most likely adversely affected by the contamination include avian

species which feed extensively on other animals, and forage predominantly in the most highly contaminated portions of the estuary. Species such as black duck which feed primarily on polychaetes and other marine macroinvertebrates in the harbor are likely accumulating high levels of PCBs, as was described previously in Section 4.5.1. High levels of PCBs in the edible portions of black duck and other gamebirds may pose serious concerns over the hunting of these species for purposes of human consumption. The PCB levels in muscle tissue measured by SES (>100 ppm) were well above the FDA poultry limit of 3.0 ppm (with a fat content basis) (SES, 1988).

Vegetational studies of the salt marshes in New Bedford Harbor were also completed (SES, 1988; Bellmer, 1988) to determine any toxicological or stress (*e.g.*, chlorosis or morphological aberrations) effects in the endemic macrophytic vegetation. Results of these studies indicated that there was no evidence of toxicity or stress in the vegetation, even though elevated levels of both PCBs and metals (copper, chromium, lead, zinc) were measured in the marsh sediments and high metal concentrations were found in the vegetation. The metal-enriched marshes were found to have primary productivity rates comparable to nearby non-contaminated marshes. Because the harbor marsh vegetation has elevated metal concentrations, salt marsh detrital material is a source of metals to detrital-based food webs to which this plant is exported.

The authors did not speculate on the apparently unaltered saltmarsh structure and function. Environmental risk attributed to elevated concentrations of metals in saltmarsh vegetation was also not addressed. Exposure of mollusc-consuming birds such as the black duck may be particularly significant in light of the overall regional decline of this species due primarily declining quality habitat.

A wetland functional assessment was completed (IEP, 1988; Bellmer, 1988) using the Army Corps of Engineers' Wetland Evaluation Technique (WET). This methodology was unable to distinguish differences in ecological functioning between the contaminated and uncontaminated sites because the methods is not capable of identifying subtle differences in wetland systems. Bellmer (1988) suggested that to assess ecologic functioning, the size wetland may be considered directly proportional to the greater number of functions and degree of function effectiveness.

4.7.3 Ecological Risk Assessment

As part of the Remedial Investigation and Feasibility Study for the New Bedford Harbor Superfund site, a baseline ecological risk assessment for the New Bedford Harbor Site was prepared by EBASCO Services (1990b) to quantify risks to aquatic organisms exposed to elevated levels of PCBs and certain heavy metals (*i.e.*, copper, cadmium, and lead). A primary purpose of the risk assessment was to evaluate the various options for remediating the contaminated harbor. The study centered on a joint probability analysis addressing the probability of both contaminant levels in the different portions (zones) of the harbor and the sensitivity of of biota exposed to the contaminants (*i.e.*, a particular species displays a particular biological effect). Much of the data collected for the previously described fate and transport prepared by Battelle Memorial Institute (1990) was applied in the ecological risk assessment. In addition to the joint probability analysis, other work completed included a comparison of the PCB levels measured in the harbor to the US EPA AWQC; toxicity tests using harbor sediments; and an assessment of data collected on the faunal communities in the harbor. Conclusions were based on the following:

- The physical, chemical and biological routes of exposure;
- Field exposure of harbor organisms to the contaminants; and
- The degree of exposure.

Exposure of biota (*i.e.*, "receptors") to a contaminant was estimated from four exposure routes including direct contact with the water column; contact or ingestion of sediment; direct contact with sediment pore water; and ingestion of contaminated prey. Twenty-eight species representing five ecogroups known to

occur in New Bedford Harbor were evaluated; the five ecogroups included marine finfish, crustaceans, molluscs, polychaetes, and macroalgae. Habitat location, life stages of the species, and feeding modes and mechanisms were considered (Refer to Chapter 3 for information on the living resources of the study area) in identifying the ecogroups for the assessment, and the species selection was based on criteria such as habitat location, trophic level, and species reproductive potential. The economic significance of a species, based on its commercial or recreational value, was also considered.

To assess the transfer of contaminants in organism issue burdens, two different food chains reprentative of New Bedford Harbor were investigated using an empirical model; the modeled food chains included:

- lobster as the top-level predator: plankton as a food items for blue mussel, hard clam and green crab; hard clam and polychaetes as food items for green crab; and blue mussel, green crab, and polychaetes as food items for lobster; and

- winter flounder as the top-level predator: plankton as a food items for hard clam and juvenile green crab; polychaetes and hard clam as prey for juvenile green crab; and polychaetes and plankton as food items for winter flounder.

Results of the food chain model used in the risk assessment report concluded that the consumption of PCB-contaminated food may account for the majority (as high as 95 percent) of PCB residue concentrations in New Bedford Harbor. For the selected receptor species comprising the various trophic levels and habitat preferences, highest total PCB tissue burdens were found in organisms collected from the Inner Harbor, and levels successively decreased from the north zones of the Inner Harbor to the southerly areas in the Outer Harbor. Polychaete worms that are in direct contact with the sediments were found to have the highest PCB tissue levels. Winter flounder also had high whole body tissue levels.

The report included mapped zones in the harbor to explain the chronic effects probabilities for various species. Results indicated that the US EPA's chronic marine AWQC was exceeded by the mean PCB concentration in the water column in all zones (the entire Upper Acushnet River estuary and Inner Harbor), except Zone 5 (*i.e.*, the Outer Harbor). The results of the assessment of the exposure of biota to PCB-laden sediment indicated a significant risk to the receptor aquatic organisms in New Bedford Harbor.

PCB concentrations in the sediment and sediment pore water from all areas of the harbor were found to be toxic to one or more species in all major taxonomic groups. For the Upper Acushnet River estuary, the probability of sediments being toxic to marine fish approached certainty. These results were found to be consistent with the results of laboratory bioassays using New Bedford Harbor sediments; Inner Harbor sediments were found to be toxic to benthic invertebrates and fish

The New Bedford Harbor risk characterization revealed that potential risk was most severe in Zones 1 and 2 (north of the Coggeshall Street Bridge), but risk was evident for all modeled zones north of the hurricane barrier. Risk of chronic exposure to marine fish exposed to pore water was close to 100 percent. Results showed that with the assumptions and methodology applied and the concentrations of total PCBs typically found in the upper estuary (prior to the Hot Spot cleanup) and Inner Harbor, more than 80 percent of the fish species in the Inner Harbor could be adversely affected. The report concluded "... marine fish are at high risk of impact due to chronic exposure to dissolved PCBs for the entire area inside the Hurricane Barrier" (EBASCO, 1990b).

For macroinvertebrates, results indicated that PCB concentrations upriver of the Coggeshall Street Bridge (again, the study was based on concentrations measured prior to the Hot spot cleanup) would be expected to impact approximately 20 percent of the molluscan species found there, but concentrations typically measured in the other portions of the harbor would be likely impact less than 10 percent of the molluscs. For crustaceans, there was a 40 percent likelihood of adverse impact due to exposure to PCBs in the Hot

Spot and Zone 1 (*i.e.*, the area between the Wood Street Bridge and the southern boundary of the Hot Spot), and levels would exceed the US EPA's Maximum Allowable Toxicant Concentration (MATC). South of the Coggeshall Street Bridge, crustaceans were expected to incur less than a 5 percent likelihood of adverse impact due to the PCBs present in the area.

For macroalgae, the report projected a risk of a 30 percent or greater probability that the average dissolved PCB concentration encountered by a typical marine algal species north of the Coggeshall Street Bridge would exceed the respective chronic benchmark value.

In summary, the EBASCO (1990b) study concluded, that based on numerous site-specific and laboratory studies, New Bedford Harbor is an ecosystem under stress due to PCBs contamination. All approaches used to assess ecological risk associated with PCB contamination indicate that the contaminant levels in Zones 1-3 (all waters north of the Route 6 bridge) have the potential to significantly impact biota in the harbor, as well as the overall integrity of the harbor as an integrated functioning unit. Community or ecosystem-level impacts due to PCBs and heavy metals could not be thoroughly evaluated because the state of development of risk assessment methods precludes quantification of adverse impacts relating to the complex inter-relationships of the biotic and abiotic conditions in New Bedford Harbor, and the varying responses that each receptor organism has depending on the levels of various contaminants to which it is exposed.

In the US EPA Cleanup Plan (EPA, 1992c) agency staff summarized the ecological risk assessment stating that the risk to biota was greatest for bottom-dwelling organisms that are in direct contact with PCB-contaminated sediments. Exposure to these contaminants likely results in an increased mortality and decreased reproduction rates in the organisms inhabiting New Bedford Harbor. US EPA resource managers concluded that PCB contamination is causing a decrease in available food resources for marine life in the Superfund Site.

4.7.4 Ongoing Assessments

Early studies leading to assessment of chemical contaminant fate and risk from exposure in the vicinity of the New Bedford Harbor Superfund Site have been based on the monitoring of bulk chemical concentrations and the modeling of selected chemical, physical, and biological pathways. Current US EPA studies are leading to more sophisticated experimental design, improved analytical chemical methods, more clearly defined endpoints, and an improved understanding of contaminant bioavailability. Ongoing studies are also likely to benefit from revised environmental risk assessment guidelines that are now in preparation by the US EPA. These advances may lead to an improved assessment of site-specific phenomena leading to an even better understanding of the fate and effects of chemical contaminants in the New Bedford Harbor area.

The US EPA has developed and implemented a long-term monitoring program for assessing the effectiveness of remediation of the New Bedford Harbor Superfund Site (Nelson, 1996). It was developed by the Atlantic Ecology Division of the US EPA's National Health and Environmental Effects Research Laboratory in Narragansett, Rhode Island. This monitoring and assessment program includes the following features:

- Data are compiled and analyzed using a geographical information system (GIS) that facilitiates visual interpretation;
- A glossary of technical terms is provided;
- A comprehensive bibliography provides detailed background on the information the information provided;

- A PC-compatible diskette is provided; it includes actual data and documentation of the procedures used;
- The experimental design is both statistically rigorous to allow for quantitative assessments and flexible enough to accommodate changes over time;
- It is a long-term (30-year) monitoring plan;
- It has been designed to quantify both spatial (throughout the harbor) and temporal (over time as various phases of the remediation are completed) trend monitoring;
- It is based on the goal of the New Bedford Harbor monitoring program to assess remediation effectiveness by quantifying spatial and temporal changes in contaminant concentrations and availability; and
- It will determine the extent of compliance with applicable or relevant and appropriate requirements (ARARs).

As part of on-going studies, the Army Corps of Engineers (ACOE) (Curry, 1995) analyzed sediment chemistry and invertebrate abundance and diversity data from 24 stations in Areas I, II, and III. The ecological principle addressed in the analysis was that sampling stations characterized by chemically degraded or disturbed habitats have different assemblages, abundance and diversity of species, as compared to species from non-contaminated and less disturbed stations. Disturbed and highly polluted habitats characteristically have high numbers of "pioneering" individuals and a low species diversity. In contrast, less polluted, less disturbed habitats generally have a higher species diversity with lower numbers of longer-lived individuals. Based on this premise, an analysis was completed identifying the indicator species present at various stations; the diversity of species; and the numbers or biomass indicating the magnitude of the adverse effects of toxic chemicals and disturbed habitats.

The analysis was completed, comparing numbers of species and individuals to station sediment concentrations of PCBs less than versus greater than 2 ppm; and metal (lead, copper, chromium) concentrations less than versus greater than 100 ppm. Conclusions of the ACOE analysis were:

- There was a statistically (95 percent confidence level) greater number of polychaete individuals sampled from the more PCB and metal-contaminated sediments than from the less polluted sediments; and
- There was a statistically (95 percent confidence level) greater number of polychaete and gastropod species sampled from the less PCB and metal-contaminated sediments than from the more highly polluted sediments.

4.8 HUMAN HEALTH IMPACTS

The US EPA (US EPA, 1989a) as well as the Agency for Toxic Substances and Disease Registry (ATSDR, 1992) have developed guidance documents which describe logical procedures for completing public health assessments that characterize the nature and extent of hazards and serve as a tool for adequate protection of public health. The US EPA document was released in providing a framework for developing risk information necessary for decision-making of remedial sites. The ATSDR health risk assessment is a qualitative and quantitative process and includes the following components: hazard identification, dose-response (or toxicity) assessment, exposure assessment, and risk characterization.

The potential for human health effects from exposure to contaminants in the Acushnet River, New Bedford Harbor and Buzzards Bay was assessed as part of the Draft Final Baseline Public Health Risk Assessment; New Bedford Harbor Feasibility Study (EBASCO, 1989). The assessment focused on estimating risks from exposure to four contaminants: polychlorinated biphenyls, cadmium, copper, and lead. Existing conditions were assessed, although natural reduction in concentrations by transport of the contaminants from the area

or by degradation were not considered. Human health risk assessments must consider all media that may be probable exposure pathways, and four were identified as the principal pathways of exposure including:

- direct contact with sediments;
- ingestion of sediments;
- consumption of seafood; and
- inhalation of airborne contaminants.

A screening evaluation was conducted and it was found that direct contact with surfacewaters and incidental ingestion of surfacewaters represented only a small percentage (value not specified in the reference document) of the potential exposure to PCBs and/or an insignificant level of exposure to metals, and as a result, these pathways were not evaluated.

Exposure to contaminants via the sediments were evaluated for three areas within the New Bedford Harbor site. The three areas assessed for exposure,which coincide with the fishery resource closure areas as previously discussed including:

- Area I - Wood Street bridge to Coggeshall Street Bridge;
- Area II - Coggeshall Street Bridge to the hurricane barrier; and
- Area III - South of the hurricane barrier to the limits of the shellfish closure area.

Exposure from eating seafood was assessed for a larger area; it extended beyond Area III into Upper Buzzards Bay. The four areas considered for assessing ingestion of seafood were:

- Area 1 - Wood Street Bridge to the hurricane barrier;
- Area 2 - The hurricane barrier to Wilbur and Ricketsons Points;
- Area 3 - Wibur and Ricketsons Points to Rock Point, Negro Ledge and Mishaum Point; and
- Area 4 -Upper Buzzards Bay seaward of Area 3.

At the time of the human health assessment, limited air data were available, and the air sampling data were collected at locations to best assess possible tidal influences on airborne contaminant concentrations. Only air data for PCBs were used in the site assessment. It was suggested that due to the locations where the samples were collected (a mudflat area between the Wood Street and Coggeshall Street Bridges), these data may not be representative of probable human exposures because the sampling sites are locations where people would not be present.

The human health impacts were evaluated for both non-carcinogenic and carcinogenic effects. For non-carcogenic effects of toxicants, unacceptable risk occurs when exposures exceed levels that may result in teratogenic and developmental effects (US EPA, 1991b).

4.8.1 Exposure Assessment

Exposure scenarios were developed to estimate the amount of contaminants people may take in via each exposure pathway. Exposure scenarios were developed considering likely exposure points; concentrations of contaminants at the exposure points; the expected frequency and duration of exposure; and other relevant exposure parameters. Both a conservative upper estimate and a more probable estimate of exposure were calculated. The conservative upper estimate of exposure was developed using maximum concentrations and high end exposure frequencies. In general, a more probable exposure estimate was determined using average contaminant concentrations and lower exposure frequencies. Issues considered when developing the exposure scenarios are summarized below.

Direct Contact With Sediments

Unrestricted access to the river and harbor in most areas, and observations of swimming, fishing, shellfishing, wading, and playing along the shoreline were reported in the Baseline Public Health Risk Assessment (EBASCO, 1989). Palmer Island, Marsh Island, Popes Island, and the Fort Rodman and Fort Phoenix State Beaches were identified as areas where recreational activities were most likely to occur, since these areas are easily accessible or are known recreational sites. Exposure to sediments was evaluated for the entire area of the river and harbor, since access is unrestricted for some harbor areas.

Exposure to sediment by direct contact during swimming, wading and or fishing was evaluated. In Area I, two locations were identified where exposure was likely: the Cove Area (northeast of the Coggeshall Street Bridge) and the Upper and Lower Estuary (approximately 2,600 and 5,200 feet (780 and 1,560 m) south of the Wood Street Bridge, respectively). Pope Island, Palmer Island and March Island were evaluated in Area II, and Fort Rodman and Fort Phoenix State Beaches were evaluated in Area III. Estimates of shoreline contaminant concentrations were used when available. Geometric mean concentrations were used to estimate the probable PCB concentrations, while arithmetic means were applied to assess metals concentrations. Maximum concentrations were used for the conservation estimates of exposure for both PCBs and metals.

Exposure assumptions were developed for young children (0-5 years), older children (6 to 16 years), and adults (17 to 65 years). Young children were assumed to be exposed when swimming or playing, and older children and adults were assumed to be exposed when fishing, swimming, and wading. The potential for health effects were estimated separately for Areas I, II, and III.

Ingestion of Sediments

In the case of human consumption of PCB-contaminated seafood, many factors are important in exposure pathways such as the preference for a particular species, the availability of the species, the portions of fish or shellfish eaten (*e.g.*, skin, fat, hepatopancreas), and the methods of preparation for consumption (*e.g.*, broiled, stewed, smoked). Exposure from ingestion of sediments was evaluated for Area I, and the recreational areas and beaches in Areas II and III as identified for the assessment of direct contact with sediments. Young children were presumed to more likely be exposed to contaminants by consuming sediments than older children or adults. This may occur as a result of putting food, toys and/or hands into their mouths, while playing in the sand. The assessment of this exposure pathway was limited to young children.

Consumption of Seafood

Winter flounder, lobster and softshell clams which resouces common to the harbor and Buzzards Bay (Refer to Chapter 3), were considered in assessing risk from eating seafood. Children and adult age groups were evaluated, as were various frequencies of consumption. PCB and metal concentrations in both edible tissue and whole body concentrations were applied.

Inhalation of Airborne Contaminants

Air data were collected from locations near the Aerovox facility. While these samples were not considered representative of locations where people would be exposed routinely, these data were used since no others were available (No rationale for other samples was provided in the reference document, and most sampling data were collected after the human health assessment was completed). In addition, an estimated background concentration presented in an earlier study was used to assess risk. Only air data for PCBs were included in the assessment, as metals were either not detected or were present at concentrations too low to warrant an assessment.

4.8.2 Public Health Risk Characterization

The public health risk characterization by EBASCO (1989) presents an assessment of both non-cancer and cancer risks. Non-carcinogenic risks were assessed by comparing a calculated exposure based on concentrations of contaminants measured in on-site soil, air, and water samples. Risks were assessed to a calculated exposure to a level in which health impacts are not expected. A ratio of these two values is referred to as a risk ratio, where a ratio of less than one indicates that health impacts from the exposure are not expected, while a ratio greater than one indicates health impacts may occur. The US EPA Superfund program has identified a risk ratio of 1 as the criterion to use in assess whether carcinogenic risks need to be calculated. If risks greater than 1 are calculated, carcinogenic risks are then typically calculated by multiplying the estimated amount of contaminant an individual is exposed to by a potency factor. The result is an estimate of the cancer risk attributable to a specific contaminant. Cancer risks for New Bedford Harbor were calculated only for PCBs.

The US EPA Superfund program has established criteria to use in evaluating the results of calculations of risk. Risk assessment calculations generate an estimate of the increased likelihood that an individual will develop cancer due to exposure to the contaminant being evaluated (*e.g.*, PCBs). The estimate is typically expressed as an exponential number such as 10^{-4}. This value represents a 0.0001 (1 in 10,000) increase in the chance of an individual contracting cancer. For most situations, the US EPA considers incremental risks of less than 10^{-6} as acceptible; those between 10^{-4} and 10^{-6} as potentially acceptible but requiring further investigation; and those greater than 10^{-4} as requiring remediation to reduce human health risks (US EPA, 1991b). For this study, carcinogenic risk estimates were based on a target total risk to an individual at a range of 10^{-4} to 10^{-7}, while total site cancer risk level estimates of 10^{-5} were also calculated.

Results: Direct Contact with Sediments

Both non-carcinogenic and carcinogenic public health risks were identified for Area I. Young children were concluded to have greatest non-carcinogenic risks from direct contact with sediments. PCBs accounted for most of the non-carcinogenic risk, and the non-carcinogenic ratios for PCBs in Area I suggested a potential health risk. Carcinogenic risks for Area I ranged from 10^{-6} to 10^{-2} with most scenarios exceeding the US EPA target range.

For Areas II and III non-carcinogenic risk estimates were not considered a public health risk. Within Area II, conservative estimates of carcinogenic risks, while above the US EPA target risk range for PCBs, were suggested to be overly conservative. This conclusion was made as it was assumed people had greater accessibility to the contaminated area than the actual conditions. Probable exposure scenarios resulted in risk estimates within the US EPA target risk range. None of the carcinogenic risk estimates for Area III exceeded the US EPA target risk range.

Results: Ingestion of Sediments

A potential public health risk for young children exists within Area I from the ingestion of sediments. Non-carcinogenic risks above the US EPA criteria were associated with exposure to both PCBs and lead. Estimated cancer risks were above the US EPA target risk range, and represent a potential health risk to children.

No significant public health risks were identified in Areas II and III. Non-carcinogenic risks associated with exposures at recreational areas, under probable conditions, were below the US EPA criteria. While conservative conditions resulted in risk above the criteria, they were not representative of likely exposures because the assumptions for public access to the contaminated site were greater than actual conditions. Carcinogenic risks for Area II followed a similar pattern. While certain conservative estimates of risk were

slightly above the US EPA target risk range, risks associated with probable exposures were within the US EPA criteria. Area III risks were within the US EPA criteria.

Results: Ingestion of Seafood

Eating seafood caught within the New Bedford study area presents a public health risk based on both non-carcinogenic and carcinogenic risk evaluation. Exposure to PCBs and lead in the seafood were identified as the greatest risk associated with any species caught any Area; however public health risks were identified for each of the contaminant evaluated including PCBs, cadmium, copper, and lead. Young children were found to have the greatest risk associated with the consumption of seafood contaminated with cadmium and copper. Incremental carcenogenic risks associated with seafood consumption were greatest for the lobster as the food item, particularly when the tomalley is also consumed.

Results: Inhalation of Airborne Contaminants

Non-carcinogenic risks from inhalation of PCBs in air were not assessed because air data were limited. Carcinogenic risks were estimated. Carcinogenic risk estimates for the probable and conservative exposure scenarios were above the US EPA target levels; however the data used to calculate these risks were collected from areas very near probable source areas, and not in areas commonly used by people. Cancer risks associated with estimated background levels of PCBs were within the EPA target range.

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5.0 NEW BEDFORD HARBOR RESOURCE IMPACT EVALUATION

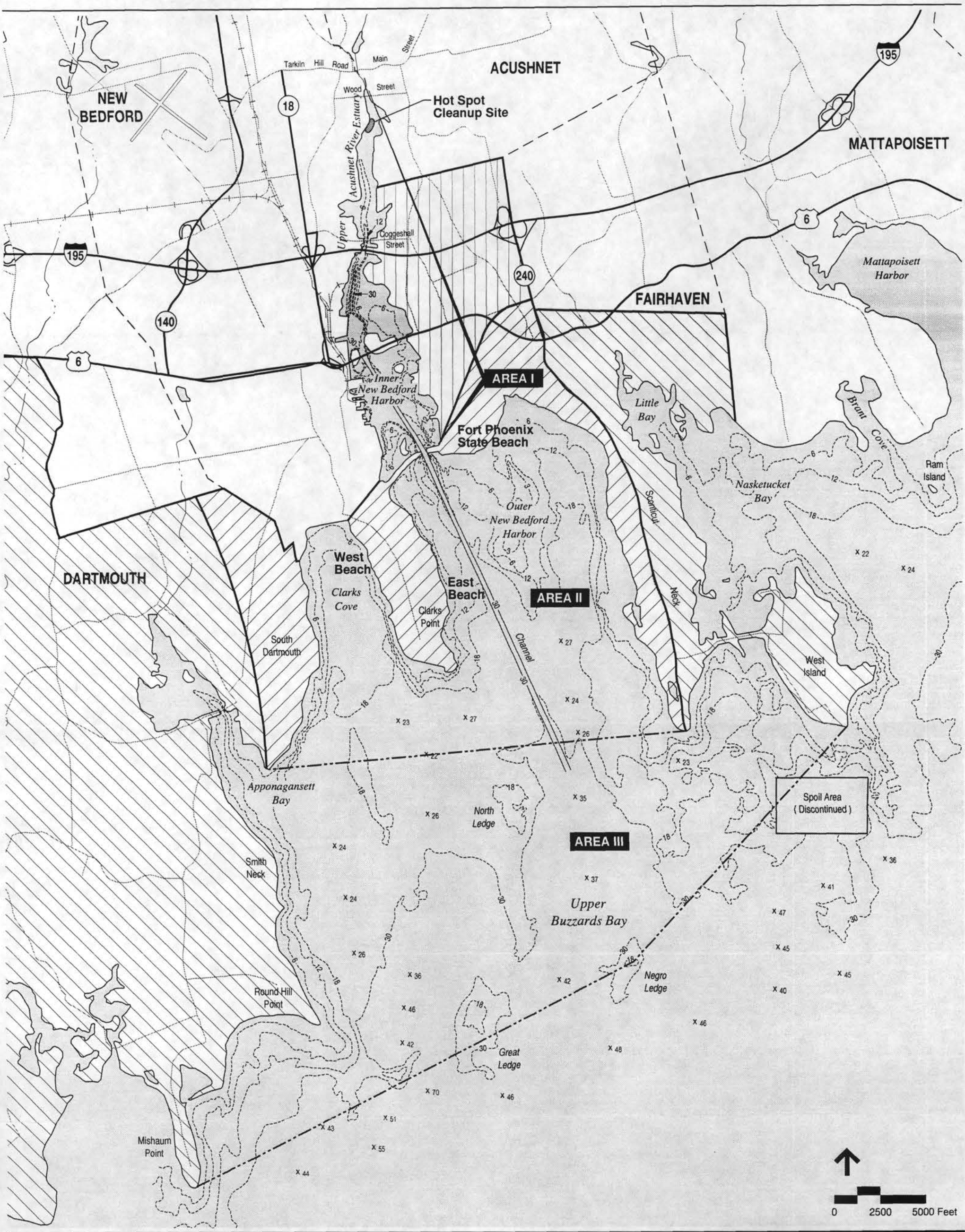
5.1 INTRODUCTION

This resource impact evaluation provides a review and assessment of the economic values lost due to polychlorinated biphenyl (PCB) contamination of the Acushnet River estuary, New Bedford Harbor, and Upper Buzzards Bay (hereafter, "the harbor area") as discussed in Chapter 4. The evaluation is based on studies conducted to ascertain the costs of alternative restoration actions and the lost use values which resulted (and continue to result) from the contamination. These restoration costs and lost use values together represent the natural resource damages caused by PCB contamination within the New Bedford Environment (Refer to Figure 5-1).

The intent of the resource impact evaluation is to provide an understanding of the nature of the damages caused by the PCB contamination and the methods used to estimate them. The chapter begins with a brief review of the federal natural resource damage assessment framework applicable to New Bedford Harbor. In Section two, the costs of actions that may be implemented to restore injured resources and their anticipated effects on PCB concentrations are summarized, and the existing lost use-value estimates are described. Notes at the end of the chapter are included to provide additional information about economics concepts related to the damage assessments.

5.2 OVERVIEW OF NATURAL RESOURCE DAMAGE ASSESSMENT RULES

The assessment regulations establish a procedural framework allowing federal natural resource agencies ("Trustees") to develop claims for the costs of restoration, rehabilitation, replacement, and/or acquisition (restoration) of equivalent injured natural resources and lost public use values pending completion of restoration actions.[1] However, the timing of the discovery of PCBs within the harbor was such that most of the claim procedures evolved concomitantly with Trustee efforts to select a restoration action and assess lost use values. A practical implication of these circumstances is that additional judgment on the part of the Trustees will be required to gauge more precisely the natural resource damages to harbor resources. Judgments will be needed because the Trustees are now considering restoration actions for the site, and the law stipulates that a nexus exists between restoration actions and the damaged natural resources, in the sense that such actions must return injured natural resources to baseline levels.[2]



Fishing Resource Closure Area Boundaries (MADPH)

Resource Impact Evaluation Zones (refer to text and Mendelsohn, 1986)

- Zone I
- Zone II
- Zones III and IV

Note: Soundings are in Feet at Mean Low Water

Sources: Mass GIS; USGS, 1977; NOAA, 1983; Weaver, 1982; Camp Dresser & McKee, Inc. 1990

Vanasse Hangen Brustlin, Inc.

New Bedford Harbor Trustee Council

Figure 5-1

New Bedford Environment Resource Impact Evaluation Information

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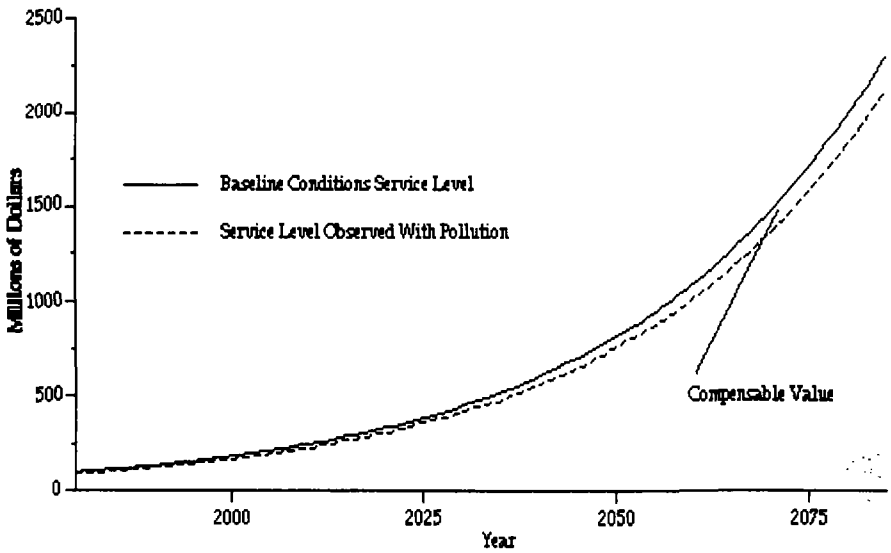
5.2.1 Measures of Natural Resource Damages

According to the rules (as presented in the Code of Federal Regulations [CFR]), the restoration cost is the basic measure of damages, and Trustees are allowed to collect these costs in all cases. The rules also provide Trustees with the discretion to add to this measure the value of any resource services lost to the public from the date of contaminant release until restoration is complete. These values may include losses annually throughout a period extending from the time of the initial decrease in service flow(s) until the time at which the resources and the services the resources provided are returned to baseline conditions.[3] The term compensable value is used to describe the amount of money required to compensate the public for the loss in services provided by injured resources.[4]

Compensable values are intended to measure fully all lost public economic values. However, only losses directly related to the public's use of the injured resources, or the services provided by these resources, are included in compensable value. In particular, adverse effects on human health are not included within compensable value because these are not damages to natural resources. Also, compensable value does not include any private economic damages related to the secondary or indirect effects on individuals, businesses, or other non-governmental organizations which may be associated with a contamination event (43 CFR §11.14 and 11.62).

Compensable values are that portion of natural resource damages which result from reductions in the benefit flows obtained from natural resource use. Such benefit flows may be considered synonymous with service flows, and according to federal rules, "Traditionally humans have valued natural resources in monetary terms on the basis of services provided by the resources. This method may logically be extended to valuing damages to an injured resource on the basis of changes in services" (Federal Register 1994b, p. 14272). Compensable value may also be viewed as the residual (lost) value existing between the baseline conditions service level and those natural resource service levels that may be reached over time due to restoration actions (Refer to Figure 5-2).

Figure 5-2 **BASELINE CONDITIONS SERVICE LEVEL, SERVICE FLOW WITH POLLUTION, AND COMPENSABLE VALUE**



Reliability is the critical criterion governing the selection of methods for calculating compensable values (43 CFR §11.83).[5] Besides reliability, two additional issues associated with the selection of a method to measure natural resource values merit mention. These are: 1) the difference between measures of natural resource values and measures of economic impact; and 2) the double-counting of natural resource damages.

Measures of economic impacts, as calculated from data on incomes and expenditures and regional input-out analysis, represent measures of how actions may be expected to change regional incomes or other economic activities (Edwards 1990).[6] However, unless resource costs are subtracted from the incomes that expenditures provide, such data simply index the transfer of income within a region, and do not measure changes in social economic values.[7] Also, induced or indirect economic impacts (usually measured using economic impact multipliers) must be treated similarly, and typically do not create any economic value (Edwards 1986).[8] A practical implication of the difference between measures of natural resource damages and economic impacts is that, in the search for actions that restore natural resource services to baseline conditions, input-output analysis and other forms of economic impact analysis can not be substituted for benefit-cost analysis.[9]

The double-counting of natural resource damages refers to calculations which count benefits or costs more than once (43 CFR §11.84). One type of double-counting occurs when damages calculated over extended time periods do not include increases in use due to restoration actions. Another type, noted by Edwards (1986), results when, for example, an analysis of a road improvement project includes in the benefit the value of saved travel-time over fifty years, but at the same time also includes as a project benefit any projected increases in property values expected from the improvement. The damages that may be double-counted and the potential extent of such double-counting, is difficult to determine without detailed knowledge of the assessment methods employed, the user groups considered, and any assumptions adopted to overcome data deficiencies or otherwise carry the calculations forward.

5.2.2 Assumptions in Natural Resource Damage Assessments

Assumptions, while genuinely required by the assessment rules, sometimes provide pathways for value judgments and/or untested hypotheses to influence outcomes. Three assumptions influential in the calculation of natural resource values concern individuals:

- the social discount rate and benefit time horizon;
- the cost of time spent in recreation; and
- the availability of substitute resource services

Assumptions concerning the social discount rate and benefit time horizon are common in studies of natural resource values because users of natural resources obtain benefit flows through time. The social discount rate (Quirk and Terasawa 1991) represents the opportunity cost of the money available for investment in social goods and services (e.g., the building of a public fishing pier, the purchase of public park lands, a consultant's design and engineering of a town sewage system).[10] The benefit time-horizon is the period of time over which the benefits and costs of natural resource use are evaluated. Within the context of natural resource damage assessments, the benefit time horizon may be equated with the recovery period, or period required for injured resources to recover to a state where services reach baseline levels.[11] The discount rate and benefit time-horizon allow values obtained at different times to be legitimately compared as expected-present-value representations of future annual benefit amounts.

Assumptions concerning the cost of recreation time are important because the cost of non-work time in recreation typically makes up the largest portion of implicit site values. Assumptions concerning this cost are required because it is difficult to find circumstances where a market-based estimate of the value can be obtained.[12] As a result, recreation benefit estimates are very sensitive to assumptions concerning the value

of time allocated to recreation (Bockstael et al., 1987). In fact, a recent meta-analysis of seventy-seven recreation studies (Kerry and Kaoru, 1990) reveals time cost as the most statistically significant factor influencing estimates of natural resource values.

Assumptions concerning natural resource substitutes are components of damage assessments because information about user perceptions of alternative sites and substitute activities is often lacking and expensive to obtain. Where acceptable substitutes exist, instead of a shortfall in the supply of a natural resource causing a loss of the benefit flow, groups can use substitute resources and maintain benefits. In effect, substitutes will often limit value losses due to use restrictions and/or congestion at any one site among a set of substitutes (i.e., the availability of substitute sites reduces benefit value associated with an individual site [Cuddington et al., 1981]). Hence, where substitute resources exist but are not accounted for, natural resource damage assessments will be based on benefit levels that are over-stated.[13]

5.3 NATURAL RESOURCE DAMAGES IN THE HARBOR AREA

The natural resource damages associated with PCB contamination of the New Bedford Harbor area include the costs of restoration actions and the value of services lost to the public from the date of contaminant release until restoration of equivalent resources is completed. Lost services are caused by changes in resource use conditions, leading to reduced or smaller natural resource benefit flows. Changes in resource use conditions may result from regulations which restrict use or cause changes in resident preferences for such use. As discussed in Chapter 3, present use restrictions within the harbor include a prohibition on all types of fishing within Area I, a prohibition on the taking of bottom-feeding fish and lobsters from Area II, and a prohibition on the taking of lobsters from Area III. Concerning use opportunities, these restrictions forced the total loss of the urban recreational fishing experience within Area I and the loss of that part of the near-shore fishing experience within Area II which depends on the freedom to keep bottom-feeding fish (e.g., tautog, winter flounder, eels). The restrictions also prohibited the use of Areas II and III by commercial and recreational lobster harvesters.[14]

Citizen preferences for natural resources are clearly motivated by an extensive set of factors, both environmental and man-induced. For harbor residents, factors that could have motivated changes in resource use include circumstances such as the near concurrence of US Food and Drug Administration (FDA) actions to reduce PCB tolerance levels in edible wildlife, and Massachusetts Department of Public Health (MDPH) emergency regulations restricting some forms of resource use due to PCB contamination. At a minimum, such actions likely served to increase local awareness of health risks attributed to PCBs. Also, in 1981, a New Bedford TV station produced *Lobster Roulette*, which described the New Bedford Harbor PCB problem by focusing on the possible health consequences of consumption of PCB-contaminated seafood; and in early 1982 the US Coast Guard announced the discovery of a PCB Hot Spot in the Acushnet River estuary with sediments containing up to 20 percent PCBs (Industrial Economics, 1985).

While the PCB contamination of the harbor is extensive, the baseline ecological risk assessment indicates that significant ecosystem risks are localized (Refer to Chapter 4), and are indicated only for Area I (i.e., the upper estuary and Inner Harbor) (EBASCO, 1990d). Direct contact with and/or ingestion of shoreline sediments was found to pose human health risks only in the northern portion of Area I (i.e., north of the Coggeshall Street Bridge); and exposure to PCB (and metals) contamination from direct contact with and/or ingestion of surface waters was not found to present a human health risk within any area (EBASCO 1989a). In contrast, consumption of PCB- and lead-contaminated clams, winter flounder, and lobsters were found to present health risks within Areas I through III.

5.3.1 Costs of Cleanup Actions

The costs of alternative cleanup actions are documented in the feasibility studies of remedial alternatives for the Hot Spot and Site-Wide operable units (EBASCO 1989b; EBASCO 1990a,b,c). The actions were evaluated using multiple criteria, including the projected effects of the actions on natural resources and public health risks (Refer to Table 5-1). As natural resource uses in the harbor area include principally the harvest of fish and shellfish for consumption and recreation activities (e.g., use of local beaches), the human health Target Cleanup Levels (TCLs) are most important for judging and projecting changes in resource use.

Table 5-1 1990 PCB TARGET CLEANUP LEVELS FOR THE HARBOR[1]

TCL Category	Sediment	Surface Waters	Biota RTLs[2]
Human Health TCLs	10-50 ppm[3]	0.03 ug/l (ppb)[4]	2 ppm edible tissue
Ecosystem TCLs	0.1-1.0 ppm		0.2 mg/kg (ppm)

[1] Source: EBASCO (1990a,b,c), ppm = parts per million, ppb = parts per billion
[2] Recommended tissue level
[3] Human health TCLs for sediments are based on contact and an acceptable level of incremental carcinogenic risk from expose to a contaminant at a Superfund site of less than one-in-ten-thousand events (1×10^{-4}). Cleanup to 10 ppm yields an incremental risk of 1×10^{-6} while cleanup to 50 ppm is expected to result in an incremental risk of 5×10^{-5}
[4] Surface water criteria developed to protect resource use under the former 5 ppm tolerance level

Table 5-2 shows projected costs (in 1994 dollars) for the Hot Spot action and Site-Wide Action Alternatives 3 and 8. Actions 3 and 8 differ mainly in the target cleanup level, with the 10 ppm level projected to involve dredging and confining a volume of sediments three times greater than the 50 ppm level. Actions 3 and 8 are shown because they included the dredging and confinement requirements of the cleanup actions now under consideration.[15] The feasibility studies project levels at a time ten years after implementation has been achieved. Comparisons of the projected levels and those established to protect human health and resource use permit assessments of the use restrictions which are likely to be required under the alternatives.

TABLE 5-2 ACTUAL AND PROJECTED COSTS OF CLEANUP ACTIONS

Action	Activity	Cost (Millions of 1994 dollars)[1]
Hot Spot (5.5 years to complete)[2]	Dredge and dewater 14,000 cy of sediment with PCBs greater than 4,000 ppm; dispose of untreated dewatered sediment in a confined disposal facility.	$28[3]
Site-Wide Alternative 8 (6 years to complete)[4]	Dredge 308,000 cy of sediment with PCB greater than 50 ppm; dispose of untreated dewatered sediment in confined disposal facilities	$39[5]
Site-Wide Alternative 3 (6 years to complete)[4]	Dredge and dewater 926,000 cy of sediment with PCBs greater than 10 ppm; Dispose of untreated dewatered sediment in confined disposal facilities	$122-194[5]

[1]Economic values converted to 1994 dollars using the implicit price deflator for personal consumption expenditures (Bureau of Labor Statistics, 1987 = 100).
[2]Actual time between record of decision and completion of the dredging activities.
[3]EBASCO (1989b); construction and operation costs through completion of the Hot Spot dredging, nominal dollars 1993-1995 (US EPA 1995).
[4]EBASCO (1990b,c); time for completion does not include time required to obtain permits or purchase required land disposal sites.
[5]The costs of land acquisition and remediation of 43 acres of harbor wetlands are not included.

For the 50 ppm clean-up, the ambient water quality criteria is anticipated to be met in all areas, and residual PCB concentrations in lower food chain species such as hard clams, mussels, and crabs are projected to fall below the FDA tolerance level. However, the tolerance level is not expected to be met for winter flounder within Area I or lobsters within Areas I, II, or III (EBASCO, 1990c). Implementation of Action 8 would likely require a maintenance of current prohibitions on the harvest of lobsters in Areas I through III, as well as regulations prohibiting the taking of bottom-feeding fish from Area I.

For the 10 ppm cleanup, the water quality criteria and the FDA tolerance level for mussels, hard clams, and crabs are projected to be met in all areas (In fact, the FDA levels are projected to be met with remediation of only the estuary to 10 ppm). Within the lower Inner Harbor (i.e., south of Popes Island or Area Ic), PCB concentrations for all ages of winter flounder are also projected to fall below the FDA level. Within the Outer Harbor and Upper Buzzards Bay (Areas II and III), lobsters are projected to remain at or near the FDA level, while PCB concentrations in winter flounder of all ages would be well below the action level (EBASCO, 1990b). As a result, the 10 ppm clean-up would likely allow the prohibition on the taking of bottom-feeding fish to be relaxed for Areas Ic and II. However, an indefinite prohibition on the taking of lobsters from Areas I through III would still seem to be required, although more recent data collected by the Massachusetts Division of Marine Fisheries (DMF) (Refer to Chapter 4) indicate that PCB levels in lobster are decreasing. With regard to ecological risks, the assessments indicate "no demonstrable difference in the percentages of marine fish, crustaceans, and mollusks whose MATCs [maximum acceptable toxicant concentrations] would be exceeded due to exposure to water column or sediment PCB concentrations following remediation to a 50 ppm TCL verses remediation to a 10 ppm TCL" (EBASCO, 1990c).

5.3.2 Lost Resource Use Values

Studies of lost use values associated with the harbor site include a preliminary assessment of damages (Industrial Economics, 1985) and three subsequent assessments to better measure the largest damages (McConnell and Industrial Economics 1986; McConnell and Morrison, 1986; Mendelsohn 1986).[16] Table 5-3 summaries the damage estimates produced by these studies. The estimates, as discussed in detail below, are taken from studies of:

- the added costs of commercial lobster harvesters who moved fishing trips outside of Areas II and III;
- the added costs of recreational anglers who moved trips outside of Area II;
- reduced demands for planned beach recreation; and
- coastal property value decreases associated with public awareness of the PCB contamination.

Commercial Lobster Fishery

The prohibition on lobster harvesting within an approximately 18 square mile portion of outer harbor and surrounding coastal areas was one of the first actions taken in response to the discovery of the PCB contamination. The restrictions were promulgated during September of 1979, when the DPH used emergency regulatory authority to prohibit all fishing in Area I as well as the taking of lobsters from Areas II and III. Evidently, this followed a general non-compliance with the industry-supported ban on lobster fishing in Area II that was initiated during 1977, shortly after the MDPH first issued warnings concerning consumption of contaminated lobsters (Industrial Economics, 1985).

Interviews with harvesters suggested that some were forced to change fishing practices due to the harvest prohibition, and that these changes increased fishing costs (Industrial Economics, 1985). Harvesters indicated responses to the restrictions involved continuing to lobster outside of the closed areas; switching from lobster to some alternative fishery; or leaving commercial fishing entirely (McConnell and Morrison, 1986).[17] Although those who changed their behavior due to the restrictions could have experienced added costs, difficulties with measuring the incomes of those who left the fishery limited the analysis to only the extra costs of those who remained in the fishery. The added costs of compliance with the restrictions was used as a proxy measure for the combined willingness-to-pay of those who fished previously within the closed areas and were forced to change their behavior as a result of the prohibition. In such case, if fishing is considered more or less the same within and without the restricted area, then harvesters forced to fish outside of the area should be willing to pay at most the costs of moving in exchange for not having to comply with the restrictions.

TABLE 5-3 LOST USE VALUE ESTIMATES FOR THE HARBOR AREA

Resource User Group	Theoretical Benefit Measure	Proxy Benefit Measure	Size of User Group	Lost Value During 1994	Total Lost Value[1]
				millions of 1994 dollars	
Commercial Lobster Harvesters	Willingness to Pay to Eliminate PCB Contamination	Added Fishing Costs	28 Harvesters	0.1	3.9
Recreational Anglers	Willingness to Pay to Eliminate PCB Contamination	Added Fishing Costs	10,000± Households	0.1	4.1[2]
Beach Recreationists	Willingness to Pay to Eliminate PCB Contamination	Decrease in Household Consumer Surplus	25,000± Households	0.2-0.3	11.2-15.2[2]
Coastal Homeowners	Willingness to Pay to Eliminate PCB Contamination	Decrease in Coastal Housing Values	4,520 Home Owners	0.8-1.1[3]	37.9-55.1

[1]Economic values converted to 1994 dollars using the implicit price deflator for personal consumption expenditures (Bureau of Labor Statistics, 1987 = 100).
[2]McConnel and Morrison (1986); present value of annual damages calculated using a 106-year time horizon (1980-2085) and a 3 percent social discount rate.
[3]Annual damage amount calculated using the property value losses estimated by Mendelsohn (1986), a 106 year time horizon (1980-2085), and a 3 percent social discount rate.

A population of 54 potentially affected firms was identified using Massachusetts DMF fishery licensing records from 1975 and lobster catch report data from 1973-1984. Interviews were conducted with 32 of the firms to determine how the restrictions affected them (4 firms refused to be interviewed, and 18 could not be reached). From this information, it was found that 10 of the firms did not use the habitat within Areas II and III. For the remaining firms, it was estimated that 73 percent (32) remained active in the fishery after the restrictions were announced, and that 27 percent (12) could have quit the lobster fishery in part because of the restrictions. Of the 32 firms which continued to fish, four were found to have stopped using Areas II and III for reasons unrelated to the restrictions. The remaining 28 were taken to comprise the group which remained active in the fishery, and for whom the effect of the restrictions was the added costs of moving trips outside of Areas II and III.

The catch reports of eight of these firms were used to determine the number of trips likely to have been moved due to the restrictions. This varied seasonally, with the proportion of trips greatest during the winter and spring (90 percent), and lowest during the summer (20 percent). For the average harvester, it was determined that the restrictions resulted in the movement of 59 fishing trips each year (53 percent of the annual total). The interviews revealed that added-costs to move trips involved primarily increased fuel and time costs, and increased costs for vessel maintenance and trap replacement.[18] Adding up the costs for

all 28 firms yielded a total willingness-to-pay to avoid the restriction of roughly $73,000 annually (1985 dollars). This annual loss was converted to an expected-present-value amount using a 106- year time horizon (1979-2085) and a 3 percent social discount rate (i.e., it was assumed that the added costs would occur annually for 106 years into the future). The estimate of total loss was $2.8 million in nominal 1985 dollars, or equivalently, $3.9 million when measured using 1994 dollars (Table 5-3).

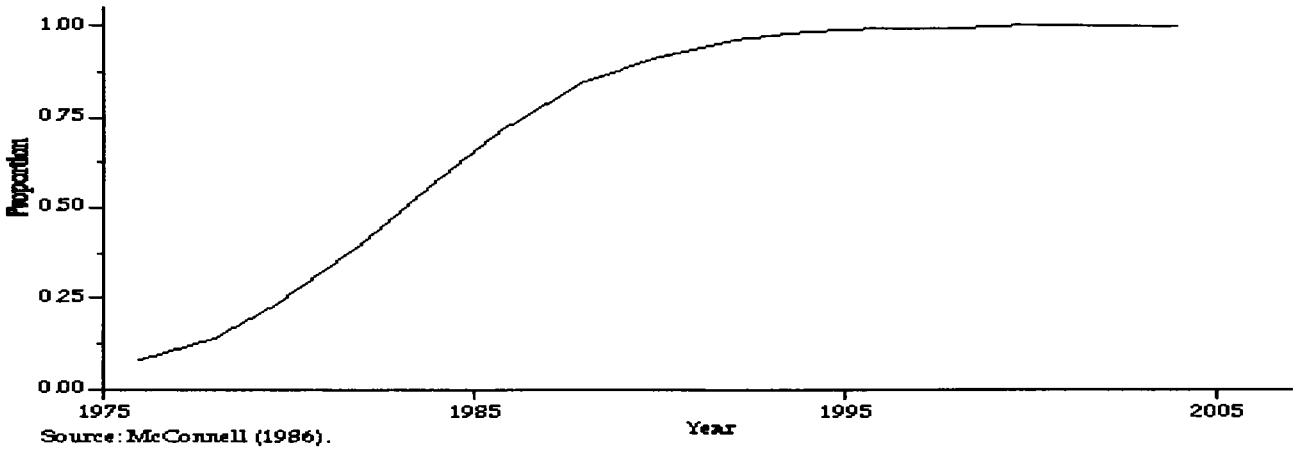
Recreational Fishing and Beach Recreation

The fishing restrictions also applied to natural resources used by recreational anglers. Additionally, the discovery of PCB contamination in the harbor is thought to have raised concerns over possible health effects attributed to exposure to PCBs. Such concerns could have led to changes in resident preferences for natural resource use. In particular, such changes were thought to have led area households to view some beaches as tainted and less desirable due to PCB contamination, and to have caused recreational anglers to move fishing trips further south, outside of Area II (McConnell and Industrial Economics, 1986).

Although it is certainly plausible that the use restrictions or changes in preferences for natural resource use may have altered the behavior of area households, the estimates of lost recreation values were not based on observed changes in behavior. Instead, for beach users, data on potential changes in behavior was obtained from a telephone survey. For recreational angling, information about responses to the contamination was obtained from conversations with local anglers and household survey questions concerning the likely use of Area 2 in the absence of PCB contamination. The survey data were then used to infer lost use values.[19] The recreation damage estimates were also based on user willingness-to-pay for a harbor free of contamination. For beach users, this value was approximated as the difference between the benefits of beach access with and without the contamination, and was calculated by subtracting consumer benefits from beach visits under the contaminated situation from benefits under hypothetical conditions of no contamination. For lost angler use values, willingness-to-pay was approximated as the added costs that could be avoided (or cost savings that could be obtained) if the harbor were free of PCB contamination (if fishing trips were not moved south).

For the recreation studies, household awareness of the contamination was considered a prerequisite for behavioral change, and damages were calculated only for households aware of the contamination. Through time, the proportion of households aware of the contamination was expected to increase, with the likely rate of increase taken from a statistical relationship estimated from responses to a survey question concerning when the household first became aware of the contamination (Refer to Figure 5-3). This relationship, estimated during 1986 when about 80 percent of households reported awareness of the contamination, projected that 98 percent of households would be aware of the contamination by 1994, and that by the year 2000, virtually all area households would be aware of the contamination.

Figure 5-3 PROPORTION OF AREA HOUSEHOLDS AWARE OF PCB CONTAMINATION, 1975-2005

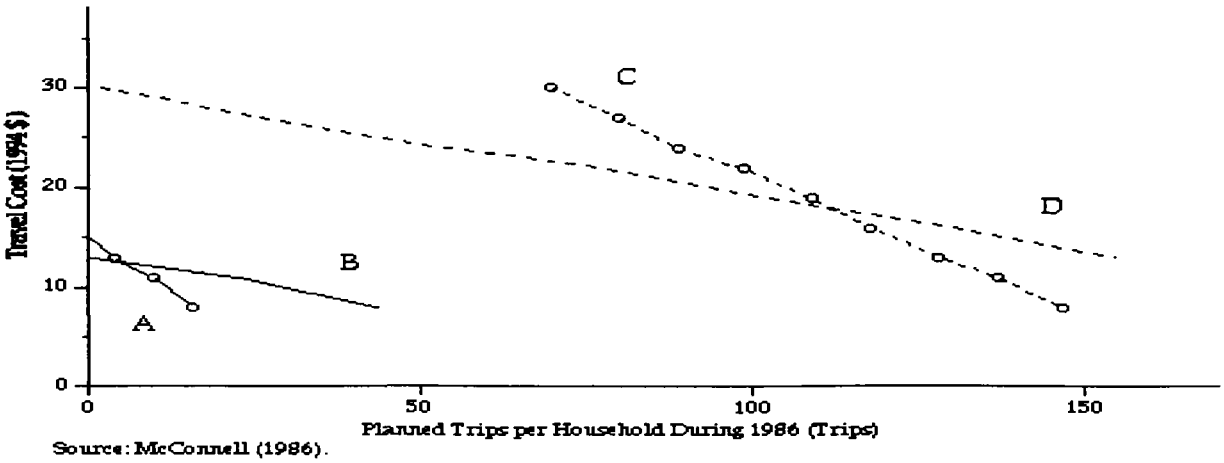


Source: McConnell (1986).

Changes in angler behavior were determined from the awareness function and responses to questions about how frequently household members used Area II for recreational fishing during 1985; and how frequently they would fish in the area in the absence of PCBs. For beach users, potential behavior changes were determined from the awareness function and household responses to questions about total planned beach visits both with and without PCB contamination.

The beach use-values lost due to the contamination were determined from an analysis of changes in demands for beach use at the household level. This analysis involved estimating demands for planned beach trips with the PCB contamination, and also under hypothetical conditions of no contamination. Figure 5-4 shows these estimated demands for beach use (i.e., the number of beach trips planned for a range of prices under the alternative scenarios). Willingness-to-pay for beach trips was calculated as the consumer surplus associated with the planned demands, with the value lost annually calculated as the difference in the surplus estimates with and without the contamination.[20]
To calculate aggregate annual damages, an average household damage using data from only households aware of the contamination was multiplied by the number of households projected aware of the contamination. To determine the number of households aware of the contamination, year-to-year through time, the household awareness function was multiplied by the number of households in the area.[21] Using the demand curves shown, per-household damages were calculated to be $6.18 (1986 dollars), and included average household losses from reduced use of both the East and West ($2.88) and Ft. Phoenix ($3.30) beaches.[22] Lastly, the damages from lost use annually were converted to an expected-present-value loss over a 106-year time horizon (1980-2085) using a 3 percent social discount rate. For 1986, the lost value was calculated to be about $250,000, and the total expected-present-value estimate of lost beach use was $11.4 million (1986 dollars), or equivalently, $15.2 million using 1994 dollars (Refer Table 5-3).

Figure 5-4 HOUSEHOLD TRIP DEMANDS FOR AREA BEACHES WITH AND WITHOUT PCBS



Source: McConnell (1986).

A=East-West Beaches with PCBs; B=Fort Phoenix Beach with PCBs; C=East-West Beaches without PCBs; and D=Fort Phoenix Beach without PCBs

As Figure 5-4 shows, planned household trips to the beach increase under the hypothetical no-contamination scenario. In fact, the analysis of the planned trips for the no-contamination scenario indicated that planned attendance would likely exceed the capacity of the beaches. To account for the possibility that capacity constraints and/or congestion would lead to smaller household benefits from beach access, the use benefit estimates were revised downward during the summer months. Adjusting the estimates to conform with capacity limits yielded an expected present-value loss of $8.3 million (1986 dollars), or about $11.2 million when measured using 1994 dollars.

To calculate the added costs of moving fishing trips out of Area II, the total number of fishing trips thought moved due to the contamination was multiplied by the cost to move a trip. The cost to move a trip was estimated to be $1.60 during 1986.[23] Responses to questions concerning use of Area II during 1985, and how this use could be expected to change in the absence of PCB contamination during 1986, were used to determine the number of fishing trips expected to be moved. In this regard, roughly 65 percent of households indicated that Area II had been used an average of six times during 1985, and for the no-contamination scenario, 77 percent of angling households indicated Area II would be used on average 12 times, annually. Using these responses, it was estimated that nearly 42,000 fishing trips would be moved out of Area II during 1986. During 1994, with a greater proportion of households aware of the contamination, it was projected that just over 7,500 angling households would move more than 52,000 trips outside of Area II.[24]

The awareness function and the planned-use responses from those households aware of the contamination were used to project the number of recreational fishing trips moved annually due to the contamination, and this number ranged from just over 11,000 during 1979 to more than 53,500 during 2005 and beyond. To calculate the total value of damages to recreational users, the annual added cost attributed to moving the trips out of Area II was converted to an expected present-value loss using the 106-year time horizon and a 3 percent discount rate. The total loss was estimated at $3.1 million (1986 dollars), or about $4.1 million in nominal 1994 dollars (Refer to Table 5-3).

Coastal Amenity Values

Amenity values are associated with amenity resources, or natural areas thought to possess some aesthetic, scenic, or recreational use potential (Cuddington et al., 1981). In practice, amenity values are often measured to assess the benefits of potential recreation sites (e.g., as which might be created as part of a water resources development project). It is a relatively straight-forward extension of the amenity value concept to consider the coastal areas in the vicinity of the harbor as amenity resources, valued by residents because of a broad suite of potential uses such as beach recreation, fishing, sunning, birding, and water skiing. In addition, there is evidence to indicate that where amenity values exist, they are reflected in real property values (Freeman, 1974; Smith, 1978). That is to say, in the presence of amenity resources, property values include a component which represents the capitalized value of the future benefit flow expected from natural resource use.[25] This benefit flow may take the form of reduced access costs to public resources such as beaches, or valuable coastal natural resource experiences not available to the public. Within the amenity value framework, coastal property owners are viewed as obtaining a flow of natural resource use benefits from access or proximity to harbors and near-shore ocean environments.[26]

Given the circumstances surrounding the discovery of PCBs within the harbor, it is plausible that resident preferences for natural resource use decreased due to awareness of the contamination. It is also plausible that such changes were motivated by perceived risks associated with area natural resource use, and that information about these issues became available to those interested in purchasing homes within the harbor area. Further, it is also conceivable that such developments could result in reduced natural resource use by residents, leading to smaller flows of use-related benefits. Ultimately, these changes could lead to decreased resident willingness-to-pay for local natural resource use opportunities.

Because changes in amenity values are thought to be reflected in the prices of real property, the amenity value study used changes in property values associated with the PCB contamination as a proxy measure for property-owner willingness-to-pay for a harbor free of contamination. According to Mendelsohn (1986), "If residents obtain less utility from using the harbor once harbor contamination occurs, the (sic) residents will pay less for access once they are aware of the contamination. This reduction in access value will then be visible in the pattern of residential property values." As for the previous assessments, the rational for using reduced property values as a measure of natural resource damages is that homeowners should be willing to pay at most the value of any property (amenity) value losses caused by the contamination in exchange for a harbor free of contamination.

The amenity-value loss estimate is based on a repeat-sale analysis of area housing values. To implement the analysis, information was collected for those owner-occupied houses in single-family neighborhoods located within two miles of the shoreline which sold more than once during 1969-1985 (1,030 homes). The information included "sale-pair" dates and market values, location and distance to the shoreline, and the date and value of any improvements. To complete the data collection, the housing data were supplemented with national and regional macroeconomic data (i.e., price deflators, unemployment levels, and mortgage interest rates) and census data on neighborhood characteristics.

Determining only that proportion of housing-value changes associated with the contamination required the development of a statistical model capable of explaining the changes in home values observed over time. Additive and multiplicative versions of a general multi-factor model were selected as best representing the information contained in the observed home-value changes. The models described the changes in the repeat-sale values as being dependent on the length of time between the sales; the value of home improvements made during the between-sale interval; and indices of mortgage interest rates, neighborhood education levels, and the PCB contamination.[27]

The objective of the modeling effort was to "determine if there [was] a decline in house values associated with the time the PCBs became widely known and if the decline is more evident in houses which are closer

to the PCB pollution." (Mendelsohn, 1986). The author assumed that if statistically significant declines could be found, then damage estimates from lost amenity values could be inferred. Several indicators of the PCB contamination were considered to implement the analysis, although each was based on the time when awareness of the contamination became widespread (i.e., not on the date when the contamination was first discovered). According to the study, the 1979 fishing restrictions were the first actions which indicated to the public that the contamination was a serious problem, and continued coverage of the issue during 1980-1981 served to maintain public awareness. Consequently, all sale-pairs with dates bracketing 1980 were considered to be consistent with the timing of the pollution event, and the distance of the properties from the shoreline was used to test for effects due to proximity to the PCB contamination.

Analysis of the models showed value decreases correlated with the timing and proximity of the contamination that were statistically significant, but only marginally so.[28] In addition, the best performing model(s) accounted for only about 15 to 20 percent of the changes in sale values observed. Figure 5-5 shows the contaminant effects described by the modeling. On average, value changes associated with proximity to the contamination and consistent in timing with the event were found to be -$5,600 (-10 percent) for homes within Zone I (i.e., Area I or the Inner Harbor) and -$6,300 (-15 percent) for homes within Zone II (i.e., Area II or the Outer Harbor south to the imaginary line from Rickersons Point in Dartmouth to Wilbur Point in Fairhaven) (Refer to Figure 5-1). The statistical results provided evidence that the relative value of being close to the water had dropped in Zones I and II (Mendelsohn 1986).

To calculate the total loss in property value attributable to the contamination, the average value losses indicated by the regression analysis were multiplied by the number of houses located within the study area. Table 5-4 shows the loss amounts by zone and town, and Table 5-3 shows the total loss estimates. As noted above, while amenity-use values may be expected to take the form of annual benefit flows, the amenity-value loss shown in Table 5-3 is an estimate of the capitalized value of this benefit flow. For comparison purposes, an approximation for the value of the annual benefit flow, calculated using the social discount rate and time horizon adopted for the other assessments, is also shown in Table 5-3.

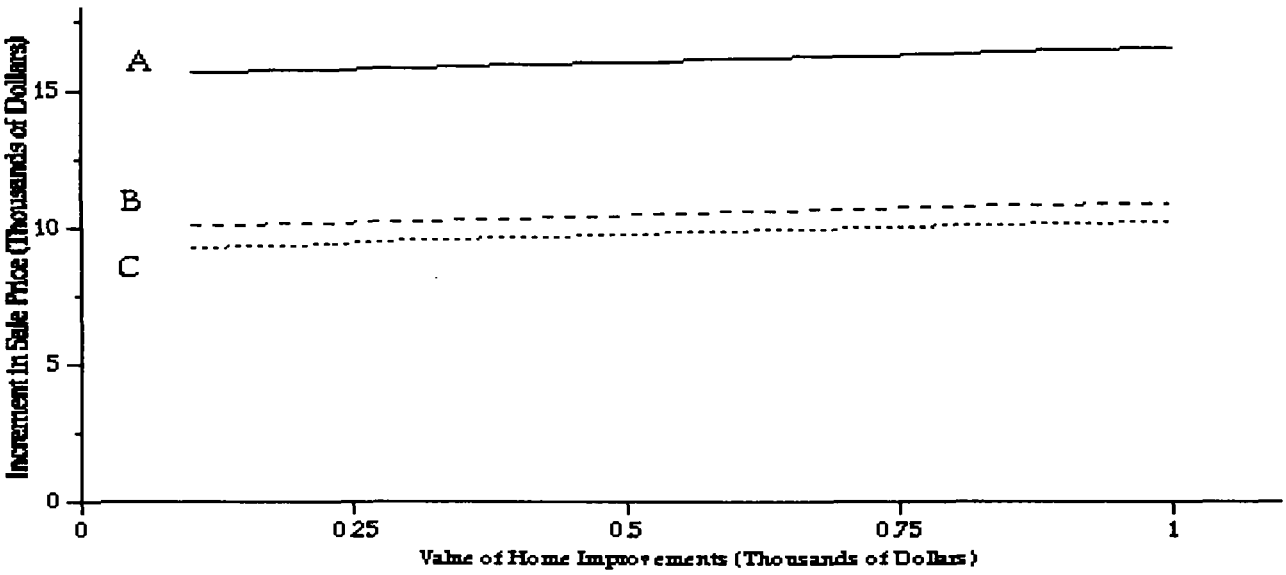
Table 5-4 ESTIMATED AMENITY VALUE LOSSES BY ZONE AND TOWN[1]

Zone	Dartmouth	Fairhaven	New Bedford
		millions of 1994 dollars	
I	—	13.2-18.0	—[2]
II	7.9-14.0	9.6-12.5	7.2-10.6

[1] Source is Mendelsohn (1986). All homes located within two miles of the shoreline, with the average distance about one-half mile. Lower-range estimates calculated from the additive model and upper-range estimates calculated from the multiplicative model. Nominal 1985 values converted to 1994 dollars using the implicit price deflator for personal consumption expenditures (Bureau of Labor Statistics, 1987=100).

[2] The study excluded 1,420 homes in New Bedford within two miles of Area I.

Figure 5-5 RELATIONSHIP BETWEEN THE VALUE OF IMPROVEMENTS AND SALE PRICE INCREMENT FOR COASTAL HOMES WITHIN THREE ZONES OF PROXIMITY TO PCB CONTAMINATION



Source: Mendelsohn (1986) .

A=Homes East and West of Zone 2; B=Homes Within Zone 2; and C=Homes within Zone I.

5.3.3 Other Damages

Other natural resource damages are lost use-values which were not considered within the existing assessments. Such damages would include damage amounts suspected as being relatively small during the mid-1980s when the assessments were produced, and/or additional damages, perhaps caused by changes in the composition of user groups or in the extent of the contamination over time. With the exception of the preassessment screen (Industrial Economics 1985), the literature and Administrative Record concerning the site provide little additional information about PCB-induced damages. In particular, no evidence could be found for damages fundamentally different from those considered by the Trustees during the mid-1980s. Reasons for this may include that PCB concentrations within the harbor area have remained relatively stable, and that the use restrictions required by the contamination have not changed since their promulgation during 1979.

The preassessment screen identified several categories of potential damages not considered subsequently within the assessments. These included lost recreational uses of area shellfish habitat (e.g., quahog and lobster), extraordinary business costs associated with commercial property development in and around the harbor, and decreases in lobster consumption benefits due to consumer avoidance behavior. Of these categories, only the extraordinary business costs incurred by property owners and developers were identified as being potentially significant (Industrial Economics, 1985).

With regard to recreational use of area shellfish habitat, the preliminary assessment indicated that there were no areas where shellfishing would be allowed but for the PCB contamination (i.e., Area I, that was closed to all fishing due to the contamination, was already subject to a shellfishing prohibition because of

sewage contamination). It is also possible to consider whether PCB contamination may become a binding constraint on the use of shellfish habitat sometime in the future, especially given that habitat lost to sewage contamination has increased during the 1980s and plans for upgrading area treatment plants are now developed (Conservation Law Foundation 1988) and scheduled for implementation in 1996. In this regard, Schwartz and others (1991) note that: 1) ingestion of contaminated food is thought to account for the largest portions of PCB burdens in biota, and 2) that PCB concentrations in the near-shore water column, where bivalve mollusks develop and obtain food, are much lower than those in sediments and pore waters. Hence, it is suggested that shellfish are less susceptible to contamination by PCBs than bottom-feeding fish and arthropods. This relative resistance of shellfish to PCB contamination is also reflected within the Site-Wide feasibility studies, where it is indicated that implementation of either the 10 or 50 ppm cleanup action is expected to result in bivalve shellfish PCB concentrations within Area 1 below the 2 ppm FDA action level (EBASCO, 1990b,c).

The preliminary assessment also de-emphasized the damages that may have resulted from reduced lobster consumption and recreational use of near-shore lobster habitat (Industrial Economics, 1985). Evidently, interviews with area lobster wholesalers indicated that sales volumes were not affected significantly by public awareness of PCB contamination at the harbor. The anticipated minor effect, as well as difficulties obtaining data specific to the area, suggest that better measurement of this potential damage may not have met a rules-test limiting assessments to cases where anticipated assessment costs are expected to be less than damage amounts. The preliminary assessment also identified a population of about 100 recreational lobster harvesters who could have incurred collectively as much as $7,500 annually in added costs to move trips outside of Areas II and III. Again, the small projected damage amount, as well as the above-mentioned concerns about enforcement of the lobster harvest restrictions, seems to indicate that the restrictions may not have significantly impacted this resource user group.

The extraordinary business costs incurred by property owners and developers consisted primarily of one-time only costs associated with permitting and construction (e.g., added sampling costs to determine site characteristics). Although the preliminary estimate included a cost for just on-going projects ranging between $1.1 and $2.8 million, such costs are excluded from consideration by the assessment rules, which exclude from compensable value any private economic damages related to the secondary or indirect effects on individuals or businesses that may be the result of a contamination event.

5.3.4 Double Counting

Adding together the midpoints of the damage estimates of Table 5-3 yields lost-use damages of about $68 million. However, recreational fishing and beach resources are amenity resources, and so simply adding together the estimates from the alternative assessments will double-count some benefits. For the present case, the amenity assessment includes 4,520 households which form a subset of the households in the recreation survey. In a worst-case double-counting scenario, all of the coastal home owners within Zones I and II also use area beaches and recreational fishing resources. Applying this bounding assumption, the proportion of households with recreational fishing damages who are also coastal home owners ranges from 100 percent during 1979 to about 40 percent by the year 2000 and beyond. For beach recreation, the corresponding worst-case proportions are 40 percent during 1979 to just less than 10 percent by 2000 and beyond.[29] Multiplying these proportions by the midpoint of the annual damage estimates for recreational fishing and beach resources yields maximum double-counted damages of about $2 million each for beach resources and for recreational fishing resources.[30]

Notes

1. The regulations identify standardized and cost-effective procedures for assessing natural resource damages, and assessments performed by a federal or state natural resource trustee in accordance with the rules are provided the evidentiary status of a rebuttable presumption (43 CFR §11.11). The "Response to Comments" sections of the 1994 regulations and the previously proposed revisions provide perhaps the best source of information concerning many practical aspects of the regulations (Federal Register 1991, 1993). In addition, Dower and Scodari (1987) provide an early overview of the assessment framework, and more recently, the National Oceanic and Atmospheric Administration proposed its own procedures for assessments under authority granted by the Oil Pollution Act of 1990 (Federal Register 1994a).

2. While Trustees are not bound to implement only restoration actions designed to replace exactly those natural resource services determined as lost, Trustees who do propose actions that differ from those used as a basis for damages are required to explain the reasons for the differences at public hearings (43 CFR §11.81 and Subpart F). Restoration actions are open to legal challenge in this regard.

3. Baseline conditions, or the baseline services level, means the resource conditions that would have existed at the assessment area had the contaminant discharge under investigation not occurred. Resource conditions are broadly defined to include the physical, chemical, or biological properties that the injured resources would have exhibited, or the services that would have been provided by those resources, had the discharge not occurred (43 CFR §11.71-72). As such, the rules view the measurement of human uses of natural resources as providing a valid means to index baseline resource conditions, but not the only index of such conditions.

4. Compensable value includes the value of lost public of the services provided by the injured resources, plus lost non-use values such as existence and bequest values (43 CFR §11.83). Non-use values are likely to be significant only when irreversible or long-lasting injuries occur to well-known, unique natural resources, and no evidence was found for any lost non-use values at the New Bedford site.

5. The development of large portions of the assessment procedures has been driven by concerns over the reliability of the methods available to measure resource values, and the literature on the issue is immense and not easily summarized. The initial version of the rules considered measures of resource value changes obtained from competitively-determined market prices the most reliable, with measures of resource values determined indirectly from analysis of related goods and services markets less reliable, and changes in resource values measured using hypothetical market data least reliable.

6. Input-output analysis describes the financial linkages among the networks of input suppliers and producers within a (regional) economy. Input-output analysis is used generally to predict gross changes in regional output, income, and employment.

7. Social economic values are net economic values, and represent the net value result after subtracting resource costs (i.e., the value of foregone production when productive resources are used to produce one good or service instead of something else) from measures of gross value.

8. Economic impact multipliers, as generally used in input-output analysis, show the ratio of gross impacts (changes) in output, income, or employment generated initially by expenditures associated directly with consumption or investment activities (e.g., the building of a fishing pier). As such, economic impact multipliers inflate estimates of economic activity associated with direct project expenditures. However, both direct and indirect impacts of consumption or investment activities on regional output, income, or employment are gross measures of economic value that do not consider the opportunity costs of using productive resources to obtain the values.

9. Benefit-cost analysis is a method which compares gross economic values and the opportunity costs of using productive resources to obtain the values. In benefit-cost analysis, "benefit" is synonymous with value, or the maximum willingness-to-pay for a good or service, including environmental resources and services (Edwards 1990, p. 23). The focus of benefit-cost analysis is on whether the total value of a project or regulation exceeds its resource or opportunity costs. In contrast, the focus of input-output analysis is on changes in gross economic activity and the self-sufficiency of an economy. See Edwards (1990, p. 10) for a repudiation of the use of input-output analysis as a surrogate for benefit-cost analysis and the measurement of social economic values.

10. The social discount rate is a money opportunity-cost concept that closely parallels the concept of the rate of interest as an opportunity-cost of money. More specifically, if one were to invest money in a business, one measure of the opportunity cost of the investment would be the rate of interest available for the money if placed in a savings account. One may think here of the saying "time is money," in the sense that money held over time will yield an interest payment, and this interest payment, where it represents the next-best use of the money, is the opportunity cost of the money (i.e., in this example, the opportunity to gain the interest payment is given up when the money is invested in a business).

An important result of the existence of a money opportunity cost is that a dollar available today is worth more than a dollar available one year from now (with the difference the annual interest payment available in the market or some other next-best return available to the owner of the money). While the rate of interest is a "backward-looking" concept (e.g., one only knows the interest rate after money is left on deposit and an interest payment is received), the discount rate is employed only to evaluate the relative attractiveness of future investments, and so is "forward-looking." As one looks at the future benefits and costs of an investment, a positive opportunity cost of money results in a "discounting" of the values of future benefits and costs when they compared with benefits and costs which occur today (i.e., as was noted above, the opportunity cost of money implies that a dollar available today is worth more than a dollar available one year from now). When the relative values of investments made by society are evaluated, a social discount rate is employed to represent the opportunity-cost of the money owned by society and available for investment in public goods and services. The main effect of accounting for the opportunity cost of money is that investment benefits and costs available only in the future are viewed as relatively less valuable than those available today, with the magnitude of the discounting of such future values determined appropriately by the social discount rate.

11. The "recovery period" is defined to be either the length of time required to return services of the injured resources to baseline conditions or a lesser period of time selected by an authorized official (43 CFR §11.14 and 11.73). As such, the recovery period may be influenced by the restoration alternatives implemented.

12. One activity similar to the travel-to-the-recreation-site activity, especially for short, or day-length, recreation trips, is job-related commuting. The literature developed by travel planners to measure commuters' travel-time values indicates that average values are between 25 percent and 50 percent of wage rates (Cesario, 1976).

13. Analytical strategies for determining natural resource values should incorporate the influence of substitutes (Cuddington et al., 1981; 43 CFR §11.84). Where substitutes exist, appropriately accounting for them will ensure that natural resource values are not calculated as if such resources were unique. The differences in use values of unique and substitutable resources are typically significant. For example, a study by Edwards and Gable (1991) indicates that, for a coastal Rhode Island town of about 1,500 households with an average household income of $25,000, a complete loss of beach services could reduce cumulative household benefits by $29 million (1980 dollars). However, where erosion is localized and a substitute beach is available close nearby (one quarter-mile more distant), benefit losses were estimated at only $0.65 million.

14. In other cases, resource uses which might have been affected by the PCB contamination were already restricted due to high levels of some other contaminant (e.g., shellfishing within Area I affected by high fecal coliform levels).

15. A recently proposed action involves dredging 475,000 cubic yards of sediments with PCB concentrations greater than 10 ppm and depositing the material in three containment facilities. Also, an undetermined but relatively small amount of sediments with concentrations greater than 50 ppm would be removed from portions of the 43 acres of wetlands bordering the east side of the estuary (US EPA 1995). However, proposals to combine the action with harbor maintenance dredging will likely require further modifications to this action.

16. The estimates were developed by academic and private-sector economists according to the draft guidelines for damage assessments under development during the mid-1980s (Federal Register, 1985).

17. Some harvesters also reported that deploying traps further from shore resulted in fewer days, especially during the winter, when conditions were judged safe for fishing, and others reported reduced fishing success initially when forced to place traps on unfamiliar grounds.

18. The average annual added cost was estimated at $2,594 during 1985, and included $541 of time costs, $281 of fuel costs, $38 of vessel maintenance, and an additional $1,734 for gear replacement. All of the added costs were estimated from market-based estimates of values. For example, per-trip time costs were calculated by multiplying the hourly average income ($8.46) earned by captains and fishermen in the Massachusetts commercial fisheries during 1985 by the median increase in vessel steaming time per trip (65 minutes) reported by twelve harvesters who moved trips outside the restricted areas. Fuel costs were calculated by multiplying the increased steaming time by an hourly consumption rate and the market price of fuel, and maintenance costs were based on the increased steaming time and industry-standard costs per hour of operation. Lastly, gear replacement costs were based on market prices for traps and the responses of nine harvesters to questions concerning increases in trap losses annually due to the restrictions. According to these harvesters, on average, an additional 53 traps per year (23 percent) were lost due to the movement of trips outside of the restricted areas.

19. The survey was based on a random sample of households with listed telephone numbers in the cities and towns of New Bedford, Fairhaven, and Dartmouth. The survey was completed during March 1986 (545 interviews). Participants were required to have lived in the area for at least one year, were at least 18 years of age, and were household members who decided which beaches to visit or where to saltwater fish.

20. According to the authors (McConnell and Industrial Economics ,1986, p. 12), "These benefits of access are estimates of what the representative user [household] would pay annually for the right to visit each beach." The study used consumer surplus, or the triangular area underneath a goods or services demand curve but above the market price, to approximate willingness-to-pay (43 CFR §11.83). Edwards (1986, pp. 6-13) provides a simple explanation of the value concepts underlying willingness-to-pay and consumer surplus.

21. The total number of area households (51,498) was assumed to remain unchanged over the benefit time horizon.

22. Linear demand models with R^2s not reported. For each beach, demands shown are for conditions where closest two substitutes cost $35 and $65 per trip (economic values adjusted to 1994 dollars using the implicit price deflator for personal consumption expenditures). The trip costs (prices) used to estimate the planned demands were determined using the travel cost method (43 CFR §11.83) and the trip quantities were determined from the responses to the telephone survey. Roughly 25 percent of households aware of the contamination indicated plans to use area beaches, with median expectations for use (trips) to East and

West and Ft. Phoenix Beaches at 10 and 5, respectively. For the scenario where the PCB contamination did not exist, nearly 50 percent of households indicated plans for beach use, and median expectations were for 15 and 9 trips annually for the same beaches.

23. The average cost to move a fishing trip out of Area 2 was calculated as the simple average of the cost estimated to move a shore trip ($0.72) and a boat trip ($2.47). Both estimates were produced using the factor cost method and included added costs for time and transportation, with time valued at the after-tax wage rate and transportation costs obtained from market-based indices.

24. The proportion of households aware of PCB contamination during 1986 that were also recreational angling households was found to be 20 percent, or about 7,850 households. During 2005, with all area households projected aware of the contamination, the number of angler households aware of the contamination was projected to be just over 10,000.

25. Capitalized values are present-value representations of a series of future annual values (i.e., a flow of income or benefits). In general, the present value of an indefinite flow of future income may be calculated using the formula

$$C\ V = \sum^{t=\infty} (A_t) / (1 + i)^t$$

where A_t is the income value in year t and i is the personal discount rate appropriate for the income considered.

26. According to the amenity-value framework, the measured decreases in coastal home values are total value representations of the flows of natural resource use-values expected lost due to reduced use of area natural resources. That is to say, the expected future services for the near-the-water amenity and for recreation are capitalized into the housing price, and expectations of both owners and buyers are for reduced future area natural resource use due to the PCB contamination. Hence, amenity values may be viewed as an *ex ante* value concept (Bishop and Heberlein, 1979).

27. The additive model describes a housing market where amenity (use) value does not depend on the value of the home, but simply adds to it. The multiplicative model describes a housing market where the existence of amenity resources produces proportional increases in real property values.

28. Model R^2 is 0.18 with N=1,330 sale pairs. Figure 5-5 shows results for sales bracketing 1980, mean levels of interest rate and high school variables, and adjusted for price trends within Zone I and for homes east and west of Zone II. While the results shown use national macroeconomic indexes and property value changes to evaluate the effects of the contamination, an alternative model which employed regional macroeconomic variables showed no significant effects in Zone I, slightly more pronounced effects in Zone II, and a slightly higher total value loss (Mendelsohn, 1986, p 39-40). According to the author, more than half of properties with a sale after 1980 had also sold at least once during 1969-1980.

29. The number of households with beach-use damages ranged from about 10,000 during 1979 to just over 51,000 during 2000 and beyond. Households with recreational fishing damages numbered about 2,000 during 1979 and just over 10,000 during 2000 and beyond (McConnell, 1986).

30. The concept of amenity resources is broad, and in particular, could include benefits from proximity to employment opportunities based on natural resource use. Hence, it is possible that the amenity damages might include some damages which represent increased costs of accessing area lobster resources. The likely amounts of such double-counting are thought to be extremely small or negligible.

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6.0 EXISTING AND ON-GOING MONITORING PROGRAMS

6.1 INTRODUCTION

To supplement the previous chapters describing coastal resources and contamination, and the resources impacts attributed to contamination, the following text sections and summary tables are provided to describe existing and on-going monitoring programs relative to the New Bedford Environment. This information was collected by contacting researchers and resource managers at the US EPA, National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (ACOE), various Departments within the Massachusetts Division of Fisheries, Wildlife and Environmental Law Enforcement's Division of Marine Fisheries (MDMF), the Massachusetts Executive Office of Environmental Affairs (EOEA), the local municipalities, and numerous academic and private organizations. Effort was made to include not only monitoring that is or will be completed specific to the harbor clean-up, but also other biological, physical, and chemical sampling programs that are occurring in and near the New Bedford Environment that could be used in evaluating restoration success. Information is provided on the organization and principal investigator completing the monitoring and the primary purpose of the monitoring program. Also, where applicable, brief summaries are provided on the parameters being sampled; general sampling locations and frequency; and the media (e.g., computer versus hard copy logs) and format in which the data are being compiled.

6.2 PROGRAMS ADDRESSING PHYSICAL AND CHEMICAL CONDITIONS

At least ten programs are currently monitoring physical and chemical conditions in the New Bedford Environment or nearby Buzzards Bay (Refer to Table 6-1). Most relevant to the harbor remediation is the long-term monitoring program designed and implemented by the US EPA to document spatial and temporal changes in contaminant concentrations in the sediments and water column, and availability potentially adversely affecting biota and human health. The sampling protocols for this long-term monitoring follow those previously used in the US EPA's monitoring prior to, during, and following the clean-up of the New Bedford Hot Spot area. The monitoring plan involves a probabilistic sampling design, applying a systematic hexagonal grid layout of each of the harbor areas (i.e., upper, lower, and outer harbors) to objectively select monitoring stations; approximately 25 sampling stations are located in each area (a total of 76 stations). The monitoring includes measurement of concentrations of PCBs (18 congeners tested) and eight metals in the sediments; bioassays for contaminant acute toxicity to biota; sediment grain size, total organic carbon content, and acid volatile sulfides; measurement of contaminant bioaccumulation by blue mussel (*Mytilis edulis*); and bioaccumulation studies using the marsh-dwelling mummichog (*Fundulus heteroclitus*) to document contaminant linkages between the wetlands and the rest of the harbor system. The monitoring will continue over a 30-year period following remediation of the harbor, as required by the Superfund regulations. The full-scale monitoring frequency has yet to be determined by the US EPA (e.g., possibly between 3 and 5-year time frames), and will be dependent on the timing, duration, and type of remediation techniques applied in the harbor restoration.

As part of the US EPA long-term monitoring program, the ACOE is involved with the actual field sampling oversight and data compilation (Program 4). This sampling work is generally completed by a contractor with ACOE oversight.

Other physical and chemical monitoring is occurring in and proximate to the New Bedford Environment. Measurement of nutrients, silicate, light transmission, and dissolved oxygen (DO) have been monitored at eight stations in Buzzards Bay on a monthly basis since October 1987 by the University of Massachusetts at Dartmouth to document water quality trends in the Bay (Table 6-1, Program 7). Several of these sites are near New Bedford Harbor, and sampling has also occurred in both the Inner and Outer Harbors. The Buzzards Bay Coalition (Program 6) is also monitoring nutrients, DO, and several other constituents four times per summer at five stations within the New Bedford Environment. Although not a chemical constituent, fecal coliform is monitored by the Massachusetts Division of Marine Fisheries (MDMF) in the Outer New Bedford Harbor, Clarks Cove and other nearby waters for purposes of classifying shellfish harvesting areas based on water quality (Program 2).

As a US EPA regulatory requirement, various water quality parameters are routinely sampled from the effluents from each of the wastewater treatment plants operated by the City of New Bedford (Program 8) and the Towns of Fairhaven (Program 9) and Dartmouth (Program 10). Physical and chemical parameters sampled daily or weekly include DO, pH, total suspended solids, settable solids, biological oxygen demand (BOD), and fecal coliforms. Nutrients and oil and grease are generally sampled on a monthly basis, while bioassays to determine the toxicity of the effluents on specific test organisms (e.g., mysid shrimp, sheepshead minnow) are completed four times per year.

Although NOAA's Status and Trends Program was discontinued in 1993, monitoring data addressing PCB, hydrocarbon, and metals in sediments are still being synthesized for stations in the vicinity of the New Bedford wastewater treatment plant and other Buzzards Bay sites (Program 5). This work is being completed to identify linkages between significant coastal contaminant areas and changes in living marine resource populations.

6.3 PROGRAMS ADDRESSING BIOLOGICAL CONDITIONS

As previously discussed in Section 6.2, the US EPA's 30-year monitoring program of the New Bedford Harbor Superfund site includes biomonitoring (Table 6.2, Program 13). The monitoring includes the collection of grab samples to identify macrobenthic species abundance, richness, and composition; bioassays of the harbor sediments to test for acute toxicity in marine organisms; and setting out blue mussels and mummichog in the harbor and wetland areas to determine the extent of contaminant bioaccumulation. The MDMF also monitors the bioaccumulation of PCBs in the edible portion of American lobster (*Homarus americanus*) captured in the harbor area; sampling is completed at 11 stations in Area III once each spring (Program 5). Bioaccumulation and histopathic studies have also been conducted by NOAA in its Status and Trends Program (Program 15) and other research activities (Program 12) occurring in New Bedford Harbor, and additional data will likely be collected and analyzed in the future.

The MDMF conducts finfish monitoring studies to identify the total amount and distribution of annual commercial catches. Data from commmerical fishermen's annual logs are compiled to identify the harvest from specific sampling areas, including Area 14 which includes all of Buzzards Bay (Program 1). Trawl surveys are also completed by the MDMF in Area 14 and other state waters as part of their finfish stock assessment studies (Program 4). Data are collected twice per year on total species weight; fish length, age, maturity; and the presence of any observed external pathologies. The location of trawl transects are randomly selected, and may include stations within one mile of the hurricane barrier. Anecdotal

information on anadromous fishery resources in the Acushnet river watershed is also periodically collected by the MDMF (Program 8).

Recreational fishery data are routinely (bimonthly) collected by NOAA's National Marine Fisheries Service using telephone and field surveys techniques to identify catch per trip effort and fishing pressure, including commonly used fishing areas along and near New Bedford Harbor (Program 14). The MDMF also irregularly collects recreational fishery data from the New Bedford Harbor area, although this is generally anecddotal information (Program 7).

Shellfish resources in New Bedford Harbor have been infrequently monitored by the MDMF. A resource inventory was completed in 1983, although a detailed study with sampling from approximately 50 stations is expected to be completed during the summer of 1996 (Program 6). Outer Harbor shellfish relay (transplant) information is also maintained by the City of New Bedford (Program 9) and the Town of Fairhaven (Program 10), although these data are verified and maintained by the MDMF (Program 6). The Town of Dartmouth (Program 11) conducts limited shellfish sampling, relying mostly on monitoring conducted by the MDMF. The Woods Hole Oceanographic Institution (WHOI) previously monitored hard clam (*Mercenaria mercenaria*) and soft-shelled clam (*Mya arenaria*) populations for several continuous years in the New Bedford Environment, while some sampling is still being conducted for contaminant bioaccumulation in these species from an Inner Harbor site (Program 18). The WHOI program also includes monitoring of two reference sites in Little Buttermilk Basin.

The UMass monitoring program previously discussed in Section 6.2 has also been collecting data on phytoplankton, zooplankton, fish larvae, and bacteria plankton since October 1987 (Program 19). Eight Buzzards Bay sampling stations are monitored monthly, and data are collected from both the Inner and Outer Harbors.

Avifauna data for the New Bedford Harbor and Upper Buzzards Bay are collected from local representatives of the National Audubon Society (Program 17), as well as the Llyod Center in South Dartmouth, Massachusetts (Program 16). The Audubon's database includes information from four monitoring areas within the Inner and Outer Harbors, and comprises summer and winter surveys that have been continuous since 1986. Avian studies as well as other research projects in the Upper Buzzards Bay area are periodically conducted by the Lloyd Center.

Two additional programs address habitats in the New Bedford Harbor area. In 1996, the MDMF Wetlands Conservancy Program will be conducting a survey of eelgrass and other submerged aquatic vegetation in Buzzards Bay, employing aerial photographic interpretation and extensive random sample groundtruthing techniques (Program 2). This program includes follow-up investigations every 5 years to document changes in distribution and general condition of submerged aquatic vegetation habitats. The MDMF Natural Heritage Program monitors rare, threatened and endangered species in the region, and inventories species sitings and designations of critical and exemplary habitat sites throughout Massachusetts (Program 3). A number of state-designated habitats have been identified within and in the vicinity of the New Bedford Environment (Refer to Chapter 3), although this information is primarily qualitative.

TABLE 6-1

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
PHYSICAL AND CHEMICAL CONDITIONS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
1	MA Executive Office of Environmental Affairs Coastal Zone Management Office 100 Cambridge Street Boston, MA 02202 Dan Martin 617 727-9530 (x452)	resource and land use mapping using geographical information system (Mass GIS); depository for coastal aerial photographs at 1:48,000				Mass GIS layers	photogrammetric maps and 1994 aerial photographs of New Bedford Harbor and Acushnet River watershed found here
2	MA Division of Marine Fisheries 18 Route 6A Sandwich, MA 02563 Dave Whittaker 508-888-1155	water quality program relative to shellfish resources; measure fecal coliform for shellfish water classification	fecal coliform; sometimes total coliform; water temperature; rarely PCBs, metals, pathology	defined stations within Clarks Cove and Outer New Bedford Harbor	monthly	maintained on local PC; some data available on Mass GIS	MDMF recently completed a New Bedford Harbor pollutant sources study; the document and addendums are available in the Sandwich Office
3	US EPA Atlantic Ecology Division 27 Tarzell Drive Narragansett, RI 02882 William Nelson 401-782-3000	New Bedford long-term (30 years) monitoring program in accordance with Superfund	metals, PCBs, sediment acid volatile sulfides, total organic carbon, grain size	76 randomly selected geometric grid stations distributed throughout the Inner and Outer Harbors	over a 30-year monitoring period; to be determined by the USEPA	Microsoft access; world-wide web; in conformance E-Map protocols	Samplings were completed prior to the hot spot dredging in 1993; and in 1995 after the hot spot dredging was completed
4	U.S. Army Corps of Engineers 424 Trapelo Road Waltham, MA 02254-9149 Mark Otis 617 647-8895 Jay McKay 617-647-8142	remediation monitoring	none at present; likely PCBs, metals, PAHs in sediments and biota; will follow USEPA, NOAA status and trends sampling protocols	none at present; will likely include Inner and Outer Harbors	none at present		monitoring work will be conducted to document remediation efforts; determine changes one time in response to clean-up; ACOE carries out USEPA sampling program (see Program 3 above); future may include sampling for maintenance dredging of federal channel
5	National Marine Fisheries Services 2725 Montlake Boulevard East Seattle, Washington 98112 Herb Sanborn 206 860-3341	National Status and Trends Program	PCBs, hydrocarbons in sediments; grab samples from upper 2-4 cm; cores for metals analysis from upper 6-8 cm	Buzzards Bay; sampling sites in vicinity of the New Bedford wastewater treatment plant		Reflex database or Filemaker being converted to Oracle database	Although the S&T program was discontinued in 1993, some information is still being analyzed

TABLE 6-1 (Cont'd)

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
PHYSICAL AND CHEMICAL CONDITIONS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
6	Buzzards Bay Coalition P.O. Box 268 Buzzards Bay, MA 02532 Eileen Gunn (New Bedford area) 508-759-1440 Joseph Costa (overall program) 508-748-3600	monitor Buzzards Bay water quality	inorganic and organic nutrients, dissolved oxygen, temperature, salinity	5 nutrient stations; Main Street, Acushnet; Coggeshall Street Bridge; Popes Island; Fairhaven Shipyard; Ricketsons Point jetty, other data from Fairhaven Shipyard only	nutrients: 4 times during summer; monthly sampling at Fairhaven Shipyard for DO, termperature, salinity	hard copy logs	volunteer program; program may expand with additional volunteers; sampling also in Clarkes Cove
7	UMass-Dartmouth Biology Department 255 Old Westport Road No. Dartmouth, MA 02747 J.T. Turner 508-999-8229	long-term water quality monitoring for MDMF	ammonia, nitrite-nitrate, phosphate, silicate, light transmission, dissolved oxygen	8 stations in Buzzards Bay; 3 of stations in mid-bay south of New Bedford Harbor; sampling in Inner and Outer Harbor	on-going; monthly since October 1987	no information provided; not GIS	
8	City of New Bedford Wastewater Division 294 Liberty Street New Bedford, MA 02740 Ron LaBelle 508-991-6159	compliance monitoring, WWTP	DO, pH, TSS, BOD, settable solids, fecal coliform, TKN, PO_4, NH_3, oil and grease, bioassays	City waste treatment plant	daily: DO, BOD, pH, TSS, settable solids; 3 times/day: fecal coliform; monthly: TKN, PO_4, NH_3, oil and grease; quarterly: bioassays	hard copy logs, OPSPAC software	sampling program for primary treatment plant which is releasing 22 mgd
9	Town of Fairhaven Fairhaven Treatment Plant 5 Arsene Street Fairhaven, MA 02719 Linda Simmons 508-979-4032	compliance monitoring, WWTP	DO, pH, TSS, BOD, settable solids, fecal coliform, metals, toxicity tests	Town waste treatment plant	metals - in sludge, once per year (priority metals); fecal coliform - weekly during May-Oct; toxicity tests - quarterly	hard copy logs	sampling program for secondary treatment plant which is releasing 2.5 mgd
10	Town of Dartmouth Water Pollution Division 759 Russels Mills Road So. Dartmouth, MA 02748 David Andrade 508-999-0740	compliance monitoring, WWTP	DO, pH, TSS, BOD, settable solids, TKN, fecal coliform, toxicity tests	Town waste treatment plant	daily: DO, pH, TSS, BOD, settable solids, fecal coliform; weekly: fecal coliform; quarterly: bioassays	hard copy logs	sampling program for secondary treatment plant which is releasing 1.5 mgd

TABLE 6-2

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
LIVING RESOURCES AND HABITATS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
1	MA Division of Marine Fisheries Cat Cover Marine Laboratory 92 Fort Avenue Salem, MA 01970 Tom Hoopes 508-745-3107 (x112) 508-745-3142 (fax)	fish and shellfishery statistics and data processing; GIS mapping; Federal Aid Reports	harvest in weight	Area 14 (includes all of Buzzards Bay) in state waters	Annually, based on licensed fishermens logs	GIS; area data layer with 6 classification types; and point coverages showing sampling stations	time lag in release of Federal Aid Reports due to data synthesis process
2	MA Division of Marine Fisheries Wetlands Conservancy Program One Winter Street Boston, MA 02108 Charles Costello 617-292-5907 617-556-1049 (fax)	eelgrass mapping in Buzzards Bay to identify distribution of seagrasses over time using aerial photographic interpretation and field reconnaissance - Coastal Change Analysis program (C-CAP)	presence or absence of eelgrass; using May 1996 aerial photographs followed up by ground truthing	random field sampling within suitable habitats	July 1996 followed by proposed 5-year sampling intervals	Mass GIS data layer in digital format	Qualitative field notes; will be published on the photomap (September 1996)
3	MA Natural Heritage and Endangered Species Program Division of Fish and Wildlife Route 135 Westborough, MA 01581 Brad Blodget (x152) Tom French Andrea Arnold (x154) Gretchen Eliason 508-792-7270	identify state-listed rare, threatened and endangered species sites; exemplary habitats; certify vernal pools	rare animal and plant species (siting lists)	only known site is a section of the Acushnet River floodplain directly downstream of the New Bedford Reservoir		mapped data sheets; some available on Mass GIS; mostly hard copy data sheets	
4	MA Division of Marine Fisheries 18 Route 6A Sandwich, MA 02563 Arnie Howe 508-888-1155 508-888-6842 (fax)	fishery resource stock assessment project; trawl transects	all species-aggregate weight, individual fish measured; possibly checked for age, maturity, external pathologies	Area 14 (includes all of Buzzards Bay); specific trawl surveys have been completed within 1 mile area seaward of hurricane barrier; random survey sites	Sampling is done in May and September; unlikely that each station is sampled more than once a year	Database through 1995; maintained as Oracle database at the NMFS NEFC, Woods Hole, MA	one station per survey; randomly selected stations based on depth categories: 0-30 ft; 30-60 ft, 60-90 ft; 20 minute surveys; some less but greater than 13 minutes; those less than 20 minutes are prorated

TABLE 6-2 (Cont'd.)

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
LIVING RESOURCES AND HABITATS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
5	MA Division of Marine Fisheries Cat Cove Marine Laboratory 92 Fort Avenue Salem, MA 01970 Jack Schwartz 508-745-3113 (x122) 508-745-3124 (fax)	contaminant monitoring in lobster	PCB concentrations in American lobster (edible portion); composite sample of 3 lobsters from each station	11 stations in Area III; Stations JJJ - ZZ (See Kolek and Ceurvels, 1981)	1 time each spring	r-base computer file; printed out in Word Perfect	Since 1991, samples have been measured by comparison with 18 congeners adopted by NOAA and US EPA. Prior to this, date Aroclor 1254 was standard
6	MA Division of Marine Fisheries 18 Route 6A Sandwich, MA 02563 Dave Whittaker 508-888-1155 508-888-6842 (fax)	shellfish stock assessment and shellfish harvesting water classification	standing crop analysis in special circumstances - sampling planned for 1996 (last one was 1983)	fecal coliform stations located in all growing areas; standing crop stations in Inner and Outer Harbors	fecal coliform measured monthly in Clarks Cove and New Bedford Outer Harbor; very infrequent shellfish monitoring	acreages for classification types reported on local PC and maintained on MassGIS; mapping of growing areas by town	standing crop studies have been very limited; sampling stations are randomly selected but will avoid known debris sites; 50+ stations; DMF compiles relay data from municipalities (See programs 9 and 10)
7	MA Division of Marine Fisheries Cat Cove Marine Laboratory 92 Fort Avenue Salem, MA 02563 Paul Diodati 508-745-3107 (x109) Drew Kolek 508-888-1155	recreational fisheries	anecdotal recreational fishing data	may include jetties and boat ramps along Inner and Outer New Bedford Harbors; hurricane barrier	variable		NMFS surveys are more thorough and quantitative
8	MA Division of Marine Fisheries 18 Route 6A Sandwich, MA 02563 Phil Brady 508-888-1155	anadromous fish population monitoring	incidental sampling of blueback herring and alewife; no data on population size or health	qualitative surveys of herring runs; estimates of numbers of fish observed from Acushnet saw mill and Hamlin Street in-river structures			
9	City of New Bedford Shellfish Warden Brad Borque 508-991-6289	shellfish closures and monitoring within City waters; relay (transplant) program field oversight	number of bushels in relay according to date and town			hard copy logs	MDMF collects water quality information for classification; analysis at New Bedford lab cannot be used for classification purposes

TABLE 6-2 (Cont'd.)

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
LIVING RESOURCES AND HABITATS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
10	Town of Fairhaven Board of Health Pat Fowle 508-979-4023	shellfish closures and monitoring within Town waters; relay (transplant) program field oversight	number of bushels in relay according to date and town			hard copy logs	MDMF collects fecal coliform data for Town
11	Town of Dartmouth Natural Resources Department 400 Slocum Road Dartmouth, MA 02747 John Sherman 508-999-0713	shellfish sampling and water quality monitoring for shellfish bed closures	fecal coliform, shellfish relays			hardcopy logs	MDMF has oversight of shellfish monitoring program; fecal coliform samples analyzed at Town lab
12	National Marine Fisheries Service Narragansett Laboratory Tarzell Drive Narragansett, RI 02882 Sharon MacLean 401-782-3258	histopathic studies on eel muscle and liver tissue	tissue slides; small sample of sediment PCB data for eel harvest locations				project is on-hold; may be started up again in future
13	US EPA Atlantic Ecology Division 27 Tarzell Drive Narragansett, RI 02882 William Nelson 401-782-3000	New Bedford Harbor long-term monitoring program	grab samples for macrobenthos; bioassays for harbor sediment toxicity; bioaccumulation in mussels		variable; long-term sampling frequencies to be determined by US EPA		1993 Baseline Monitoring Report will be released by US EPA in early July 1996; future monitoring will follow protocols used during 1993 sampling
14	National Marine Fisheries Service Fisheries Statistics Division 1315 East-West Highway Silver Spring, Maryland 20910 Dave Van Voorhees 301 713-2328	recreational fishery survey at national scale	catch/trip; effort resource use by coastal versus non-coastal residents; fishing pressure ratings for each geographical category	randomly selected field sites in 3 areas: ocean less than 3 miles (which includes New Bedford Harbor); ocean greater than 3 miles; and inland salt pond categories	estimates every 2 months	ASCII or SAS database; ASCII files can be uploaded to extrapolate information; site register	telephone survey-random digit dialing in coastal counties for fishing effort field survey for catch by coastal versus non-coastal county residents

TABLE 6-2 (Cont'd.)

EXISTING AND ON-GOING MONITORING PROGRAMS IN THE ACUSHNET RIVER, NEW BEDFORD HARBOR, AND BUZZARDS BAY
LIVING RESOURCES AND HABITATS

PROGRAM NUMBER	ORGANIZATION AND PRINCIPAL INVESTIGATOR	PROGRAM PURPOSE	SAMPLING PARAMETERS	SAMPLING LOCATIONS	SAMPLING FREQUENCY	DATABASE MEDIA/FORMAT	COMMENTS
15	National Marine Fisheries Service 2725 Montlake Boulevard East Seattle, WA 98112 Herb Sanborn 206 860-3341 Sue Pierce (database management) 206 860-3304	National Status and Trends Program	contaminants in fish and macrobenthos; tissue sections, liver, giles, kidney contaminant levels, bile for hydrocarbon metabolites; winter flounder, lobster, blue crab target organisms	several sampling stations in the vicinity of New Bedford wastewater treatment plant; other Buzzards Bay locations		Reflex or Filemaker database; being converted to Oracle database	Although S&T Program was ended in 1993, data are still be analyzed and may be of use in future programs
16	Lloyd Center P.O. Box 87037 South Dartmouth, MA 02748 Mark Mellow 508 990-0505	natural history data collection; public information education	primarily avian and mammal inventorying; salt marsh impacts; macroinvertebrate studies	various locations in Upper Buzzards Bay, and South Dartmouth area	variable		various studies are being completed to inventory avian and mammal use in the Upper Buzzards Bay region
17	National Audubon Society Washington, D.C. Michael Boucher 4 Paquette Drive North Dartmouth, MA 02747 508 996-3910	avian monitoring in the New Bedford Harbor area	species inventorying; sightings and calls	Inner and Outer New Bedford Harbor; Fort Phoenix State Beach and Popes Beach	one day each winter; one day each summer	hard copies; tally sheets	data has been collected since 1986; Michael Boucher with assistance from Dan Zimmerberlind (401)739-3754
18	Woods Hole Ocemographic Institution Mail Stop #2 Woods Hole, MA 02543 Judy McDowell 508-289-2557	long-term monitoring of clam population dynamics and reproduction	45 PAHs, 7 PCB congeners, 12 trace metals in hard clams and soft-shelled clams	one station in large flat near Tin Can Island within Inner Harbor; two reference sites in Little Buttermilk Basin	sporadic	PC Excel, Quatro Pro spread sheets	NOAA and Sea Grant studies previously completed to address reproductive impairment and disease due to contaminants in clam populations
19	UMass-Dartmouth Biology Department 285 Old Westport Road No. Dartmouth, MA 02747 J.T. Turner 508-999-8229	long-term plankton monitoring for MDMF	phytoplankton zooplankton, fish larvae, chlorophyll, bacteria plankton	8 stations in Buzzards Bay; 3 of stations are located in mid-bay and south of New Bedford Harbor; sampling within Inner and Outer New Bedford Harbors	monthly	various computer databases; not GIS	primary productivity has been measured for 2.5 years at 3 mid-bay stations as part of Master's thesis