Herring River Tidal Restoration Project

Conceptual Restoration Plan

Submitted to: The Towns of Wellfleet and Truro and the Cape Cod National Seashore

Prepared and Submitted by: The Herring River Technical Committee, with technical support provided by ENSR/AECOM, Inc.

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- Wellfleet Fire Department
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- Maintenance Division, CCNS
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- Natural Resources Management Division, CCNS
- National Park Service, Water Resources Division
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EXECUTIVE SUMMARY

The Herring River runs from Wellfleet Harbor northeast about four miles to Herring Pond in north Wellfleet, and northwest a similar distance to Ryder Beach in south Truro. Historically, the river was bordered by nearly 1100 acres of coastal wetlands. The estuary contained a productive river herring run and shellfishery, as well as extensive saltmarsh habitats.

In 1909, the natural condition was changed dramatically when the mouth of the river was diked at Chequesset Neck (see Photo 1). The dike was constructed with the intent of controlling mosquitoes and creating arable and developable land. Subsequent ditching and stream channelization was intended to drain the system's wetlands even further.

Photo 1: Since 1909, tidal exchange into Wellfleet's Herring River has been restricted by a dike fitted with three six-by-six foot culverts; two culverts are fitted with clapper valves to allow drainage but block the inflow of seawater; the third culvert has a partially open sluice gate that allows some seawater to flow into the river.

The cumulative effects of these modifications have been far reaching. Former saltmarshes are now disturbed freshwater wetlands or dry deciduous woodlands of comparatively low ecological value. Water quality is degraded with high acidity, low dissolved oxygen, and high fecal coliform bacteria. The first two of these have caused fish kills; the third has led to closure of shellfish beds both upstream and downstream of the dike. With poor tidal flushing and degraded water quality for predatory fish, nuisance mosquito production remains high.

Since the 1980s, understanding of this environmental degradation has grown, thanks to research efforts at the Cape Cod National Seashore (CCNS), which has management responsibility for much of the floodplain, and awareness of the citizens in the Town of Wellfleet. Full restoration of the Herring River estuary would increase the salt marsh acreage of Wellfleet Harbor by about 60%.

In August 2005, a Memorandum of Understanding (MOU) signed by the Town and CCNS created a Herring River Technical Committee (HRTC) charged with assessing the feasibility of tidal restoration. The HRTC consists of a broad spectrum of local, state and federal representatives. In January 2006, after reviewing all the science related to restoration of the Herring River, the HRTC concluded:

"…tidal restoration of the Herring River Saltmarsh is feasible and will provide numerous and substantial public benefits. As outlined in the Technical Committee's Synopsis, significant improvements in water quality would provide subsequent public health, recreational, environmental, and economic benefits. Our recommendation includes a new structure capable of full tidal restoration. The new structure should incorporate controlled gates to provide incremental increases in tidal exchange. This would allow for well thought out management, supervision, monitoring, and evaluation (HRTC 2006)*."*

This recommendation was accepted by the Wellfleet Board of Selectmen and the National Park Service. As a next step, the HRTC was charged with initiating formal planning for the restoration. This Conceptual Restoration Plan (CRP) is the first step in that planning.

Initial hydrodynamic modeling has shown that full tidal restoration of the river would require a new dike structure at Chequesset Neck. Alternatives for this structure are presented, including both gated structures and an open bridge. A preferred alternative is not included in this CRP. That selection would depend on more detailed hydrodynamic modeling, further planning, and additional public input. Provision is also made to include recreational and access opportunities as part of the restoration, for boating (canoeing & kayaking), fishing and hiking.

In the 100 years since the current dike was constructed, development has occurred on or near the coastal floodplain. This includes private residences, wells and septic systems, low-lying roads and a golf course. Floodplain restoration, allowing nearly the full tidal range into the valley, would affect some of these developments. Plans are outlined to identify and resolve all of these issues. Much of that work is already underway, including meetings with directly affected abutters. The protection of low-lying development may require additional, smaller control dikes at Mill Creek and/or on the main stream at High Toss Road and Bound Brook Island Road. (The HRTC has also recommended a control dike at Pole Dike, to initially isolate Upper Pole Dike Creek from the project pending the resolution of abutter issues there.)

The restoration will cause a major and extensive change in vegetation, with large areas presently covered by shrubs and trees reverting to saltmarsh grasses (see Photo 2). Plans are outlined to manage and monitor this process. Plans are also presented for monitoring and controlling mosquito populations. Finally, the CRP analyzes the effects of the restoration project on water quality and sediment transport in the downstream harbor, concluding that risks are low, but recommending targeted monitoring and management steps.

This restoration plan is based on the principle of "adaptive management" where, throughout the expectedly long restoration process, management actions are carefully monitored and analyzed with respect to project objectives prior to taking further action. This approach recognizes and accommodates for the inevitable uncertainties inherent in a habitat restoration project of this complexity and magnitude.

The restoration of the Herring River saltmarshes will be an expensive project, far beyond the funding capacities of the small towns of Wellfleet and Truro. State, federal and private funding will be pursued for this work. However, in-kind matching contributions from Town departments will be needed to match state and federal support.

The next step for planning the restoration is execution of a second MOU by the Towns of Wellfleet and Truro and the National Park Service signifying acceptance of this conceptual plan. If approved, that MOU would initiate detailed planning, design, and permitting. All of these steps will be subject to formal and informal public input and comment. No final plans or decisions have yet been made.

Photo 2: View of the lower basin of The Herring River just above Chequesset Neck.

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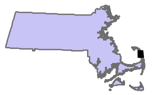
"A river should never kill its fish..." -Gordon Peabody

1 Introduction and Project Overview

For the past 40 years the scientific community has clearly documented, and society has increasingly recognized, the functions and values associated with coastal wetland systems. Estuarine communities, formed by complex mixing of tidally-driven saltwater and freshwater discharge, are among the most productive ecosystems on the earth. The subtidal waters and intertidal saltmarshes of these areas are vital for pollution control, storm surge protection, fish and shellfish habitat, waterbird use and overall near-shore productivity (Odum 1969, 1971; Nixon 1982; Teal 1986). Unfortunately, for many decades prior to this recognition many of the coastal marsh areas along the Atlantic Coast were subjected to long-term diking and drainage efforts with the intent of controlling mosquito populations and for agricultural and land development. These alterations dramatically changed the hydrologic patterns of tidally dependant wetlands. As tidal inundation and flushing were reduced natural estuarine function was impaired. In the Gulf of Maine watershed (from Cape Cod to Nova Scotia) nearly 30% of coastal wetlands have been altered by tidal restrictions. In the last decade, considerable efforts have been expended by many agencies and groups in the region toward identifying impacted coastal wetlands and implementing plans for restoring the tidal regimes and thus the natural functions of these areas (GOMC 2004).

The purpose of this Conceptual Restoration Plan (CRP) is to present a strategy for restoring ecological integrity to one of the largest impacted estuaries in New England: the Herring River located in Wellfleet and Truro, Massachusetts (Figure 1). Originally open to Wellfleet Harbor at Chequesset Neck, the inlet/mouth of the Herring River was diked in 1909, drastically restricting the frequency, range, and duration of tidal inundation. Subsequent drainage activities along the River further altered the hydrologic conditions. As the largest diked estuary within the Cape Cod National Seashore (CCNS), research performed by the National Park Service (NPS) and other cooperating institutions has been ongoing for approximately 35 years to document the effects of these hydrologic alterations and to lay the groundwork for restoration of this important ecological and cultural resource. The identified impacts from this research include the loss of productive saltmarsh habitat, water quality degradation, nuisance insect production, loss of fisheries, loss of shellfish habitat, and subsidence of the floodplain surface elevation.

At the heart of the issue is the difference in tidal range between the unrestricted Wellfleet Harbor side of the dike versus the Herring River side of the dike. On the Harbor side of the dike, the typical daily tidal range is 10 feet (from average high tides of 5 feet to low tides of -5 feet NAVD88), while on the River side this range is typically 2.0 feet (from average high tides of 0.9 feet to low tides of -1.1 feet NAVD88, NPS unpublished data, July 2007).



USGS Topographic Quadrangle
Wellfleet, MA

N

0 1,250 2,500 5,000 Feet

Site Locus

Herring River Tidal Restoration Project
Conceptual Restoration Plan
Wellfleet and Truro, MA

SCALE	DATE	PROJECT NO.
1:30000	May 2007	04479-003-300

ENSR | AECOM

Figure Number

1

J:\Water\ProjectFiles\P40\4479_CZM\4479003\GIS_May2007\Projects\Fig_Site Locus.mxd

(Note that all elevations in this document use the North American Vertical Datum of 1988 [NAVD 88]. In Wellfleet Harbor, mean low low water (MLLW) is -5.56 feet NAVD 88. See Figure 2 and the Glossary for more information on NAVD88, MLLW, and other tidal datums.)

Hydrologic modeling by NPS has indicated that reconfiguration of the Chequesset Neck Road dike and modified tidal controls could restore the tide-restricted River and its bordering saltmarsh habitat. The restoration project's fundamental concept is to implement changes that will increase important social, economic, cultural, and aesthetic values in addition to numerous environmental and ecological benefits within the 1100 acres former estuary. The NPS, representatives from various federal, state, regional, and local agencies and organizations, private land owners, and others have worked together over a number of years planning this restoration effort. In August 2005, the NPS and the Town of Wellfleet entered into a Memorandum of Understanding, which resulted in the formation of the Herring River Technical Committee (HRTC, see Section 3.1). The HRTC has reached consensus on the need for and importance of this restoration and has formulated a well-defined set of project goals consolidating research and the information necessary in order to assess project alternatives.

This Conceptual Restoration Plan is the key result of the HRTC's efforts. The CRP is intended to:

- describe existing conditions of the Herring River,
- present a history of past resource management of the Herring River,
- explain the need for restoration,
- describe, at a conceptual level, alternative measures to restore tidal exchange to the Herring River,
- discuss anticipated impacts, mitigation measures, and adaptive management objectives,
- determine subsequent steps needed, and
- document the public review process of the HRTC.

The assessment of alternatives and their potential environmental consequences are fundamental to the forthcoming environmental review processes pursuant to the Massachusetts Environmental Policy Act (MEPA) and the National Environmental Policy Act (NEPA).

The following nine elements comprise the goals of this restoration project:

- Restoration of the natural tidal range and salinity throughout the floodplain including all tributary stream basins;
- Reestablishment of the physical connection with the marine environment for exchange of nutrients, organic matter, and biota;
- Restoration of the natural sediment budget to counter wetland subsidence;
- Improvement of water quality realized by increased salinity, alkalinity, and pH, and decreased metals and coliform bacteria;
- Control of salt-intolerant plants including invasive species;
- Reestablishment of native saltmarsh plants and animals;
- Improvement of estuarine fish and shellfish habitat;
- Improvement in the natural control of mosquitoes and other nuisance insects;
- Improvements in recreational access: boating, finfishing, shellfishing, bird watching, etc.

As noted above, the primary means, or driver, of river floodplain habitat restoration will be incremental increases in the exchange of tidal floodwaters between Wellfleet Harbor and the tide-restricted estuary and river. This exchange will occur by removing, replacing, or reconstructing the tidal control structure that has existed at the mouth of the river since 1909. The intent of improved tidal exchange is to reestablish hydrology, hydrography, and salinity distribution of the system to a desired and acceptable degree for the benefit of important tidal river and estuarine processes including the support of desirable estuarine animal and plant life.

Tidal restoration will occur gradually over an extended period of time and also will entail concurrent monitoring of environmental response to assess the achievement of project goals including the assessment of stakeholder concerns. This will ensure that the restoration proceeds in a manner that minimizes any potential adverse effects. A critical factor in the restoration design process is to achieve tidal flooding up to the spring high tide elevation of 5.1 feet (NAVD88) in order to restore ecologically sustainable estuarine habitats, but limit tidal flooding in areas where low-lying properties may need flood protection. To accomplish this objective, this CRP has considered site-specific tidal control alternatives (structures) that will restrict the elevation of spring and storm tides to 5.1 feet NAVD88. Importantly, major portions of the floodplain do not include low-lying properties sensitive to tidal flooding; for these areas, spring- and storm-tide heights would not be limited by tide-control structures.

2 Project History, Purpose and Need

2.1 Historical Overview of Alterations to the Herring River System

The original Herring River estuary included about 1100 acres of saltmarsh (both high marsh and low marsh), intertidal flats, and open-water habitats. The river, its tributary streams, and the estuary into which they flow, form a prime example of a system that has suffered decades of extensive post-colonial hydrologic and consequent ecologic disturbance as a result of human activities (Portnoy & Reynolds 1997). Despite the blockage of tidal flooding in 1909, persistent nuisance mosquito problems prompted a wetland drainage program that accelerated in the 1930s. The tidal river and creeks were straightened and channelized, and the expansive bordering saltmarshes ditched in an effort to increase drainage. Dredge spoils were placed on the river's banks, further isolating the river's main channel from its floodplain. These actions were undertaken reportedly to create arable land and to control nuisance mosquitoes (Whitman & Howard 1906).

Wetland drainage made it possible to construct roads, which fragmented the river floodplain, a golf course (the Chequesset Yacht and Country Club, CYCC) and several residences on or very close to the original wetland. Several decades of observation and study were required before land managers and a significant portion of the broader public recognized the ecological damage that had occurred as a result of past actions.

2.1.1 The Chequesset Neck Road Dike

The Herring River passes under Chequesset Neck Road through an earthen dike, which was constructed in 1909 and rebuilt in 1974. The dike contains three six-foot wide openings as part of a cast-in-place reinforced concrete box culvert. Two culverts are equipped with top-hinged timber flap gates and one is equipped with a vertical lift sluice gate. The flap gates open outward to allow discharge of water to Wellfleet Harbor, while the sluice gate allows bi-directional flow (see Photo 3). The most recent formal inspection of the dike by a professional engineer to assess its physical condition occurred on November 17, 2003 (MacBroom 2003). The inspection also addressed the structure's suitability for sustaining higher flow velocities if the gates were more fully open.

Photo 3: Existing tide gates at Chequesset Neck Road

2.1.2 The modified river channel and ditched saltmarsh

The Herring River and its tidal floodplain have suffered significant human-induced alterations. To increase the rate of river water flow to Wellfleet Harbor, segments of the river were straightened. Dredge spoils removed from the river bed were deposited on the river bank in many locations. In addition, saltmarsh habitats were ditched to enhance floodplain drainage.

Channelization and straightening of the tidal river cut off many creek meanders between High Toss Road and the present Route 6, significantly reducing the length of the river. In some places, old meanders are still evident and are hydraulically connected to the river main stem by culverts that pass under the river bank spoil pile.

2.2 Low-lying Roadways

Following dike construction roadways were built within the floodplain. Roads were built across streams and adjacent to and upon wetland areas. In addition to the information presented in the following sections that briefly discusses the roads that cross the Herring River, additional and more detailed information can be reviewed in Section 6.0 of this report and in the Low-lying Roadway Analysis Report (ENSR 2007). This report discusses all low-lying roads including those that cross streams in the other basins.

2.2.1 High Toss Road

High Toss Road crosses the Herring River approximately one mile upstream of the Chequesset Neck Road dike. This road (see Photo 4), is an unpaved, infrequently traveled, single-lane road that provides access from Pole Dike Road to Griffin Island. The road is only slightly higher than the adjacent wetlands. At the western end of the road, a tidally restrictive, 60-inch diameter, 24-foot long concrete culvert conveys the Herring River beneath the road.

Photo 4: High Toss Road

2.2.2 Bound Brook Island Road

Photo 5: Bound Brook Island Road crossing the Herring River

Bound Brook Island Road crosses the Herring River where the river changes from a north-south orientation to an east-west orientation. Much of this frequently traveled road between its intersections with Pole Dike Road and Old County Road is low-lying. A 60-inch concrete culvert (see Photo 5) conveys the Herring River beneath Bound Brook Island Road.

2.2.3 Pole Dike Road

This frequently traveled link between West Main Street and Bound Brook Island Road crosses Pole Dike Creek - a three foot diameter culvert. This culvert likely would restrict restored tidal flow; however, the decision on whether to include the Upper Pole Dike wetland in the tidal restoration project has been deferred pending more data on abutting private properties.

2.3 Private Residences

A few residences have been developed on lands at elevations below the historic river floodplain elevation in the decades following dike construction. Building on low-lying lands was possible as a consequence of tidal restriction and other river floodplain drainage efforts. Evaluations have been conducted on the two such private properties that contain structures below the elevation of the spring high tide elevation (5.1 feet NAVD 88), documenting the existing conditions and considering alternatives that could be implemented to address these conditions under the restored tidal regimes (ENSR 2005 and ENSR 2007).

2.4 Chequesset Yacht and Country Club

The Chequesset Yacht and Country Club (CYCC) is a semi-private, nine-hole golf course constructed between 1929 and 1933. Since that period, CYCC has filled small areas of lowland on their property in order to extend the length of certain fairways and accommodate additional tee box areas; however, the course has remained in its original configuration since construction.

Photo 6: Low-lying portion of CYCC

The property currently occupies approximately 106 acres of land that abut a portion of the Wellfleet Harbor shoreline to the south, CCNS lands to the west and northwest, and private properties to the east and northeast. Land elevations on the property range from below mean sea level and approximately 60 feet. Despite a relatively large amount of upland habitat on the property, much of the golf course (portions of five of the nine fairways) was constructed at low elevations in the river floodplain adjacent to Mill Creek (see Photo 6). Despite diking of the floodplain, these lands have remained subject to saturated soil conditions, shallow inundation, and occasionally surface-water flooding due to heavy precipitation, seasonally high groundwater elevations, high-tide events in Herring River, and the presence of fine-textured soils (i.e. decomposed salt-marsh peat and marine clay). The CYCC contains both terrestrial and palustrine habitats including freshwater-dominant wetland areas, a portion of Mill Creek, man-made channels and impoundments, a very small saltmarsh area, and pitch pine–oak forest. A plan and environmental evaluation for course reconfiguration has been prepared on behalf of the CYCC that discuss existing site conditions and the planned project, which is linked to the Herring River restoration project (Horsley Witten Group and Howard Mauer Design 2006).

2.5 Dike Deterioration and Subsequent Management Decisions

By the 1960s, structural deterioration caused some of the tidegates to rust in an open position. As a result, tidal range and salinity in the Herring River increased (Moody 1974) and shellfish began to recolonize above the dike (Snow 1975). However increased tidal range in the river also caused periodic flooding of the CYCC and other properties during storm tides.

As the Town considered dike repairs, estuary and saltmarsh restoration advocates, including the then recently formed Association for the Preservation of Cape Cod (APCC), appealed to the Town to replace the dike with a bridge to promote estuary restoration (Portnoy 2007). Nevertheless, in 1971 the Town of Wellfleet voted to allocate $37,500 towards repair of the damaged dike. In 1973, the Conservation Commission issued an Order of Conditions approving the project, but included a condition requiring that the structure allow tidal water levels matching those seen prior to dike repair in order to achieve saltmarsh restoration. They further required that the new dike accommodate anadromous fish passage. Amid controversy, the State rebuilt the dike in 1974 (see Photo 7).

Photo 7: Dike reconstruction in 1974

Following dike reconstruction, APCC-sponsored observers began collecting data and reporting on water levels and salinity (Moody 1974) and plant community composition (Snow 1975) in areas upstream of the dike. Tide height monitoring showed that the new dike's gate opening was too small to achieve the tide heights prescribed in the Order of Conditions. Local fishermen complained that siltation had increased and shellfish had declined since the new dike was built (Tangvik 1979). As a result, the APCC objected to the Massachusetts Department of Public Works for not allowing sufficient flow through the dike. However, the sluice gate openings remained at six inches (i.e. a six-inch high opening in the gates). In 1977, the State Attorney General ordered the Town of Wellfleet to transfer control of the dike to the Department of Natural Resources (now the Department of Environmental Protection, DEP) so that increased tidal flow could be attained in the interest of restoration (Portnoy 2007).

In 1980, a large die-off of American eels (*Anguilla rostrata*) focused attention on the poor water quality conditions in the Herring River. The Division of Marine Fisheries and the

National Park Service identified the cause of the eel kill to be high acidity and aluminum toxicity in turn caused by diking and marsh drainage. These water-quality problems would eventually (October 2003) cause DEP to list Herring River as "impaired" under the federal Clean Water Act Section 303(d), for low pH and high metal concentrations.

Within a year of the eel kill the Park Service determined that the sluice gate opening did not provide the tide heights mandated in the 1973 Order of Conditions (Portnoy 1980, 1982). The dike's sluice gate was opened slightly to a 6.5-inch high opening to allow some additional tidal flow.

Under continuing pressure from the Department of Environmental Quality Engineering (now the Department of Environmental Protection) the Town increased the sluice gate opening to 20 inches in 1983. That same year, the NPS documented summertime oxygen depletions and river herring kills for the first time and subsequently took steps to protect river herring and avert kills by blocking their emigration from upstream ponds in order to prevent the fish from entering anoxic waters (Portnoy et al. 1987).

Despite these poor habitat conditions, concerns about increased mosquito production, among other issues, prevented a larger sluice gate opening. However, mosquito breeding research conducted from 1981 to 1984 by the NPS documented that the principal nuisance mosquitoes emerging from the diked river floodplain were freshwater and brackish species, not those from saltmarsh habitats (Portnoy 1984). In 1984 the sluice gate opening was increased to 24 inches and has remained at this setting since then.

In 1985, the State classified the river as "prohibited" due to bacterial contamination. Work by NPS researchers would eventually show the bacterial contamination to be another symptom of restricted tidal flow and reduced salinity (Portnoy & Allen 2006).

A series of studies through the late 1980s and early 1990s assessed the effects of tidal restoration in the Herring River on both natural resources and private and public infrastructure. In 1987, Rutgers University completed an evaluation of hydrologic alternatives for tidal restoration and predicted that beneficial ecological effects would result (Roman 1987). In 1990, a water budget study of the Mill Creek tributary described options for controlling flooding on the CYCC golf course (Nuttle 1990). In 1991, a US Geological Survey study determined that tidal restoration would not threaten private groundwater wells located near the river (Fitterman & Dennehy 1991).

In 2001, the NPS and the University of Rhode Island completed and presented hydrodynamic and salinity modeling to assess effects of dike opening or dike removal on tide heights, salinity, and sediment movement both seaward of the structure and on the entire floodplain above the dike (Spaulding and Grilli 2001). Additional modeling to evaluate a much wider dike opening was undertaken in 2005 (Spaulding and Grilli 2005). The NPS completed additional studies in 2003 addressing the potential for saltwater intrusion of wells (Masterson 2004, Martin 2004) and sediment re-suspension near shellfish beds (Dougherty 2004) under modeled restoration alternatives. Also in 2001, the Wellfleet Conservation Commission voted to support estuarine restoration within the Herring River floodplain and formally requested assistance and funding to promote restoration from Massachusetts Coastal Zone Management's Wetland Restoration Program (WRP).

Numerous other local, state, and federal agencies and groups began more formal involvement and support for the project: among these were the NOAA Habitat Restoration Center, US Fish and Wildlife Service, Natural Resources Conservation Service, and The Nature Conservancy. More formal discussions and planning to address the reconfiguration of the golf course and associated funding needs began with the CYCC in 2004 and have been ongoing. In 2005 the Wellfleet Town Meeting approved $1.2 million of Land Bank funds for acquisition and open space protection of the low-lying portion of the CYCC lands. In 2005 the NPS and Town of Wellfleet completed a Memorandum of Understanding (MOU, see Appendix A) agreeing to work together on the project, and establishing the HRTC and Stakeholder Group to advance the project. The U.S. Senate Appropriations Committee secured $500,000 from the NOAA Coastal and Estuarine Land Conservation Program for the CYCC land acquisition shortly after the MOU was signed.

Over the past several years there has been growing momentum, supported by scientific and engineering studies, to bring this river restoration project to a reality.

2.6 Project Purpose and Need

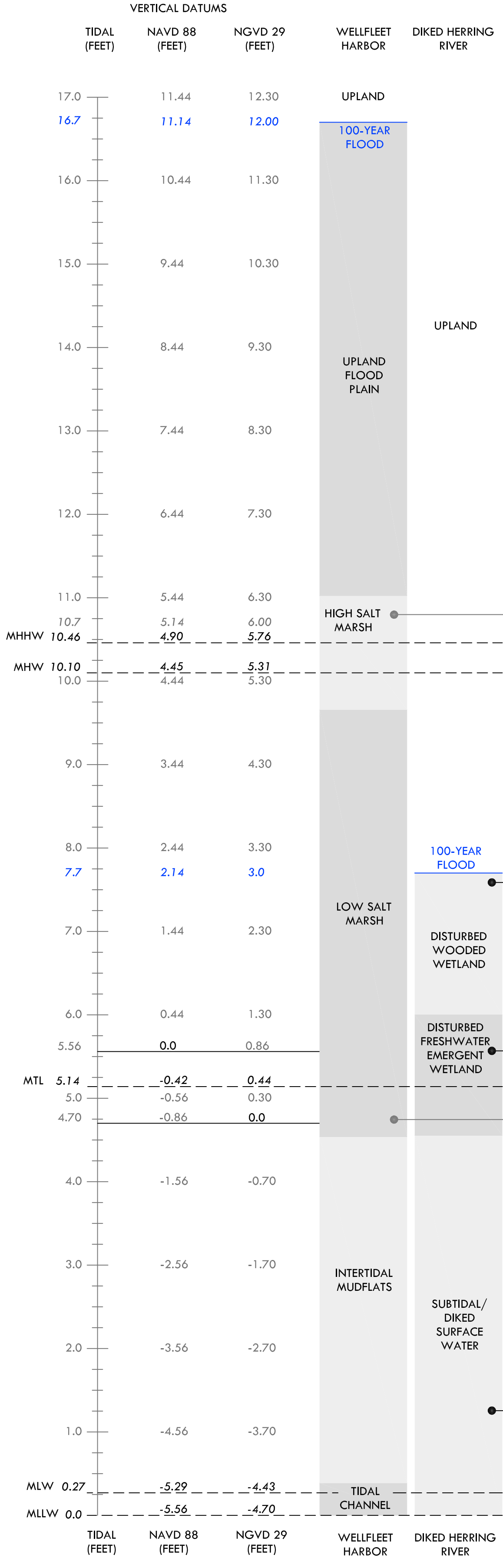
As described in the previous section, and further supported by the information presented in Section 4.0 describing the existing environmental conditions, the ecological characteristics of the Herring River basin have suffered dramatically from tidal restriction, saltmarsh drainage efforts, and infrastructure development in the river floodplain. The restoration of the Herring River was proposed by APCC, NPS, and others more than 30 years ago. Currently, natural resource protection agencies, conservation organizations, municipal agencies, and the public understand the important need for coastal resource restoration and now broadly support this concept for the Herring River. The following sections present the case for tidal restoration of the river system.

2.6.1 Estuarine Restoration: Understanding the Baseline Condition

Ecological restoration has been an increasing focus of the scientific and regulatory communities for the past several decades, as recognition has grown of impacted natural ecosystems and the inability to mitigate for the impacts by creation of "replacement" systems. Broadly, ecological restoration is defined as the process of reestablishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function (NOAA). More specifically to the Herring River project, wetlands restoration is "*the act, process, or result of returning a degraded wetland or a former wetland to a close approximation of its condition prior to disturbance*" (WRP). Fundamental to understanding the existing degraded conditions, and for planning estuarine restoration, is a clear understanding of the tidal regime and dependent ecosystem of Wellfleet Harbor.

Land surface elevation with respect to tidal levels is the primary factor determining conditions within an estuary. For consistency and to follow current standards, all elevations within this CRP are expressed using the most current geodetic datum, the North American Vertical Datum of 1988 (NAVD88). Figure 2 (following page) provides a reference to compare geodetic datums to tidal datums. Tidal datums, such as Mean Lower Low Water (MLLW), popularly used on NOAA charts and tide tables, vary from location to location. NAVD88 is constant throughout North America and is typically used by engineers and land surveyors. Tidal datums are based on local tidal benchmarks that are operated by the National Ocean Service (NOS). The tidal datums shown in Figure 2 are based the closet NOS tidal benchmark in Cape Cod Bay, at Sesuit Harbor, East Dennis, and may vary slightly at Wellfleet Harbor. See the Glossary for more thorough definitions of tidal and geodetic datums.

The significance of tidal inundation to saltmarsh ecology is well documented (Nixon 1982, Teal 1986). Regularly flooded saltmarshes, or low saltmarshes, are flooded during all high tides and occur at elevations from about mean tide level to mean high water. These marshes are dominated by smooth cordgrass (*Spartina alterniflora*). High saltmarshes are only flooded during semi-monthly spring tide cycles and are generally situated between mean high water and the highest reach of the tide. High marshes are dominated by salt meadow grass (*Spartina patens*) along with two commonly associated species – spike grass (*Distichlis spicata*) and black grass (*Juncus gerardii*). Figure 2 also compares tidal flooding levels in Wellfleet Harbor below the dike to the Herring River above the dike. From these basic guidelines come the initial criteria for establishing tidal flooding above the dike to just above the mean high water level to promote the restoration of both low and high saltmarshes in areas that historically supported them. In practice, the system will function in a much more complex fashion due to a variety of factors. For example, tidal levels will vary due to winds, currents, and micro-topography. Freshwater dilution and mixing with saltwater will cause salinity to vary in different sub-basins. Previous saltmarsh surfaces have subsided, likely to different degrees, and may also recover elevation, through sediment accumulation, at different rates. Accordingly, in addition to more refined modeling to predict the response of the system under different tidal control options, the CRP includes an iterative and adaptive approach to manage incremental restoration in response to observed and measured conditions.



Definitions:
MHHW - Mean Higher High Water
MHW - Mean High Water
MTL- Mean Tide Level
MLW - Mean Low Water
MLLW - Mean Lower Low Water

Notes:

1. Add 0.86 feet to NAVD 88 elevations to obtain NGVD 29 elevations.

2. The relationships between the geodetic datums and the tidal datum are estimated using the tidal station at Sesuit Harbor, East Dennis, the closest station to the project site. The actual tidal datum may differ slightly.

Figure 2. Relationships between Datums and Conditions in Wellfleet Harbor and the Herring River under Existing Conditions

2.6.2 Summary of Adverse Ecological Effects from Tidal Restriction, Marsh Drainage, and Floodplain Alterations

Ecologists have developed a clear understanding of the adverse ecological effects that tidal flow restrictions have on estuarine habitats and tidal rivers like the Herring River (Breemen 1982, Portnoy 1999, Roman et al. 1984, Sinicrope et al. 1990, Steever et al. 1976, Thom 1992, Zedler 1988). For the Herring River system, adverse ecological effects resulting from dike emplacement, saltmarsh ditch-draining, stream culvert installation, and road construction, include:

Tidal Range Restriction – Lack of Tidal Inflow and Outflow

The tidal range restriction of the current dike – from a harbor side range of more than ten feet to less than two feet above the dike – causes myriad environmental problems for the estuarine habitats.

Plant Community Changes - Saltmarsh Habitat Reduction and Invasive Species

The reduction of salt water input onto the river floodplain and intensified marsh drainage efforts (ditch-draining) had a gradual, but dramatic, impact upon the species composition of the naturally occurring saltmarsh plant communities by removing salt and dewatering soils. The reduction in salinity denies saltmarsh plants, such as *Spartina alterniflora, S. patens*, and *Juncus gerardii* among others, their competitive edge over herbaceous freshwater wetland species, such as cattail (*Typha* spp*)*. Cattail-dominant plant communities gradually replaced characteristic saltmarsh vegetation. Aerial photographs taken in 1938 show the river floodplain apparently dominated by cattails. By the 1960s, the intensified drainage for mosquito control further dewatered the soils and allowed upland grasses, forbs, and even trees to replace the cattails (Portnoy & Soukup 1982). For example, black cherry (*Prunus serotina*) and pitch pine (*Pinus rigida*) are now dominant in areas that were once naturally occurring saltmarsh habitats. Drainage made it possible for upland plants to invade the floodplain and shade out wetland species adapted to the previously saturated soils. By the 1970s much of the original Herring River wetlands had been converted from saltmarsh to upland forest and shrublands (Portnoy and Soukup 1982). Meanwhile, original subtidal and intertidal substrates between the dike and High Toss Road have converted to a large monotypic stand of common reed (*Phragmites australis*).

Elimination of Salt Water Inputs and Water Quality Degradation

Elimination of salt water input to the estuary and marsh dewatering together resulted in a dramatic degradation of the estuarine water quality with severe ecological consequences. Saltmarsh diking and drainage allows air to enter the normally anaerobic subsurface environment of the saltmarsh, converting it to an aerobic environment where both organic material and iron-sulfur minerals can be readily oxidized. In saltmarsh peat, a product of iron-sulfur mineral oxidation is sulfuric acid, which lowers pH when reaching surface waters. Low pH can cause fish kills and, in 1980, thousands of adult American eels (*Anguilla rostrata*) were killed as a result of a large pulse of acidic water released into the

Herring River main channel following a period of heavy rainfall. Main stream pH was highly acidic (pH 4), while ditches were ten times more acidic (Soukup & Portnoy 1986). These ditches contained water so acidic that predatory fish that normally prey upon floodwater mosquito larvae were chemically blocked from major mosquito breeding sites (Portnoy 1984). Low pH causes leaching of toxic metals, particularly aluminum and ferrous iron, further degrading water quality.

The elimination of tidal flushing in the Herring River wetland system that still contained abundant organic matter, caused regular summertime dissolved oxygen depletions and fish kills in the river main stem (Portnoy 1991). Conditions were worst in mid-summer, when oxygen demand was highest, and compelled NPS to begin controlling the emigration of juvenile herring (*Alosa* spp.) to avert complete mortality and loss of the anadromous run (Portnoy et al. 1987).

Sedimentation Cessation and Land Subsidence

Measurements indicate that, relative to sea level, much of the diked Herring River floodplain is approximately three feet below its prior, pre-dike elevation and the surfaces of existing saltmarsh seaward of the dike (Portnoy & Giblin 1997a). Tidal restrictions radically affect the important process of sedimentation on the saltmarsh. Coastal marshes must increase in elevation at a pace equal to or greater than the rate of sea-level rise in order to persist. This increase in elevation (accretion) is dependent on several processes, including transport of inorganic sediment into an estuary and its deposition onto the marsh surface during flood tides. This sediment transport must occur to promote the growth of *Spartina* grasses and to gradually increase the elevation of the marsh surface. However, the 1909 diking has effectively blocked inorganic sediment from reaching the saltmarshes within the Herring River basin. Additionally, marsh drainage has increased the rate of organic peat decomposition by aerating the sediment and also had caused sediment pore spaces to collapse. All of these processes have contributed to severe historic and continuing subsidence in Herring River's diked wetlands.

Nuisance Insect Production

Construction of the dike and salt-marsh drainage were management measures meant to reduce populations of nuisance insects, primarily mosquitoes. The principal nuisance mosquitoes that currently emerge from the diked river floodplain are freshwater and brackish species, not those from saltmarsh habitats (CCMCP unpublished data, Portnoy 1984). Reduced tidal range, marsh drainage, and degraded water quality also has made it impossible for predatory fish to reach the surface of the marsh to feed upon mosquito larvae.

Impeding Herring Migration

An estuary is by definition open to the ocean, allowing river herring and other anadromous fish to use estuaries as staging areas as part of their seasonal migrations to and from breeding habitats. An unrestricted estuary features a gradual transition in salinity from seawater to freshwater, providing migratory species (anadromous herring and catadromous American eels) a salinity gradient in which to adapt physiologically. The dike physically impedes migratory fish passage (P. Brady, personal communication) and creates an artificially abrupt transition from seawater to fresh river water. As described above, the tidal restriction also upsets wetland biogeochemical cycling which in turn severely degrades the chemical quality of aquatic habitat.

2.7 Summary of Purpose and Need

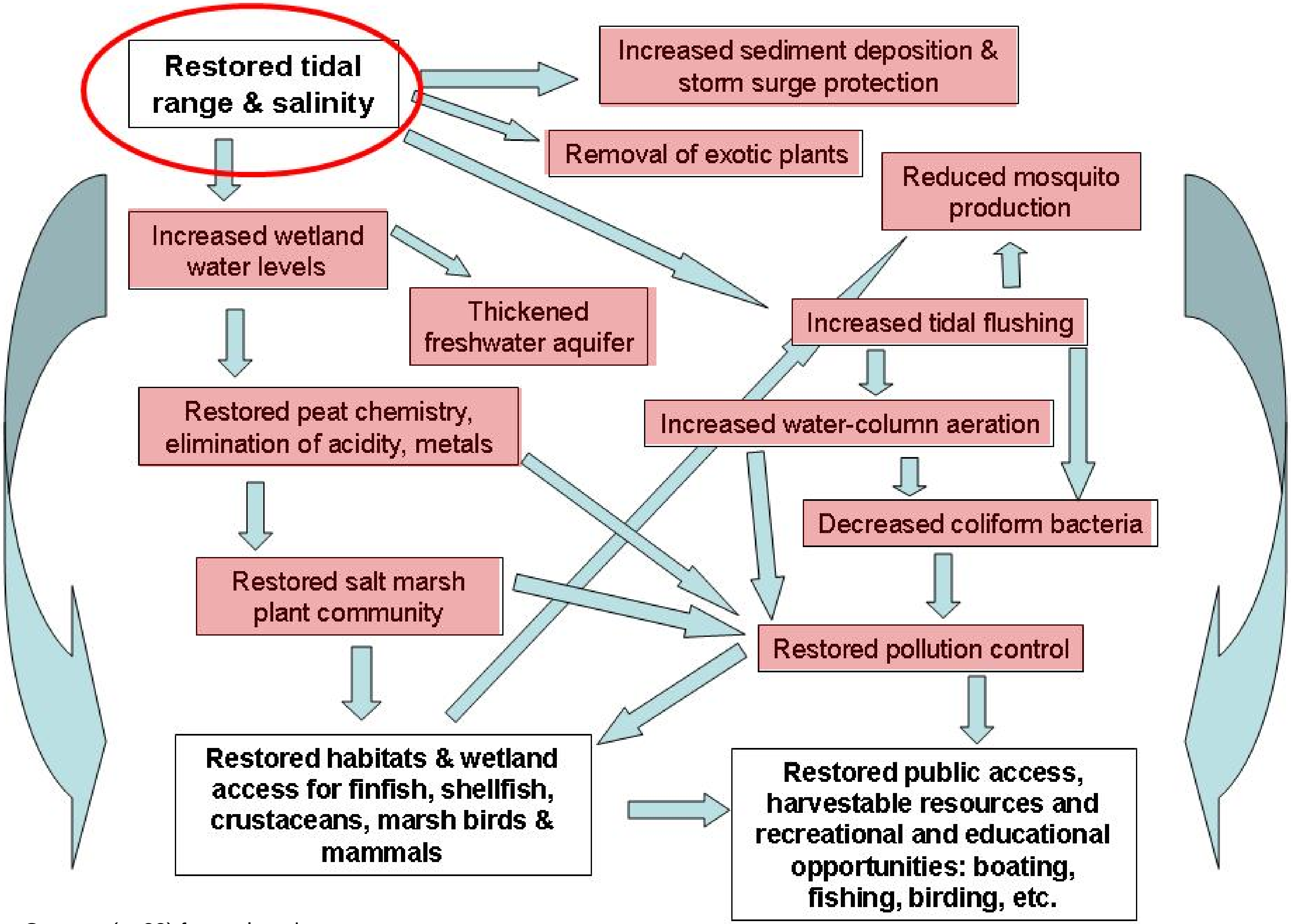
As described above, there are numerous elements of the Herring River system that have been impacted by long-standing tidal restrictions. The basic purpose and need of the Herring River Restoration Project is to implement changes in the current tidal controls to restore natural estuarine habitats and their functions to the maximum extent practicable. Expected changes in the system resulting from restored tidal regime are diverse but interdependent. They are summarized in Figure 3 and further described in the text that follows (from Portnoy 2004).

Restored tidal range leads to higher sediment transport and deposition onto the wetland surface, as sediment-carrying flood tides again flood over creek banks and onto the marsh platform. This surface has subsided over the past 100 years of diking; therefore, restored sedimentation can allow the wetland surface to rise, thereby increasing storm-surge protection for roads and other structures at the edge of the floodplain.

Restored tidal range, i.e. higher high tides, lower low tides and, thus, increased intertidal volume, greatly increases tidal flushing. Better flushing will reduce floodwater mosquito breeding on the wetland surface, dilute the presently high fecal coliform counts that have closed river-mouth shellfish beds, and improve water-column aeration by flooding the wetland twice each day with oxygen-rich Cape Cod Bay water.

Tidal restoration would also result in higher average water levels in the estuary's wetlands, with associated additional benefits. For example, groundwater modeling predicts that the freshwater lens, the source of drinking water for all properties surrounding the floodplain, will thicken with a higher mean water level in the estuary. Within the wetland proper, higher water levels will resaturate wetland soils that have been drained by diking and ditch drainage since 1909, and reverse the chemistry that has caused high acidity, mobilized toxic metals and triggered fish kills in receiving waters. Despite higher high tides and an increased mean water level, low tides will actually be lower with tidal restoration, improving low-tide drainage and reducing mosquito breeding sites on the wetland surface. Improved water quality also would reduce mosquito production by enhancing aquatic habitat quality for the mosquito's major predatory fish species, including mummichogs (*Fundulus heteroclitus*) and sticklebacks (*Gasterosteus* spp).

Figure 3. Ecological and Social Benefits of Herring River Tidal Restoration



See text (p. 22) for explanation.

Restored salinity will stress many of the salt-sensitive non-native plants that have invaded the floodplain and enable recolonization of native saltmarsh plants. Higher salinity also would reduce the survival time of coliform bacteria, adding to the dilution effect of increased tidal flushing to further depress fecal coliform counts in shellfish beds.

The reestablishment of tidal range, salinity, overall water quality, and the salt-marsh plant community, will restore hundreds of acres of wetland habitats and access to those habitats by finfish, shellfish, marsh birds and mammals. For people, this means better boat access throughout the Herring River estuary, on higher tides across an open marsh instead of the presently drained shrub thicket, with fewer mosquitoes. More importantly, it also means more extensive, abundant and diverse marine resources for observation, education and harvest both within the estuary and in nearby coastal waters.

3 Project Planning, Partners, and Process

As referenced in the historical discussion in the previous section, there have been many local, state, and federal partners and non-governmental organizations involved in the efforts to restore the Herring River. The process has encompassed many years of scientific and engineering investigations, but also has included a systematic public review process to ensure that all concerns and interests are recognized and considered. This section is intended to summarize the process that has transpired and to recognize the primary partners that have been involved in the planning process.

Since the Town of Wellfleet owns the Chequesset Neck Road dike, and the Cape Cod National Seashore manages roughly 80% of the Herring River floodplain, these two parties have logically been at the forefront of planning for the restoration of the Herring River. In August 2005 these two parties formally agreed to work together to restore the River by signing a Memorandum of Understanding (MOU) that established a “process and framework that will determine whether a restoration of the Herring River is feasible and subsequently develop a conceptual plan of the restoration goals and objectives to meet stakeholder needs should restoration be deemed appropriate.” Prior to signing the MOU, in January 2005, the Town of Wellfleet Board of Selectmen agreed “in principle to the fact that restoring the Herring River saltmarsh will be beneficial to the public interests and the environment and is a project worth proceeding with, with the caveat that a memorandum of understanding is signed between the NPS and the Town of Wellfleet and the development of a comprehensive restoration plan and filing for permits to proceed.” (see MOU in Appendix A).

3.1 The Herring River Technical Committee

The MOU specified the formation of a technical committee and a stakeholder group, and provided criteria for the composition of both groups and their intended functions. The Herring River Technical Committee (HRTC) was designated to consist of a representative from the NPS, one from the MACZM-WRP, and other individuals selected by the Town. In its operational form the HRTC has included the following representatives from local commissions and boards/agencies:

Sworn-In Voting Members:

Gordon Peabody	Chair, Member-at-large
Hillary Greenberg	Wellfleet Conservation and Public Health Agent
John Portnoy	Cape Cod National Seashore
Tim Smith	MA CZM Wetland Restoration Program

Robert Hubby	Wellfleet Open Space Committee
Joel Fox	Wellfleet Shellfish Advisory Committee
Andy Koch	Wellfleet Shellfish Constable
Carl Breivogel	Wellfleet Herring Warden
John Riehl	Wellfleet Natural Resource Advisory Committee
Jack Whalen	Chequesset Yacht & Country Club
Gary Palmer	Selectman, Town of Truro
Eric Derleth	US Fish & Wildlife Service
Stephen Spear	Natural Resources Conservation Service
Diane Murphy	Cape Cod Cooperative Extension Service
Steve Block	NOAA Restoration Center
Advisory Members:	
George Heufelder	Barnstable County Health Department
Peter Watts	Herring River Stakeholders Group Chair
Gabrielle Sakolsky	Cape Cod Mosquito Control Project

The HRTC was directed to review and summarize the scientific and technical information on the Herring River system, receive and consider input related to community concerns, develop and submit recommendations to the Board of Selectmen on the feasibility of restoration of the system, and develop a conceptual restoration plan should it be deemed appropriate. Within the HRTC, a variety of subcommittees were formed to address specific areas of concern associated with the restoration process, and each subcommittee produced reports summarizing the issues.

In January 2006, the HRTC produced a "Full Report of the HRTC" (Appendix C) which summarized their findings and recommended that:

"tidal restoration of the Herring River Saltmarsh is feasible and will provide numerous and substantial public benefits. As outlined in the Technical Committee's Synopsis, significant improvements in water quality would provide subsequent public health, recreational, environmental, and economic benefits. Our recommendation includes a new structure capable of full tidal restoration. The new structure should incorporate controlled gates to provide incremental increases

in tidal exchange. This would allow for well thought out management, supervision, monitoring, and evaluation."

As directed by the MOU, that finding by the HRTC has lead to this CRP. Acceptance of this CRP will initiate the formal process of developing a specific, detailed restoration plan.

The Herring River Stakeholder Group was designated to also include representatives from the Town and the CCNS, as well as landowners potentially affected by a restoration, the shellfish/fishing community, Cape Cod Mosquito Control, Division of Marine Fisheries, NRCS, and NOAA. The stakeholder group has been charged with communicating to the HRTC their interests and concerns, ensuring that public and private concerns are understood and incorporated in the development of recommendations and continuing to provide community input into the development of the restoration plan.

Moving forward, the restoration effort remains focused on both technical and public review components. A second MOU is under development between the NPS/CCNS and the Towns of Wellfleet and Truro. This second MOU is intended to move the CRP into a more detailed stage and envisions the creation of a Herring River Restoration Committee to advance that objective. From a more technical perspective, MA CZM's Wetlands Restoration Program has completed topographic mapping of the Herring River floodplain. This mapping is critical for more detailed evaluation of tidal control options through hydrodynamic modeling, currently under way. Both the state (MEPA) and federal (NEPA) environmental impact review process will be undertaken simultaneously, leading to the selection of a preferred alternative and a detailed restoration plan and permitting.

3.2 Project Funding Needs and Sources

Funding sources for the Herring River restoration project have been actively sought and developed for several years. Funding is not anticipated at the local level, but rather from a variety of state, federal, and private funding sources. Indeed, funding for work completed to date has been from such varied sources. Specific tasks that have been conducted and/or those anticipated to need funding include:

- Topographic survey and mapping
- Hydrologic modeling and other technical analyses
- Engineering and design plans and specifications
- CYCC land acquisition, reconfiguration plans, and construction
- Assessment of impacts and mitigation to private landholdings
- Environmental Impact Statements/Reports and environmental permitting
- Construction modifications at Chequesset Neck Road, other potential tidal control

locations, and other low-lying roadways

Among the funding sources that have already contributed to the efforts and those considered viable for future needs include:

- NOAA Coastal and Estuarine Land Conservation Program (CELCP)
- MACZM-WRP
- Coastal America Foundation
- Wellfleet Land Bank
- USFWS Coastal Wetland Conservation Grants
- USFWS North American Wetland Conservation Grants
- National Park Service
- Corporate Wetlands Restoration Partnership
- USDA Natural Resources Conservation Service
- The Nature Conservancy
- American Rivers
- Ducks Unlimited
- Conservation Law Foundation
- Gulf of Maine Council on the Marine Environment
- NOAA Restoration Center, direct funding and partnership grants

4 Existing Environment

The following sections provide a description of the types and general conditions of natural and man-made features currently present in the Herring River system.

4.1 The Herring River

The Herring River, its floodplain, its tributary streams, and the estuarine habitats into which the river and streams flow, is the largest tidal river and estuary complex on the outer Cape. Most of the river floodplain is within the jurisdictional boundaries of the Cape Cod National Seashore (CCNS). The river itself extends from Wellfleet Harbor northeast for nearly four miles to Herring Pond near Newcomb Hollow Beach (Figure 1). The river system, approximately defined by the landward limit of the river's floodplain and including adjacent wetland habitats and those of tributary streams, encompasses approximately 1,100 acres. The Herring River is a prime example of a tidal river system that has suffered decades of extensive hydrologic and subsequent ecologic disturbance as a result of human activities.

The Herring River passes under Chequesset Neck Road through an earthen dike, which was constructed in 1909 and rebuilt in 1974. The dike contains three six-foot wide openings as part of a cast-in-place reinforced concrete box culvert. Two culverts are equipped with large, top-hinged timber flap gates and one is equipped with a vertical lift sluice gate. The flap gates open outward to allow discharge of water to Wellfleet Harbor, while the sluice gate allows bi-directional flow.

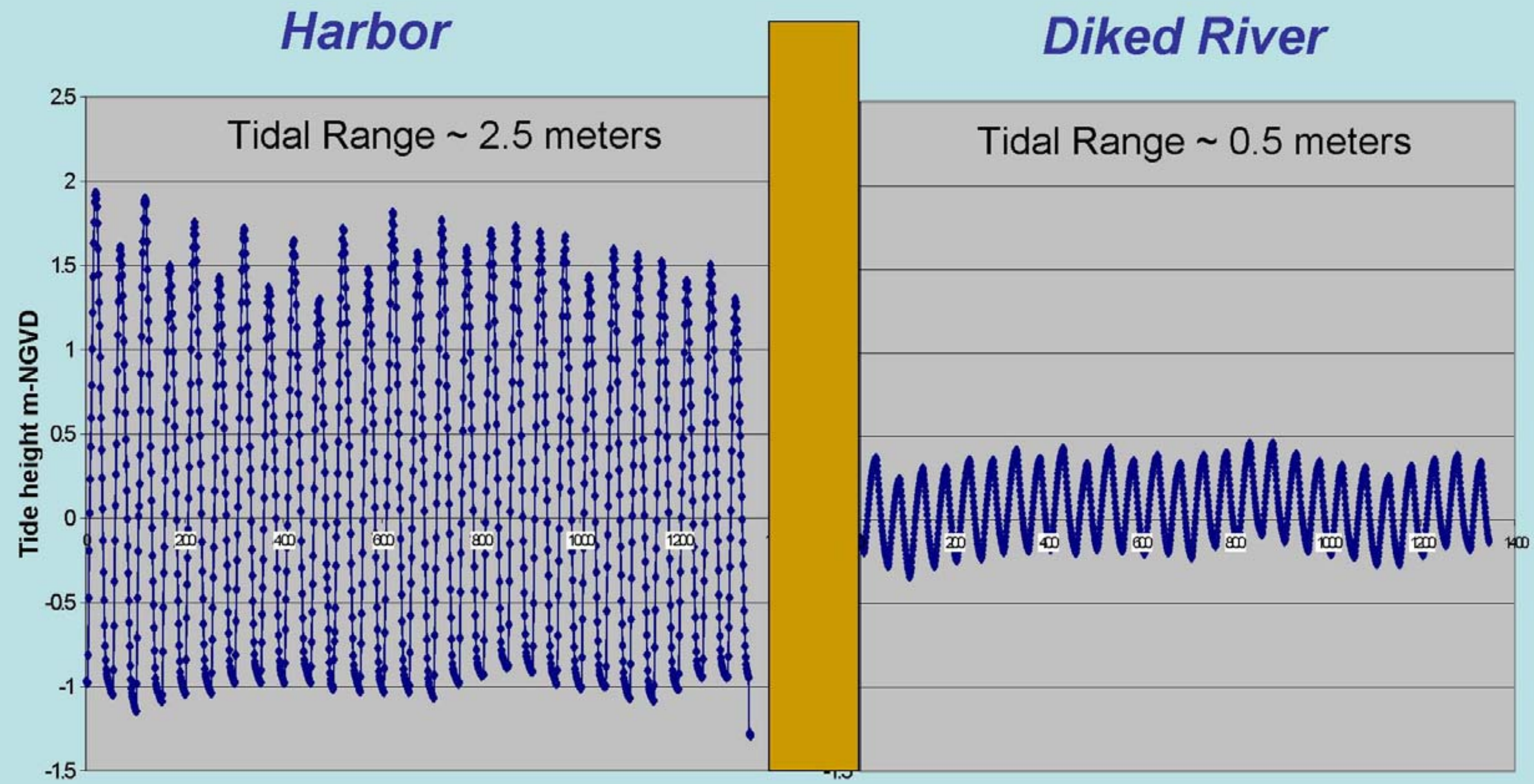
4.1.1 High tide heights and ranges

The presence of the dike has dramatically reduced the height of high tides in the river basin and has greatly impeded drainage from the basin during low tides. While the normal tidal range in Wellfleet Harbor just seaward of the dike is –5 to +5 feet NAVD88, the normal tidal range in the Herring River above the dike is only –1.1 to +0.9 feet (Figure 4). As a result, seawater reaches only approximately 3000 feet north of the dike. Under the original natural conditions seawater would reach well upstream to points located beyond Old County Road and would support most estuarine plants and animals.

4.1.2 Physical modifications to the river channel

The river has suffered the emplacement of tidal restrictions and river channel modifications. Segments of the river were straightened and channelized in efforts to increase the rate at which the river water flowed toward the ocean during ebb tides. The spoils that were generated along these segments from channelizing were deposited on the riverbank, creating a barrier to water flow between the river and its adjacent floodplain. In addition, saltmarshes were ditched in a widespread and often misapplied and unsuccessful effort to control mosquitoes by increasing floodplain drainage.

Figure 4. Hydrographs of Existing Tidal Range in the Herring River and Wellfleet Harbor



Tides above and below the present Herring River dike. The dike both reduces high-tide height and impedes low-tide drainage, thereby reducing tidal range in the river. Salt marsh productivity is directly related to tidal range. Large differences in water levels above and below the dike cause very rapid flows and impede fish passage.

4.2 Tributary Stream Basins

In addition to the Herring River's upper and lower basins, the restoration project area is composed of important stream sub-basins including: Duck Harbor, Mill Creek, Bound Brook, and both Lower and Upper Pole Dike Creek (Figure 5).

Each basin is distinct physically, and thus chemically and biologically, because of its elevation and hydrologic relationship to the Herring River and Wellfleet Harbor. Therefore, tidal restoration will influence each basin to different degrees due to a basin's land-surface elevation and distance from the harbor. Distance alone will affect both tide heights and salinity distribution (Spaulding & Grilli 2001, 2005).

In addition, each basin has a different land-management history and has therefore undergone a unique set of habitat impacts such as habitat fragmentation from road construction and residential development. It follows that tidal restoration will affect each basin differently and to a different degree. A summary description of each basin, mapped on Figure 5, is provided below.

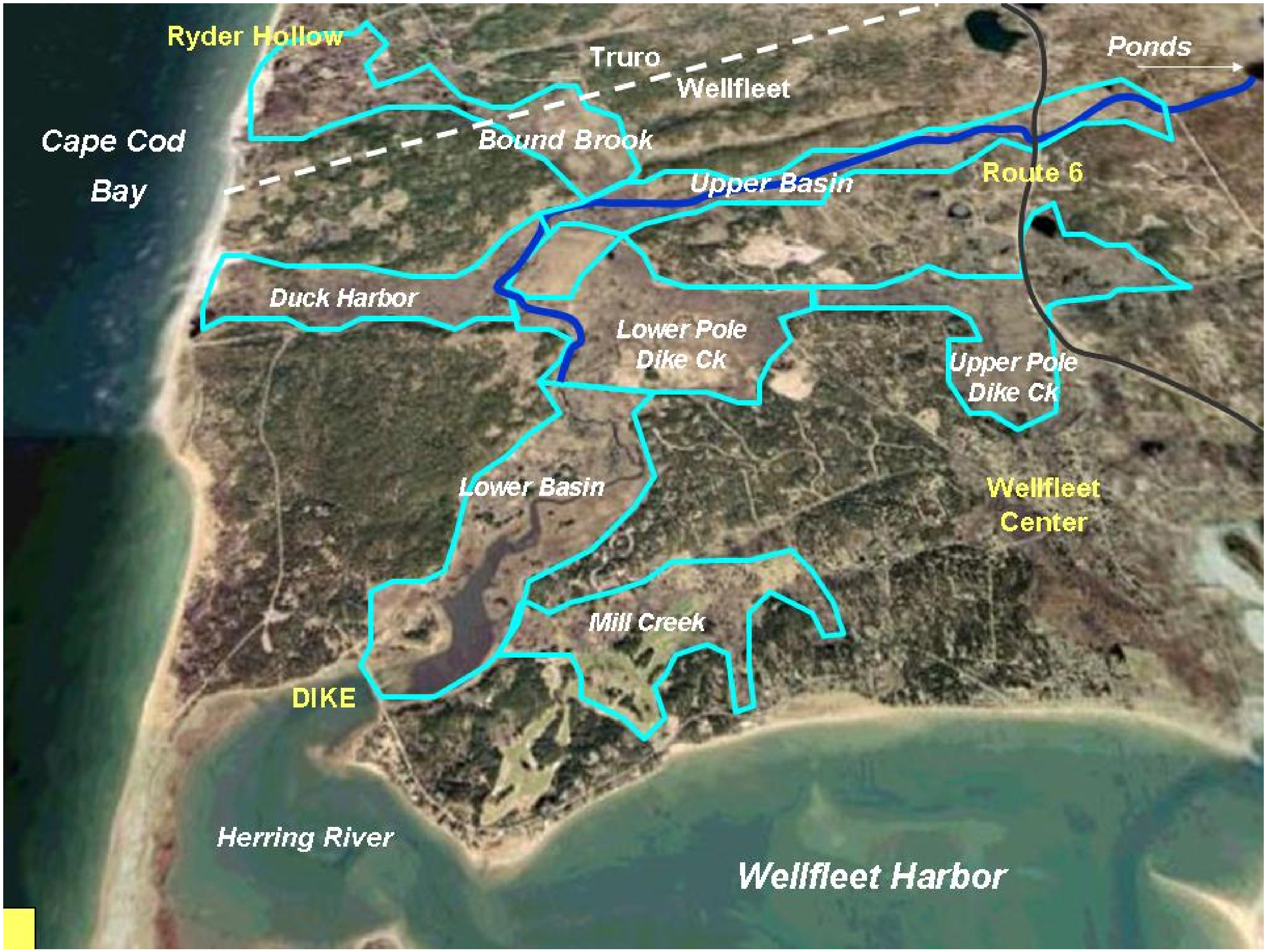
Lower Basin: The Lower Basin area of the Herring River is the southern-most portion, situated immediately upstream of the Chequesset Neck Road dike and extending northerly to the High Toss Road crossing. This basin covers roughly 170 acres, and includes subtidal, riverine, vegetated wetland, and fringing upland floodplain habitats. The only remaining saltmarsh in the Herring River system (approximately 13.6 acres) is located here, along with about 40 acres of exotic *Phragmites*.

Mill Creek: The Mill Creek tributary extends easterly of the Herring River approximately 1600 feet above the Chequesset Neck Road dike. The former floodplain portion of the Mill Creek basin comprises just over 100 acres. *Phragmites* marsh and disturbed wooded wetland habitat covers much of this floodplain in the Mill Creek basin, although there is some saltmarsh vegetation on the creek banks at the mouth of Mill Creek itself. In the 100 years since the Herring River dike was constructed, a golf course (Chequesset Yacht and Country Club – CYCC) and several private properties were constructed in the former Mill Creek floodplain.

Lower Pole Dike Creek Basin: This central portion of the Herring River basin extends north from High Toss Road to the north side of Merrick Island, easterly to Pole Dike Road, and is bounded on the west by the Duck Harbor basin. Covering approximately 180 acres, this basin is at the confluence of flows from the Herring River, Pole Dike Creek, Bound Brook, and Duck Harbor basins. This is the most severely drained portion of the original saltmarsh with soil pH almost everywhere below 4 (Figure 7, extent of acid sulfate soils), extremely acidic surface waters, and vegetation dominated by dry deciduous woodland.

Upper Pole Dike Creek Basin: Extending east of Pole Dike Road and covering wetland and former floodplain north of Wellfleet Center and east of Route 6, this distinct basin area

Figure 5. Delineation of Herring River Sub-basins



comprises approximately 180 acres of what is today freshwater marsh, dominated by cattail (*Typha angustifolia*). This basin contains by far the most private property abutters within the Herring River system. Unlike most of the other major basins, this area has not been extensively surveyed, modeled, or studied. Pending the outcome of further studies, including detailed hydrologic modeling currently underway, restoration of the Upper Pole Dike Creek basin will likely require a small dike with a tidal control device, possibly where the old rail-road dike crosses Pole Dike Creek just south of the Wellfleet Transfer station.

Bound Brook Basin: The Bound Brook basin area extends northerly from the Herring River above Old County Road. This basin comprises upwards of 240 acres, including a large wetland area that extends into the Ryder Hollow area of Truro. Due to generally low elevations, the peat has remained saturated, albeit fresh, and vegetation comprises wetland shrubs and cattail.

Upper Basin: The northern-most portion of the Herring River system extends northeast along the Herring River, crossing Route 6 and ending just below the headwater ponds within the CCNS. This 180-acre area currently supports primarily wooded wetland habitat along the Herring River.

Duck Harbor Basin: Extends westerly from the river main stem to the Duck Harbor barrier beach and comprises about 130 acres of floodplain north of Griffin Island and south of Bound Brook Islands. Black cherry woodland and acid sulfate soils (pH < 4) are typical in the eastern portion, while wetland shrubs dominate in the lower, and thus wetter, western portion except where it grades up to the barrier beach.

4.3 Water and Sediment Chemistry / Quality

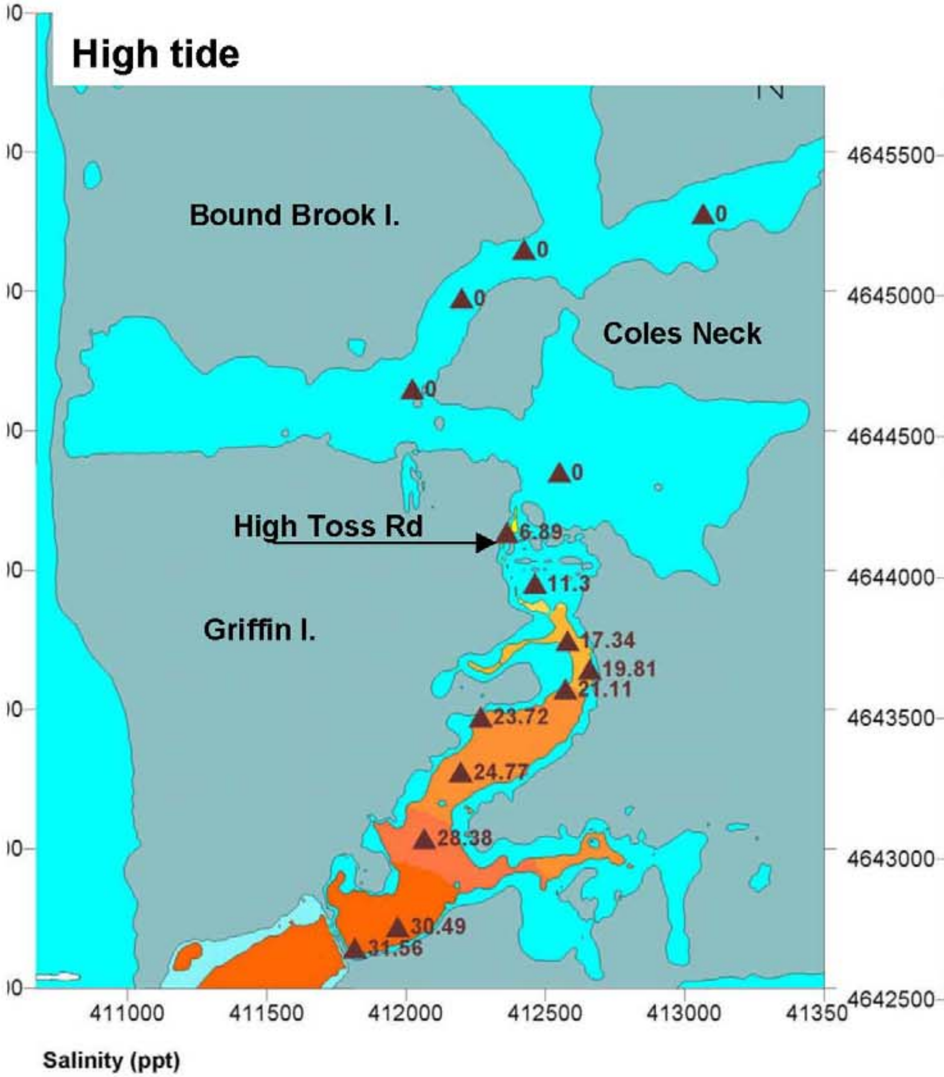
Numerous studies (reviewed in Portnoy 1999) have demonstrated that tidal restrictions, which reduce salinity and tidal flushing of estuarine habitats and dewater salt-marsh peat, increase the potential for poor water quality in aquatic ecosystems by disturbing natural biogeochemical cycling.

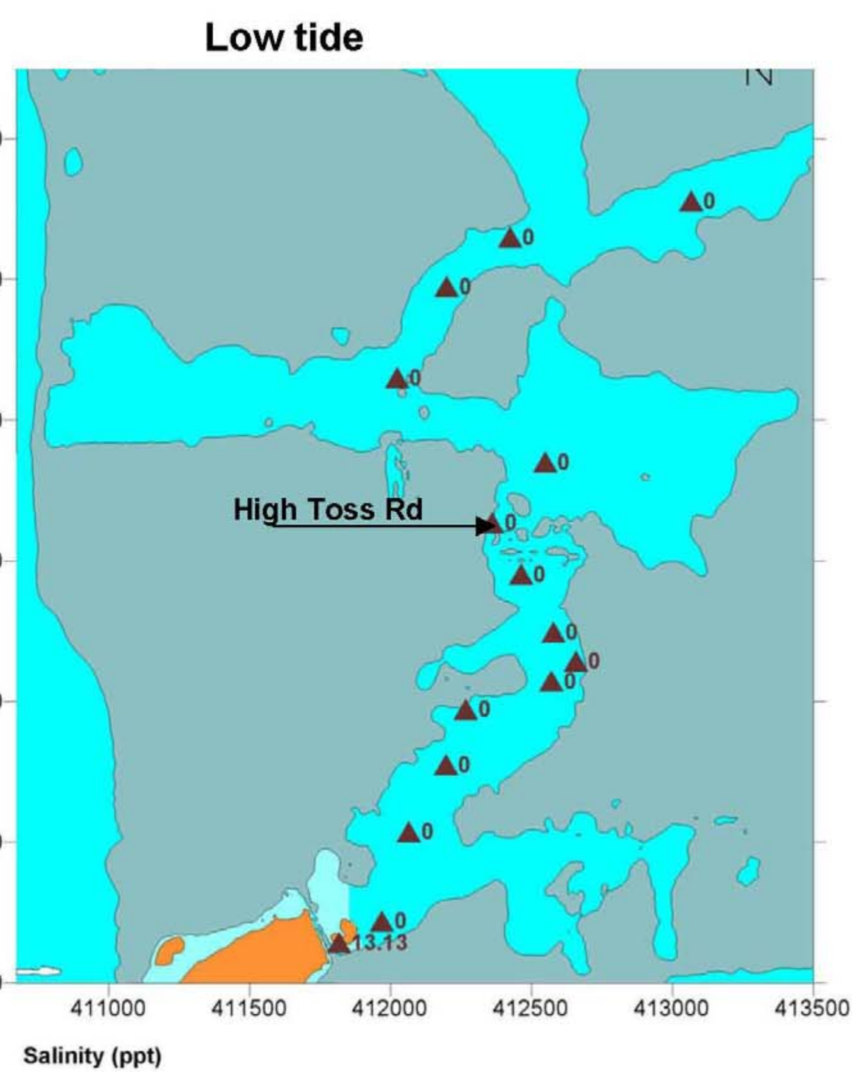
4.3.1 Salinity

Prior to construction of the main dike in 1909, the surface waters and surficial sediments within the Herring River estuary were flooded regularly with water ranging from full-strength seawater (32 parts per thousand [ppt]) at the river mouth, to probably at least 25 ppt at High Toss Road, 20 ppt at Old County Road and 10 ppt at the present Route 6. These estimates are based on the analysis of plant remains in sediment cores (Orson, R.A. in Roman 1987), and on hydrodynamic modeling of an unrestricted system (Spaulding & Grilli 2005). With the present tidal restriction, seawater extends upriver only a few thousand feet, just seaward of High Toss Road (see Figure 6). Under current diked conditions, even at high tide, brackish waters extend only to High Toss Road and at low

Figure 6

Current salinity distribution in the Herring River flood plain. At high tide, brackish water extends only about 3000 feet upstream of the dike, and does not reach High Toss Road. Low tide salinity is near zero throughout most of the river above the dike structure. Thus, estuarine animals and plants are severely limited.





tides salinity is near zero throughout most of the river above the dike. The remainder of the system north of High Toss is freshwater. Besides the profound effects of salinity reduction on vegetation, reduced pH buffering and ionic strength made Herring River's waters highly vulnerable to the chemical disturbance described below.

4.3.2 pH and metals

Diking and draining original saltmarsh habitats along the river have resulted in significantly increased surface water and soil acidity due to oxidation of the sulfur that naturally occurs in saltmarsh peat (Soukup & Portnoy 1986); the production of acid sulfate soils and acidified surface waters is an impact of salt-marsh drainage recognized throughout the world (Bremen 1982, Melville 1999). Wellfleet Harbor with its surface water at approximately pH 8 provides a natural reference site in comparison with the acidity levels found throughout parts of the river system. Acid sulfate soils with acidity levels at less than pH 4 can be found throughout much of the Duck Harbor, Lower Pole Dike Creek, Lower Basin and Mill Creek sub-systems (Figure 7). These conditions create major problems as the soils leach toxic acidity and aluminum from native alumino-silicate clays into surface water, stressing and killing aquatic organisms.

4.3.3 Dissolved oxygen

The elimination of tidal flushing in a wetland system that, albeit diked, still contained abundant organic matter, has caused regular summertime dissolved oxygen depletions and fish kills in the river main stem (Portnoy 1991). Conditions are worst in mid-summer, when oxygen demand is highest (see Figure 8), and has in the past compelled NPS to control the emigration of juvenile herring (*Alosa* spp.) to avert complete mortality and loss of the anadromous run (Portnoy et al. 1987). Conditions have improved since annual dredging of the main stem, purportedly for mosquito-control drainage, ended in 1984.

4.3.4 Fecal coliform

Tidally restricted estuaries also accumulate fecal coliform bacteria, producing concentrations during low tides and after heavy rain events that have led to the closure of local shellfish waters (Portnoy & Allen 2006). Fecal coliform was monitored at nine surface water stations in the Herring River from High Toss Road to Egg Island in 2005 (see Figure 9). Because of the low human population density along the Herring River, coliform here probably derive from wild animals. Hydrodynamic modeling (Spaulding & Grilli 2005) has shown that the dike decreases the dilution of coliform-rich river water, with relatively clean Cape Cod Bay seawater, by at least 13 times; this explains why fecal coliform (FC) is most abundant just below and above the dike structure. It also explains why coliform concentrations are highest during low tide, when high-FC river water predominates. If tides were restored and FC concentrations typically observed in the "contaminated" reaches of Herring River were diluted 13 times by clean bay water, resulting concentrations would be low enough to permit the re-opening of shellfish beds that have been closed for over 20 years. FC would probably be further reduced by increased salinity, which is well known to decrease coliform survival time in the environment (Bordalo et al. 2002).

Figure 7. Acid Sulfate Soils in Herring River Marshes

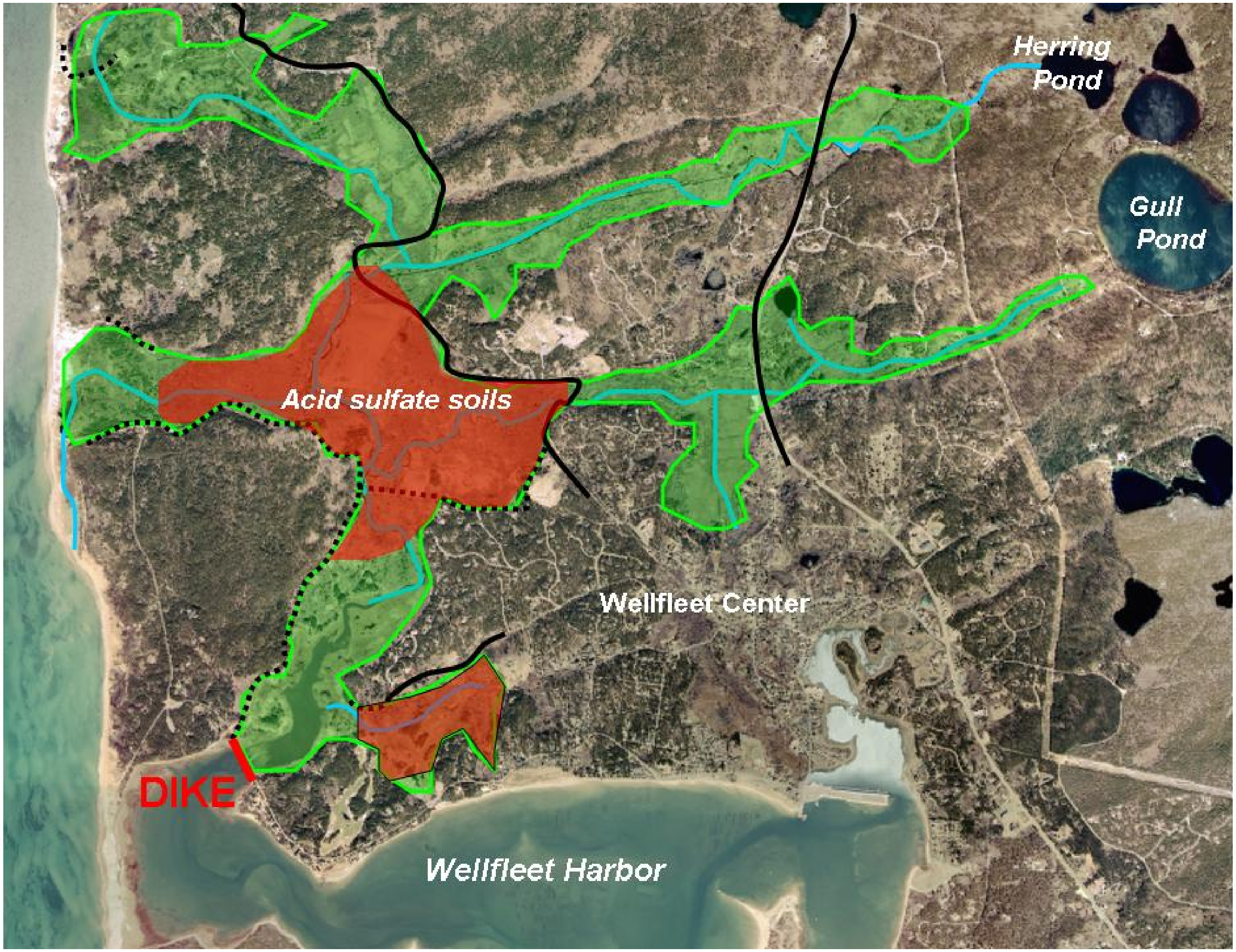


Figure 8. Summertime Dissolved Oxygen Depletions

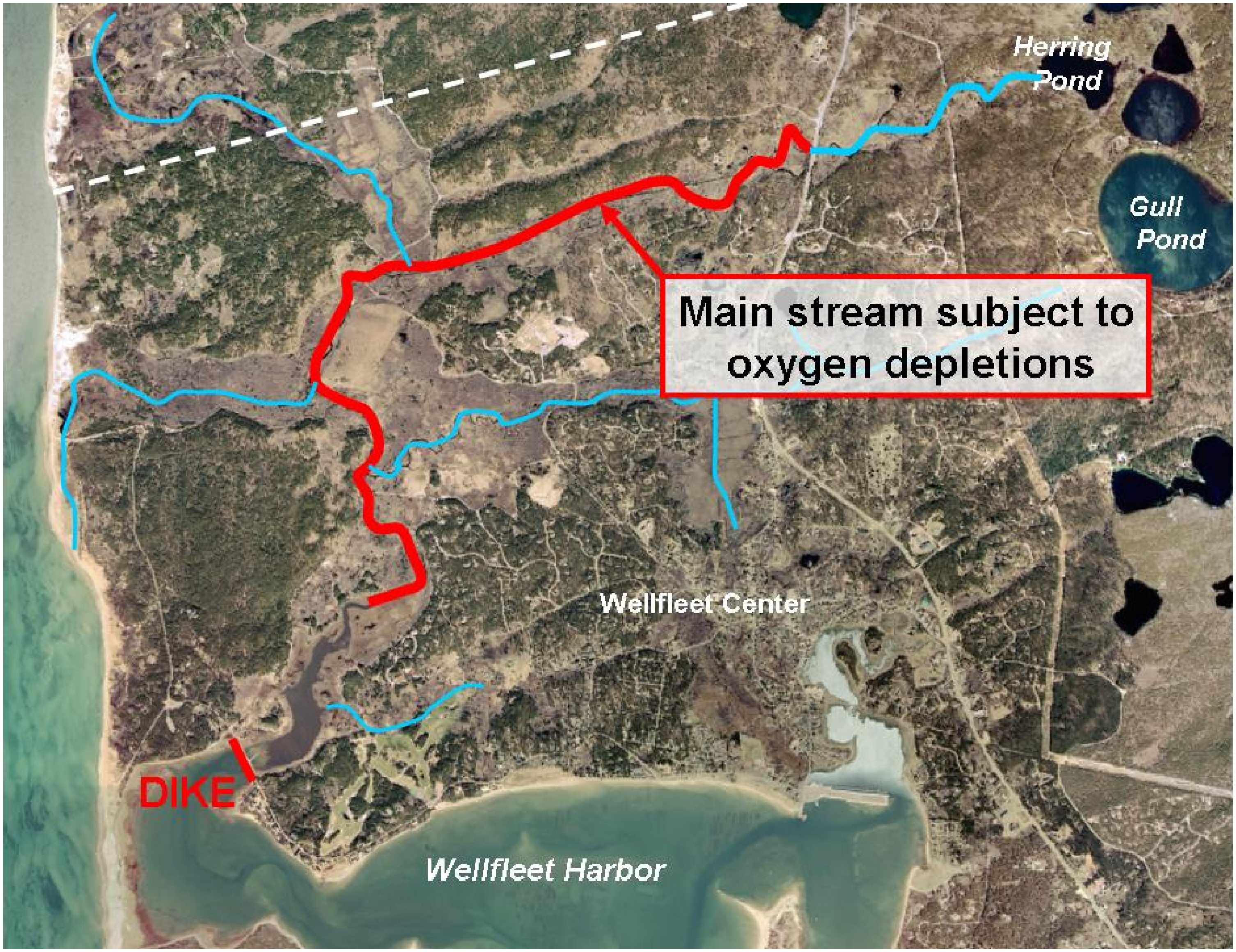


Figure 9. Fecal Coliform Concentrations in Herring River

Typical low-tide fecal coliform concentrations (colony-forming units per 100 ml) in Herring River. Fecal bacteria tend to accumulate around tidal restrictions because of poor tidal flushing, and low salinity increases bacteria survival time (Portnoy & Allen 2006). Shellfish harvest is prohibited if concentrations exceed 14 CFU/100 ml.

4.4 Surficial Geology

The Geological Map of the Wellfleet Quadrangle classifies most of the land area surrounding Wellfleet Harbor as either post-glacial outwash plain deposits or more recent marsh and swamp deposits. This glacial outwash valley comprises the aquifer that is integrally tied to the Herring River's hydrologic regime. Outwash plain deposits in the area are characterized by a combination of fine and coarse gravelly sand with a high content of quartzite stones. Boulders, cobbles, and stones are also found in the area. The marsh and swamp deposits, on the other hand, are soils characterized by decaying marine detritus, mixed with differing amounts of marine silt, sand, and clay (Oldale 1968).

4.5 Biota

Biota are collectively all of the animal, plant and microbial life in an area. Knowledge of the occurring species of plants and animals is critical for understanding any ecological system. This information is particularly important prior to implementation of restoration activities, as it provides a baseline dataset for current conditions against which any changes can be compared. Certain species are considered sentinels or bioindicators and their presence can be an indicator of a habitat's health.

4.5.1 Estuarine habitats

An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it and with a free connection to the open sea (Cowardin et al. 1978). An estuary generally includes a range of subtidal and intertidal habitats, vegetated and unvegetated, that are influenced by regional tidal patterns. Subtidal habitats of the estuary typically include the beds of tidal rivers and creeks with a salinity gradient that ranges from full seawater to freshwater. Intertidal habitats of a New England estuary typically include mud flats exposed between high tides, low saltmarsh, high saltmarsh, brackish marsh, freshwater tidal marsh, and shrubland (Swain and Kearsley 2000). Excellent examples of some of these habitats, primarily subtidal and intertidal flats and saltmarsh, are presently found on the seaward side of the Chequesset Neck Road dike.

Estuary habitats at the mouth of the Herring River on the up-river side of the dike do not have a free connection to the open sea. These habitats are, therefore, not subject to the free exchange of sediment, nutrients, organic matter and biota with the ocean. This condition has existed for nearly a century. Furthermore, the remaining saltmarsh includes drainage ditches dug to drain standing water for mosquito control. Technically, therefore, while once functioning as a classic example of an estuary, the mouth of the Herring River contains habitats that are more typical of freshwater and brackish marsh.

Saltmarsh

Saltmarshes are intertidal wetland areas that typically occur at the mouths of coastal rivers in high-salinity waters and are vegetated by communities of salt-tolerant plants (Tiner 1987). In regions such as New England that are subject to a semi-diurnal tidal pattern (see

Glossary) the lower elevations of the saltmarsh (or "low marsh") are subject to daily inundation by tidal waters while higher saltmarsh elevations (or "high marsh") are subject to tidal inundation only during spring high tides and storm events. Each of these zones has a characteristic set of plant species adapted to conditions resulting from specific tidal flooding regimes. The following diagram depicts a typical profile of an estuarine habitat extending from a tidal river channel landward to upland habitat (Figure 10).

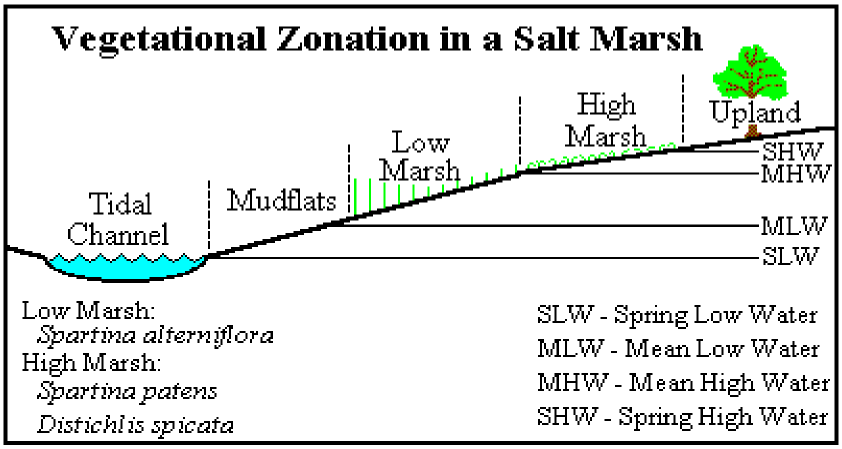


Figure 10: Generalized Saltmarsh Zonation

Numerous factors influence the formation of a saltmarsh, including climate, hydrology, and physical factors. Climatic factors include precipitation and temperature, hydrologic factors include tides, wave energy and patterns of fresh groundwater discharge, and physical factors include elevation, slope, sediment and soil composition, surface water, and salinity. Saltmarshes form in protected shallow-waters between the land and ocean and both salt and freshwater affect their formation. As these areas are somewhat physically protected, with slowly flowing waters, sediments carried both downstream from rivers and upstream by flood tides accumulate and are slowly colonized by saltwater grasses (Warren 1997). *Spartina alterniflora*, for example, creates habitat for other organisms, such as ribbed mussels (*Guekensia demissa*) and fiddler crabs (*Uca* spp.), which then create a positive feedback for cord-grass, which increases sediment deposition and helps to form the saltmarsh community (Warren 1997). With time, the saltmarsh develops into a rich, complex, and diverse community. Saltmarsh habitats play an important role in pollution control, storm surge protection, fish and shellfish nursery habitat, waterbird use, and overall near-shore marine productivity. As tidal range increases, saltmarsh productivity does as well (Steever et al. 1976).

Saltmarsh habitat in the Herring River

While once present in vast expanses within the Herring River estuary, tidal restriction and drainage efforts have converted these characteristic, highly productive saltmarsh habitats into freshwater wetland habitats, including river floodplain woodlands, shrub-dominant marsh areas, and *Phragmites*-dominant marshes. Only 13.6 acres of saltmarsh persists above the Herring River dike, where before 1909 diking there were approximately 1,100 acres of productive coastal wetland habitats.

Subsidence of the marsh surface

In addition to the dramatic change in the plant community on the marsh surface since dike construction, the marsh surface itself has subsided considerably. Measurements indicate that much of the coastal floodplain is approximately three feet below its historic elevation and the surfaces of existing saltmarshes seaward of the dike (Portnoy 1999). Restricting daily tidal exchange between Wellfleet Harbor and the estuary effectively eliminated the important process of sedimentation on the saltmarsh surface. The import of inorganic sediment into an estuary and its deposition onto the marsh surface during flood tides must occur to promote the growth of *Spartina* grasses and to gradually increase the elevation of the marsh surface to keep pace with sea-level rise. The dike effectively blocked the inorganic sediment from reaching the saltmarshes within the Herring River basin.

While the deposition of organic sediment on the marsh surface continued, marsh draining increased the amount of available oxygen at the marsh surface and boosted the rate at which this organic material degraded. Marsh drainage also promotes the drying and compaction of saltmarsh peat. This compaction of pore spaces in the marsh peat and the lack of continuous sedimentation have resulted in subsidence of the marsh surface in the river basin.

Landward extent of existing saltmarsh at harbor margins

Expansive areas of saltmarsh habitat exists on the harbor side of the dike north of Great Island. The boundary of this saltmarsh habitat coincides with the spring high tide mark, which is approximately elevation 5.1 feet NAVD 88 (See Figure 2). These areas illustrate the normal habitat and reference conditions that are targeted by the Herring River restoration project.

Submerged aquatic vegetation

Submerged aquatic vegetation (SAV) in a New England estuary typically includes eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*). As primary producers, SAVs contribute to net estuarine productivity by manufacturing organic matter and releasing dissolved oxygen into the water column. SAVs are also important to the ecosystem as they provide habitat for many animal species and stabilize the sediment surface, thus promoting water clarity (Stevenson et al. 1979). SAVs are sensitive to nutrient loading and decline in embayments where excess nitrogen and/or poor flushing cause algae blooms. Thus, they are good indicators of development impacts on water and general estuarine habitat quality.

SAV Presence in Herring River

According to the NPS, there is a relatively extensive community of widgeon grass and a smaller area of eelgrass in an area just above the dike. Both are often covered by macro-algae. The NPS has plans to map and monitor existing SAV communities in the near future.

4.5.2 Freshwater wetland habitats

The dramatic decrease in tidal range and salinity in the Herring River basin from diking resulted in conditions that favored the conversion of characteristic saltmarsh plant communities to freshwater plant communities. These new freshwater marsh habitats emerged atop a thick substrate of saltmarsh peat, rather than on top of peat that developed from the decomposition of freshwater plants. This freshwater plant/saltmarsh peat mismatch contributes to a number of the unnatural and undesirable conditions in the Herring River floodplain.

Plant communities found along the Herring River were surveyed during the 1980s and described as follows:

Phragmites australis-dominant marsh

Phragmites australis, or common reed, occurs downstream of High Toss Road. *Phragmites* has some salt tolerance and therefore competes for space against freshwater wetland plants at moderate salinities, e.g. 10-20 ppt. When tidal flow was restricted, the river's salinity levels were greatly reduced, which allowed for *Phragmites* to invade places previously dominated by *Spartina alterniflora* and *S. patens* (see Photo 8). Besides the large monotypic stand just upstream of the dike, scattered small patches of *Phragmites* occur throughout the Herring River basin. Where this plant dominates close to the dike (within about 1,200 meters), small stands of *Spartina alterniflora* and *S. patens* occur at lower elevations adjacent to the river while a shrub zone, dominated by poison ivy *(Toxicondendron radicans*) and northern bayberry (*Myrica pensylvanica*) occurs slightly higher (Art 1981; Beskenis and Nuzzo 1984).

Photo 8: *Phragmites*-dominant marsh along Herring River

The Invasive Plants Atlas of New England (IPANE) lists this tall (2 to 4 meters), stout grass species an invasive plant. IPANE indicates that "*Common reed can grow in a variety of habitats. It is most often found in wet or marshy areas. This plant grows best in fresh water, but also can be found in brackish, acid or alkaline wetlands. It is also found at the interface between wetlands and uplands*" (Mehrhoff et al. 2003). *Phragmites* tend to tolerate polluted conditions, which gives it an advantage over other plants that do not possess this tolerance. Wetland restoration project often are designed to control *Phragmites* because it will form expansive monotypic stands and by doing so displace valuable native coastal wetland plant communities, primarily saltmarsh.

Recent research (Saltonstall 2002) has documented the presence of numerous genetic strains of *Phragmites australis* throughout the world, including both native and non-native types occurring in New England. The native type is now classified as the sub-species *Phragmites australis* ssp. *americanus* (Saltonstall, P.M. Peterson & Soreng 2004). This sub-species was historically a common, non-invasive component of New England wetland plant communities. But, once the invasive type was introduced from Europe, it spread rapidly and outcompeted the native type, which is now rare compared to the massive stands of non-native *Phragmites* found in many locations. The presence of native *Phragmites* has just recently gained the attention of ecologists and its implication for tidal restoration projects in still unclear. For the Herring River, *Phragmites* has always been assumed to be the non-native type, but this needs to be confirmed and explored before implementation of the restoration project.

Typha-dominant marsh

Cattail dominated *(Typha* spp.*)* communities tend to occur as the river loses more salinity. *Typha* is more indicative of fresh water and thus dominates the edges of the river, often along with *Phragmites*, as close as 1,200 m upstream of the dike (see Photo 9).

Photo 9: *Typha*-dominant marsh along Herring River

River floodplain woodland and shrub-dominant habitats

Tree species including, red maple, pitch pine, aspen, and black cherry comprise woodland areas that were once saltmarsh habitats. Some of these former woodland areas exhibit freshwater wetland hydrology while other areas lack sufficient soil inundation and/or saturation and are upland. In many other areas, shrub-swamp is the predominant habitat type where saltmarsh once existed.

Black cherry woodland

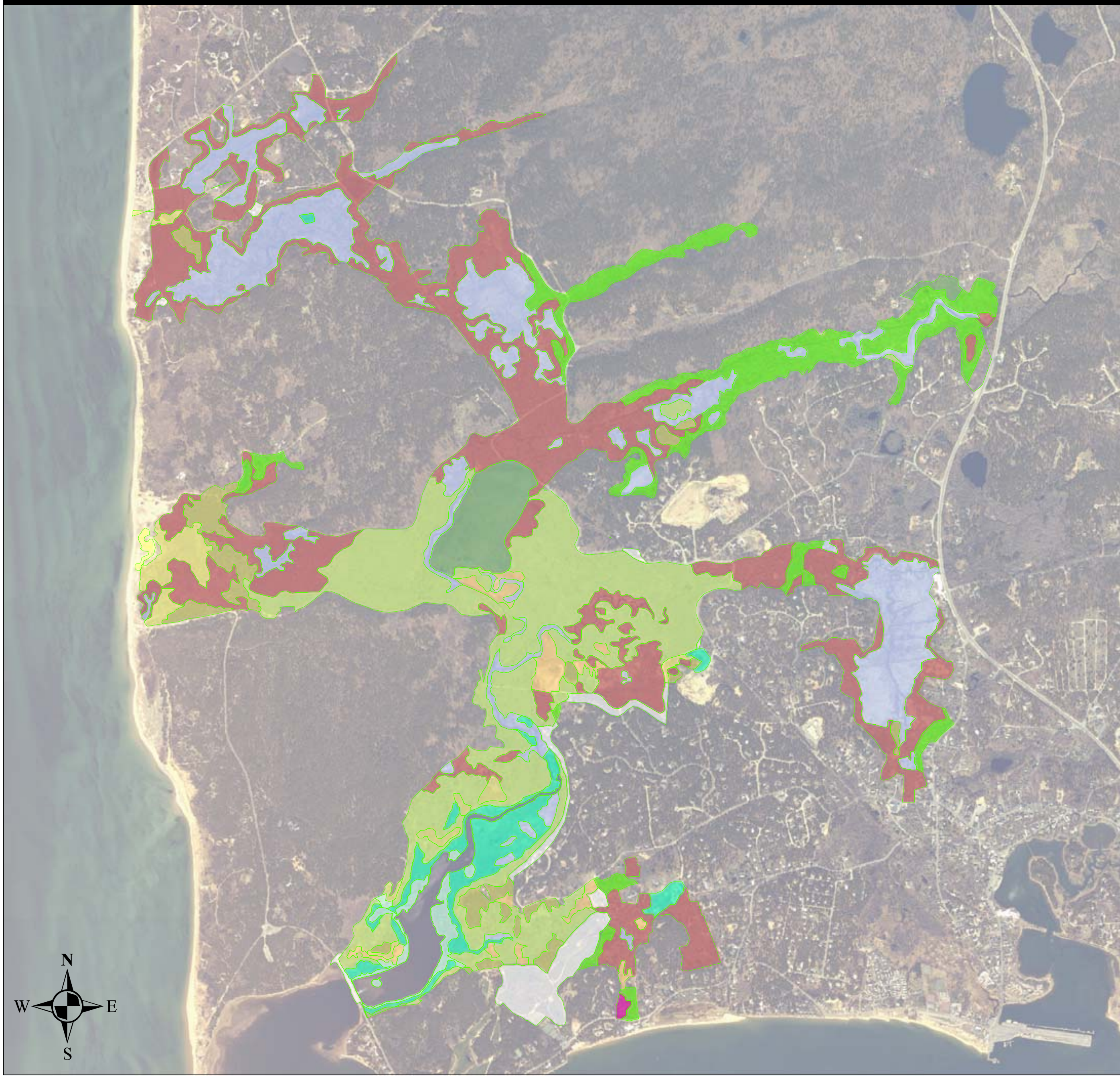
This vegetation cover type (Dry Deciduous Woodland in Figure 11, Vegetation Map) is typical of Duck Harbor and Lower Pole Dike Creek sub-basins. *Typha* and *Phragmites* are rare and black cherry can be found along with an understory of old field species, including goldenrod (*Solidago* sp.), Canadian lettuce *(Lactuca canadensis*), common velvet grass *(Holcus lanatus*), and Alleghany blackberry *(Rubus allegheniensis*). These old field species continue to

Herring River Vegetation

Updated from 2000 aerial photos with 2007 field observations .

Figure 11

Cape Cod National Seashore
National Park Service
U.S. Department of the Interior



Legend

- FRESHWATER MARSH
- BRACKISH MARSH
- SALT MARSH
- DUNE GRASSLAND
- HEATHLAND GRASSLAND
- OLD FIELD HERBACEOUS
- WET SHRUB
- DRY SHRUBLAND
- PINE WOODLAND
- DRY DECIDUOUS WOODLAND
- DRY DECIDUOUS FOREST
- WET DECIDUOUS FOREST
- DEVELOPED

TYPE	TYPICAL SPECIES
FRESHWATER MARSH	Typha angustifolia, Scirpus cyperinus, Calamagrostis canadensis, Juncus spp., Sparganium americanum.
BRACKISH MARSH	Phragmites australis, Scirpus pungens.
SALT MARSH	Spartina alterniflora, Spartina patens,
DUNE GRASSLAND	Ammophila breviligulata, Deschampsia flexuosa.
HEATHLAND	Arctostaphylos uva-ursi, Morella pensylvanica, Vaccinium angustifolium, Hudsonia ericoides, Hudsonia tomentosa, Corema conradii.
OLD FIELD HERBACEOUS	Schizachyrium scoparium, Deschampsia flexuosa, Holcus lanatus, Festuca rubra.
WET SHRUBLAND	Vaccinium corymbosum, Clethra alnifolia, Rhododendrum viscosum, Decodon verticillatus, Cephalanthus occidentalis, Alnus spp., Chamaedaphne calyculata.
DRY SHRUBLAND	Morella pensylvanica, Quercus velutina, Amelanchier spp.
PINE WOODLAND	Pinus rigida, Gaylusaccia baccatta, Deschampsia flexuosa, Vaccinium angustifolium.
DRY DECID. WOODLAND	Prunus serotina, Amelanchier spp., Viburnum spp.
DRY DECIDUOUS FOREST	Quercus velutina, Quercus alba, Fagus grandifolia, Robinia pseudoacacia.
WET DECIDUOUS FOREST	Acer rubrum, Rhododendron viscosum, Clethra alnifolia.

HOW THIS MAP WAS MADE:

Seemingly “natural” vegetation communities often contain unexpected assemblages of species because of habitat alterations caused by human intervention. For example, Herring River's diked and drained floodplains have dry woodland communities where wet shrubs and marshes would be expected to occur. This general vegetation map of Herring River shows these human-influenced plant communities which are very different from the floodplain types that would result from restoration of tidal influences.

To make this map, color infra red aerial photos were interpreted and assigned vegetation types from a broad classification system of New England plant communities (Sneddon, Leslie, Vegetation of Cape Cod National Seashore Natureserve, 2004). New vegetation classes were then added based on extensive field observations to reflect actual vegetation within the tidal-deprived floodplain. In particular, the apparent wet woodland types dominated by red maple interpreted from aerial photography are actually dry woodlands dominated by black cherry and shadbush.

0 155 310 620 930 1,240 Meters

File: HRveg2000_nvc07

Date:082007

dominate miles upstream from the dike, where meadowsweet (*Spiraea latifolia)*, smart-weeds (*Polygonum* spp.), and goldenrods are all prominent (Art 1981; Beskenis and Nuzzo 1984).

Other Invasive Plants

A 2001 study (Martin and Hanley 2001) of Herring River vegetation identified the following additional invasive plant species: multiflora rose (*Rosa multiflora*), bittersweet nightshade (*Solanum dulcamara*), watercress (*Rorippa nasturtium-aquaticum*), oriental bittersweet (*Celastrus orbiculata*), Morrow's honeysuckle (*Lonicera morrowii*), and Japanese honeysuckle (*L. japonica*). These species and others that have been found in the area (including velvet grass, black locust, cheatgrass, and curly dock) could be eliminated or greatly reduced through tidal restoration (Smith 2005).

Another invasive species that has the potential to become a nuisance around Herring River is purple loosestrife, *Lythrum salicaria*. It has already been identified on the shore of Higgins Pond, which connects to Herring Pond, where the Herring River originates (Martin & Hanley 2001).

4.5.3 Fish and wildlife

The following sections discuss finfish, shellfish, birds, mammals, insects, reptiles and amphibians, including rare animals known to occur in the system and surrounding areas. The NPS currently runs a monitoring program documenting the presence of shellfish, estuarine fish, birds, and mosquitoes in the Herring River system.

River herring

River herring include two anadromous species: alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) (Haas-Castro 2006). The alewife ranges from Labrador to South Carolina, while the blueback's range is from Nova Scotia to Florida (Haas-Castro 2006). Alewives typically live about ten years and grow up to 36 cm (14 in), while bluebacks typically live for about seven or eight years and can grow up to 32 cm (13 in) (Haas-Castro 2006). Procreation of these fish, and the persistence of an individual herring run, depends on a reliable connection, with good water quality, between the marine environment and their freshwater spawning ponds (Naiman et al. 2002).

River herring typically migrate up and down the Herring River from March through early December. The majority of adults are present in the river system from March through mid-June. Herring spawn in ponds including Gull, Higgins, Williams, Herring, and Black and in the upper reaches of the river. The young of the year (or "fry") make their seaward migration from July through November, although it is possible for large schools of fry to go downstream as early as mid-June and as late as mid-December (see Figure 12).

Figure 12. Herring River Anadromous Fish Run

Herring River, Wellfleet, MA
Anadromous Fish Run

Scale 1:30 — 3,000 0 3,000 6,000 9,000 Feet — Prepared: 10/29/2007

N

Legend

anadromous fish runs

MassGIS 2005 - NRCS Data Layer
Department of Fisheries, Wildlife and Environmental Law Enforcement (DFWELE)

Agency: NRCS
Field Office: HYANNIS SERVICE CENTER
State and County: MA, BARNSTABLE

District: CAPE COD CONSERVATION DISTRICT

Riverine estuaries form important migratory staging areas for anadromous river herring and catadromous eels (see below), allowing them time to adjust physiologically to radical changes in salinity. Tidal restrictions, like the Herring River dike, create a much steeper salinity gradient between marine and freshwater environments, making it more difficult for migratory species to adapt. Observed acidification (Soukup & Portnoy 1986) and summertime oxygen depletion (Portnoy 1991) have likely contributed to the decline in Herring River herring since the river was diked (Portnoy & Reynolds 1997).

Other anadromous and catadromous fish species

During the 1980s white perch and hickory shad were found at the mouth of the Herring River (Roman 1987). White perch can be found in abundance in the estuary and use the upper main stream and ponds as spawning sites. Like the alewife and blueback herring, white perch use the river to spawn in late spring, from April to June. White perch spawn over sandy bottoms, and are plentiful in coastal ponds with connections to the sea, brackish bays, estuaries, and river mouths (Bigelow & Schroeder 1953).

In addition to anadromous fish, the catadromous species, American eel (*Anguilla rostrata*), is also found in the river. Eels spend most of their lives in the upstream freshwater ponds and migrate to the open sea to spawn. The young eels, known as "elvers" enter the river on their way to the ponds in April and May and the adults travel the river on their way out in June.

Other fish species

There are also resident and transient fish in the river and its tributaries. These estuarine and freshwater species use these waterways for specific life stages, seasonal migrations or spend all of their lives in the river. Thus, the Herring River acts as an important habitat for dozens of nekton species, although diversity and abundance decline precipitously with distance above the dike (Roman 1987). When the dike's opening increased in 1984, large numbers of Atlantic menhaden began to utilize the ecosystem upstream from the dike as a nursery (Wellfleet Comprehensive Plan 1994). Other fish that have been found in the river include Atlantic mackerel, Atlantic silverside, bluefish, chain pickerel, common killifish, three-spine stickleback, golden shiner, hogchoker, pumpkinseed, sheepshead minnow, striped killifish, tidewater silverside, and winter flounder (Gwilliam 2006).

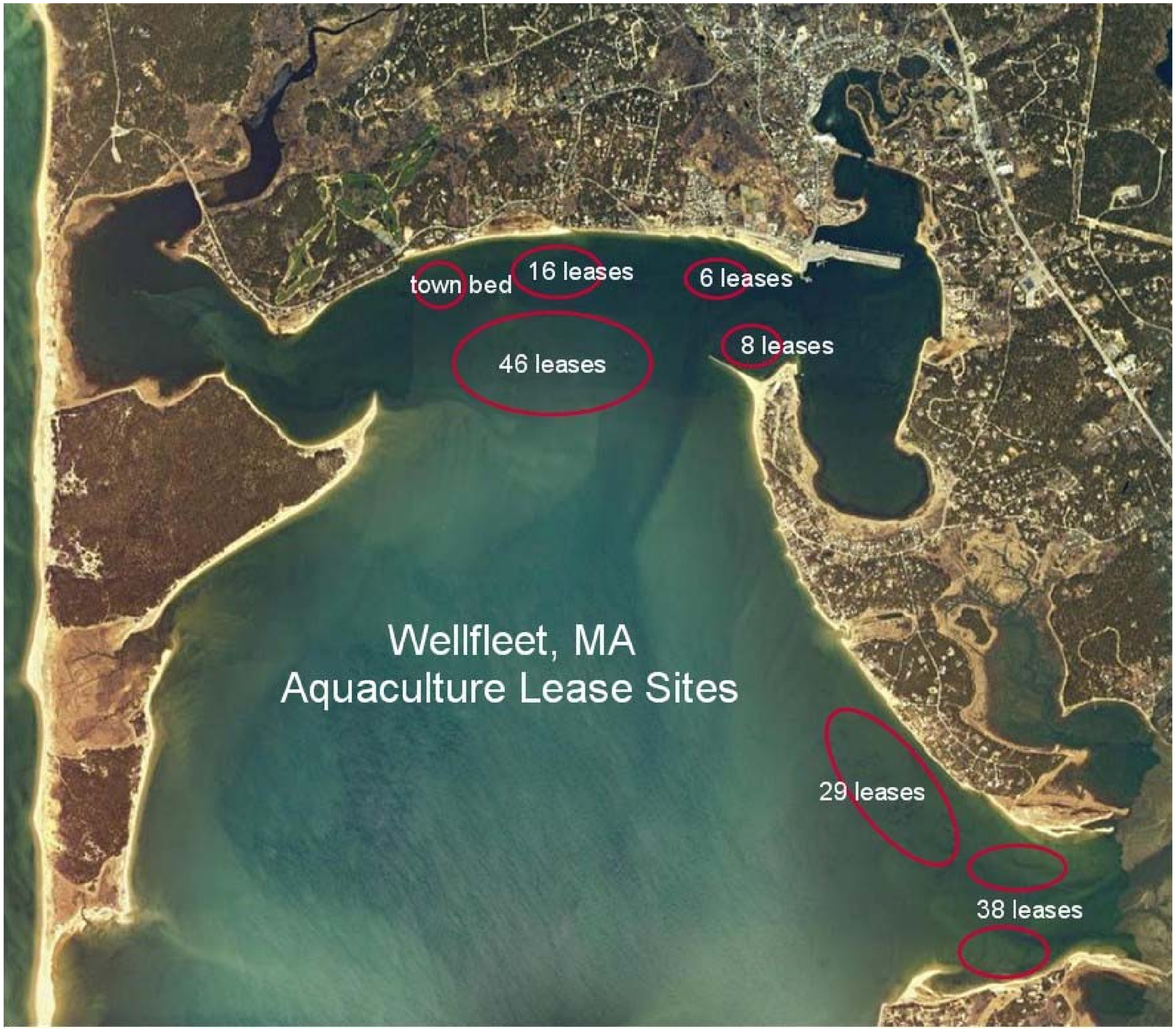
Shellfish resources

Oysters and soft-shelled clams could at one time be found widely in the Herring River estuary; oysters currently extend only a few tens of meters upstream of the dike structure, due to low salinity and pH. In addition, poor tidal flushing and consequently high fecal coliform both above and, for 3000 feet below, the dike have kept otherwise dense beds of oysters in the river mouth closed to harvest (Figure 13), and may even threaten the large aquaculture beds farther downstream (Figure 14) (Portnoy & Allen 2006). The Division of Marine Fisheries has prohibited shellfishing and shellfish propagation in all areas on the upstream side of the Chequesset Neck Road dike, for 3000 feet seaward of the dike, and

Figure 13. Designated Shellfish Closure Areas

Status of shellfish closures in Wellfleet Harbor including Herring River, fall 2007. State coliform sampling determines whether shellfish beds are open to harvest in "conditionally open" areas; typically these areas are closed for several days after major rain events. The waters just above and below the Herring River dike have been closed to shellfishing due to observations of high fecal coliform since the mid-1980s.

Figure 14. Aquaculture Lease Areas



farther depending upon season and rainfall. Although under current conditions this area remains closed to shellfishing due to bacteria contamination, it should be noted that the abundant resident oyster population still has great value, in providing spawn to the harbor, because it is protected from harvest. Thus, the mouth of the river presently functions as shellfish sanctuary with benefits to shellfish propagation throughout the harbor, something that the town may wish to perpetuate.

Birds

Many birds use saltmarsh habitats for breeding, foraging and roosting, including several species of waterfowl, raptors, wading birds, shorebirds and songbirds. Seasonal use of intertidal and saltmarsh habitat also varies, with some species using the saltmarsh for breeding and others during migration or the wintering period. The habitats, and consequently many of birds, found in the Herring River likely are different today when compared to what existed prior to the construction of the Chequesset Neck Road Dike. Much of the change in bird occurrence and use likely has been the result in the change of a system dominated by intertidal flats and cordgrass (*Spartina* spp.) to one that currently is dominated by freshwater (cattail and common reed) and mixed upland vegetation. Concurrent with these changes has been the resulting poor water quality conditions in the Herring River, e.g. acidification and oxygen depletions, and the limited tidal range that has adversely affected forage fish populations that are important seasonal food resources for many birds.

Species common to shrub thickets and freshwater habitat likely have increased in the Herring River floodplain as conditions changed landward of the dike due to the tidal restriction. These include, red-winged blackbirds, song sparrows, prairie warblers, common yellowthroats, eastern towhees, and grey catbirds. Many of these species are abundant nesters elsewhere on Cape Cod and southeastern Massachusetts (Veit and Peterson 1993). Tidal restoration eventually will permanently alter the current habitat conditions for some of these species and where it is possible, cause them gradually to shift to appropriate habitats higher in the Herring River system.

Several high priority tidal creek and saltmarsh-dependent species such as saltmarsh sharp-tailed sparrows, willets, American black ducks (especially winter), common and roseate terns, as well as several species of shorebirds and wading birds (USFWS, 2006) are expected to benefit directly through restoration of nesting (*Spartina* dominated habitat) and/or foraging opportunities (primarily estuarine fish) in the Herring River. Other species, including but not limited to, osprey, northern harrier, belted kingfisher, and American bittern will benefit from the restoration of foraging habitat.

Mammals

Small mammals, such as mice, voles, and shrews are very abundant in marsh grasses around Herring River. Larger mammals, such as coyotes, river otters, raccoons, and deer also utilize the floodplain. The most common group of mammals found in saltmarsh habitats in the New England region are rodents, such as the meadow vole (*Microtus pennsylvanicus*), which are an important prey-species for Northern harriers and other raptors. Other common mammals of the saltmarsh include red fox, opossum, chipmunk, and muskrat (Smith 1997).

Most of these mammals are, at most, indirectly affected by saltmarsh restrictions and therefore tidal restoration may have an insignificant effect on them. The prevalent mammals in the area are generalists, highly adaptable, and likely to move to adjacent habitat unaffected by tidal restoration (Smith 1997).Mosquitoes

Surveys of both mosquito adults and larvae by both the NPS and CCMCP in around the Herring River floodplain have identified a normally brackish-water breeder, *Ochlerotatus cantator*, as the dominant species. This insect is also the most common biter of humans throughout outer Cape Cod, where diked marshes are considered a primary source of this nuisance species. At least 17 other mosquito species occur here, but only a few feed on people. Work on mosquito breeding ecology (Portnoy 1984) has shown close links among diking, consequent water quality impacts, and nuisance mosquito production, with *O. cantator* benefiting from surface-water acidification that excludes predatory fish from floodwater breeding sites.

Reptiles and Amphibians

Snapping turtles (Chelydra serpentine) and the American toads (*Bufo a. americanus*) are typically found within saltmarshes (West & Skelly 1997). Turtles such as the State-listed diamond-backed terrapin and eastern box turtle (further described below) are also known to use saltmarshes for habitat (Carlisle et al. 2002). It is also likely that many other species of reptiles and amphibians including green frog (*Rana clamitans melanota*), Fowler's toad (*Bufo woodhousii fowleri*), painted turtle (*Chrysemys picta*), eastern garter snake (*Thamnophis s. sirtalis*), and northern water snake (*Nerodia s. sipedon*) utilize saltmarsh habitats similar to those found at the Herring River and Wellfleet Harbor estuary. In a Cape Cod National Seashore study, spring peepers, bullfrogs, green frogs, and pickerel frogs were heard calling from Gull and Herring ponds (Paton et al. 2003).

Northern diamondback terrapins, the signature reptile of southern New England saltmarshes, is fairly abundant but at the apparent northern limit of its range in Wellfleet Harbor just seaward of the dike. A few individuals have been observed upstream of the Herring River dike structure.

Rare animal species in the Herring River system

The Herring River system contains habitats for a number of State-listed rare animal species and no Federally-listed rare species. The State-listed species include northern harrier (*Circus cyaneus*), diamondback terrapin (*Malaclemys terrapin*), eastern box turtle (*Terrapene c. carolina*), water willow stem borer (*Papaipema sulphurata*), and four-toed salamander (*Hemidactylium scutatum*). The Natural Heritage and Endangered Species Program (NHESP) of the Massachusetts Division of Fisheries and Wildlife provides maps of areas that contain habitats supporting rare species.

Northern Harrier

Harriers (*Circus cyaneus)* regularly hunt throughout the year within the Herring River floodplain and surrounding heathlands. In addition, this State-listed threatened species regularly hunts and may breed in the Bound Brook area (Bowen 2006) in which case increased tide heights and salinity and consequent vegetation changes with tidal restoration may affect nesting locations and success. Harriers typically nest and forage in grasslands, rather than shrubby woodlands.

Diamondback terrapin

The terrapin is a marine turtle that will use the brackish marsh habitats of the Herring River estuary as foraging habitat and will use sandy shoreline habitats along the river as nesting habitat. Cape Cod is the northern extent of its range. In Massachusetts this species of reptile is state-listed as threatened. This animal would likely extend, or more accurately reestablish, its range in Herring River with tidal restoration.

Eastern box turtle

Eastern box turtles are a relatively common terrestrial reptile on Cape Cod that will use dry and moist woodland and marsh habitats. The pine barrens and oak thickets that are present in areas adjacent to the Herring River estuary are considered optimal habitat types for this species. Upland habitats that support communities of bearberry (*Arctostaphylos uva-ursi*), lowbush blueberry (*Vaccinium angustifolium*), and bracken fern (*Pteridium aquilinum*), which are common upland habitat plant species near the estuary, are also preferred habitat for the turtle (Degraff 1986). In Massachusetts, NHESP lists this reptile as a species of special concern. Box turtles frequent at least the edges of the diked floodplain, especially during dry summer periods when they move into fresh surface water for hydration.

Water-willow stem borer

Water-willow stem borer is a nocturnal moth found only on the coastal plain of southeastern Massachusetts and Cape Cod, in the shallowest portions of vernal ponds and seasonally flooded swamps and along upland edges of streams, ponds, and other permanent bodies of water. Only wetlands supporting a significant amount of water willow (*Decodon verticillatus*) within a restricted shallow-water zone are inhabited by this species according to the NHESP. Water-willow stem borers use water willow to lay eggs, for feeding, and growth. Along the margins of the Herring River and its tributaries there are numerous water willow communities that are known to support the stem borer (Beskenis and Nuzzo 1984); these sites were recently surveyed, mapped, and studied (Mello 2007). In Massachusetts this moth is a State-listed threatened species. In informal discussions, NHESP staff have expressed an appreciation for the benefits of whole-system restoration to thousands of native plant and animal species, and support tidal restoration provided it occurs gradually to allow salt-sensitive and rare animals like the stem borer to shift its local range.

Four-toed salamander

Adult four-toed salamanders are terrestrial amphibians and are usually found in forested areas near their breeding habitat. Breeding habitat is found in wetland areas that contain *Sphagnum* moss under which this salamander deposits it eggs. Their distribution is limited to areas that provide both breeding and upland habitats in close proximity. According to NHESP records, there are presently a number of locations along the Herring River and its tributaries where there is habitat suitable for this species. These habitats were surveyed and mapped (Cook 2006); breeding (egg masses and attendant females) were found above Route 6, in the Bound Brook sub-basin, and in Upper Pole Dike Creek marshes. This animal, which does occur and breed elsewhere on the outer Cape, prefers steep *Sphagnum* hummocks over open water for nesting sites. In Massachusetts this amphibian is a species of special concern. As for the stem borer, NHESP staff understand the system-wide ecological impacts of diking and support estuarine restoration provided that it is undertaken gradually to allow animals to re-adjust to lower-salinity environments within and adjacent to the floodplain.

5 Project Description

The reconnection and gradual incremental increase in tidal exchange between the Herring River estuary and Wellfleet Harbor is the primary proposed process for tidal restoration envisioned for the Herring River floodplain and its adjoining tributary stream basins. Increased tidal exchange will result in several important beneficial changes to the Herring River's estuarine characteristics and floodplain features, which include improvements to water and sediment quality, coastal wetland habitats, and fisheries and shellfish habitat. The restoration project comprises the following objectives:

- Restoration of the natural tidal range and salinity throughout the floodplain including all tributary stream basins.
- Reestablishment of the physical connection with the marine environment for exchange of sediment, nutrients, organic matter, and biota.
- Restoration of a natural sediment budget to counter wetland subsidence and sea level rise.
- Improvement of water quality realized by increased salinity, alkalinity, and pH, and decreased metals and coliform bacteria.
- Elimination of salt-intolerant plants including non-native species, especially common reed (*Phragmites autstralis*).
- Reestablishment of native saltmarsh plants and animals.
- Improvement of estuarine finfish and shellfish habitats and physical access to those habitats.
- Improvement in the natural control of mosquitoes and other nuisance insects.
- Improvement of recreational access: boating, finfishing, shellfishing, bird-watching, etc.

5.1 Targeted Level of Restoration

Restoration of the full natural tidal range has been considered the ecological goal throughout as much of the Herring River floodplain as practicable, including up to the 100-year flood level (9.1 feet NAVD88). However, in certain areas, tidal flooding must be limited to protect existing land uses. Where such land use considerations prevent full tidal range restoration, the goal is to restore the maximum high tide up to the mean spring high-tide level, an elevation of 5.1 feet NAVD88. This elevation has ecological significance as it corresponds with the average elevation of existing high saltmarsh habitat seaward of the

Chequesset Neck Dike. Before the system was diked, the area at or below the 5.1-foot contour would have encompassed about 1100 acres of estuarine wetlands.

Examples of existing land use that might preclude full tidal restoration include, but are not limited to, the Chequesset Yacht and Country Club (CYCC) property in the Mill Creek sub-basin, segments of low-lying roads at several stream crossings, residential properties, and existing wells or septic systems. These issues are discussed in greater detail in Sections 2, 5.4, and 6. Detailed planning for these areas will be subject to comprehensive hydrologic modeling and input from the affected landowners and other residents of the Wellfleet and Truro communities. However, throughout much of the floodplain, current land use may not be in conflict with full tidal restoration to 9.1 NAVD88. For these areas, the tentative plan is to remove all artificial restrictions to tidal flow to restore natural physical, chemical and biological estuarine functions. This would allow storm tides to deposit sediment on the surface of the saltmarshes, allowing them to naturally accrete as sea level continues to rise (Orson et al. 1987).

5.2 Hydrodynamic Modeling

Any modification to the tidal regime of the Herring River requires design and evaluation using sophisticated hydrodynamic modeling. Initial hydrodynamic assessments were conducted in the 1980s (Roman, 1987). More recent studies, *Hydrodynamic and Salinity Modeling for Estuarine Habitat Restoration at Herring River, Wellfleet, Massachusetts* (Spaulding and Grilli 2001) and *Simulations of Wide Sluice Gate Restoration Options for Herring River* (Spaulding and Grilli 2005) provide one-dimensional hydrodynamic modeling (see glossary) information for the Herring River. The 2001 and 2005 reports were prepared as part of the planning for the river restoration project, specifically the planned opening, reconstruction, or replacement of the dike.

The one-dimensional models were developed and applied to evaluate water levels, flows and salinities in the Herring River under a series of alternative sluice and tidal gate configurations in the dike at Chequesset Neck Road. The 2001 study evaluated potential changes in management of the existing Chequesset Road Dike structure, while the 2005 update evaluated potential changes including larger openings in the dike (up to 100 feet), fitted with sluice gates to allow for incremental openings of the culvert. A peer review of these modeling studies, largely substantiating their conclusions, was also conducted in 2006 (Woods Hole Group, Inc. July 2006).

The 2005 hydrodynamic evaluation included data collection by the NPS to measure water levels and salinities on both sides of the dike and flows up the river. Data were collected to characterize flow, as well as salinity and temperature, upstream and downstream of the dike under varying tidal conditions. Data collected were used to develop the model and to compare with model predictions.

To validate the predictions of the alternative scenarios, the model was first applied to current openings at the existing dike and water levels within the Herring River floodplain.

Model predictions were compared with measured values and the report provided several comparisons of observed and predicted water level values that indicated model predictions were well matched to observed data. The model was then applied to predict water levels in the river with several alternative configurations of the sluice and tidegates, ranging from minor modifications to the existing structure to removal of all culvert restrictions. This series of model runs used an average tide to drive water levels throughout the model. Presented in the report are predicted high and low water levels for each alternative configuration. A 100-year storm was applied to a subset of configurations to predict the maximum water level under extreme storm conditions.

The results of these model runs were used in the assessment of restoration alternatives. In general, the hydrodynamic modeling indicated that use of the existing culverts, even if opened to their maximum 18-foot wide capacity, would not result in sufficient tidal flushing to promote estuarine restoration due largely to the inability of the system to drain adequately during the ebb tides. However, installing wider culverts of at least 100 feet in total width in the dike would allow the potential restoration of a tidal regime in the Herring River comparable to that in Wellfleet Harbor (Figure 15).

Comprehensive two-dimensional hydrodynamic modeling (see glossary) is now being completed utilizing recently obtained, detailed topographic and bathymetric data from the Herring River and adjacent floodplain. Unlike the previous one-dimensional modeling, water levels, salinities and velocities at all road crossings and other impediments to tidal exchange will be included in the model. Updated modeling results are expected by spring 2008 and will be used interactively with design alternatives to evaluate multiple scenarios of tidal flows throughout all portions of the Herring River floodplain. In this manner the alternative will be selected that best addresses the appropriate balance between restoring the natural hydrology of the Herring River estuary while protecting existing land uses.

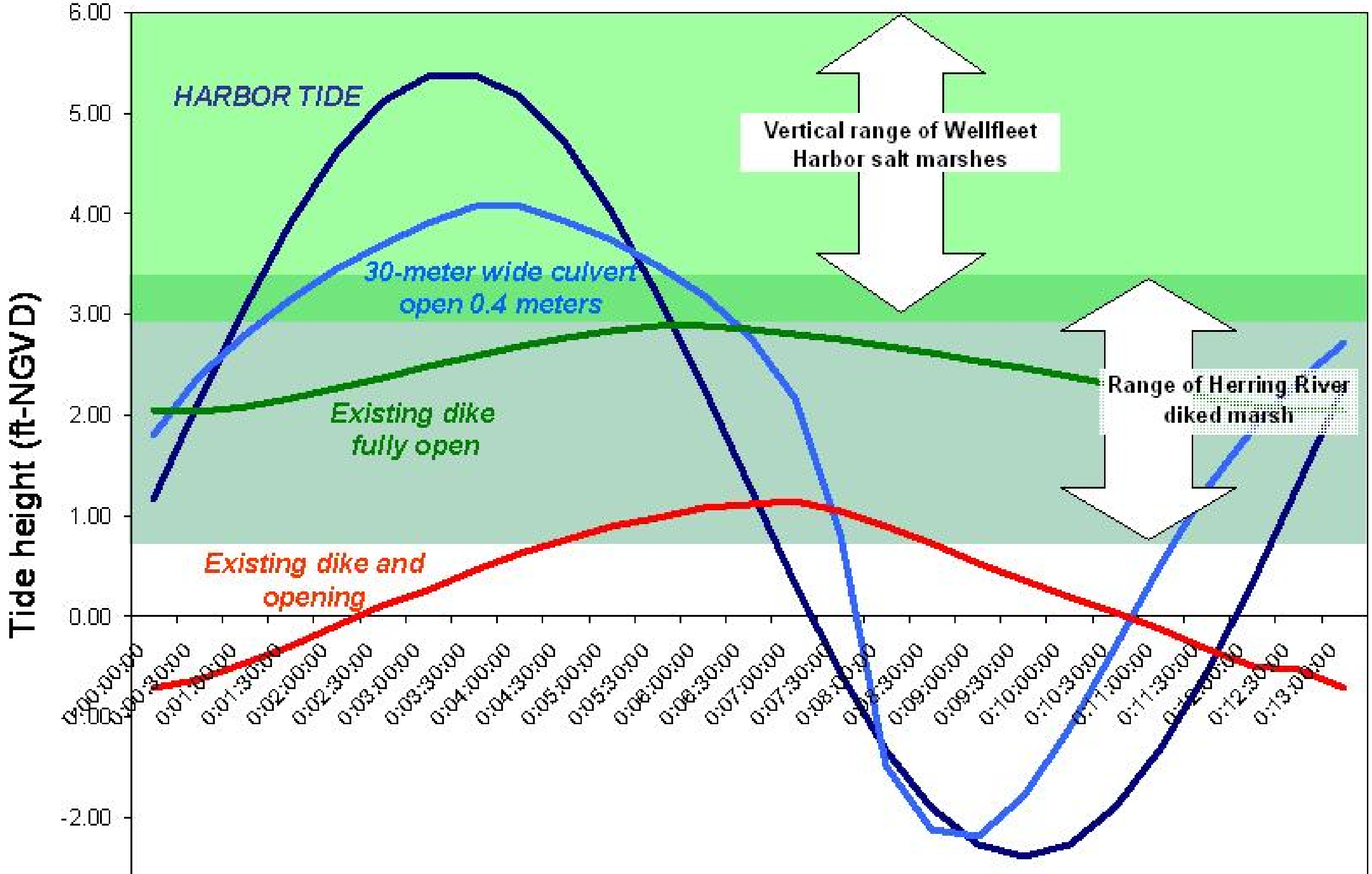
5.3 Description and Assessment of Alternatives

The basic goal of the Herring River Restoration Project is to increase the amount of tidal exchange between the Herring River and Wellfleet Harbor. All alternatives under consideration would allow for the gradual incremental increase in tidal exchange to restore saltmarsh systems and other ecological functions in the river and its floodplain. To accomplish this, significant modifications to the existing dike structure are necessary. Over the past several years four basic alternatives have been considered:

1. No Action: leaving the existing tidegates in place and managing tide heights in the Herring River under existing conditions.

2. Complete opening of the existing culverts to their maximum (18-foot) extent;

Figure 15. One-Dimensional Hydrodynamic Modeling Results



The existing (2007) Herring River dike and culvert opening reduce Wellfleet Harbor's seven-foot tidal range to about 1.5 feet. Hydrodynamic modeling shows that fully opening the existing culverts raises both low and high tide heights, and actually reduces tidal range. In contrast, a much wider culvert system (here 30 meters or about 100 ft) achieves moderately higher high tides, much lower low tides, and thus a six-foot tidal range. Salt marsh productivity increases with tidal range.

Source: Spaulding and Grilli 2005

3. Replacement of the existing dike with a structure with a total opening width of 100-130 feet, fitted with sluice gates to allow to full tidal control and management. The options evaluated for replacing the existing culvert structures include:

- Option 1: Cast-in-place culverts with 8-foot wide cells.
- Option 2: Pre-cast arch spans.
- Option 3: A 2-span bridge structure.
- Option 4: A trestle bridge structure

4. Constructing an open bridge span with no tidal control at the existing Chequesset Neck Road Dike and establishing tidal control with several smaller structures at strategic upstream locations to regulate the limit of tidal flooding as deemed necessary by further hydraulic analyses and public input.

5.3.1 Factors Evaluated During Review of Alternatives:

All alternatives and options under consideration must be evaluated along the following criteria:

- Project costs
- Logistics of construction
- Hydraulics/structural/geotechnical engineering considerations
- Public access to Griffin Island: during and after construction
- Management implications, such as controlling incremental tidal level increases and protection of properties from flooding
- Project aesthetics
- Recreational access for boating, fishing, etc.

5.3.2 No Action Alternative

The No Action Alternative does not achieve the project purpose and need of restoring the estuarine ecological functions to the Herring River system and therefore did not fulfill the mission of the HRTC. Taking no action would result in the continued degradation of the Herring River system including:

- continued encroachment of invasive plant species,
- loss of native plant communities and habitats,

- adverse impacts to water quality and associated effects to finfish, shellfish, and other aquatic biota,
- high populations of nuisance mosquitoes,
- continued subsidence of former saltmarsh peat soils,
- continued decoupling of the coastal floodplain from nearshore waters, depressing the export of energy, nutrients and biota that sustain nearshore productivity (e.g. Wellfleet Harbor) and,
- loss of other natural functions provided by this estuary as described within Section 4.0 of this CRP.

Consequently, the No Action alternative is not considered viable.

5.3.3 Opening of existing culverts to maximum extent

Earlier modeling studies (Roman 1987, Spaulding and Grilli 2001) evaluated the option of completely opening the existing three culverts in the Chequesset Neck Road Dike. The modeling showed that although this would result in a substantial increase in tide heights and area of inundation upstream of the dike, drainage on the ebb tides would be impeded at the dike. Accordingly, opening the existing structure would actually decrease both the tidal range and flushing and therefore not achieve the goal of restoring the functions of the Herring River estuary, while increasing the likelihood of harmful flooding.

5.3.4 Modified tidegate controls at Chequesset Neck Road dike

The more recent hydrodynamic modeling effort (Spaulding and Grilli 2005) indicated that increasing the width of the tidal control openings at Chequesset Neck Road would be needed to attain sufficient ebb and flow for tidal flushing of the estuary. This is logical considering the original width of the mouth of the Herring River across the entire Chequesset Neck is nearly 500 feet. The modeling indicated that a total opening width of at least 100 to 130 feet (versus the current 18-foot width of the existing tidegates) would be sufficient to restore greater than 80% of the tidal regime above the Chequesset Neck Road Dike (see Photo 10). Additionally, the

Photo 10: Digital Image of potential culvert expansion at Chequesset Neck Road.

modeling report recommended that the culvert opening at High Toss Road should be increased to at least 30 feet to remove the restriction to tidal flow at that crossing.

Maintaining primary tidal control at Chequesset Neck Road has a number of advantages. Most notably, it would limit the control, management, operation and maintenance of the tide control structures to one location. It also would limit design efforts and construction-phase impacts to one location. Consequently, this alternative is anticipated to be generally the most efficient and cost-effective when compared to multiple upstream control structures.

A number of options for the design of the modified tidal control structure at Chequesset Neck Road have been developed in a report entitled *Preliminary Analysis for Alternatives for Modifying Tidal Flooding Controls at Chequesset Neck Road Dike* (June 22, 2007) prepared by ENSR and DMJM Harris. The following discussion is taken from that report. The conceptual plans/figures that are referred to in the text are provided in Appendix D of this report.

Four options have been evaluated to a conceptual design level for the alternative that modifies tidegate controls at the Dike. All options assume that the existing culverts will remain in place and in use, although possibly with new sluice gates. The four options are:

- Option 1: Cast in place culverts with eight-foot wide cells
- Option 2: Pre-cast arch spans
- Option 3: A two-span bridge structure
- Option 4: Trestle bridge

The trestle bridge option, comprised of multiple short spans with solid bent structures, was also originally investigated. However it was eliminated from further analysis due to high construction costs and lengthy construction duration associated with additional substructure elements.

5.3.5 Design/construction considerations

Modification of the existing dike and tidal control structures at Chequesset Neck Road requires a detailed understanding and assessment of numerous factors, including:

- the condition of the existing structures, geotechnical conditions at the site,
- traffic control and public access,
- construction duration and logistics,
- aesthetics, recreational suitability, etc.

Preliminary site investigations and previous reports indicate that the visible components of the existing culvert are in good condition and acceptable for continued use (MacBroom 2003). Therefore it has been assumed that the existing culvert would remain in place and would account for 18 feet of the necessary total opening dimension required to achieve the desired the tidal restoration. An evaluation of optional alignments to the existing Chequesset Neck Road Dike showed there were no obvious advantages to altering the alignment or footprint of the dike/roadway. Geotechnical conditions as reported from previous investigations in the 1970s were reviewed and considered in the evaluation of options (Christo Engineers, 1973). Additional geotechnical studies eventually will be needed but will be dependent on the design alternative/option that is ultimately selected.

Initially, building two openings of equal length on either side of the existing culvert was considered to maintain the center of the existing channel. However, for the arch (Option 2) and two-span bridge (Option 3), this meant doubling the construction of abutment units and cofferdams and lengthening the construction duration. This approach was abandoned and the alternative of building all openings on the north side (toward Griffin Island) of the existing structure currently is believed to be the most cost effective.

Due to the light traffic volumes encountered in the off season (September through May), it was assumed that Chequesset Neck Road could be closed for the duration of construction of all options. Traffic would be detoured to an alternate route and construction would be completed in the off season. This would allow for significantly shorter construction duration, due to the lack of staging that would be required if Chequesset Neck Road had to remain open to traffic. Construction costs would also be reduced by eliminating additional support of excavation provisions that would be necessary to keep one lane of traffic open at all times. Closure of the entire roadway precludes the need for placing excavation support at the centerline of the roadway that would be required to maintain one lane of traffic open. The estimated savings of complete road closure during construction is approximately 15% of the total cost of the entire structure.

Many issues could affect the decision of which option should be selected. Without consideration to priority, these include:

Aesthetics – Sluice gates to control tide levels in the Herring River will be placed on the Wellfleet Harbor side of the structure. From a structural stand point, it is far more practical and less expensive to take the hydrostatic force exerted on the sluice gates in the form of pushing force causing bearing pressure on the structure rather than pulling force causing tension on the structure. All three options will be fitted with similar sluice gates. Therefore from the Wellfleet Harbor side, all options have nearly similar aesthetics; however, the Herring River side of the structures will vary in appearance.

Cost – according to preliminary estimates, initial construction costs of all the three options are approximately the same (within 10 percent). All costs shown are based on a 100 foot opening and will increase should a larger opening is selected. Costs given in the following paragraphs only are for the construction of the structure(s) and do not include the affiliated site work which may cost another $2,000,000. The structure cost estimate includes items such as: superstructure and substructure concrete, reinforcing steel, structural steel, bridge bearings, bridge expansion joints, bridge deck membrane waterproofing, asphalt, protective screen, excavations, ordinary and gravel borrows, temporary earth support system, and the sluice gates. The affiliated site work includes: adjustment of the roadway profile and alignment, repavement, reconstruction of roadway slope protections, signage, lighting, drainage, adjustments to sidewalks/shoulders, and landscape/site improvements.

Lifetime cost – this is a function of the future maintenance cost and harder to quantify, however certain options have more maintenance costs over the lifetime of the structure.

Construction Duration – It is currently anticipated that construction of all options would be feasible within one, six to nine-month season (September-May) if the roadway were closed to traffic.

Ease of opening up channel completely in the future – Options 2 and 3 are most conducive to any future decision that completely eliminates tidal controls at the Chequesset Neck Road Dike. However, all alternatives can be designed to accommodate complete removal of tidal control structures in the future should it be warranted.

Consequences of selecting a 130-foot versus 100-foot total opening – Options 1 and 3 easily accommodate the selection of a larger opening without increasing the cost of the structure significantly, whereas increasing the total opening under Option 2 (precast arches), will increase costs significantly.

Allowance for future recreational boat navigation to and from the Herring River and Wellfleet Harbor. The long, dark, relatively narrow and shallow channels inside culverts (Option 1) likely would not be suitable for small canoes or kayaks for safety reasons. Even inspection crews likely would have to treat the culvert channels as confined space and inspect them following established safety protocols. Option 2 (precast arches) and Option 3 (two-span bridge) would lend themselves well to recreational boat uses when the sluice gates are open or removed.

Hydraulics – deep foundations may be required for some options to resist the hydrostatic pressure created by channelizing the water flow. Although all options have a similar total opening, for the box culvert (Option 1), significant friction would develop between the concrete boxes and the surrounding soil that is anticipated to fully resist the hydrostatic pressure. The backfill soil weight placed on top of the culvert boxes further increases the resisting frictional force, making it likely that deep foundation (piles) would not be required. For Options 2 and 3, the friction developed between their foundations and soil may not be sufficient to take the hydrostatic force and thus deep foundation (piles) may be required.

5.3.6 Description of options for modifying the tidegate controls at the existing Chequesset Neck Road Dike

Three options have been evaluated for modifying the tidegate controls. All options assume that the existing culvert remains in place and in use. The plans referenced below are provided in Appendix D.

Option 1 – Culvert

This option involves the use of cast-in-place culverts with 8 foot-wide cells. This option is similar to the existing condition and can easily accommodate any length of total opening selected by adding as many cells as are necessary. The approximate cost of this option is estimated at $2,200,000 (structure only). As noted above, affiliated site work is estimated to cost another $2,000,000. The advantages and disadvantages of this alternative are summarized below:

Advantages:

- Low maintenance cost
- Most conventional
- Adding extra cells could accommodate opening increase from 100 feet to 130 feet.
- No deep foundations required

Disadvantages:

- Aesthetics
- Longest construction duration (approximately nine months)
- Difficult to inspect interior of structure
- No possibility to completely open channel
- No possibility of future recreational boat traffic (due to safety reasons)

Option 2 – Precast Arch

This option consists of either a two or three-span precast arch structure (depending on the size of opening required by the hydraulic analysis). Arch segments are proprietary items that are 8-foot wide segments and can vary in length from 12 to 48 feet (48 feet shown for Option 2). (Please note that the 8-foot wide segments refer to the width in the same direction as the width of the roadway (perpendicular to roadway traffic) as opposed to the length of each arch [48 feet]). Therefore, the entire structure is made of several 8-foot wide segments placed side by side. Wingwall and headwall panels are also precast and would be placed on cast-in-place footings. Cast-in-place channel beds also would be used. Deep versus shallow foundations would be evaluated when additional geotechnical information becomes available, but would most likely be similar to the bridge option. If a structure longer than 100 feet is required, a three-span arch will be required. The approximate cost of this option is estimated at $2,200,000 (two-span structure only). Similar to the other options under evaluation, an additional $2,000,000 is estimated as the cost for affiliated site work. The major advantages and disadvantages of this option are summarized below:

Advantages:

- Aesthetics
- Low maintenance cost
- Shortest construction timeline due to the precast arch elements (approximately 6 to 7 months)
- Can be opened up completely (without gates) in the future
- Possibility of opening for recreational small boat traffic

Disadvantages:

- Gate dimensions are a function of predetermined arch span lengths
- Cost of this option increases significantly if the total opening size is increased to greater than 114 feet (two 48-foot arches plus existing 18-foot wide culverts) as three arches would be required instead of two.
- Not as easy to open to boat traffic as bridge option (Option 3)
- May require pile (battered or vertical) foundation.

Option 3 – Bridge

This option consists of a two-span bridge with either precast concrete box beams or steel girders. Cast-in-place abutments, pier and channel beds would be used. Abutments and piers would be supported by either spread footings or pile foundations, depending on geotechnical requirements. The bridge can easily be lengthened to accommodate an increased opening size without increasing the number of spans. Also, if it is determined later that the existing culvert is not viable for future use, the bridge may be built directly over the existing culvert and the culvert demolished at a future date. The approximate cost of this option is estimated at $2,400,000 (structure only, again with an additional $2,000,000 estimated for affiliated site work). The major advantages and disadvantages of this option are summarized below:

Advantages:

- Aesthetics
- Easiest to completely open up in the future
- Easy to inspect
- Flexibility of accommodating larger openings by increasing span lengths with the least amount of cost increase.
- Easiest to open to boat traffic (highest vertical clearance)
- May be constructed over existing culverts if existing culverts are deemed not viable

Disadvantages:

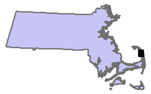
- Longer construction duration than Option 2 (approximately seven to eight months)
- Higher lifecycle cost (due to larger future maintenance cost estimated at 10 - 15% of construction cost)
- May require pile (battered or vertical) foundation.

5.3.7 Open Bridge Alternative with tidegate control at selected up-stream locations

An Open Bridge Alternative with no tidal controls at the existing Dike on Chequesset Neck Road would provide the potential for full tidal restoration (up to 9.1 feet NAVD88) in portions of the Herring Creek floodplain. This alternative also would necessitate the construction of several smaller structures in the upper watershed that would include tidegate controls to regulate the limit of tidal flooding within specific sub-basins (Figure 16). This alternative has been less comprehensively evaluated when compared to the previous alternatives/options. Hydraulic analyses would have to be completed and cost estimates would need to be generated to adequately evaluate the Open Bridge Alternative for comparison with the options that include tidal regulation at Chequesset Neck Road Dike. If this alternative is pursued there also will be additional costs associated specifically with the evaluation. However, in general terms, if this alternative is selected it is thought to have the following advantages and disadvantages:

Advantages:

- There would be unrestricted access under the Chequesset Neck Open Bridge allowing recreational boating and other unrestricted access to and from Wellfleet Harbor and the Herring River Lower Basin.



USGS Topographic Quadrangle
Wellfleet, MA

N

Feet
0 875 1,750 3,500 5,250 7,000

Potential Upstream Tidegate Control Locations under Open Bridge Alternative

Herring River Tidal Restoration Project
Wellfleet and Truro, MA

SCALE	DATE	PROJECT NO.
1:30000	June 2007	04479-003-300

ENSR | AECOM

Figure Number

16

J:\Water\ProjectFiles\P40\4479_CZM\4479003\GIS_May2007\Projects\FigB_UpsTidegate_OpenBridgeAlt.mxd

- An unobstructed bridge span likely would be more aesthetically pleasing from the Wellfleet Harbor side.
- With tidal control now installed at multiple upstream locations, tidal management for an individual sub-basin that needs infrastructure protection, may not limit tidal restoration elsewhere in the system, e.g. Mill Creek likely has a potential maximum tide height to 5.1 feet NAVD88.
- The Lower Basin and any other sub-basin that would not be adversely impacted by tide heights greater than 5.1 feet NAVD88, would gain significant additional sediment accumulation on storm tides, allowing the floodplain wetlands to more effectively keep pace with rising sea level rise, in turn providing increased storm surge protection for surrounding development.

Disadvantages:

- The overall cost of this alternative may be higher than other alternatives because it necessitates the construction of a bridge at Chequesset Neck Road and several structures with tidal regulation at key locations in the upper watershed.
- Without a control structure in place at the mouth of the river, road segments adjacent to the Lower Basin may have to be raised and fortified and the control structures will have to be larger and more robust in order to withstand exposure to storm tides and surges.
- Increased effort and coordination would be required to manage tidegates at more than one location.

Without control gates at Chequesset Neck Road, there would be free tidal flow into and out of the Lower Basin. However, the Herring River restoration plan is built around the concept of "adaptive management", a controlled step-by-step process (see Section 7).

Simply constructing and opening an open bridge in one step would not be consistent with adaptive management, unless it is constructed with temporary control gates that could be removed when no longer needed.

The process of constructing and managing the open bridge option needs further study.

5.4 Known Restoration Design Concerns

5.4.1 Mill Creek

Mill Creek is an 80-acre sub-basin located east of the Herring River and just south of Old Chequesset Neck Road and north of the CYCC. Because Mill Creek is just upstream of the Chequesset Neck Dike, and portions of the drainage are very low, this sub-basin needs special consideration.

The presence of portions of five CYCC fairways and several private residences, near or below proposed maximum spring tide heights (5.1 feet NAVD88) necessitates either the construction of a dike with some degree of tide control at the mouth of Mill Creek or that these features be relocated (CYCC fairways) or protected from increased tidal flooding. In addition, four of the five domestic water-supply wells within the river floodplain that are thought to be sensitive to saltwater intrusion occur in the Mill Creek watershed and may need to be relocated.

All restoration options with tidal control at Chequesset Neck Dike (managed to a maximum tide height of 5.1 feet NAVD88) and the open bridge alternative (full tidal restoration) would permit tidal restoration in Mill Creek. For the open bridge alternative, a new dike and control structure would need to be constructed at the mouth of Mill Creek. Additionally, because of other project constraints (see below), this new dike and structure may have to be managed to mimic existing water level conditions in Mill Creek.

Project partners, including the CYCC, have worked together over the last couple of years and the CYCC now has tentative plans to relocate low fairways above the proposed spring tide heights of 5.1 feet NAVD88. However, funding for this large construction project is uncertain. Further, although engineering studies of the affected private residences have identified several alternatives for flood-protection of the properties, agreement with the owners and funding are not yet attained. These high and potentially prohibitive costs compel a serious analysis of the costs and benefits of including 80-acre Mill Creek in the 1100-acre restoration project and may necessitate consideration of the construction of a dike and water control structure that prevents any increased tidal flooding in the Mill Creek watershed. The type (and eventual cost) of any dike and control structure constructed at the mouth of Mill Creek will be dependent on whether tidal control is implemented at the Chequesset Neck Road Dike.

Blocking all tidal exchange into Mill Creek will avert tidal-flooding effects to low-lying lands within the CYCC and to private residences. However, those portions of the golf-course fairways that were built on the original saltmarsh will still flood during periods of high water table and precipitation. These impacts will increase over the long term as the diked floodplain continues to subside and groundwater rises along with sea level. The Mill Creek floodplain also includes acid-sulfate soils, which presently release acidity and metals into receiving waters. This discharge will continue and may worsen with the blockage of all seawater entry. Tidal restoration in Mill Creek would restore normal saltmarsh geochemical cycling which would cause toxic metals (from acid-sulfate soils) or old pesticide applications to be immobilized. Continued diking and drainage of Mill Creek will cause these toxins to remain active and toxic to aquatic life. Without tidal flushing, mosquito control in Mill Creek will remain difficult and will be exacerbated by the sub-basin's poor water quality. Recent hydrologic work by the U.S. Geological Survey, which may be pertinent to Mill Creek, indicates that wells adjacent to artificially restricted saltmarshes are more vulnerable to saltwater intrusion under diked conditions than with tides restored (Masterson & Garabedian 2007). Most fundamentally, diking off Mill Creek disconnects 80 acres of original tidal wetlands from the marine environment, blocking the exchange of materials, energy and biota that sustain nearshore coastal productivity.

A detailed updated topographic survey of the area around the Mill Creek confluence with the Herring River is needed to initiate the process of an engineering design for a dike/tidegate control at this location. A dike was apparently located across Mill Creek near the confluence with the Herring River as part of a historical tidal gristmill operation. The feature is still identifiable, but the extent to which it is serviceable for the anticipated future needs of tidal control is unknown. Additionally, if the location is deemed to be culturally sensitive, an archeological assessment will have to be completed before construction is initiated. A previous investigation that considered the prospects of a dike across Mill Creek to protect low-lying portions of the CYCC and other developed portions of the Mill Creek floodplain indicated that a pumping system likely would be needed during high precipitation and runoff events to remove impounded fresh water from behind the dike (Nuttle 1990). The option of a Mill Creek Dike will be evaluated in greater detail by the ongoing two-dimensional hydrologic modeling that is occurring as a component of planning for the Herring River Restoration Project (Woods Hole Group 2007).

5.4.2 High Toss Road

High Toss Road extends across the Herring River roughly one mile upstream of the Chequesset Neck Road Dike. It is a key location in the Herring River system to evaluate potential options for controlling tidal flooding, but also has to be evaluated for its importance for maintaining public access to Griffin Island (Figure 16). This unpaved, single-lane road extends across approximately 1000 feet of Herring River floodplain. Currently, a 60-inch diameter, 24-foot long culvert conveys the Herring River beneath High Toss Road near the western end of the dike. Except for the Mill Creek sub-basin, tidal control at High Toss Road could provide a tidal regime for both saltmarsh restoration as well as flood protection for large portions of the upper Herring River basin.

Dependent on the decision on the size and type of tidal control at Chequesset Neck Dike, additional hydraulic analyses would need to be completed for this location. Previous, hydrodynamic modeling (Spaulding and Grilli 2001) has indicated that the culvert opening at High Toss Road will need be increased to at least 30 feet to remove the restriction on tidal flow. Should the Open Bridge Alternative be selected at Chequesset Neck Road, High Toss Road (where it crosses the floodplain from Rainbow Lane west to Griffin Island), would need to be raised from the current elevation of 3-4 feet to between 10-12 feet (NAVD88). To ensure protection from major coastal storms and to prevent flood damage to areas upstream of this location, it is also likely that the entire High Toss Road Dike structure would have to be widened and have appropriately sized tidal sluice gates installed. Engineering designs and the costs for such a structure, although thought to be significant, have not been evaluated.

5.4.3 Pole Dike Road

Pole Dike Creek extends east from the Herring River just upstream of the High Toss Road crossing. Pole Dike Road crosses the creek at a relatively narrow (approximately 400 feet wide) wetland crossing, providing linkage from West Main Street to Bound Brook Island Road. This road crossing is a key location when considering future conditions relative to tidal flooding in the Upper Pole Dike Creek system to the east of this crossing (see Figure 18). Currently, Pole Dike Creek is conveyed under the road crossing via a 32-inch diameter, 40-foot long culvert. It should be noted that the 172-acre Pole Dike Creek wetland area upstream of Pole Dike Road was not included in the 2005 hydrodynamic modeling due to the lack of bathymetric data. The recently updated topographic mapping includes this sub-basin, and further evaluation of this area can now be completed during the two-dimensional hydrodynamic modeling. If warranted, the Pole Dike Road crossing would appear to be a suitable location for controlling tidal flows to the east (upstream). The old railroad dike could also be the site of a tidal control structure; it crosses Pole Dike Creek immediately to the west of the present road crossing.

5.4.4 Bound Brook Island/Old County Roads

As indicated in Figure 18, the Herring River flows under this roadway between the mid- and upper-basin portions of the Herring River floodplain. As such, it is another key location that warrants further evaluation during the consideration of potential tidal restoration options. Tidal controls could be installed at the road crossing over the Herring River just north of Merrick Island, which would regulate tidal inundation over all upstream areas. Alternatively tidal control could be installed at the Bound Brook crossing north of this location which could regulate inundation in the Bound Brook wetlands up into Truro. The recently updated topographic mapping permits further evaluation of this area that can now be completed during the two-dimensional hydrodynamic modeling.

5.4.5 Chequesset Neck Road Dike - Sluice gate considerations

For the application of modified tidegate controls at the Chequesset Neck Road Dike, a series of sluice gates six to eight feet wide and six to ten feet tall, positioned across the width of the channel is anticipated (see Figure 17). A total of 13 to 17 units would be required to span a 100 foot width.

The sluice gates would be fabricated of a cast iron/nickel alloy or stainless steel, with hardware of stainless steel or nickel/copper alloy. Higher quality materials (stainless steel or nickel/copper alloy) are more expensive but more resistant to corrosive environments. Self-contained actuators would limit the amount of ground space needed for installation, and can be hydraulically, electrically, or manually powered. The operating stem and stem cover would extend approximately 14 feet above the top of culvert. Sluice gates may be constructed with a combined flap gate feature to allow for increased flexibility of operating the structure. Flap gates are likely to be useful only when the sluice gates are fully, or nearly fully, closed after a coastal storm when the gates could remain closed and still allow drainage from the inland areas. However, flap gates may also complicate incremental

Figure 17. Sluice Gate Schematic

Sluice Gate Schematic

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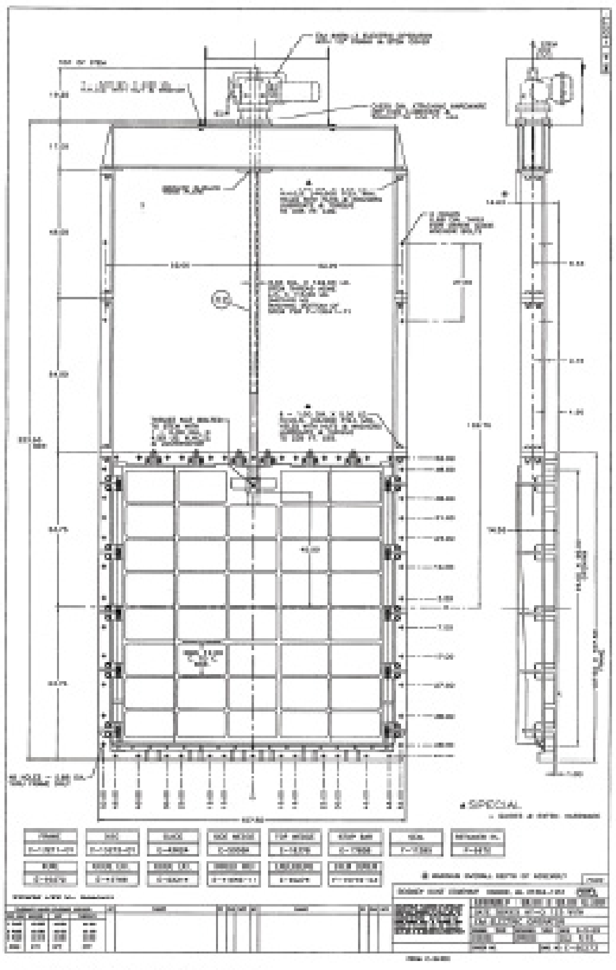


Chesquessett Neck Road Dike Sluice Gate Application

For this application, ENSR recommends a series of sluice gates 6 to 8 feet wide and 6 to 10 ft tall positioned across the width of the channel. A total of 13 to 17 units will be required to span a 100 ft width.

The sluice gates will be fabricated of a cast iron/nickel alloy or stainless steel, with hardware of stainless steel or nickel/copper alloy. Higher quality materials are more expensive but more resistant to corrosive environments.

Self-contained actuators will limit the amount of ground space needed for installation, and can be hydraulically, electrically, or manually powered. The operating stem and stem cover will extend approximately 14-ft above the top of culvert.

Sluice gates may be constructed with a combined flap gate feature to allow for multiple uses of the structure.

restoration, as they would tend to let high volumes of water out at ebb tides and considerable less in at flood tides. Again, an interactive hydraulic model will be needed to assess the needs and operations of the tidegate controls.

5.5 Restoration of Herring River Sinuosity

As described in Section 2, the Herring River was channelized during the first half of the 20th century, in order to enhance drainage for mosquito control. Recent studies (French and Stoddart 1992, Reed et al. 1999, Desmond et al. 2000, Williams et al. 2002) have indicated that restoration of natural sinuosity and channel geometry has significant benefits to the ecological health of channelized tidal river systems. Any restoration of the river's sinuosity likely will occur in the latter phases of the Herring River Restoration Project after comprehensive analysis including hydrologic modeling and construction of new tide control structures.

5.6 Selection of a Preferred Alternative

The selection of a preferred alternative for this large restoration project currently is deferred until all parameters, including the completion of two-dimensional hydrodynamic modeling, have been fully evaluated and the public input required under MEPA and NEPA has been completed (see Section 8 for additional details). Using recently obtained detailed topographic mapping, comprehensive hydrodynamic modeling will be applied to the various alternatives to more fully evaluate the effectiveness of each option. Associated issues, such as those related to low-lying roads, public access, effects on private properties, recreational uses, aesthetics, costs, etc., will continue to be assessed in the selection of a preferred alternative to carry forward into more detailed design phases.

The prescribed process (through the MOUs between CCNS and the Towns of Wellfleet and Truro) includes the formation of the Herring River Restoration Committee (HRRC) and the development of a Detailed Restoration Plan as part of concurrent MEPA and NEPA processes. These environmental review procedures ensure a thorough public process of assessing alternatives and minimizing/mitigating environmental impacts. Subsequent to these reviews, the project will be subject to specific local, state, and federal permitting requirements.

5.7 River Access

The Herring River Restoration Project including its adjacent saltmarshes will create new opportunities for use and enjoyment of the valley. Historically, the Herring River was much used by the local citizenry, including shellfishing, finfishing and recreational boating (canoeing/kayaking; Photo 11). Much of this use is well-remembered by many of the current residents of Wellfleet and Truro. The continued degradation of the river has now made most of these historic uses unappealing, difficult, or impossible.

Photo 11: Recreational boating opportunities are anticipated to improve with tidal restoration.

Restoration of access will be necessary to allow enhanced use of the restored Herring River system. Project design is anticipated to take advantage of the construction phases of the restoration project to create additional access. This access will be balanced with the other important project goals including preserving ecological health of the river and marshes and minimally disturbing wildlife. Any changes in river access will be part of the environmental review of the project.

5.7.1 River Access Locations

Locations where roads cross the Herring River provide potential sites for access to the river for shellfishing, finfishing and a diversity of recreational purposes. These points include enhanced access (including fishing piers) on both the upstream and downstream sides of the Chequesset Neck Road Dike, High Toss Road, Pole Dike Road and Bound Brook Island Road. Each of these crossing points could be the site of construction during the restoration project. There will also be construction projects for low-lying roadways and culvert enlargements. During this construction, river access sites likely could be created and could involve nothing more that a kayak/canoe put-in site with a small area for parking.

5.7.2 Walking Trails

The restoration of the river valley will create many open sites and vistas of great natural beauty. A set of walking trails and view points along the Herring River valley would allow visitors to enjoy those vistas (see Photos 12 and 13).

The creation of a trail system will be a component of the Herring River Restoration Plan and will be consistent with the need to preserve natural ecosystems and the concerns of adjacent landowners.

Photos 12 and 13: Activities such as fishing and hiking will be promoted by the restoration project, and natural vistas of the estuary will be enhanced.

6 Project Impact Assessment and Management Needs

6.1 Introduction

Planning for the implementation of this complicated tidal restoration is arguably the most critical component of the larger project. Sustained management will be needed to minimize the potential for impacts to infrastructure, private property, and existing floodplain habitats as increased tidal flooding is implemented.

As an example, and as discussed below in detail, mature woody vegetation presently existing on former saltmarsh habitats and comprising a very large amount of biomass on the river floodplain, will die as a result of incremental salt water inundation. Without active management, some of this standing dead wood will eventually fall to the ground and likely would enter into waterways, perhaps impeding the movements of river herring and other finfish. The shade produced by standing dead shrubs and trees may also reduce the growth of recolonizing saltmarsh plants, which require high light levels. Finally, the occurrence of an extensive stand of dead woody vegetation, which could persist for many years, may be unacceptable to the public. Therefore, appropriate measures to address this specific type of impact are integral components of project planning.

6.2 Incremental Approach to Restoring Tidal Flow as Part of an "Adaptive Management" Strategy

The modified tidal control structure at Chequesset Neck Road (or at alternative locations) will be designed so that planned tidal flows can increase incrementally over a relatively long time period. A carefully planned monitoring program will be implemented to document changes to floodplain characteristics within the Herring River basin and the smaller sub-basins within the project area. The project design will include easy adjustments to tidal flow in the event of unanticipated and unacceptable changes. The approach of monitoring changes as tidal flows are gradually increased and assessed and reacting to these changes defines an "adaptive management" strategy for this project. Section 7.0 outlines the adaptive management plan anticipated for the Herring River restoration project. Issues that have been anticipated and planned for as part of the adaptive management strategy include impacts to low-lying roads, private residences and the CYCC.

6.3 Private Property and Infrastructure Protection and Mitigation

In the hundred years since the Herring River dike was constructed, there has been considerable intrusion into the old floodplain by roadways, private residences and a golf course. This CRP reflects a decision by the HRTC to work in good faith with any abutter – private or public - affected by the restoration to mitigate and remediate adverse impacts.

In many cases, this process is already well underway. Meetings have been held with private homeowners in Wellfleet to discuss issues concerned with affected residences, septic systems and wells. Similar meetings are planned for homeowners in the Ryder Beach area of Truro. The effects of restoration on low-lying roadways have been explored with the Departments of Public Works of Wellfleet and Truro as well as the Maintenance Division of the CCNS. Concerns of the Wellfleet shellfish community are also reflected in this Plan.

6.3.1 Low-lying public roadways

Following dike construction, the roadways were built within the river floodplain at relatively low elevations. These roads were constructed as public access roadways across streams and adjacent wetland areas.

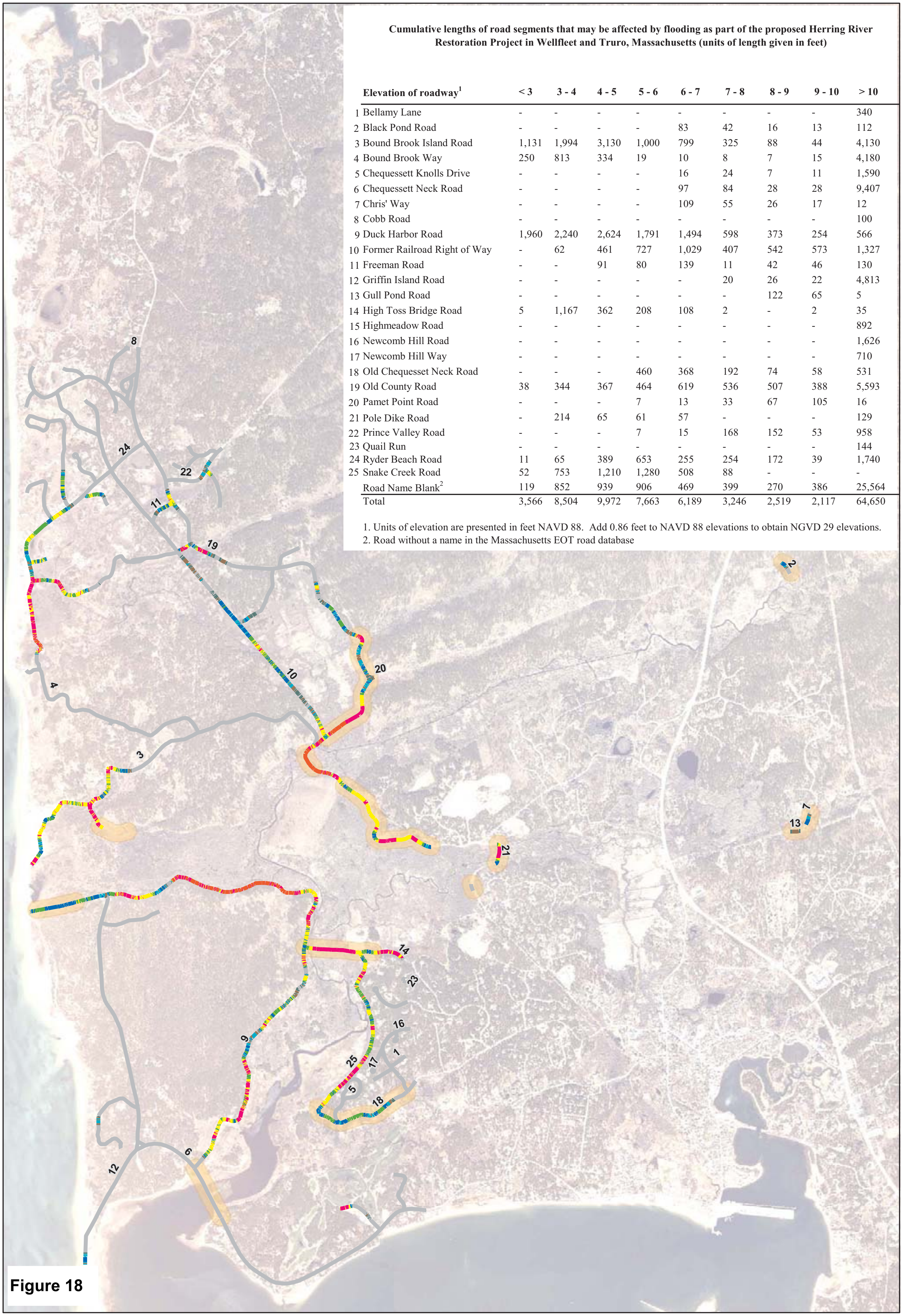
Planned tidal restoration will ultimately result in a significant increase in the high-tide elevations throughout the expansive Herring River floodplain. A number of low-lying public roadways and private properties have elevations below the targeted tidal restoration elevation of 5.1 feet (NAVD 88, see Figure 18). A review of the low-lying roadways in the floodplain has been performed (ENSR July 2007) and the following summary is provided from that report. There are a number of different options to consider for each roadway area that could be affected by restored tidal flows; these include:

- Raising the roadway elevation in its current location
- Realigning the horizontal location of the road to higher ground
- Tolerating a certain degree or frequency of roadway flooding
- Abandoning a specific road or portion of road, subject to Town approvals

Hydraulic analysis would be necessary before any road crossing the river is realigned or raised. Some of these roadways are generally well-traveled and provide important access for residents. Well-made plans for alternative travel routes during any reconstruction work are critical. In several locations the opportunity to restore wetland functions where the roadway may be relocated or abandoned will also be a consideration.

Road Raising

Raising a road involves placing fill to create new road beds with paved or unpaved surfaces above a specific elevation. A number of the low-lying roads in the Herring River are not adjacent to higher ground, but may need widening. This is the case with High Toss Road, Old County Road, and Pole Dike Road. In order to raise these roadways and avoid costly retaining wall construction, the toe of each roadway embankment would need to extend horizontally into adjacent wetland resource areas, such as Bordering Vegetated Wetland (310 CMR 10.55) and Riverfront Area (310 CMR 10.58), which would alter these areas. In addition, raising a road that traverses a wetland area would likely adversely affect tidal



Cumulative lengths of road segments that may be affected by flooding as part of the proposed Herring River Restoration Project in Wellfleet and Truro, Massachusetts (units of length given in feet)

	Elevation of roadway[1]	< 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	> 10
1	Bellamy Lane	-	-	-	-	-	-	-	-	340
2	Black Pond Road	-	-	-	-	83	42	16	13	112
3	Bound Brook Island Road	1,131	1,994	3,130	1,000	799	325	88	44	4,130
4	Bound Brook Way	250	813	334	19	10	8	7	15	4,180
5	Chequessett Knolls Drive	-	-	-	-	16	24	7	11	1,590
6	Chequessett Neck Road	-	-	-	-	97	84	28	28	9,407
7	Chris' Way	-	-	-	-	109	55	26	17	12
8	Cobb Road	-	-	-	-	-	-	-	-	100
9	Duck Harbor Road	1,960	2,240	2,624	1,791	1,494	598	373	254	566
10	Former Railroad Right of Way	-	62	461	727	1,029	407	542	573	1,327
11	Freeman Road	-	-	91	80	139	11	42	46	130
12	Griffin Island Road	-	-	-	-	-	20	26	22	4,813
13	Gull Pond Road	-	-	-	-	-	-	122	65	5
14	High Toss Bridge Road	5	1,167	362	208	108	2	-	2	35
15	Highmeadow Road	-	-	-	-	-	-	-	-	892
16	Newcomb Hill Road	-	-	-	-	-	-	-	-	1,626
17	Newcomb Hill Way	-	-	-	-	-	-	-	-	710
18	Old Chequesset Neck Road	-	-	-	460	368	192	74	58	531
19	Old County Road	38	344	367	464	619	536	507	388	5,593
20	Pamet Point Road	-	-	-	7	13	33	67	105	16
21	Pole Dike Road	-	214	65	61	57	-	-	-	129
22	Prince Valley Road	-	-	-	7	15	168	152	53	958
23	Quail Run	-	-	-	-	-	-	-	-	144
24	Ryder Beach Road	11	65	389	653	255	254	172	39	1,740
25	Snake Creek Road	52	753	1,210	1,280	508	88	-	-	-
	Road Name Blank[2]	119	852	939	906	469	399	270	386	25,564
	Total	3,566	8,504	9,972	7,663	6,189	3,246	2,519	2,117	64,650

1. Units of elevation are presented in feet NAVD 88. Add 0.86 feet to NAVD 88 elevations to obtain NGVD 29 elevations.
2. Road without a name in the Massachusetts EOT road database

Herring River Restoration Project

Summary of Low-Lying Roads Analysis

< 3 ft, 3 - 4 ft, 4 - 5 ft, 5 - 6 ft, 6 - 7 ft, 7 - 8 ft, 8 - 9 ft, 9 - 10 ft, > 10 ft

Road Elevations (NAVD 88)

Roads analyzed using December 2006 survey points, all other roads analyzed using ACOE 2005 LiDAR survey.

0 2,500 5,000 Feet

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exchange between areas upstream and downstream of the road by creating a causeway. Including supplemental surface water conveyance(s) along the raised road would mitigate this type of adverse effect to a degree and be in the interest of the habitat restoration goals of the larger project. In addition, if certain roadways have stormwater collection facilities, then the rims of the structures would need to be raised, or the structures would need to be re-set to match proposed grades.

Road Realignment

Realignment of roads involves relocating segments of road that will be inundated frequently to nearby higher ground. Realignment would entail tasks such as acquiring new rights-of-way for the roads, transitioning relocated road segments into remaining segments, relocating stormwater facilities and other utilities. A prime example of where this approach might be implemented is along Bound Brook Island Road east of Merrick Island, where the existing landscape slopes upward adjacent to the existing road location, and moving the roadway to that higher ground would be a logical consideration. Note that one possibility for a roadway realignment of Pole Dike Road would be to relocate a portion of it to the old rail road grade that extends across the wetland just east of the Pole Dike Creek crossing.

Tolerating Some Degree of Flooding

Some low-lying roadways along the coast have historically been subjected to varying degrees of flooding during coastal storms. When such flooding occurs infrequently, such as during rare-event storms (e.g., 10- to 100-year storm events), the affect on public use may be minimal and can be accommodated. Issues to consider in such instances include public health and safety relative to access. There may be instances where such infrequent flooding could be tolerated. This will require further assessment as more detailed hydrologic analyses are conducted.

Roadway Abandonment

In addition to the low-lying infrequently traveled roadways discussed above, there are several locations where road abandonment is a consideration. These include Snake Creek Road which runs north from Old Chequesset Neck Road along the east side of the Herring River, Duck Harbor Road from High Toss Road to Griffin Island Road, High Toss Road from Snake Creek Road (Rainbow Lane) to Griffin Island, and an unnamed road that runs south from the Ryder Beach parking area toward Bound Brook in Truro. Any decision on such roadway abandonment would be subject to public hearings in the respective towns.

6.3.2 High Toss Road

High Toss Road is an infrequently traveled, unpaved, single-lane road that provides an access from Pole Dike Road to Griffin Island. For the portion of High Toss Road west of its intersection with low-lying Snake Creek Road (Rainbow Lane) and nearest the Herring River channel, wetland habitat abuts both the northern and southern margins of this road. This portion of road is at elevations between 4.0 and 5.0 feet (NAVD 88). Much of the surrounding wetland area is at or just below the road surface elevations. It appears that raising this portion of High Toss Road west of Rainbow Lane to an elevation several feet above the existing elevation would necessitate construction of sloped roadway embankments. This construction would result in substantial alteration to vegetated wetland areas and create a more substantial causeway.

Avoiding or minimizing wetland impacts by road relocation or lateral realignment in this section would not be possible due the lack of adjacent land at higher elevations and a close proximity to existing wetland areas. Using vertical retaining walls in place of embankments to minimize direct wetland alteration, while possible, will very likely be considered cost prohibitive and the causeway that would result may not serve the interests of the larger restoration project.

The elevations along the portion of High Toss Road between Rainbow Lane and Pole Dike Road are primarily near or above 5.0 to 6.0 feet. This portion of road has wetland habitat immediately abutting its northern margin, but generally lacks wetland habitat along its southern margin where lateral realignment onto adjacent higher ground can avoid wetland alteration.

A 60-inch diameter, 24-foot long culvert conveys the Herring River beneath High Toss Road near its western end. Replacing this pipe culvert with a larger conveyance structure, such as an open-bottom arch or box culvert, would alleviate the apparent flow restriction caused by the existing culvert and create better conditions for fish passage. As noted previously, the hydrodynamic modeling conducted to date has indicated that the hydraulic capacity required to provide sufficient ebb and flow at High Toss Road for estuarine restoration warrants a new culvert roughly 30 feet wide. Under the open bridge with upstream control option, this culvert structure at High Toss Road may require a tidegate control that limits upstream tidal flooding and protects private properties.

Another consideration relative to High Toss Road involves its potential use as a temporary access road to Griffin Island and Great Island should Chequesset Neck Road be closed for a period to expedite construction at the dike. Should this use be warranted, upgrades to High Toss Road (as well as Duck Harbor Road) should be evaluated in combination with both this temporary use and long-term needs.

6.3.3 Pole Dike Road

Pole Dike Road is a frequently traveled, paved public road, the northernmost portion of which crosses Pole Dike Creek (see Photo 14). This portion of roadway, which is a relatively short length of road, is at elevations below 5.0 feet (NAVD 88). The densely vegetated wetland areas that border the creek are close to both margins of the road. Avoiding or minimizing wetland impacts by road relocation or lateral realignment would not be possible here due to both the lack of adjacent land at higher elevations and proximity to existing wetland resource areas (although as noted below, the use of the nearby railroad bed is a consideration). It appears that raising the roadway by the necessary number of feet would result in some amount of wetland alteration from construction of sloped roadway embankments. If retaining walls were used in place of sloped embankments, wetland alteration could be greatly reduced or unnecessary.


Photo 14: Pole Dike Creek at Pole Dike Road

A 32-inch diameter, 40-foot long culvert conveys Pole Dike Creek beneath the road. Replacing this pipe culvert with a larger conveyance structure, such as an open-bottom arch or box culvert, would alleviate the apparent flow restriction caused by the existing culvert and create better conditions for fish passage. Again, this structure may be considered another control point for regulating tidal inundation within the 172-acre wetland system upstream of this location along Pole Dike Creek.

The HRTC has also discussed the potential of relocating a portion of Pole Dike Road to the old railroad grade that extends across the wetland just east of the creek crossing. This relocation would actually be a more direct route for a roadway connecting Wellfleet village with the Bound Brook area. The viability of this option is not currently known.

6.3.4 Bound Brook Island Road


Photo 15: Herring River along Bound Brook Island Road

Bound Brook Island Road crosses the Herring River where the river changes from a north-south orientation to an east-west orientation (see Photo 15). This paved road is frequently traveled as compared to High Toss Road. The 60-inch concrete culvert, which conveys the Herring River beneath Bound Brook Island Road, would very likely impose a flow restriction with tidal restoration at this point along the river.

Elevations of the roadway between Pole Dike Road and Old County Road are predominantly below 5.0 feet. The portions at the lowest elevations (below 3.0 feet) are just south of the Herring River crossing where wetlands are in close proximity to both margins. Avoiding or minimizing wetland impacts by road relocation or lateral realignment would not be possible in these locations due to the lack of adjacent land at significantly higher elevations and a close proximity to existing wetlands. Raising the roadway by the necessary number of feet would result in substantial wetland alteration from construction of sloped roadway embankments. If retaining walls were used in place of sloped embankments in these lowest road segments, the potential for wetland alteration would be greatly reduced.

The two segments of Bound Brook Island Road that are at slightly higher elevations -- the portion that abuts Merrick Island and west of the Pole Dike Road intersection – abut lands that are at higher elevations. It may be possible to realign these road segments onto higher ground so that wetland impacts are avoided or minimized. A 60-inch concrete culvert conveys the Herring River beneath Bound Brook Island Road. This culvert may be adequately sized for current conditions. Replacing this pipe culvert with a larger conveyance structure, such as a wide box culvert, may be necessary to accommodate increased tidal flooding. This location is another point where an upstream tide control structure may be considered to control tidal inundation in the upper reaches of the Herring River system.

6.3.5 Old County Road

Old County Road is a frequently traveled, paved public road that crosses the Truro-Wellfleet town boundary. In Wellfleet, this road has two stream crossing locations, one at Bound Brook and the second located to the north at Paradise Hollow. Each is discussed separately below.

Bound Brook Crossing

Along its southernmost portion in Wellfleet this road crosses Bound Brook and the densely vegetated wetland areas that border this stream. This wetland is close to both margins of the road. The elevations of the road in this segment are between 3.0 and 4.0 feet (NAVD 88) and the abutting wetland areas appear to be at elevations just below this range. The 24-inch diameter culvert that conveys Bound Brook beneath the road appears damaged and/or otherwise obstructed.

Avoiding or minimizing wetland impacts by road relocation or lateral realignment would not be possible in this segment of Old County Road due to close proximity of existing wetland resource areas. It appears that raising this section of roadway would result in substantial wetland alteration from construction of sloped roadway embankments. Using vertical retaining walls in place of embankments to minimize direct wetland alteration, while possible along this segment of roadway, will likely be considered cost prohibitive and the causeway-like structure that would result may not serve the interests of the larger project.

Paradise Hollow Crossing

The northernmost portion of Old County Road in Wellfleet crosses a stream within Paradise Hollow, which is tributary to Bound Brook. The low-lying length of roadway at this crossing point is minimal compared to other segments. The elevation at the centerline of the road was surveyed to be 3.37 feet (NAVD88). As with other LLR segments that cross streams, completely avoiding or minimizing wetland impacts by road relocation or lateral realignment would not be possible here due to lack of adjacent land at higher elevations. Using vertical retaining walls in place of embankments to minimize direct wetland alteration and increase the road elevation may be practical in this location.

The existing culvert in this location is an eight-inch diameter pipe. The pipe appears partially obstructed by sediment and other debris. Replacing this pipe culvert with a larger conveyance structure, such as an open-bottom arch or box culvert, may be appropriate here.

6.3.6 Alternative public access routes and emergency access

Planning for reconstruction of the dike at Chequesset Neck Road must also include an assessment of impacts to fire department (FD) and emergency medical technician (EMT) vehicle access routes and alternative access options. Wellfleet's fire chief has raised a number of issues pertaining to FD and EMT vehicle access needs. As presented to the HRTC, these issues are:

- Bypass fire and EMT access will be needed to Griffin Island using High Toss Road and Duck Harbor Road during dike reconstruction. This will require the widening of both roads, strengthening the roads and crossings and ensuring adequate turning radii for fire truck passage.

- To reduce inconvenience to residents and visitors, winter is the preferred time for dike reconstruction.

- Access will be needed to Bound Brook Island as well as maintaining traffic flow on Bound Brook Road, during reconstruction of the Herring River culvert at Bound Brook and at the crossing of Bound Brook itself.

- A detailed survey is needed from Merrick Island north to determine where Bound Brook Island and Old County Roads may need to be raised to avoid flooding at 5-foot tides. Old maps (c. 1890) show a way running north from Pole Dike (starting about where the transfer station is now) to cross the Herring River at the present crossing near Bound Brook, but avoiding the valley north of that point.

- Snake Creek Road, (on the east side of the river, south of the occupied housed down to Old Chequesset Neck Road), is not needed for fire or EMT access (HRTC 2006).

6.3.7 Private Residences

During the past several years of research and consideration of the Herring River restoration proposal, topographic and survey investigations have been directed at locating any private residences that may have structures located at elevations low enough to be directly affected by tidal restoration up to the spring high tide elevation. Several such residences have been located, and studies have been conducted at two locations to identify the potential impacts and recommend mitigation measures.

The same survey searched for on-site wastewater leaching fields/pits that occurred within the 100-year floodplain and thus might be sensitive to increased tide heights (Slade Associates 2006).

Nearly all residences surrounding the river floodplain derive their water supply from private wells set in the fresh groundwater aquifer. There have been concerns that the restoration of seawater flow across the floodplain could cause saltwater intrusion into some of these wells; however, work by US Geological Survey and National Park Service hydrogeologists has shown that very few of these wells could be adversely affected (Fitterman & Dennehy 1990, Martin 2004, Masterson 2004). In fact, most recent modeling indicates that restoring tides to diked marshes, and thereby increasing their average surface-water level, actually causes the adjacent freshwater aquifer to thicken (Masterson & Garabedian 2007), providing even more protection from saltwater intrusion than exists under today's tide-restricted conditions. Further, hydrogeologic studies of fresh/saline groundwater relationships around coastal marshes (summarized in Martin 2004) have shown that saline tidal water does not intrude into the freshwater aquifer, even in unrestricted marshes (See Figure 19). A nearly complete inventory and analysis of all private properties (nearly 200) within 250 feet of the expected spring-tide flooding height in Herring River (See Figure 20) have at the date of this writing found only five vulnerable wells. Meanwhile, the USGS has installed and periodically monitors seven wells that penetrate the freshwater/saltwater interface in groundwater below developed uplands adjacent to Herring River; this monitoring will continue both to test model predictions and to ensure that any rise in the fresh/salt interface, however unlikely, is documented.

6.3.8 Mill Creek Property Owners (Including the Chequesset Yacht and Country Club)

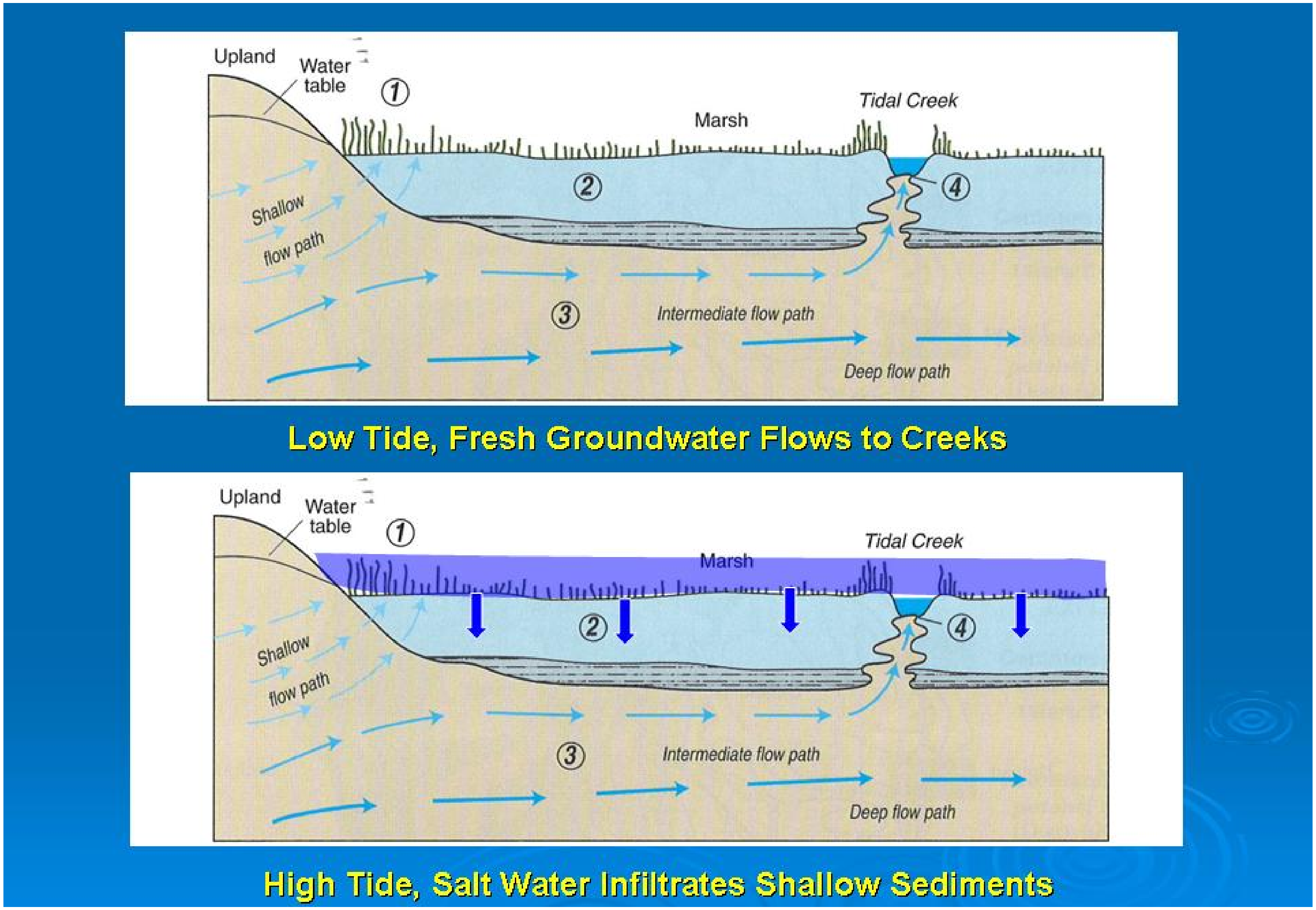
Mill Creek is a tributary of the Herring River, joining the main river stem from the east between Chequesset Neck and Newcomb Hill. As noted in Section 4, there has been significant construction in or adjacent to the Mill Creek floodplain in the past 100 years.

Mitigation plans for private residences – including those in the Mill Creek basin – have been outlined above.

Also in the Mill Creek basin is the Chequesset Yacht and Country Club (CYCC). CYCC is a semi-private, nine hole golf course. It was constructed between 1929 and 1933. The property currently occupies about 106 acres on Chequesset Neck. Property elevations range from below mean sea level to approximately 60 feet.

As a portion of the course lies within the Mill Creek floodplain, reconfiguration of the course has been considered to maintain a playable layout given increased tide heights with

Figure 19. Hydrogeology of Seawater/Freshwater Flows in Unrestricted Salt Marshes



Hydrogeologic studies on Cape Cod and elsewhere show that, even at high tide in unrestricted salt marshes, seawater intrusion is limited to shallow wetland sediments, and does not penetrate the underlying freshwater lens. Freshwater discharges into the estuary mostly along the upland/wetland border and through permeable creek bottoms.

Figure 20. 250-Foot Zone from Anticipated Spring-Tide Elevations

Examination of water quality results from properties near Herring River and from wells close to other nearby Cape Cod embayments, and computations based on the known relationship between water-table height and the depth of the freshwater aquifer (Martin 2004), concluded that only those properties within 250 feet of the Herring River estuary had any chance of being affected by tidal restoration. Further hydrologic analyses showed that only those wells placed within or very close to the original coastal flood plain (less than ten wells) had the potential for saltwater intrusion with tidal restoration.

river restoration. Planning studies have been undertaken and preliminary course plans developed to address this issue (Horsley Witten Group 2006). Plans have considered the construction of four new golf holes in the higher elevations located in the western half of the property to replace areas in the historic floodplain portions of the course that could be impacted by certain proposed tidal regimes. (Partial funding for this move, via Town acquisition of 25 acres using Land bank funds, was approved at Wellfleet Town Meeting, Spring 2005). Discussions and assessments are continuing concerning this area as well as the larger Mill Creek basin area in terms of proposed tidal regimes and selection of the most appropriate alternative. Construction of a new flood protection dike across Mill Creek remains an alternative to afford tidal controls for this sub-basin (See 5.4.1). As described in a previous section, a historic dike was located across Mill Creek extending north of the golf course that could be considered as a location for a new control point, with a separate tidegate structure installed to regulate tide levels in the Mill Creek basin.

6.4 Habitat Management During Project "Transition" Phase

6.4.1 Vegetation management on tidal floodplain

Purpose and Need

The increased tidal exchange between the Herring River estuary and Cape Cod Bay will result in gradual changes to numerous tidal floodplain characteristics. The planned increase in tidal exchange and flooding will be achieved in incremental steps over a number of years. One of the most significant, noticeable, and desirable changes to occur during this period will be to the composition of existing plant communities. There will be a gradual transition from one set of plant community types to another as adjustments to environmental parameters, such as tidal inundation, frequency, soil saturation, and, most notably, salinity occur. The plant community transition from one type to another can be referred to as the "transition sequence". Management of floodplain vegetation, specifically the removal of dead shrubs and trees, during the transition sequence will have the following objectives:

- Encourage restoration/reestablishment of *Spartina*-dominant marsh;
- Improve floodplain aesthetics;
- Removal of woody debris that might impede fish passage;
- Removal of large trees that will eventually die, topple and leave holes on the wetland surface for mosquito breeding.

Predominantly shrubland and woodland plant communities exist on areas of the river floodplain that were once vegetated with salt-marsh plants including salt meadow grass (*Spartina patens),* smooth cordgrass (*S. alterniflora),* black grass (*Juncus gerardii*), and spike grass *(Distichlis spicata)*. Woody plants will not tolerate flooding with seawater, however gradually these effects occur and will ultimately result in standing dead woody debris covering a large portion of the floodplain.

Large volumes of woody debris on the floodplain surface will create two problems. First, much of it could be deposited in the Herring River channel and in the river's numerous tributary streams and ditches. Fallen woody debris and the additional material it will trap could impede the passage of migratory fish and other animals to and from spawning habitats. Second, woody debris laying on the surface of the floodplain may retard the establishment of marsh grasses by preventing seed access to soil surface, preventing germination, and shading or smothering young seedlings when debris is rearranged by tidal flow. More aggressive invasive plants may not be so inhibited and thus could become established first. Therefore, appropriate measures will be needed to manage woody plants in order to protect the fishery habitat and to promote the establishment of natural saltmarsh flora. A vegetation management program will be an integral part of the overall comprehensive incremental restoration management plan.

Defining Vegetation Management Zones

The six individual basins of the Herring River floodplain serve as logical units for planning vegetation management: Mill Creek, Lower Basin, Lower Pole Dike, Duck Harbor, Upper Basin, and Bound Brook (Table 1 and Figure 4). Together, these basins comprise nearly 600 acres in which vegetation management activities are likely necessary. The Upper Pole Dike basin and areas to the east of Route 6 are not included in this estimate, pending results of hydrologic studies that will include these areas.

Table 1: Summary of River Sub-basins in which Vegetation Management Activities will be Occur

Name	Approximate Size (acres)*	Vegetation Communities Present
Mill Creek Basin	26	Predominantly hardwood tree and shrub species with a few acres of pines. *Phragmites* expanses.
Lower Basin	60	Mix of hardwood tree and shrub species. *Phragmites* expanses.
Lower Pole Dike Basin	172	Mix of hardwood tree and shrub species
Duck Harbor	120	Predominantly hardwood tree and shrub species with approximately 12 acres with a mix of pine
Upper Basin	121	Mix of hardwood tree and shrub species
Bound Brook Basin	85	Approx. 85 acres of hardwood tree and shrub species and approx. 6 acres with a mix of pine

*The estimated area of each respective basin which is anticipated to require vegetation management

The NPS has developed mapping based on 2001 MassGIS orthophotography that shows vegetated habitats and the 6-foot and 10-foot contour elevations within the National Seashore boundary (Figure 11). This mapping, along with detailed topographic data and additional hydrologic modeling will be used to target and quantify areas where specific management activities, such as tree removal, will be necessary, identify ecologically sensitive areas, such as rare species habitat, and prioritize areas for management.

6.4.2 Vegetation Management Prioritization, Options, and Considerations

Potential techniques for dealing with woody vegetation include cutting, chipping, and burning. Combining techniques will be considered as part of a flexible vegetation management approach.

Primary and Secondary Management

The vegetation management protocols consist of "primary management" techniques and "secondary management" techniques. Primary management is the cutting of the vegetation, while secondary management is the processing and removal of the biomass that has been cut. Primary management will be accomplished using mechanized tools such as hand-held loppers, chain saws, mowers, brush hogs, or larger, wheeled or treaded machines that both cut and chip. Woody vegetation with diameters of three or more inches could be sold as biofuel, either as chips or logs. Appropriate options for smaller diameter cut woody vegetation will need to be developed.

Secondary management will be accomplished by a number of techniques including the sale of cut hardwood, removal of wood chips, and burning brush and branches. With respect to burning, a plan for disposal or dispersion of ash will be necessary. Access, substrate type, and other factors will need to be considered to determine the most appropriate vegetation management technique.

Vegetation Community Types and Biodegradation

Vegetation cover types mapped in Figure 11 can be grouped into two categories with respect to their management during the tidal restoration process: 1) woody vegetation, i.e. shrubs and trees and 2) herbaceous / reedy vegetation. Woody species include highbush blueberry (*Vaccinium corymbosum*), northern arrowwood (*Viburnum dentatum*) black cherry (*Prunus serotina*), red maple (*Acer rubrum*) and pitch pine (*Pinus rigida*). Herbaceous species comprise common reed (*Phragmites*), cattail (*Typha*), and a wide variety of salt-sensitive sedges, grasses and forbs.

Generally, herbaceous plant species decompose more rapidly without active management, with the possible exception of *Phragmites,* which may require a combination of cutting, mowing, disking, burning, flooding, or herbicide application.

Prioritization and Timing Considerations for Vegetation Removal

Prioritizing the different management zones for vegetation management as well as prioritizing activities within each of the zones will depend primarily upon land elevation. The lower the land elevation within a management zone, the earlier the area will be affected by tidal inundation.

The timing of all vegetation management activities will require careful planning. It will be critical to avoid or reduce unintentional adverse impacts to animal activities, such as seasonal fish migration (begins mid-March) and bird nesting. Tide heights will also determine when certain vegetation removal activities can and cannot occur.

Access Issues and Privately-owned Lands

Portions of the river floodplain where restoration is proposed are on privately owned lands. For this reason, vegetation management activities on certain private lands may not be permitted. Specific protocols for notification, access, and liability need to be developed for management operations on privately owned properties.

Habitat Refuge Areas

To minimize sudden impacts to important habitats, wildlife habitat refuge areas on the river floodplain will be maintained. The purpose of these refuge areas will be to provide an undisturbed buffer for wildlife during the transition phase of the project. The quantity and proposed locations of these refuge areas have not been determined.

Preventing Erosion along upland fringes

Shrubs and trees that vegetate the upland/wetland interface at the edges of the Herring River floodplain provide habitat for many songbirds, mammals and other animals, and stabilize the soil against the erosive forces that may accompany tidal restoration. Because these plant communities occupy a zone of continual freshwater discharge from the freshwater aquifer to the coastal wetland, there is good reason to predict that their roots will remain in freshwater even after tidal restoration and this woody fringe will survive. Therefore, operations to remove woody vegetation from the floodplain should not be extended into this zone.

6.5 Tidal Restoration and Nuisance Mosquitoes

6.5.1 Background

Proposed tidal restoration will be undertaken in steps, but ultimately will cause spring tides to reach at least 5.1 feet NAVD88, inundating a large portion of the wetlands upstream of the Chequesset Neck Road crossing. Although lower low tides are also anticipated, resulting in much-improved drainage, anthropogenic changes to the marsh over the past 100 years could create stagnant-water breeding sites for floodwater mosquitoes. Marsh subsidence, old piles of dredged material and dense vegetation are all likely to impede low-tide drainage. This concern, together with the knowledge that a primary impetus for the original diking in 1909 was a locally intense mosquito nuisance, urges careful planning to avoid worsening the seasonal mosquito nuisance.

Complicating the situation even more is the fact that 80% of the Herring River wetlands are under the management responsibility of the National Park Service, a federal agency that protects native insect populations unless they threaten human health or safety by, for example, vectoring disease as determined by the US Public Health Service. Unless a public health threat develops (unlikely on outer Cape Cod), the Seashore does not have the authority to allow any actions solely intended to control native mosquitoes.

The Cape Cod Mosquito Control Project (CCMCP) does have special authority to undertake mosquito control on NPS lands that were conveyed from the state (Pilgrim and Province Lands State Parks); however, no such authority exists for the Herring River system, where CCMCP has reportedly done no work since the 1980s, except for monitoring adult mosquitoes. Nevertheless, CCMCP remains concerned about currently high mosquito production from Herring River marshes (documented in Portnoy 1984) and is supportive of ongoing efforts to restore tidal flushing, along with water quality and predatory fish populations, as ways to reestablish natural mosquito control. In addition, CCMCP represents the Massachusetts Department of Public Health in monitoring outer Cape mosquito populations for the very insect-vectored diseases that would trigger a US Public Health Service determination of a health emergency justifying active mosquito control. Thus, there appears to be considerable commonality of interests between CCMCP's duties and the restoration project, both in terms of restoring wetland hydrologic and ecological function, and in protecting human health.

6.5.2 Planning for Integrated Mosquito Control

The overarching goal of the restoration project is to restore natural hydrography, an action that should in general improve water quality, tidal flushing, fish access to the wetland surface and, thus, floodwater mosquito control. A well-recognized overarching difficulty is considerable uncertainty, despite hydrodynamic modeling, of wetland flooding depth and duration throughout spring-neap tidal cycles and after major rain events, particularly at small spatial scales. Because tidal restoration is planned to take place in steps, through incrementally opening restricting structures, system hydrology and nuisance insect production can be both monitored and adaptively managed.

Most of the public-nuisance mosquitoes on outer Cape Cod breed in flood waters, which form as pools after heavy rains or high tides on a wetland surface. These pools of floodwater can contribute to a substantial mosquito nuisance if they are inaccessible to fish predators. Because of 100 years of wetland drainage and subsidence, stream channelization, and the invasion of *Phragmites*, shrubs and trees, we are today dealing with a profoundly altered landscape. In this context, habitat manipulations, which would be inconsistent with NPS policy in an unaltered saltmarsh, may be appropriate interim measures to both 1) reestablish some semblance of natural hydrography at Herring River and 2) promote predatory fish access to mosquito breeding sites that have been created artificially by decades of wetland drainage, spoil disposal and wetland subsidence.

6.5.3 Mosquito Monitoring

Monitoring of adult mosquitoes by CCMCP will continue. In addition, CCMCP staff will identify existing (pre-restoration) larval habitat and species composition as well as monitoring both larvae and adults throughout the restoration process to assess the effects of changing hydrography and salinity on mosquito species composition, abundance and habitat use.

Water chemistry within the Herring River marshes is expected to change profoundly with restored tidal exchange, and in ways that greatly affect both immature mosquitoes and their predators; therefore, NPS water-quality staff will work closely with CCMCP in assessing developments in mosquito breeding ecology.

6.5.4 Mosquito Control and Hydrologic modeling

A first step in addressing hydrography and potential mosquito breeding is acquisition of fine-spatial-scale topographic data, accomplished in spring 2007 with aerial photogrammetric survey and mapping of the floodplain at one-foot contour intervals. This will be followed by two-dimensional modeling of tide heights and salinity throughout the 1100-acre floodplain, providing an excellent tool for identifying potential breeding sites and for focusing future surveillance.

Before tidal restoration is initiated, topographic mapping and larvae sampling will be used to map current and potential mosquito breeding sites. Not all can be anticipated, but enough is known of the species composition and breeding ecology of mosquitoes of the outer Cape to predict which species will be favored or suppressed by a predicted change in flooding period or salinity. Success in managing the restoration will depend on the following predetermined contingency plan that is responsive to hydrologic, water chemistry and mosquito monitoring data.

6.5.5 Mosquito Control Plan Implementation

The basic elements of the hydrographic and mosquito contingency plan are as follows:

- Effective mosquito control will be realized as a consequence of restored tidal flushing, water quality and predatory fish habitat. Conversely, poor mosquito control can be seen as one indicator of poor flushing and water quality, and incomplete habitat restoration.

- All work will be undertaken to restore natural tidal flooding and drainage and not solely for the purpose of nuisance mosquito control.

- Because of the long history of tidal restriction, sedimentation and stream channelization, the reestablishment of native saltmarsh tidal flow may require re-digging of filled and/or cut off creek meanders, especially during the period of incremental tidal restoration.

- Because of substantial sediment subsidence, the present wetland surface cannot be considered "natural"; therefore, the reestablishment of natural hydrography may include the digging of creeks where they did not exist before diking.

- As a result of many years of channelization, the river main stem from High Toss Road to Route 6 has a nearly continuous spoil pile along its east bank. This artificial levee will impede water flow onto and off of the wetland surface once tides are restored; therefore, it should be at least interrupted with openings allowing unimpeded water movement.

- No excavation will be allowed in Herring River marshes until pore-water salinity has been restored to at least 15 ppt, to avert production of acid sulfates and mobilization of toxic metals.

- All excavation work will be done using low-ground-pressure equipment, with excavated material spread to a depth of not more than 2 inches to avoid the formation of levees that impede water flow. Some of this material may be used to fill subsided marsh on a trial basis.

- Larvicides will be limited to those with least effect on non-target species (e.g. presently *Bti*) and used only as an interim measure. All pesticide use must be logged and promptly reported per NPS integrated pest management guidelines. If pools of standing water and intense floodwater mosquito breeding occur on the artificially subsided wetland surface, those areas will be subsequently studied and targeted for measures to make future pesticide applications unnecessary.

- The planned removal of vegetation, including invasive *Phragmites*, shrubs and trees, from the floodplain will improve both water and predatory fish movement over the wetland surface and will further promote floodwater mosquito control.

As this strategy for dealing with nuisance mosquitoes is implemented, it will be subject, like all the other actions included in the upcoming detailed restoration plan, to regulatory compliance, oversight, and public input.

6.6 Water Quality

Given poor water quality, including low pH, metals, low dissolved oxygen and high fecal coliform in the river above the dike, there have been public concerns that tidal restoration would extend these problems to harbor waters and shellfish beds below the dike; however, waters seaward of the dike are actually much more vulnerable under existing conditions than with tides restored. The tidal restriction creates all of the above water-quality problems in the diked river, e.g. generating acidity, leaching toxic aluminum, concentrating fecal coliform, and releases these pollutants into harbor waters during ebb tides. With tidal restoration, the volume of clean water will increase by at least a factor of 13, overwhelming (i.e. diluting) any pollutants that flow out of the river during the ebb. Thus, the influence of river water on harbor water should radically decrease with tidal restoration. Also, experiments have shown that resaturating Herring River's acid sulfate soils with seawater will restore normally high sediment pH, eliminating the acidity and metals problem in the river proper within weeks to months (Portnoy & Giblin 1997b).

6.7 Harbor Shellfish Resource Protection Concerns

The potential for water quality changes and sedimentation as a result of increasing tidal exchange between Wellfleet Harbor and the Herring River basin is a very serious concern for restoration advocates, the Town, and shellfish growers, many of whom make a living by raising shellfish on the tidal flats of Wellfleet Harbor. The tidal flats, which occupy a large portion of the harbor, are critical to shellfish habitat protection and aquaculture interests because of the commercial and recreational opportunities they provide (see Figures 13 and 14).

These interests must be protected; however, recent hydrodynamic (Giese, McSherry and Spencer 1994) and sediment-transport studies (Dougherty 2004) specific to Wellfleet Harbor and Herring River should relieve concerns about sediment transport to shellfish beds. Like any tidal embayment, Wellfleet Harbor is flood-tide-dominated. The flood tide velocities are greater than the ebbing velocities. This fundamental fact means tidal borne sediments are naturally carried upstream and are eventually deposited on the marshes. Harbor geomorphic features such as the Gut and Egg Island predated the original dike construction and would not, therefore, be affected by restoration. Thus, the risk of downstream transport of Herring River sediments is small. The design and operation of the new Herring River dike must include consideration of avoiding sediment transport into the harbor. On-going monitoring is in place to provide additional assurance.

6.7.1 Sedimentation monitoring program

The CCNS Natural Resources staff, in cooperation with the Wellfleet Shellfish Department, has baseline data for sediment below the dike and on aquaculture grants at Egg Island, Power's Landing, Mayo Beach, and the town's shellfish propagation bed. The existing monitoring program is expected to continue for the duration of the restoration project as part of the adaptive management approach to impact mitigation for this project. In addition, the marina/harbor sedimentation monitoring program will continue; however, marina/harbor sedimentation is not expected to be affected by the restoration.

6.8 Fisheries Habitat Impact Mitigation

While the restoration project will benefit estuarine fish in the long-run by restoring habitat and a connection with the marine environment, there may be adverse short-term effects, especially to migratory species. The following information and protection strategies are recommended prior to the commencement of the project.

6.8.1 Characterization

The Herring River is the largest estuary on the outer Cape, and therefore provides important spawning, nursery, and foraging habitat for many migratory and resident finfish

(Roman 1987, Wellfleet Comprehensive Plan 1994). Both anadromous herring and catadromous American eels must migrate through the dike and river system to spawn. Currently there is a small (twelve square feet) opening through the dike structure during flood tides, and a larger cross-section during ebb tides when two clapper valves are open; however, these openings are small, compared to the unrestricted river channel, and current velocities are rapid at times through the tidal cycle. Both of these factors limit fish passage (P. Brady, Division of Marine Fisheries, personal communication). Protection of river herring is of great concern during the restoration process. The adults' migration generally peaks in April and May, but can stretch from March to June. After spawning, the adults move seaward between May and June. Fry will move seaward from July through October, but can extend into early December (HRTC Migration Subcommittee Final Report 2006).

6.8.2 Protection Strategies

Restoration activities must be scheduled so as to avoid spring spawning migrations of adults that occur between March and June. The fry can also be protected by holding them back in Herring Pond until potentially harmful construction activities are complete (HRTC Migration Subcommittee Final Report 2006), as has been done during main stream oxygen depletions (Portnoy et al. 1987). Another alternative would be waiting to complete construction in the river until November, when most fry have completed their seaward migration. This would also avoid exposing fish and other wildlife to construction activities and potential sediment resuspension. Water monitoring as well as fish counts could be done to observe river conditions (US Department of the Interior 2007).

Also, as discussed in a previous section, there are habitat impact issues associated with the accumulation of woody debris on the river floodplain that will result during the transition phase of the project. Because woody debris might enter river channels and impede fish passage, the tentative plan is to remove dead woody vegetation from the floodplain.

6.8.3 Structural Considerations

It is imperative that each design option for the replacement tidal control structure at Chequesset Neck Road dike allow for relatively unimpeded, if not entirely unimpeded, passage of migratory fish. This must also be a consideration for the design of any upstream tidal control structure constructed along critical fish passage routes. The options that have been presented in Section 5 each provide a design concept that allows for unimpeded fish passage.

7 Operation / Maintenance Plan and Monitoring Program

As has been stressed throughout this document, the implementation of the Herring River restoration project will require a long-term, systematic plan for monitoring, management, and maintaining the tidal control structures and other features of the system. This section is intended to provide an overview of the currently envisioned program for this management. As an *adaptive management* plan, it is stressed that the nature and timing of specific management actions will depend on environmental monitoring at each step of the restoration process and upon the system's response with respect to project objectives.

7.1 Adaptive Management and Regulation of Tidal Flows

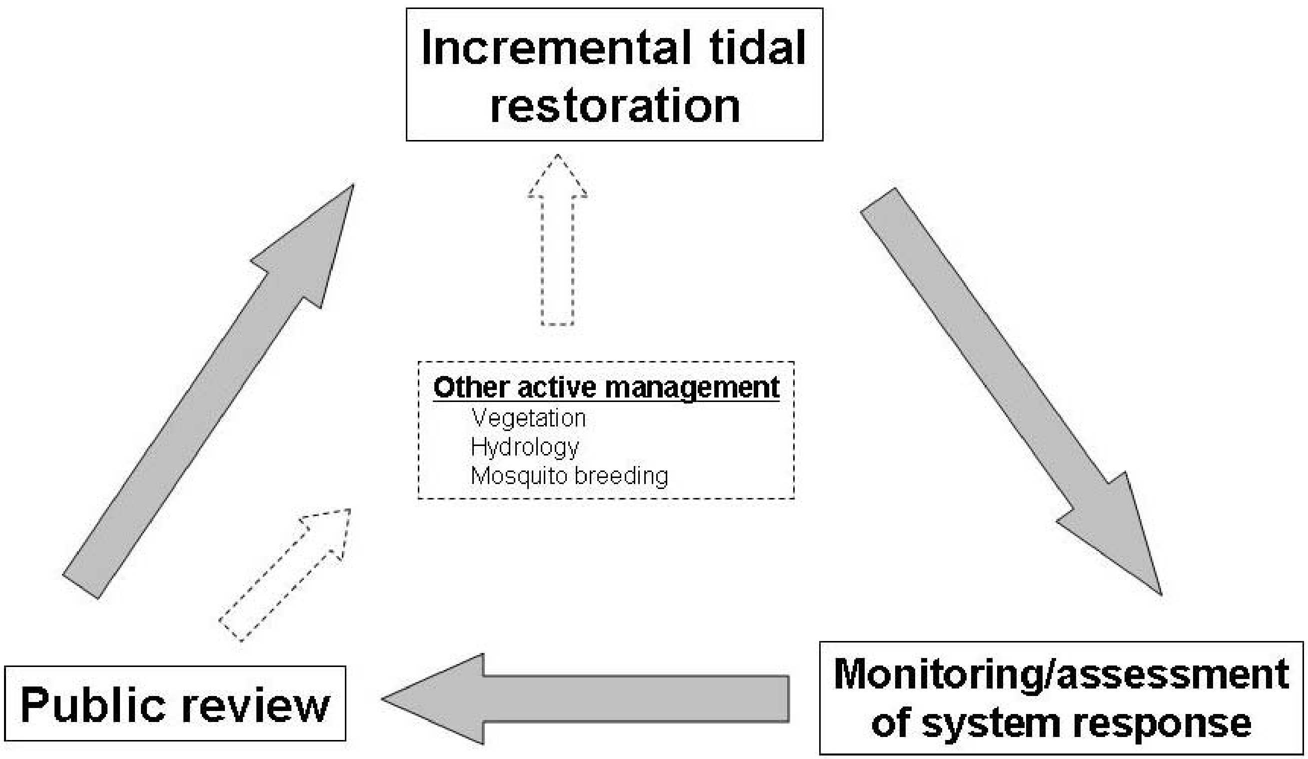
As discussed previously, the modified tidal control structure at Chequesset Neck Road (or at alternative locations) will be designed so that increases to tidal flows can be undertaken in an incremental fashion, i.e. in small steps, over a relatively long time period. During this time period, multi-disciplinary environmental monitoring that is already underway will continue. The design of tide-control structures will allow adjustments in tide heights if monitoring shows changes that are inconsistent with project objectives. The model below (Figure 21) reflects the iterative process of adapting the management protocol to the observed results. It is proposed that incremental changes in tidal flow will be the responsibility of the Herring River Restoration Committee (HRRC), including the Towns of Wellfleet and Truro, and the National Park Service. This responsibility will be explained by the Memoranda of Understanding (MOUs) developed between the Towns and the NPS. An Operation and Management Agreement will be developed in accordance with the MOUs.

The components of the adaptive management plan for the Herring River project, which will be incorporated into the Operation and Management Agreement, are summarized as follows:

Restoration Objectives: the foundation of any such plan is a clear presentation of objectives, such that decisions and directions are formulated with continual reference to those goals.

Physical Controls: under any of the alternatives being considered for implementation, there are a number of variables to consider in controlling and managing tidal regimes, including where (within the river system), when and how much to increase tidal exchange. Given the presence or absence of social constraints (e.g. low-lying roads, the CYCC, etc.) some sub-basins can accommodate greater tidal range than others; thus physical controls need to be strategically located and sized. As mentioned above, both ecological (fish migrations) and social (summertime road use) constraints should dictate the timing of adjustments in tidal exchange. Step-wise culvert openings could be suspended or

Figure 21. Conceptual Model of an Interactive Adaptive Management Process



See text (p.95) for explanation.

implemented more slowly if monitoring indicates undesirable results. In short, the Herring River proposal contains numerous opportunities for application of control measures to manage the tidal regime under any of the proposed scenarios.

Hypothesized System Response: any of the tidal control scenarios will allow for projections of how the Herring River floodplain will respond in terms of tidal regime and associated effects to vegetation, sediment, water quality, flooding of properties, etc. An important step in the establishment of the tidal control scenarios will be to predict these effects to the degrees possible via modeling and other scientific/engineering applications.

Monitoring Projected Change: as each tidal regime adjustment is implemented, systematic monitoring will be conducted to measure environmental responses. Some of the components of the anticipated monitoring are summarized below.

Technical and Public Review of Monitoring Results: technical and public review of the Herring River restoration project has been a priority since inception. This aspect will continue to be an important part of the process during implementation and monitoring.

Criteria and Protocol for Changing Physical Controls and Managing Vegetation: vegetation management issues are discussed in Section 6 of this document; the criteria for implementing such management as well as for changing the physical controls will be further developed as part of the Detailed Restoration Plan. This will include the protocol for making such physical adjustments and implementing vegetation management.

In addition to the adaptive management issues that pertain to the Herring River floodplain overall, there are particular ecological and social concerns that need to be considered within specific sub-watershed areas. The matrix below (**Table 2**) attempts to summarize these, although it should be recognized that other issues may emerge. It is anticipated that the adaptive management program will consider and adjust for each of these concerns in site-specific detail.

7.1.1 Salt water intrusion

Nearly all residences surrounding the river floodplain derive their water supply from private wells set in the fresh groundwater aquifer. There have been concerns that the restoration of seawater flow across the floodplain could cause saltwater intrusion into some of these wells; however, work by US Geological Survey and National Park Service hydrogeologists has shown that very few of these wells could be adversely affected (Fitterman & Dennehy 1990, Martin 2004, Masterson 2004). In fact, most recent modeling indicates that restoring tides to diked marshes, and thereby increasing their average surface-water level, actually causes the adjacent freshwater aquifer to thicken (Masterson &

Table 2: Herring River Ecological and Social Concerns by Sub-watershed

Issues	Mouth of River	Lower Basin	Mill Creek	Lower Pole Dike Creek	Upper Pole Dike Creek	Duck Harbor	Bound Brook	Upper Basin	Pole Dike Creek above Route 6	Main Stem above Route 6
Marine biota	X	X	X	X	X	X	X	X	X	X
Floodwater mosquitoes		X	X	X	X	X	X	X	X	
Golf course flooding			X							
Low-lying roads		X		X	X		X	X	X	
Migratory fish	X	X	X	X	X			X	X	X
Phragmites control		X	X				X			
Private structures		X	X		X					
Sediment & aquaculture	X	X								
Subsidence & hydroperiod		X	X	X	X	X	X			
Surface water quality	X	X	X	X	X	X	X	X	X	X
Groundwater quality		X	X		X		X			
Woody plant dieback		X	X	X		X	X	X	X	
Rare species - saline	X	X	X	X	X	X	X	X		
Rare species - freshwater			X	X	X		X	X		X

Garabedian 2007), providing even more protection from saltwater intrusion than exists under today's tide-restricted conditions. A nearly complete inventory and analysis of all private properties (nearly 200) within 250 feet of the expected spring-tide flooding height in the Herring River has at the date of this writing found only five vulnerable wells. Meanwhile, the USGS has installed and periodically monitors seven wells that penetrate the freshwater/saltwater interface in groundwater below developed uplands adjacent to the Herring River; this monitoring will continue both to test model predictions and to ensure that any rise in the fresh/salt interface, however unlikely, is documented.

Monitoring Results

The depth of the fresh/salt groundwater interface did not change between 1990 and 2003, meaning that the thickness of the freshwater aquifer did not change (Martin 2004).

Previous USGS studies showed that there was little chance that restoring the river would affect the private wells, as there were 20 meters of freshwater between the domestic well screens and the salt/freshwater interface (Fitterman & Dennehy 1991). Further study used computer modeling of groundwater flow to predict the thickness of the freshwater aquifer for different simulated conditions for opening or removing tidal control structures. The study showed that the freshwater aquifer would thicken, not thin, under all restoration scenarios unless it was assumed that undiluted seawater extending throughout the floodplain; this last is a highly unrealistic scenario, however, because discharging fresh groundwater will continue to mix with tidal seawater and yield a typical gradient in salinity from the mouth of the river upstream (Martin 2004).

7.1.2 Water column pH, and metals

Water quality is tested monthly at ten stations in the Herring River in locations from High Toss Road to Egg Island, including in the major tributary streams.

Monitoring Results

Monitoring has shown that the pH of the river is much lower (i.e., more acidic) upstream of the dike, especially in the vicinity of acid sulfate soils (Figure 8). PHs as low as 4 have been recorded within the river system, in contrast to the pH 8 in Wellfleet Harbor. Low pH can be directly toxic to fish, and can cause aluminum and other metals to leach from native clays in concentrations that further stress aquatic animals (Soukup & Portnoy 1986).

7.1.3 Fecal coliform

The presence of coliform bacteria has routinely necessitated the closure of shellfish beds at the mouth of the river. Shellflishing is currently prohibited upstream of the dike and for about 1000 meters downstream (Figures 9 and 13). Fecal coliform accumulate around tidal restrictions because of poor flushing (Portnoy & Allen 2006). The effects of the dike further compound the situation as lower salinity, lower pH, and lower dissolved oxygen, all found upstream of the dike, extend the lifetime of fecal coliform (Portnoy & Allen 2006). Fecal coliform bacteria are monitored at nine different surface water stations in the Herring River in locations from High Toss Road to Egg Island.

Monitoring Results

Monitoring by NPS indicates that the highest concentrations in river sediment occur from 200 to 1,400 meters above the dike.

7.1.4 Tide heights, salinity, and oxygen content

Tide heights, salinity, and oxygen levels in the river are monitored from June through September at a sampling station located approximately 1,200 meters above the dike, and in Wellfleet Harbor in the channel between Egg Island aquaculture beds and Great Island. In addition, APCC volunteers are monitoring porewater salinity in the root zone along wetland transects both seaward and above the dike structure to establish a baseline.

Monitoring Results

Monitoring indicates that tide heights, surface-water salinity, and dissolved oxygen are all at lower levels in the river upstream of the dike due to the tidal flow restriction. The entire main stream reach from the mid-Lower Basin to Route 6 is subject to summertime dissolved oxygen stress (Figure 6). Porewater salinities decline greatly with distance upland from the creek bank in the diked river.

7.1.5 Wetland water levels

Wetland water levels are lower throughout the floodplain due to diking and are predicted to recover once tides are restored (Spaulding & Grilli 2001, 2005). Wetland vegetation and biogeochemical cycling have been altered radically by the depression in wetland water levels since 1909, witness the extent of upland tree species (Figure 11) and acid sulfate soils (Figure 8) in the original saltmarsh. Currently, monthly monitoring occurs at five stations in the system.

7.1.6 Wetland vegetation and invasive species

Limiting tidal flow has resulted in the conversion of many tidal marsh habitats into shrub-dominant wetland habitats (Fig. 11) because the natural tidal flow regime has been eliminated. Currently, monitoring of wetland plant communities occurs at three year intervals and will be performed at two-year intervals following modification of the tidal control structure. Monitoring includes a minimum of four plant community sampling transects seaward of the dike and a minimum of ten sampling transects above the dike.

7.1.7 Wetland surface sedimentation

Monitoring sedimentation on the diked Herring River floodplain is especially important because much of the marsh plain has subsided about 80 cm and is now, relative to sea level, about a meter below the unrestricted saltmarshes seaward of the dike (Portnoy & Giblin 1997a). If the elevation of the wetland does not increase at a rate equal to or exceeding sea level rise, the sediment may remain waterlogged throughout the tidal cycle, discouraging the re-establishment of saltmarsh plants.

In order to monitor sediment elevation change, sediment elevation tables (SETs) are used; and in order to monitor sediment accretion, feldspar marker horizons are utilized (Northeast Coastal and Barrier Network 2005). Both of these devices were installed in 2000 at three tidally unrestricted sites downstream of the dike, three in *Phragmites* communities in the lower basin, and three in wetlands above High Toss Road.

7.1.8 Shellfish bed sedimentation

There is concern that tidal restoration may affect sedimentation seaward of the dike where there are extensive shellfish beds. Both hydrodynamic studies estimating current velocities (Spaulding & Grilli 2001, 2005) and an analysis of past and current sedimentation patterns in the river and Wellfleet Harbor (Dougherty 2004) provide strong evidence that there will be little change in sediment transport seaward of the dike structure with tidal restoration. Nevertheless, NPS surveyed sediment grain size and organic content on aquaculture beds at Mayo Beach, Egg Island, Powers Landing and the town propagation beds in 2004, and plans to repeat the survey in 2007, with help from Wellesley College.

7.1.9 Shellfish

While monitoring the sediment quality of shellfish beds has been important, it is also important to monitor shellfish species occurrence and densities in the Herring River estuary. Routine shellfish bed closures gained the attention of the public and monitoring showed declining counts of shellfish in areas upstream of the dike (Roman 1987). Monitoring is performed in areas below (harbor-side) and above (upstream) the dike with a baseline year of 2005.

7.1.10 Estuarine fish

Estuarine fish monitoring occurs three times per year below and above the dike as well as along the Herring River upstream of High Toss Road.

Monitoring Results

Monitoring in the mid-1980s (Roman 1987) and more recently as part of the CCNS Inventory and Monitoring Program (Gwilliam 2005) showed that fish diversity and abundance declined with distance above the dike structure.

7.1.11 Birds

Previous studies (Roman 1987) have shown that diking has caused the occurrence of songbirds to become more frequent, while waterfowl and shorebird species have declined in abundance, with the shift from original open marsh and mudflat habitats to shrubs. Pre-restoration monitoring has been performed since 2004 by staff and qualified volunteers from the Massachusetts Audubon Society. Monitoring is completed at five locations in the lower Herring River, including Merrick Island at the old bridge, High Toss Bridge to the north, High Toss Bridge to the south, Herring River Dike to the north, and Herring River Dike to the south. All locations except at Merrick Island are monitored year-round on a monthly basis. Merrick Island counts take place weekly and only during the spring breeding season, from April to June.

The data compiled through the Audubon Society will become available in the fall of 2007.

7.1.12 Mosquitoes and other insects

Adult mosquito monitoring is performed by the Cape Cod Mosquito Control Project (CCMCP) weekly from June to September at a station near High Toss Road. It is anticipated that the CCMCP will continue its monitoring program, but will likely modify its protocols in response to post-restoration conditions and/or as per National Park Service recommendation. The monitoring of other insects may also be incorporated into a National Park Service program.

8 Overview of Federal, State, Regional, and Local Environmental Compliance

8.1 Federal Agency Reviews and Authorizations

8.1.1 National Environmental Policy Act (NEPA)

The *National Environmental Policy Act* (NEPA) requires federal agencies to integrate environmental values into their decision making processes. The two cornerstones of NEPA are public involvement, and evaluating the environmental impacts of alternative approaches before deciding on a course of action. Federal agencies facilitate public involvement and document NEPA compliance through preparation of an Environmental Assessment (EA) to determine if the project will result in significant environmental impacts. If the EA demonstrates that the project will not result in significant impacts, the agency concludes the EA process by issuing a Finding of No Significant Impact (FONSI). If the EA indicates that the project will result in significant impacts, the agency proceeds with a more in-depth analysis of alternatives and impacts -- this more in-depth process is documented in an Environmental Impact Statement (EIS). When an agency knows that significant impacts are likely, or when there is a significant level of controversy, the agency will often go directly into the EIS process rather than prepare an EA first. When an EIS is finalized, the agency's decision is documented in a Record of Decision (ROD).

Comments from other federal agencies, state and local agencies, and the public-at-large are considered throughout the NEPA process. When multiple Federal agencies are involved in a project, a single EIS should be developed cooperatively. Integrating NEPA with other compliance processes is encouraged where ever feasible and efficient (e.g., Army Corps of Engineers permitting; state, regional and local consultation). The major steps for the EIS process are summarized below:

- Publish a Notice of Intent (NOI) to prepare an EIS
- Request public input on all aspects of the proposed analysis (types of impacts to assess, information to consider, alternatives to consider, etc)
- Evaluate alternatives
- Submit Draft EIS (DEIS)
- Finalize the EIS based on public comments received on the DEIS
- Issue a ROD

Is NEPA Permitting required for the Herring River project?

Yes, as the project includes Federal action through the CCNS and/or other Federal agency involvement and/or funding.

8.1.2 Clean Water Act Section 404 / Rivers and Harbor Act Section 10

CWA § 404 regulates discharge of dredged and fill material to waters of the United States, including wetlands under federal jurisdiction. RHA § 10 regulates activities along navigable rivers and waterways. Both are simultaneously administered by the Army Corps of Engineers.

Types of §404 / §10 Permits include the Individual Permit and the State Programmatic General Permit (PGP). In Massachusetts, there are two types of PGPs:

Category One -- Non-reporting. Eligible without screening (provided authorizations are obtained),

Category Two -- Requires screening and a written determination of eligibility under the General Permit by the Corps after coordination with the U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, National Marine Fisheries Service, and the Massachusetts Coastal Zone Management (CZM) Office.

The Corps reviews all complete applications for Category Two projects at interagency screening meetings (or "joint processing" meetings) with the State and Federal resource agencies to determine whether such activities may be authorized under the PGP.

Is CWA § 404 / §10 Permitting required for the Herring River project?

Yes, as fill in jurisdictional wetlands will be required for new tidal crossings, and a change in tidegate configuration is being proposed. As a pro-active (non-compensatory) saltmarsh restoration project, one or more PGP Category 2 permits are likely to be required.

8.2 State Agency Reviews and Authorizations

8.2.1 Massachusetts Environmental Policy Act (MEPA)

Massachusetts Environmental Policy Act (MEPA) is the state equivalent of NEPA. The purpose of MEPA is to provide meaningful opportunities for public review of the potential environmental impacts of projects for which state agency action is required, and to assist each agency in using (in addition to applying any other applicable statutory and regulatory standards and requirements) all feasible means to avoid damage to the environment or, to the extent damage to the environment cannot be avoided, to minimize and mitigate damage to the environment to the maximum extent practicable.

MEPA considers projects which may impact land, rare species, wetlands, waterways, and tidelands, water, wastewater, transportation, energy, air, solid and hazardous waste, historic and archeological resources, Areas of Critical Environmental Concern, and new, or modifications to existing, environmental regulations. MEPA is a multi-tiered process:

The Environmental Notification Form (ENF) provides basic information on the project. The ENF process usually includes on-site "Scoping Session" to solicit public and agency comments. Less complex or environmentally benign projects can receive a Certification from the Secretary of Environmental Affairs that MEPA compliance in adequate after this step.

MEPA Regulations include specific thresholds that can trigger the need for an ENF or Environmental Impact Report (EIR) (i.e., creation of more than ten acres of impervious surface area requires an EIR; creation of five to ten acres requires an ENF and, upon ENF review, an EIR is at the Secretary of Environmental Affairs Discretion).

Draft Environmental Impact Report (DEIR): The EOEA Secretary's Certificate will contain a "Scope" for the DEIR. Based on agency and public comments, the Scope will identify areas that were not adequately described in the ENF and require specific studies and details.

Final Environmental Impact Report (FEIR): Following the public comment period on the DEIS, the applicant incorporates information required by Secretary's Certificate and agency/public comments. Before final compliance, additional comments and requests for further information may be made; depending on complexity a Supplemental EIR may be required.

The ENF to FEIR Process can by lengthy (1-2 years or longer), complex, and expensive.

Is MEPA Review required for the Herring River project?

Yes, as the project includes State funding, other state permits and work within the Wellfleet Harbor Area of Critical Environmental Concern.

8.2.2 Massachusetts Waterways Licensing Program – (M.G.L. c. 91)

The Massachusetts Waterways Licensing Program (Chapter 91) is the Commonwealth's primary tool for protection and promotion of public use of its tidelands and other waterways. The Commonwealth formally established the program in 1866, but the philosophy behind Chapter 91 dates back to the earliest days of the Massachusetts Bay Colony, most notably in the Colonial Ordinances of 1641-1647. The Colonial Ordinances codified the "public trust doctrine," a legal principle that dates back nearly 2000 years, which holds that the air, the sea and the shore belong not to any one person, but rather to the public at large. The oldest program of its kind in the nation, Chapter 91 regulates activities on both coastal and inland waterways, including construction, dredging and filling in tidelands, great ponds and certain rivers and streams.

Is Chapter 91 review required for the Herring River project?

Yes, due to new structures (culverts) over tidelands, and modifications to previously licensed or unlicensed structures.

8.2.3 Water Quality Certification

Clean Water Act 401 Water Quality Certification (WQC) is required under federal law for certain activities in wetlands and waters. This law gives states the authority to review projects that must obtain federal licenses or permits and that result in a discharge to state waters. The purpose of state 401 review is to ensure that a project will comply with state water quality standards and other appropriate requirements of state law. WQC is required for any project that also requires an Army Corps § 404 wetland permit.

Is WQC Permitting required for the Herring River project?

Yes, as a §404 permit is required.

8.2.4 CZM Consistency Review

While the Massachusetts Office of Coastal Zone Management (CZM) is not a permitting agency, it does have the authority to review federal activities in the Massachusetts coastal zone to ensure that they are consistent with CZM program policies. Consequently, any coastal project that requires a federal license, is implemented by a federal agency, or is carried out with federal funds must be approved by CZM before the federal activity can take place. Overall, CZM's Federal Consistency Review gives the Commonwealth the power to ensure that federal actions meet state standards.

Is CZM Consistency Review required for the Herring River project?

Yes, as a federal activity, the project needs to be certified as consistent with MA Coastal Zone policies.

8.2.5 Massachusetts Wetlands Protection Act (M.G.L. c. 131 § 40)

The Massachusetts Wetlands Protection Act (WPA) is the state equivalent of federal Clean Water Act S. 404. Jurisdiction is with MA Department of Environmental Protection (DEP) and is administered by local Conservation Commissions. The WPA Identifies Inland and Coastal jurisdictional resource areas and specific wetland functions that are to be protected for the public benefit. The application process includes:

- Applicant files a Notice of Intent – Includes detailed delineation of wetland resource areas, quantified impacts to wetland resource areas, and plans for mitigating unavoidable impacts.
- The Conservation Commission holds a Public Hearing(s).
- At its discretion, the Conservation Commission or its Agent may schedule a Site Visit.
- Following the completion of review, the Conservation Commission issues an Order of Conditions approving or denying the work.

- The Order of Conditions may be appealed, and DEP may issue Superseding Orders.

Is WPA Permitting required for the Herring River project?

Yes, due to probable unavoidable impacts to state wetlands associated with fill for tidal crossings, dike reconstruction, and other alterations.

8.2.6 Massachusetts Endangered Species Act (M.G.L. c. 131A)

The *Massachusetts Endangered Species Act* (M.G.L c.131A and regulations 321 CMR 10.00) protect rare species and their habitats by prohibiting the "Taking" of any plant or animal species listed as endangered, threatened or species of concern by the MA Division of Fisheries & Wildlife. Taking includes the harassing, killing, trapping, collecting of species as well as the disruption of nesting, breeding, feeding or migratory activity, including habitat modification or destruction. There are three types of filings under MESA that are coordinated through the Natural Heritage and Endangered Species Program (NHESP) at DFW: 1) MESA Information Request for rare species information, 2) MESA Project Review, and 3) the Conservation and Management Permit Application. Projects resulting in a "take" of state-listed rare species may be eligible for a Conservation and Management Permit (321 CMR 10.23). Rare Species Habitat assessment or survey may be required as part of the CMP process.

Is MESA Permitting required for the Herring River project?

Yes, as the project overlaps with Priority and Estimated Habitats mapped by the NHESP.

8.3 Cape Cod Commission: Development of Regional Impact

The Cape Cod Commission is a regional land use planning and regulatory agency created by an Act of the Massachusetts General Court in 1990. The Commission reviews projects that present regional issues identified in the Act, including water quality, traffic flow, historic values, affordable housing, open space, natural resources, and economic development.

DRI review is required by law if a project exceeds a specific threshold. Examples of projects that need to go through mandatory DRI review by the Cape Cod Commission are those involving:

- subdivisions of 30 acres or more;
- development of 30 or more residential lots or dwelling units;
- development of ten or more business, office, or industrial lots;
- commercial development or change of use for buildings greater than 10,000 square feet;

- transportation facilities for passage to or from Barnstable County;
- demolition or major changes to some national- or state-recognized historic structures;
- bridge, ramp, or road construction providing access to several types of water bodies and wetlands;
- new construction or change of use involving outdoor commercial space greater than 40,000 square feet; construction of any wireless communication tower exceeding 35 feet in height;
- site alterations or site disturbance greater than two acres without a valid local permit;
- mixed use residential and non-residential developments with a floor area greater than 20,000 square feet

DRI review may also be required for projects that do not meet a threshold but are forwarded to the Cape Cod Commission from the town in which they are located. The Commission must first vote to accept this type of referral as a development that has regional impacts.

Projects requiring review under MEPA may also require DRI review. An applicant may request a joint review process with the state and the Cape Cod Commission. For an informal opinion on whether a project qualifies as a DRI, an applicant may contact a Commission staff member. In addition, the applicant or town may request a "jurisdictional determination" from the Commission; this entails a 21-day process in which the Commission will determine whether or not a project qualifies as a DRI.

8.4 State and Federal Historic Reviews

8.4.1 Federal Review

Any projects that require funding, licenses, or permits from federal agencies must be reviewed in compliance with Section 106 of the National Historic Preservation Act of 1966. Section 106 requires federal agencies to take into account the effects of their actions on historic properties. "Section 106 review," follows a specific process, which is guided by federal regulations (36 CFR 800). These regulations have created a series of steps by which federal agencies identify and evaluate historic properties that may be affected by their undertakings, assess adverse effects to those properties, and take prudent and feasible measures to avoid, minimize, or mitigate those effects. In Massachusetts, these steps are taken in consultation with the Massachusetts State Historic Preservation Officer (SHPO). The MA Historical Commission is the office of the SHPO. Other interested parties such as local historical commissions or Indian Tribes are also consulted.

8.4.2 State Review

Any projects that require funding, licenses, or permits from any state agency must be reviewed by MHC in compliance with Massachusetts General Laws Chapter 9, sections 26-27C. This law creates the MHC, the office of the State Archaeologist, and the State Register of Historic Places among other historic preservation programs. It provides for MHC review of state projects, State Archaeologist's Permits, the protection of archaeological sites on public land from unauthorized digging, and the protection of unmarked burials. These regulations set up a process that mirrors the federal "Section 106" regulations: identification of historic properties; assessment of effect; and consultation among interested parties to avoid, minimize, or mitigate any adverse effects.

Is MA Historical Commission review required for the Herring River project?

Yes, because of federal and state agency involvement, a Project Notification Form will be required to initiate formal MHC review.

8.5 Wellfleet Environmental Protection Bylaw

The Wellfleet Environmental Protection Regulations were promulgated by the Town of Wellfleet Conservation Commission pursuant to the authority granted under the Wellfleet Environmental Protection Bylaw as approved on April 28, 1986 at Town Meeting. These Regulations set forth a public review and decision-making process by which activities affecting Areas Subject to Protection under the Bylaw are to be regulated in order to contribute to the following public interests and values:

- protection of public and private water supply;
- protection of ground water quality and supply;
- flood control;
- erosion and sedimentation control;
- storm damage prevention;
- prevention of pollution;
- protection of land containing shellfish;
- protection of fisheries;
- protection of wildlife habitat

The following Wetland Resource Areas are subject to protection under the Bylaw and Regulations:

- Any freshwater wetland, inland bank, coastal wetland, coastal bank, beach, dune, flat, marsh, wet meadow, bog or swamp;
- Any estuary, creek, river, stream, pond, lake and lands under these bodies of water; land under the ocean;
- Land subject to tidal action, land subject to coastal storm flowage, bordering land subject to flooding, isolated land subject to flooding; and
- All land within 100 (200′ for rivers, streams, and fresh creeks) feet of any freshwater wetland, inland bank, coastal wetland, coastal bank, beach, dune, flat, marsh, wet meadow, bog, swamp, estuary, creek, river, stream, pond, lake, and lands under these bodies of water, and land under the ocean.

Is Wellfleet Environmental Permitting required for the Herring River project?

Yes, due to probable unavoidable impacts to state wetlands associated with fill for tidal crossings, dike reconstruction, and other alterations.

9 Regional Examples of Tidal Restoration Projects

In recent years the efforts to restore degraded wetlands have been receiving increasing attention. In Massachusetts, for example, the CZM Wetlands Restoration Program has been working towards completing 100 coastal wetland restoration projects totaling nearly 600 acres; the significance of the Herring River project can readily be seen by understanding that the 1100 acres of potential salt marsh restoration is nearly twice the amount of all these other projects combined. Gaining an understanding of other coastal habitat restoration efforts with similar goals has been a critical component of restoration planning for the Herring River project. Lessons learned from the planning and implementation of these projects is invaluable, although each situation has unique features. Descriptions of tidal restoration projects being performed in the region are provided below.

9.1 Hatches Harbor, Provincetown

A 1-kilmeter-long dike constructed in 1930 for mosquito control essentially bisected the 400-acre floodplain completely blocking tidal exchange and reducing salinity in the landward half of the wetland. As a result, native salt marsh grasses were replaced by many species of salt-sensitive plants, including 20-25 acres of the somewhat salt-tolerant *Phragmites* by the 1990s; relict *Spartina* cover in the diked marsh amounted to only about 12 acres at lowest elevations nearest the tidal creeks. The Provincetown Airport was constructed within the flood plain in the 1940s, about 20 years before Park establishment, using the pre-existing dike as protection against tidal flooding.

The need for dike repair in 1986 prompted interagency discussions about the actual flood-protection needs of the airport and the possibility of tidal restoration. Principal concerns were for tidal flooding of the airport instrument landing system and increased nuisance mosquito production. Federal Aviation Administration engineers determined critical flooding elevations for airport structures, while NPS scientists and cooperators developed a numerical hydrodynamic model of the estuarine system (Roman et al. 1995). The model showed that a wide, low culvert cross-section (8.5 meters wide x 1 meter high) should provide sufficient seawater flooding to restore 60-90 acres of salt marsh and, at the same time, dampen storm tides that may otherwise affect the airport's instrument landing system. This culvert configuration and a general restoration plan were finally approved by a planning and regulatory team representing 10 local, state and federal agencies in 1997. Pre-restoration monitoring began in summer 1997, with the new culverts installed in the winter of 1998-1999.

Despite model predictions, the new culverts were not fully opened after construction. Opening has been done in small increments to build confidence among cooperators, especially airport officials, in the reliability of the model, and because of concerns for extensive plant death due to waterlogging should the marsh fail to drain during each low tide. Experience since 1999 has allayed most concerns.

With all culverts fully open since 2005, monitoring of the marsh has shown higher high tides and lower low tides, steadily increasing the mean tidal range. Monitoring is a multi-decade process, but increasing salinity has already lowered *Phragmites* biomass and allowed salt-marsh grasses and forbs to expand rapidly across the flood plain (Portnoy et al. 2003). At the same time, high-tide heights have been controlled to levels that do not affect airport operations, and monitoring by NPS and the Cape Cod Mosquito Control Project has shown no measurable increase in nuisance mosquitoes or change in their species composition (Portnoy et al. 2004).

9.2 East Harbor, Truro and Provincetown

Before diking in 1868 East Harbor (currently mapped as "Pilgrim Lake") comprised a 350-acre tidal lagoon and 400-acre salt marsh receiving semi-diurnal tidal exchange from Cape Cod Bay through a 300-m wide inlet. Presently, tidal exchange is limited through a 1.2-meter diameter culvert. Modern salinity has ranged 3-4 ppt in the harbor proper and < 2 ppt in surrounding wetlands. *Typha angustifolia* and *Phragmites australis* dominate the lowest-elevation wetlands probably first vegetated with *Spartina alterniflora*, whereas diverse wetland shrubs occupy slightly higher elevations replacing the original high marsh halophytes (e.g. *S. patens, Juncus gerardii*). The lagoon is shallow (< 2 m), highly eutrophic and therefore subject to chronic hypoxia and summertime fish kills.

Since December 2001, NPS and the Town of Truro have cabled open clapper valves in the only remaining connection between East Harbor and Cape Cod Bay, a 4-ft diameter culvert, to see if increased tidal exchange can dilute the organic load and improve aeration of East Harbor. Shortly thereafter, the NPS funded a detailed hydrodynamic assessment of tidal restoration alternatives.

Although eutrophication and summertime oxygen stress has continued, the lagoon has shown a dramatic recovery in salinity, from 4 to 20-25 parts per thousand (about two-thirds that of seawater), and estuarine biota, including extensive widgeon grass beds, finfish, crustaceans, bivalves and other benthic animals, and wintering waterfowl.

NPS-funded hydrodynamic modeling (Spaulding & Grilli 2005) has shown that substantial increases in tidal range and flushing, and open-water and salt-marsh habitat, can be accomplished by increasing the width of the surface-water connection between the East Harbor lagoon and Cape Cod Bay to the extent possible given current land use. More complete tidal restoration awaits funding for a US Army Corps of Engineers Comprehensive Feasibility Study; this work was begun in 2006, interrupted due to insufficient funding in 2007, but may be funded again in federal fiscal year 2008.

9.3 Bridge Creek, Barnstable

The restoration project of Bridge Creek in Barnstable restored the tidal flow of approximately 40 acres of coastal wetlands in Barnstable. The creek's tidal flow had been altered by two undersized culverts, one along Route 6A and another along the adjacent Old

Colony railroad line. These inadequate culverts cut off most of the tidal flows to the upstream marsh and degraded the upstream aquatic ecosystem over time. While deemed a priority site for restoration by the Army Corps of Engineers in 1996, the project was seen as impractical as it would disrupt railway services and be a very costly endeavor (Massachusetts Office of Coastal Zone Management 2007).

Fortunately for the Bridge Creek ecosystem, a four-month closure was scheduled for the railroad line in early 2003 to complete repair work on the Cape Cod Canal railroad bridge. This closure opened up a narrow window of time to complete the first phase of the project, which was replacing the culvert underneath the railway. This phase of the project was completed in April of 2003. The project then entered its second phase, which replaced the inadequate culvert under Route 6A. This was completed in May of 2005.

Overall, the project faced many obstacles and cost $1.267 million, but was made possible through collaboration with over 38 groups and 84 individual partners (Massachusetts Office of Coastal Zone Management 2007). It required work on private residential property and the alteration of a deed restriction for access and construction of the culverts. The project was well worth the efforts, however, as it renewed the creek's full tidal range for the first time in over 100 years. This has restored the hydrology and water chemistry in the marsh, which is now recovering and fish and wildlife are returning to the area (Massachusetts Office of Coastal Zone Management 2007).

9.4 Damde Meddowes, Hingham

Damde Meddowes is located at The Trustees of Reservations World's End property in Hingham and originally was a 14-acre saltmarsh that extended east-west from Hingham Harbor to the Weir River. However, in the 1600s, settlers constructed two dams in the marsh, one near the harbor's cove and another near Weir River. In the 1880s, a second dike was constructed near the harbor end to improve access to the World's End Reservation (National Estuaries Restoration Inventory 2006). These dikes, which acted as carriage crossings as well as barriers to the marsh, had undersized culverts and even when tidegates were installed, fresh water could drain from the wetlands, but tides were prohibited from entering (National Estuaries Restoration Inventory 2006). This situation has converted the marsh into stagnant, brackish water inhabited with invasive species (Gulf of Maine Council on the Marine Environment 2005). To restore the marsh, both culverts were replaced in 2003 with four foot by eight foot concrete box culverts. The site did not initially respond as predicted by modeling output and design objectives. While high tides reach further upgradient, the impoundment was not draining adequately at low tide. Saltmarsh vegetation is also not recolonizing inter-tidal zones as quickly as expected. Intervention has been taken to establish more efficient drainage channels, but the results remain inconclusive to date.

9.5 Sagamore Marsh, Sandwich and Bourne

Before the Cape Cod Canal was deepened and widened in the mid 1930s, the Scusset River flowed freely into Cape Cod Bay and provided tidal flushing to Sagamore Marsh (Coastal America 2006). When the Canal was reconstructed, however, a 48-inch diameter culvert was installed and provided the only pathway for run-off from the marsh to reach the bay (US Army Corps of Engineers 2007). This culvert was inadequate to allow tidal flow to and from the marsh. Consequently, the marsh became degraded and dominated by *Phragmites*. Without intervention, the marsh would continue to degrade, become a fire hazard, and be ideal for mosquitoes to breed (Coastal America 2006).

Due to the poor ecological value of the marsh, the Army Corps of Engineers undertook restoration of the marsh under its Ecosystem Restoration Program. In a $2 million project, where the federal government paid 75%, the Army Corps replaced the undersized culvert with two six feet wide and six feet high box culverts (US Army Corps of Engineers 2007). They also installed an electric-sluice gate to regulate water levels. The project was scaled back from restoring a proposed 175 acres to restoring 50 acres in order to protect low-laying cottages along Scusset Beach. The highest tides were also limited to four feet due to the state-listed rare wildlife species *Hemidactylium scutatum*, four toed salamander.

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11 Glossary of Terms, Abbreviations, and Acronyms

Accretion: the seaward growth of land; opposite of shoreline erosion or retreat.

Adaptive Management: a systematic management paradigm that assumes natural resource management policies and actions are not static but are adjusted based on the combination of new scientific and socio-economic information in order to improve management by learning from the ecosystems being affected. A collaborative adaptive management approach incorporates and links knowledge and credible science with the experience and values of stakeholders and managers for more effective management decision-making.

Anaerobic: a situation where molecular oxygen is absent (or effectively so) from the environment.

Anoxic: without oxygen.

Anthropogenic: caused or derived by human activity.

Anadromous: fish species that spend their lives in the ocean, but return to freshwater streams, rivers, and ponds to spawn.

Avifauna: all birds in a specific region.

Biota: collectively all of the animal and plant life in an area.

Brackish: water that has salinity between that of freshwater (0-5 ppt) and that of saltwater (35 ppt).

Catadromous: fish species that spend their lives in freshwater streams, rivers, and ponds, but return to the ocean to spawn.

Coliform bacteria: non-pathogenic (not capable of causing disease) microbes found in fecal matter that indicate the presence of water pollution and the presence of pathogenic bacteria.

Culvert: round, elliptical, or rectangular structures that are fully enclosed (contain a bottom) designed primarily for channeling water beneath a road, railroad, or highway.

Dike: a bank (usually earthen) constructed to control or confine water.

Ebb tide: a falling tide—the phase of the tide between high water and the succeeding low water.

Estuary: a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea.

Ferrous: of, containing, or derived from iron.

Flood Tide: a rising tide – the phase of the tide between low water and the succeeding high water.

Flora: a list of all plant species that occur in an area.

Fry: newly hatched or born fish.

High Marsh: Areas of tidal marshes that are flooded on higher than average high tides and are typically dominated by Salt Meadow Hay (*Spartina patens*).

Hydrography: The study of the water cycle and its interaction with the physiographic landscape.

Hydrology: the science dealing with the properties, distribution, and circulation of water.

Hydrologic Model: a conceptual or physically-based procedure for numerically simulating a process or processes which occur in a watershed.

Hydrodynamic Modeling: The modeling of the flow field, circulation, and water surface elevations within a water body driven by external conditions, including tides, winds, inflows, outflows.

> **One-Dimensional Hydrodynamic Modeling:** a model where output is water levels and discharges in one dimension i.e. along the direction of flow in a river.
>
> **Two-Dimensional Hydrodynamic Modeling**: a model where output is water levels, discharges and velocities in two dimensions i.e. along and perpendicular to the flow in a river.

Low Marsh: Areas of marsh that are flooded by all high tides and are dominated by Cordgrass (*Spartina alterniflora*).

Mean High Water: A tidal datum. The average of all the high water heights observed over the National Tidal Datum Epoch.

Mean Higher High Water: A tidal datum. The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.

Mean Low Water: A tidal datum. The average of all the low water heights observed over the National Tidal Datum Epoch.

Mean Lower Low Water: A tidal datum. The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

Mean sea level: A tidal datum. The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g., monthly mean sea level and yearly mean sea level.

National Geodectic Vertical Datum of 1929: A fixed reference adopted as a standard geodetic datum for elevations determined by leveling. The datum was derived for surveys from a general adjustment of the first-order leveling nets of both the United States and Canada. In the adjustment, mean sea level was held fixed as observed at 21 tide stations in the United States and 5 in Canada. The year indicates the time of the general adjustment. The geodetic datum is fixed and does not take into account the changing stands of sea level.

National Tidal Datum Epoch—The specific l9-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present National Tidal Datum Epoch is 1983 through 2001. It is reviewed annually for possible revision and must be actively considered for revision every 25 years.

Neap Tide: Smaller than normal tides that occur approximately twice per month at the first and third quarter moon phase when the sun and moon are at right angles to the earth and the tidal forces counteract each other.

North American Vertical Datum of 1988: A fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico. In the adjustment, only the height of the primary tidal bench mark, referenced to the International Great Lakes Datum of 1985 (IGLD 1985) local mean sea level height value, at Father Point, Rimouski, Quebec, Canada was held fixed, thus providing minimum constraint.

Nekton: all organisms in the ocean that swim freely. There are three types, including: chordates, mollusks, and arthropods.

Oxidize: chemical process of combining oxygen with some other substance or a chemical change in which an atom loses electrons; opposite of reduction.

Palustrine: pertaining to all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 5 ppt.

Peat: soil type that is an accumulation of decaying plant matter and is water-logged and low in oxygen.

Restoration: re-establishment of previously existing wetland or other aquatic resource character and function(s) at a site where they have ceased to exist, or exist only in a substantially degraded state.

Salt water intrusion: the invasion of saltwater into freshwater areas.

Sedimentation: the deposition of transported soil particles due to a reduction in the rate of flow of water carrying these particles.

Semi-Diurnal Tides: Having a period or cycle of approximately one-half of a tidal day. The predominant type of tide throughout the world is semidiurnal, with two high waters and two low waters each tidal day. The tidal current is said to be semidiurnal when there are two flood and two ebb periods each day.

Sluice gate: a gate that can be opened or closed to control the flow of water.

Spawn: the act of reproduction of fishes.

Spring Tide: Larger than normal tides that occur approximately twice per month at new and full moon when the sun and moon are aligned and the tidal forces are reinforced.

Storm surge: the temporary rise in local sea level caused by a storm.

Submerged aquatic vegetation (SAV): aquatic vegetation that cannot tolerate dry conditions and because of this, live with their leaves at or below the water surface.

Subsidence: The sinking of the marsh surface, through compaction or degradation of marsh peat; often occurs when salt marshes are deprived of tidal flow.

Tidal flushing: the action of saltwater entering an estuary during high tides. It renews the salinity and nutrients to the estuary and removes artificially introduced toxins in the environment.

100-year flooding event: the flood elevation that has a predicted statistical frequency of occurring once every 100 years. This flood elevation has a 1% chance of happening in any year.

Acronyms and Abbreviations

APCC: Association to Preserve Cape Cod

CCC: Cape Cod Commission

CCMCP: Cape Cod Mosquito Control Project

CRP: Conceptual Restoration Plan

CYCC: Chequessett Yacht and Country Club

CZM: Coastal Zone Management

DFW: Massachusetts Division of Fisheries and Wildlife

HRTC: Herring River Technical Committee

IPANE: Invasive Plants Atlas of New England

MEPA: Massachusetts Environmental Policy Act

MOU: Memorandum of Understanding

MHW: Mean High Water

MHHW: Mean Higher High Water

MLW: Mean Low Water

MLLW: Mean Lower Low Water

MSL: Mean sea level

NAVD88: North American Vertical Datum

NEPA: National Environmental Policy Act

NGVD29: National Geodetic Vertical Datum

NHESP: Massachusetts Natural Heritage and Endangered Species Program

NPS: National Park Service

SAV: Submerged aquatic vegetation

WRP: Wetlands Restoration Program

APPENDIX A

MEMORANDUM OF UNDERSTANDING BETWEEN THE NATIONAL PARK SERVICE AND THE TOWN OF WELLFLEET PROPOSED HERRING RIVER SALTMARSH RESTORATION

SIGNED
September 14, 2005

MEMORANDUM OF UNDERSTANDING
BETWEEN
THE NATIONAL PARK SERVICE AND
THE TOWN OF WELLFLEET
PROPOSED HERRING RIVER SALTMARSH RESTORATION

This Memorandum of Understanding is entered into this 22nd day of August, 2005, by and between the National Park Service, a bureau of the United States Department of Interior, acting through the Superintendent of the Cape Cod National Seashore, and the Town of Wellfleet, a municipal corporation located in Barnstable County, Massachusetts, acting through its Board of Selectmen. The purpose of this Memorandum of Understanding is to establish a process and framework that will determine whether a restoration of the Herring River is feasible and subsequently develop a conceptual plan of the restoration goals and objectives to consider the needs of all stakeholders should restoration be deemed appropriate.

WITNESSETH

WHEREAS, the National Park Service (hereinafter "Park Service") administers and manages the Cape Cod National Seashore (hereinafter "CCNS"), a unit of the National Park System which is located partially within the Town of Wellfleet (hereinafter "Town") and includes more than 800 acres within the Herring River floodplain;

WHEREAS, the Town maintains ownership of the Herring River Dike which currently controls the tidal flow to the Herring River System as well as having jurisdiction over much of the area downstream from the structure;

WHEREAS, during a January 11, 2005 Board of Selectmen meeting, the Town agreed "….. in principle to the fact that restoring the Herring River salt marsh will be beneficial to the public interests and the environment and is a project worth proceeding with, with the caveat that a memorandum of understanding is signed between the National Park Service and the Town of Wellfleet and the development of a comprehensive restoration plan and filing for permits to proceed" (Board of Selectmen Minutes, January 11, 2005, http://www.wellfleetma.org/Public_Documents/WellfleetMA_SelectMin/S0052DB29-0052DB30)

WHEREAS, the Park Service is also interested in restoring the estuarine functions of the Herring River System so as to improve the impaired water quality, enhance fisheries and encourage the re-establishment of native habitats. The Park Service would like to work with the Town to best address mutual goals and objectives for the restoration of system through the development of a framework that will determine whether a restoration of the Herring River is feasible and subsequently develop a conceptual plan to meet stakeholder needs should restoration be deemed appropriate;

WHEREAS, the parties have determined that it is in the public interest to enter into the Memorandum of Understanding setting forth a cooperative arrangement between the parties with respect to the proposed restoration of the Herring River Salt Marsh; NOW THEREFORE, in consideration of the foregoing, the Town and the Park Service agree as follows:

1. The Town and Park Service agree to work cooperatively with one another towards addressing mutual salt marsh restoration goals through initiation of a technical committee and stakeholder group. The technical committee and the stakeholder group will be formed at the initiation of the Town within 30 days of signature of the MOU.

2. The technical committee will be composed of individuals selected by the Town and shall include a representative from the park and a representative from the Massachusetts Wetland Restoration Program, Coastal Zone Management. Potential participants could also include members of the Town Conservation Commission and/or Conservation Agent, Natural Resource Advisory Board, Board of Health, Barnstable County Department of Health and Environment, Open Space Committee, Shellfish Advisory Committee and /or Shellfish Constable, Cape Cod Cooperative

Extension Marine Program, Town Board of Selectmen, and other local, state or federal interested parties. The technical committee will:

a. Review all existing scientific and technical reports in order to develop a common understanding of the Herring River System and issues. Provide a concise synopsis of these studies to the stakeholder group and the community.
b. Receive and consider input related to community concerns conveyed through the stakeholder group.
c. Upon review of existing literature and in consideration of stakeholder interests, the technical committee will submit recommendations to the Board of Selectmen as to the feasibility of implementing some level of restoration to the system.
d. Should some level of restoration be deemed appropriate and with the Board of Selectmen's concurrence, the technical committee shall then be tasked with developing a restoration plan.

3. The stakeholder group will be composed of individuals selected by the Town and shall include the Park Service Superintendent or designee. Potential participants could also include representatives of the Congressional District, the Wellfleet Town representative to the CCNS Advisory Commission, private landowners potentially affected by a restoration, Chequessett Neck Yacht and Country Club representatives, members of the shellfishing/fishing community, Cape Cod Mosquito Control, Division of Marine Fisheries, Natural Resources Conservation Service, National Oceanic and Atmospheric Administration Restoration Center, members of the Wellfleet Forum and other interested parties. The stakeholder group will:

a. Ensure that the technical committee understands the stakeholders direct interests and concerns and considers these perspectives in their recommendation process.
b. Communicate with diverse interests within the Town to ensure public and private concerns are well represented and considered by the technical committee in their review process and in the development of their recommendations to the Town.
c. Provide a forum by which the technical committee's findings can be communicated to the larger community.
d. Should some level of restoration be deemed appropriate and with the Board of Selectmen's concurrence, the stakeholder group shall continue to be responsible for providing community input into a draft restoration plan.

4. The Park Service Superintendent or his designate and a Board of Selectman representative or their designate shall meet quarterly to monitor progress in the first year to ensure goals and objectives are being attended, and make adjustments as necessary to fulfill the purposes of the MOU.

5. Should the Board of Selectmen concur that some level of restoration is deemed appropriate based on the recommendations of the technical committee (see 2d above), a restoration plan will be developed jointly between the Town and the Park Service and in association with any other interested parties. The restoration plan would address:

a. Restoration alternatives that consider potential restoration scenarios and adaptive management strategies to ensure restoration and community goals are achieved (e.g., degree of tidal influence).
b. Roles and responsibilities of each party in developing and implementing the plan with respect to funding, compliance, operations, monitoring, and reporting.

6. Within 60 days of receipt of a restoration plan, the Town through the Board of Selectmen will review the plan and initiate a motion to accept, revise or deny the restoration plan. Concurrently, the Park Service Superintendent will also review the draft plan and determine if the park accepts the plan, proposed revisions or denies the plan.

7. In the event that the Town does not agree with any aspect of the proposed plan, the Town shall notify the Park Service and the parties agree to work cooperatively to resolve any disagreement. No aspect of this project may proceed, however, without the specific approval of the Town.

8. This Agreement and the obligations of the Park Service hereunder shall be subject to the availability of funding and staffing, and nothing contained herein shall be construed as binding the Park Service to expend in any one fiscal year any sum in excess of appropriations made by Congress or administratively allocated for the purpose of this Agreement for the fiscal year, or to involve the Park Service in any contract or other obligation for the further expenditure of money in excess of such appropriations or allocations.

9. This agreement and the obligations of the Park Service hereunder are subject to the laws, regulations and policies governing the Park Service and CCNS whether now in force or hereafter enacted or promulgated.

10. This agreement shall remain in effect for a period of five (5) years from the execution thereof and may be renewed by mutual agreement of the parties. This agreement may be terminated by either party, by providing a minimum of ninety (90) days notice in writing to the other party,

IN WITNESS WHEREOF, the parties have caused t his instrument to be executed by their respective duly authorized representatives on the day and year indicated above,

Dale Donovan
Board of Selectmen, Chair

September 14, 2005
Date

George Price
Superintendent, Cape Cod National Seashore

9/14/05
Date

APPENDIX B

HERRING RIVER TECHNICAL COMMITTEE SUBCOMMITTEES

LISTING OF MEMBERS AND SUMMARY REPORTS ISSUED

Appendix B—Herring River Technical Committee Subcommittee Report Summary Listings

Herring River Technical Committee Members:

Sworn-In Voting Members

Gordon Peabody	Chair, Member-at-large
Hillary Greenberg	Conservation Commission Agent
John Portnoy	Cape Cod Natinoal Seashore
Tim Smith	MA CZM Wetland Restoration
Robert Hubby	Open Space Committee
Joel Fox	Shellfish Advisory Committee
Andy Koch	Shellfish Constable
Carl Breivogel	Herring Warden
John Riehl	Nat'l Resource Advisory Committee
Jack Whalen	Chequessett Yacht & Country Club
Gary Palmer	Selectman, Town of Truro
Eric Derleth	US Fish & Wildlife
Stephen Spear	Department of Agriculture
Diane Murphy	Cape Cod Cooperative Extension Service
Steve Block	NOAA Restoration Center

Advisory Members

George Heufelder	Barnstable County Health Department
Peter Watts	Stakeholders Committee Chair
Gabrielle Sakolsky	Cape Cod Mosquito Control Program

The following table summarizes the Subcommittees that were formed by the HRTC, the members involved in each, and the dates of the major summary reports issued by each subcommittee. Reports are available upon request to the HRTC.

HRTC Subcommittee	HRTC Members	Date(s) of Primary Summary Reports Issued
Vegetation Management	Spear, Fox, Breivogal, and Peabody	8/29/06; 3/15/06
Stakeholder	Watts, Hubby, and Riehl	
Migration (of Fish and Wildlife)	Breivogel, Koch, and Murphy	8/25/06
Education	Hubby, Peabody, and Pornoy	3/27/06
Monitoring	Koch, Murphy, and Breivogel	5/24/07
Liaison	Riehl and Peabody	9/27/06
Permitting	Portnoy, Smith , and Greenberg	10/26/06
Restoration Impacts	Whalen, Portnoy, Fox, Peabody, Palmer, Riehl, and Sakolsky	10/26/06
Access	Riehl, Koch, and Peabody	10/26/06
Outreach	Riehl and Portnoy	10/26/06
Budgets and Grants	Smith, Spear, and Riehl	10/26/06
Administration and Management	Hubby and Riehl	10/28/06
Restoration Histories and Lessons Learned	Smith, Spear, and Peabody	10/27/06

APPENDIX C
FULL REPORT OF THE HERRING RIVER TECHNICAL COMMITTEE

January 2006

FULL REPORT
OF THE
HERRING RIVER
TECHNICAL COMMITTEE

January 3, 2006

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4. "Frequently Asked Questions: Tidal Restoration in Wellfleet's Herring River Estuary"……………………………………………………………….……...page 8

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6. Suggested additional Publications…………………………………………...page 34

7. Tidal Wetlands Bibliography (emphasizing tidal wetland restoration in New England)………………………………………………………..……page 35

Synopsis of Findings of the Herring River Technical Committee, 3 January 2006

Pursuant to the August 2005 Memorandum of Understanding (MOU), the Herring River Technical Committee has completed a review of existing scientific and technical reports and participated in numerous technical presentations regarding the Herring River, as directed. Review materials included technical issues relevant to both existing and restored conditions. This Synopsis, prepared for the Wellfleet Community and the Stakeholder Committee, is intended to fulfill the Technical Committee's charge, under Section Two (2), Part A. of the MOU.

Under currently diked conditions:

1. Tide heights, tidal range (difference between high and low tides) and salinity in the diked river are severely restricted; the dike reduces tidal range by nearly 80%, and seawater extends only three-quarters of a mile upstream and encompasses only 6.4 acres of salt marsh (less than 1% of the original salt marsh area);
2. As a result, native salt-marsh plants have been replaced by invasive species including non-native *Phragmites* (common reed);
3. Salt marsh animals, including economically important shellfish, have been eliminated throughout most of the estuary;
4. Diking and drainage degrade water quality, release acidity and metals, cause summertime oxygen depletions and fish kills, and thereby further reduce finfish and shellfish populations;
5. River herring, an historic focus of the Town, are diminished not only by poor water quality but also by high flow velocity and the physical obstruction of the dike itself;
6. With the lack of tidal flushing, poor low-tide drainage and poor water quality for predatory fish, nuisance mosquito production is often very high;
7. Low tidal flushing also allows coliform bacteria to accumulate, closing productive oyster beds, and threatening to close extensive aquaculture grants, seaward of the dike;
8. With diking and drainage the wetland has subsided up to 2.5 feet and continues to subside, reducing storm-surge protection for adjacent private and public properties.

With tidal restoration:

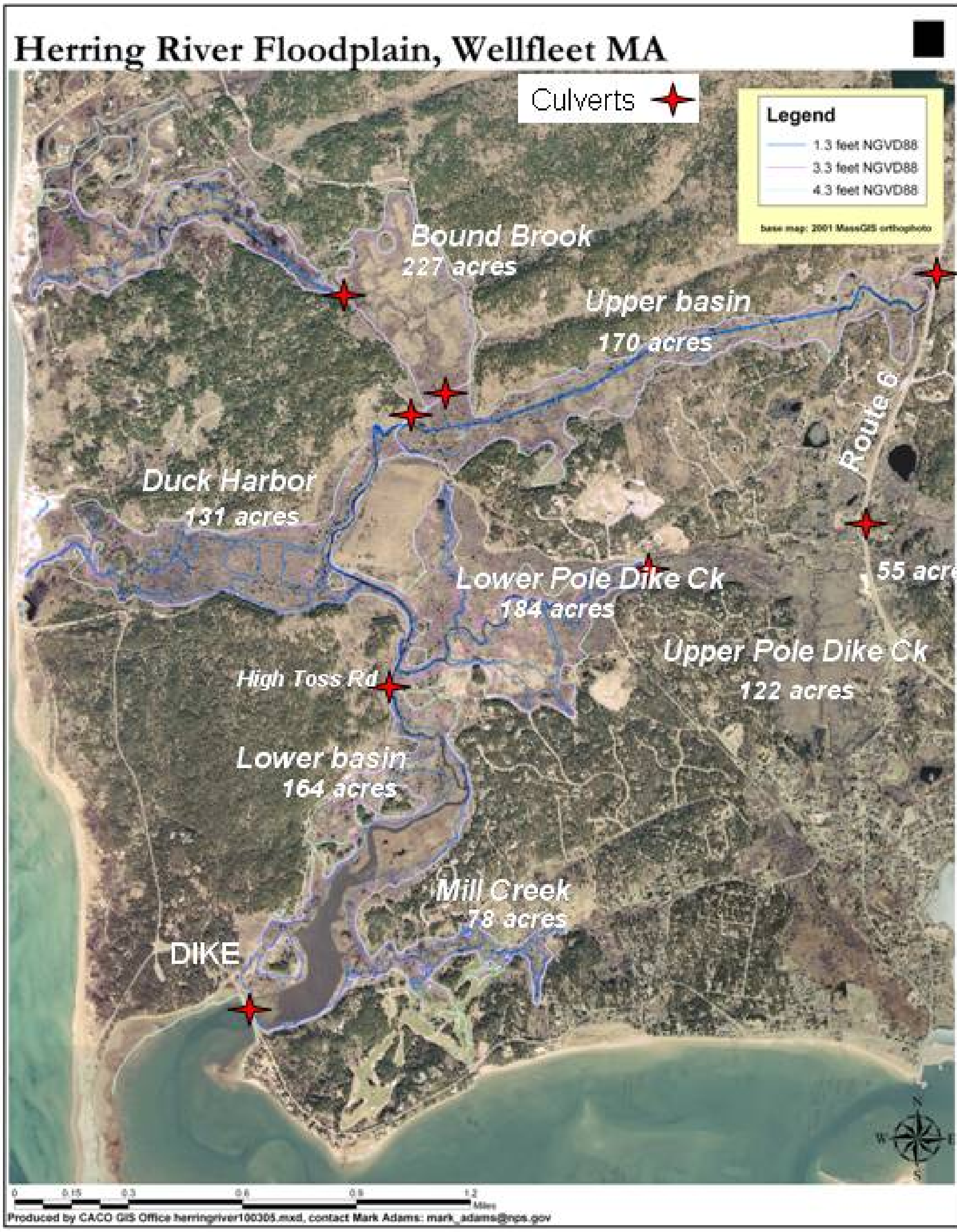
1. High tidal range, salinities and estuarine habitats can be restored, potentially to Route 6 and encompassing up to 1100 acres, approximately 100% of Herring River's original tidal wetlands;
2. Restored salinity will eliminate invasive plants, including *Phragmites*, within the flood plain;
3. Estuarine animals, including finfish and shellfish, will reestablish throughout the ecosystem extending both recreational and commercial fisheries;
4. Increased salinity and water levels will reestablish natural salt-marsh chemistry and eliminate acidity and metals contamination;
5. Increased tidal flushing will dilute other potential contaminants that may discharge into the river;

6. Increased tidal flushing will also increase water-column aeration, reduce summertime oxygen stress and promote survival of all aquatic animals including the migratory river herring, which declined precipitously with diking;
7. Increased tidal flushing, improved water quality and improved physical access for predatory fish will facilitate natural mosquito control;
8. Increased tidal flushing will reduce coliform pollution of shellfish beds seaward of the dike;
9. Sediment from the river will not flow onto downstream shellfish beds; highest flow velocities are during flood (not ebb) tides; therefore, net sediment flow will be upstream and onto the wetland surface, helping the wetland accrete and keep up with sea-level rise;
10. The stability of The Gut barrier beach is dependent on Bayside shoreline processes and will not be affected by increased tidal exchange between harbor and river;
11. Groundwater quality in adjacent supply wells will not be affected;
12. Two septic systems occur within the project area; mitigation options exist and should be investigated further;
13. Various management options exist and should be considered for any impacts to public roads throughout the restoration process. Culverts, clapper valves and road elevations may have to be addressed.

<u>Basic conceptual approach</u>

Research (hydrodynamic modeling) has shown that a new, gated structure with a wide opening at the mouth of the river, along with enlarged openings under High Toss, Bound Brook Island and Old County Roads, can accommodate controlled, incremental and carefully monitored tidal restoration. This would allow for flexible management of the restoration to protect public and private interests.

[redacted]



Map of the Herring River estuary showing sub-watersheds, their respective acreage, and the location of road culverts.

Recommendation

Pursuant to the August 2005 MOU, the Herring River Technical Committee has completed a careful, in depth review of existing technical materials regarding the Herring River. This material had been reviewed through both literature and presentations, including issues relevant to both existing and restored conditions. The Technical Committee had received input regarding community, stakeholder, and resource agency concerns from the Stakeholder Committee and has held a joint meeting with that Committee. This recommendation to the Wellfleet Board of Selectmen is intended to satisfy the Technical Committee's charge, under Section Two (2), Part C of the MOU.

The Herring River Technical Committee hereby recommends that tidal restoration of the Herring River Salt Marsh is feasible and will provide numerous and substantial public benefits. As outlined in the Technical Committee's Synopsis, significant improvements in water quality would provide subsequent public health, recreational, environmental, and economic benefits. Our recommendation includes a new structure capable of full tidal restoration. The new structure should incorporate controlled gates to provide incremental increases in tidal exchange. This would allow for well thought out management, supervision, monitoring, and evaluation.

Responses Technical Questions

Pursuant to the August 2005 MOU, the Herring River Technical Committee has considered Community and Stakeholder interests, as presented to the Committee by the Stakeholders Committee, in writing and at a joint meeting.

The Technical Committee prepared a document entitled “ Frequently Asked Questions About Tidal Restoration in Wellfleet’s Herring River Estuary”. The number reference from this document is included below as applicable as our direct response to the 29 Stakeholder Technical Questions based upon the technical findings of the Technical Committee. Note questions 1 and 17 have been reassigned as management questions #31 and #32.

These answers to Stakeholder questions are intended to satisfy the Technical Committee’s charge, under section Two (2), Part B of the MOU.

The questions including Technical Committee responses are as follows:

Technical Questions

1. What is the proposed plan for the level of restoration? **To be addressed by the restoration plan – see management question #31**
2. What is the proposed plan for the dike structure? **See Reference Document # 1 questions #14 and # 33**
3. What is the minimum elevation that would maximize salt marsh restoration for the entire system? **See Reference Document # 1 questions #12**
4. What is intended for the pole dike area? **See Reference Document # 1 questions #15 and # 39**
5. What would impacts be for the pole dike area? **See Reference Document # 1 questions #15 and # 39**
6. What is intended for the Old County Road area? **See Reference Document # 1 questions #15 and # 39**
7. What would the impacts be for the Old County Road area? **See Reference Document # 1 questions #15 and # 39**
8. Have solutions been identified for culverts in these areas? **See Reference Document # 1 questions #15 and # 39**
9. What measures will be taken to remove ground cover, brush and trees? **See Reference Document # 1 questions #30**
10. Will there be any man made relocation of vegetation or habitat? **See Reference Document # 1 questions #29**
11. Are there any endangered species threatened by restoration? **See Reference Document # 1 questions #29**
12. What will be done to facilitate emigration of free (fresh) water fish and other aquatic life away from the restored area? **See Reference Document # 1 questions #31 and # 39**

13. Will further studies be made to determine potential restoration impact on the integrity of the gut? **See Reference Document # 1 questions #24**
14. Will further studies be performed to determine how restoration will influence the movement of river sediment into the harbor? **See Reference Document # 1 questions #23**
15. Will changes of sediment in the harbor be monitored after restoration? **See Reference Document # 1 questions #23**
16. Will phragmites and sediment be removed before the dike is opened? **See Reference Document # 1 questions #30**
17. How large an area would this take place over? **To be addressed by the restoration plan – see Management question 32**
18. Will restoration introduce breeding areas for salt-water mosquitoes? **See Reference Document # 1 questions #30**
19. What issues would impact ground water at the transfer station landfill? **See Reference Document # 1 questions #8**
20. How will restoration affect the integrity of private water wells? **See Reference Document # 1 questions #16**
21. How will restoration affect the integrity of private septic systems? **See Reference Document # 1 questions #17**
22. How will restoration affect ground water levels? **See Reference Document # 1 questions #6 and # 9**
23. How will restoration affect water penetration in private homes? **See Reference Document # 1 questions #15**
24. How will the Country Club be affected by tidal influx? **See Reference Document # 1 questions #19**
25. How will the Country Club ground water be affected by tidal influx? **See Reference Document # 1 questions #19**
26. Will access to Duck Harbor be affected? **See Reference Document # 1 questions #21**
27. Will access to Bound Brook Island be affected? **See Reference Document # 1 questions #21**
28. Will Access to other town owned properties be affected? **See Reference Document # 1 questions #15**
29. Will previous pesticide use have an impact on restoration? **See Reference Document # 1 questions #26**

<u>Reference Document</u>

1. “Frequently Asked Questions About Tidal Restoration in Wellfleet’s Herring River Estuary” **refer to section 4 of this Full Report of the Herring River Technical Committee**

Frequently Asked Questions
About Diking and Tidal Restoration
in Wellfleet's Herring River Estuary
December 2005

Preface

An original "Twenty Frequently Asked Questions…" were compiled for the Town of Wellfleet and Cape Cod National Seashore in 2000 by Brittina Argow, a visiting geologist from the Association of Women Geoscientists. Ms. Argow solicited questions and concerns from the public, and provided answers based upon review of scientific literature and consultation with technical experts. In 2005, the Herring River Technical Committee followed the same procedure to expand the scope of questions and to update answers based on additional research. Relevant supporting literature is listed by number (see attached bibliography) after each answer.

Current conditions

1. *What's wrong with the status quo? Why can't the marsh just stay the way it is?*

The reality is that the marsh *won't* just stay the way it is. Because the watershed's hydrology has been changed profoundly by the emplacement of the dike and by subsequent ditching, the natural systems of the Herring River estuary and marsh are in an ongoing struggle to establish a new state of equilibrium. Over the last century such a balance has not been achieved, and so the ecosystem continues to evolve. Sediment cores retrieved from the Herring River system indicate that it had been a stable salt marsh for approximately 2000 years. The presence of salt water in the system, inhibiting freshwater plant colonization, and the balance between deposited sediment and rising sea level maintained this salt marsh ecosystem. The emplacement of the dike and ditches has artificially induced vegetation succession, creating a strange upland ecology located at elevations below mean high tide! Within our lifetimes, large regions behind the dike have progressed rapidly from a marsh to open meadow to an upland forest ecosystem. The Herring River currently suffers from episodically severe water quality problems related to this change. In addition, with the lack of regular tidal flooding for nearly 100 years, the marsh surface above the dike has severely subsided, and continues to sink. The longer that diking continues, the less marsh peat remains to protect adjacent upland structures from storm surges. There is no inexpensive and practical way to freeze the evolution of the Herring River at this current ecologically and geologically unstable point in its succession. Even if nothing were done at the dike or elsewhere in the Herring River, this area will continue to change. Management action will be necessary to stabilize the system. The most practical and economical management alternative to re-stabilize the Herring River estuary would be the restoration of a tidal salt marsh. **References: 1, 11, 12, 14, 15, 17, 20, 21, 24, 25, 26.**

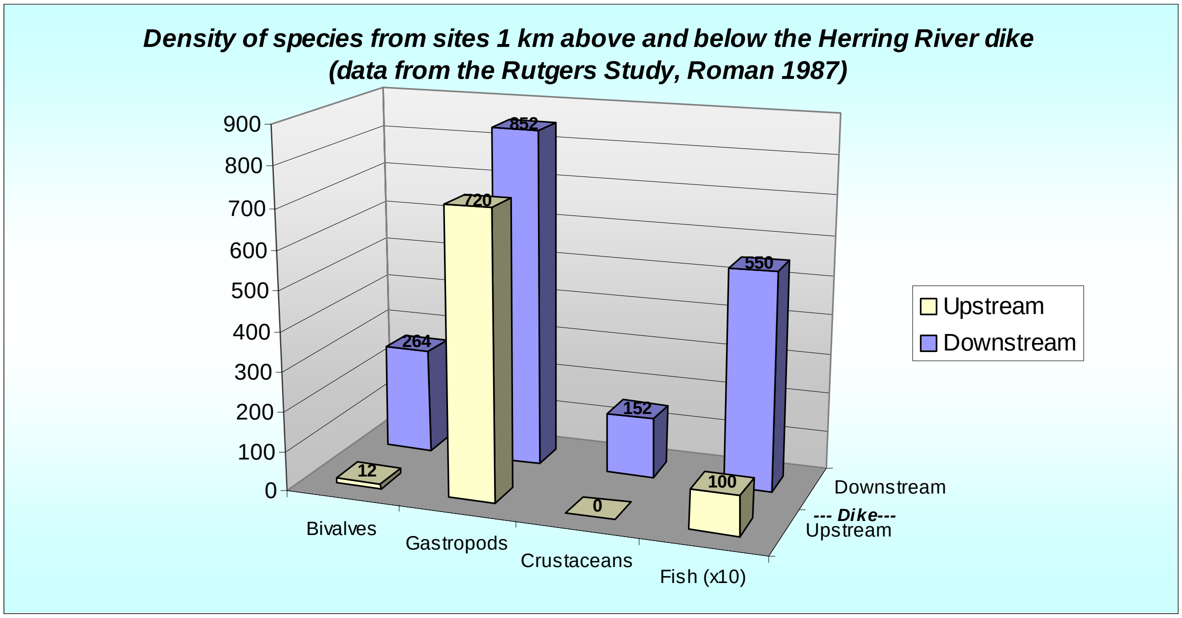
2. *Describe the comparative value of salt vs. fresh water marshes*.

   Both salt and fresh water marshes support productive ecosystems and add to the biodiversity of Cape Cod. Salt water marshes also act as nurseries for a wide variety of salt and brackish-water species, providing shelter and feeding grounds. Geologically, they protect inland areas by absorbing the energy of storm waves as they approach the shore, reducing inland erosion and trapping sediment. Hydrologically, all coastal marshes are groundwater discharge areas that ultimately return rainwater to the sea.

   Importantly, however, much of the diked Herring River flood plain does not support healthy freshwater wetlands. The original low salt marsh between the dike and High Toss Road has been invaded by exotic Phragmites, of much less habitat value to birds and fish. The original high marsh above High Toss, north to bound Brook Island Road and west through Duck Harbor has been so effectively drained that upland shrubs and trees have replaced wetland species. In addition, the drainage has caused sulfur-rich salt marsh peat to oxidize, creating several hundred acres of acid sulfate soils which leach toxic acidity and aluminum into receiving waters, killing fish.

   The Herring River, before diking, was more than just a salt marsh—it was a complex system grading from salt marshes to brackish and freshwater marshes. The lower reaches of the system were estuarine—the largest estuary on the lower Cape; based on surviving 1903 photographs, it looked much like Blackfish Creek just west of Route 6 today. Unaltered estuaries are among the most productive environments on the planet. Unfortunately, Herring River's productivity, along with that of about half of the state's original salt marshes, has been severely compromised by diking and ditching. Restoring the size of the estuary, currently restricted to the river mouth seaward of the dike, will increase the productivity of the many species that rely on this environment for spawning and nursery grounds. In the last few decades, recognition of the economic and environmental importance of estuaries and their associated salt marsh communities has spawned global restoration efforts to remediate these heavily impacted ecosystems. Wellfleet is not alone in its position as a community investigating the health of its wetland environments. For example, the Massachusetts Coastal Zone Management's Wetland Restoration Program is working with communities, other government agencies and non-profit conservation groups to remove tidal restrictions and restore salt marsh estuaries all along the state's coast. Similar programs are under way throughout the U.S. coastal zone. **References: 4, 5, 11, 17, 19, 20, 24.**

3. *Why are there fewer fish upstream of the Herring River dike? Also: What is the cause of summertime oxygen depletion and how can the problem be fixed? And what is the cause/significance of the decaying organic matter within the system?*



Although the Herring River in Wellfleet is a complex system, there are several clear causes for a reduction in fish abundance and diversity in the waters above the dike. The dike's small opening restricts water flow in and out of the upper reaches of the estuary and marsh, decreasing mean tidal range. This reduces the submerged and intertidal habitat available to fish for shelter, forage, and spawning areas. Over the past century, this has made it harder for fish to reproduce successfully and survive in their original numbers. Some species may have disappeared from the marsh entirely. Farther up the system, in the freshwater portion of the marsh, serious water quality issues pose more problems for fish species. The low pH (high acidity) of the water can kill fish directly. Acidic water also leaches aluminum out of clays in the marsh sediments, and aluminum is toxic to fish in very low doses in the water column (0.2-0.5 ppm).

In addition, the lack of regular tidal flushing with well-aerated Cape Cod Bay water leads to dissolved oxygen depletions. Despite the long period of diking and drainage, abundant organic matter remains in the system to consume dissolved oxygen particularly when water temperatures are high in the summertime. Dissolved oxygen even in the river main stem is often so low that there is none left for the fish to breathe, causing massive fish kills. In the past, oxygen depletions have coincided with the annual emigration of juvenile herring from the headwater kettle ponds, causing the mortality of tens of thousands.

A healthy salt marsh has a relatively small region of low oxygen that occurs at the interface between fresh and salt water. This occurs because at this location there is minimal tidal flushing, but organic debris is still abundant. Microbes feeding on large quantities of organic material normally consume dissolved oxygen in the water column. In the Herring River, this region of low dissolved oxygen has been expanded because of the reduced tidal range. It now extends over most of the area between

Route 6 and the dike. Comparatively few species can thrive or even survive in this acidic, toxic, low-oxygen environment.

The high organic content of marsh deposits is natural, and an unaltered marsh can handle the high volume of nutrients and biological consumption of oxygen. This is because an unrestricted marsh is "flushed" twice daily with oxygen-rich seawater. The simplest and most effective way to remedy these problems is to restore the tidal prism behind the dike. This would increase flushing and aeration (oxygenation) of water and would eliminate the acidity problem by resaturating drained marsh peats with sea water. Laboratory experiments show that these and other water quality problems begin to correct themselves within two months of inundation with seawater. **References: 11, 12, 13, 15, 17, 18, 19, 20, 24.**

4. *What is the relationship between water impoundment, sea level rise, and marsh surface subsidence?*

A natural unaltered salt marsh, such as nearby Nauset Marsh or Blackfish Creek, can compensate for gradual rise in sea level through the accumulation of organic material layered with inorganic sediment (mostly silt and clay) washed into the marsh system by flood tides. The Herring River dike blocks the influx of inorganic sediments, handicapping the marsh's ability to keep up with rising sea level. In addition, as the water table dropped further in response to ditching and channelization, the organic deposits (peats) began to dewater and shrink. The individual pore spaces between grains of sediment and organic debris had been supported by water, but as the peats dried out these pores collapsed under their own weight, and the marsh surface subsided still more. Futher, with drainage and aeration, organic material began to decompose more quickly due to the increased oxygen present in air compared to water, also contributing to subsidence. Nearly all sections of the marsh lost the highly productive *Spartina* communities. Presently, the restricted marsh surface elevation upstream from the dike is 70 cm (over two feet) lower than the natural marsh surface just downstream. A casual observer can note the differing elevations from the hill above the dike, as well as the large difference in tidal range. Mean sea level has risen 20 cm in the past century, which means that the current diked marsh surface is nearly one meter below modern high tide! If the dike were simply removed, there would certainly be significant flooding in the subsided areas of the flood plain. Therefore, a gradual opening of the dike would likely be an appropriately cautious management alternative in this environment. Increasing the tidal prism would increase the amount of inorganic sediment washed into the marsh on flood tides and would slow down peat decomposition, which over time would help the marsh to build up to an elevation consistent with modern sea level.

An excellent example of what can be expected in terms of sedimentation at Herring River after tidal restoration is provided by the Hatches Harbor Salt Marsh Restoration project ongoing in Provincetown since 1999. Monitoring there has shown rapid recovery of the marsh surface with tidal restoration - nearly a centimeter (about ½ inch) of sediment accumulation per year, which bodes well for the subsided Herring River marshes. **References: 5, 11, 14, 16, 17, 19, 22, 24**.

5. *What is the cause of the observed change from sand to mud in the diked Herring River channel?*

   As mentioned, an incoming flood tide carries mostly fine inorganic particles, silt and clay, up onto the salt marsh surface. When the dike was built, these strong flood tides were blocked. Silt and clay carried by flood tides settled in the river channels, instead of being carried onto the wetland surface as it was before tides were restricted. Increasing the tidal prism behind the dike would restore flood-tide velocities so that silt- and clay-sized particles would again be carried onto the marsh surface, instead of settling as muck in the river channel. This would have the added benefit of improving inorganic sediment supply to upstream marshes, helping them to recover their elevation and to keep up with rising sea level. **References: 5, 14, 17, 22.**

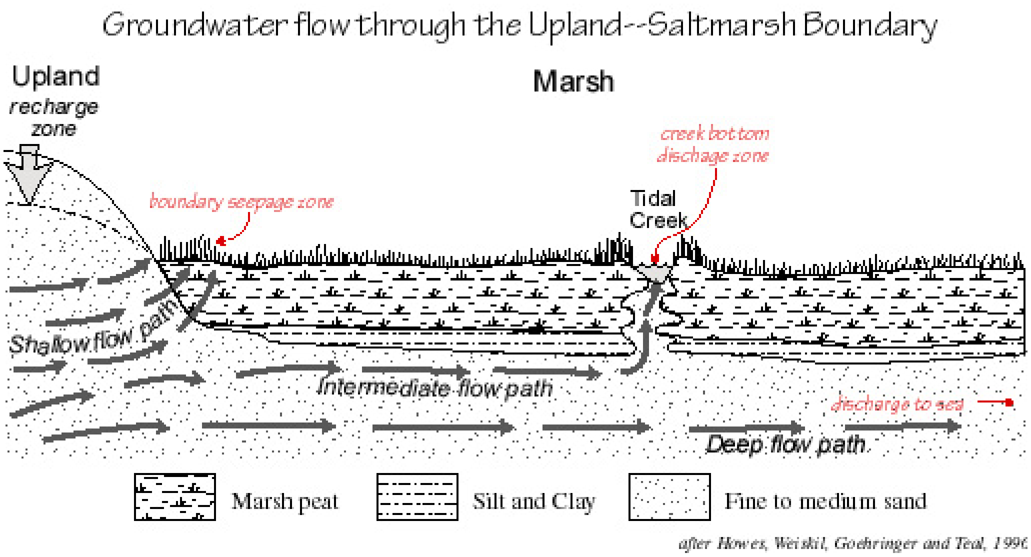
6. *What is the cause of acidification and what are its impacts?*

   The high acidity of water in parts of the Herring River system is an indirect result of the building of the dike in 1909. The dike effectively blocked most salt water flow into the system, allowing discharging groundwater to replace salt water with fresh, and salinity steadily decreased. Diking caused the water table to drop from the elevation of mean high tide elevation to that of mean sea level, the elevation at which groundwater discharges locally. Subsequent ditching and channelization of the river and marsh have further lowered the water table.

   The marsh surface upstream from the dike has subsided, but the water table has dropped even more. Large areas of salt marsh peat which have become completely drained are now well above the restricted high tide elevation. This dried-out peat is the source of the acid that finds its way into the water column in the Herring River. Salt marsh peat contains high levels of the mineral pyrite, which is composed of sulfur and iron. In normal marshes, the peat is consistently flooded daily by high tides, and an anaerobic (low oxygen) environment is maintained. When this peat is dried out, however, the pyrite is exposed to air, which has significantly more oxygen in it than does water. The iron in the pyrite essentially rusts out, liberating the sulfur, which enters the water column as sulfuric acid. This acidity kills or severely limits the range of estuarine animals like fish and shellfish. High acidity also leaches toxic minerals, especially aluminum and ferrous iron, from native clays, further damaging the aquatic fauna. Nuisance mosquitoes are one of the few animal groups who can tolerate the poor water quality, and benefit from the lack of fish predators. **References: 10, 11, 14, 15, 17, 20, 24.**

7. *Do the Herring River marshes accumulate fresh water and contribute it to the drinking water supply*?

   No. Low-lying marshes in coastal regions are discharge areas for aquifers, meaning that water flows out of, not into, the groundwater aquifer at this aquifer/marsh boundary. Groundwater always flows from the aquifer towards surface water. Water that falls on a marsh in the form of rain washes over the marsh surface and into the tidal channel network, where it is carried to the sea. The salt marsh peat that underlies the Herring River valley has a very low permeability, and therefore allows little exchange between the marsh surface and the underlying aquifer. **References: 8, 9**.



8. *What are the possible sources of nitrogen loading in the Herring River system?*

There are currently no known or suspected point sources (this is generally understood to refer to human waste) for nitrogen loading in the Herring River system. A leachate plume from the recently (summer 2005) capped Wellfleet landfill at Coles Neck appears to flow toward Herring River, but so far monitoring has not detected increased nitrogen at its likely discharge location along the river main stem. There is limited agriculture in the watershed and few fertilized lawns, so non-point sources of nitrogen pollution are minimal.

Nitrogen is naturally abundant in a salt marsh where it cycles between plants, sediment, water column and atmosphere. Most is stored within plant biomass both above and below ground, but some nitrogen is constantly being released by organic decomposition. If too much of this were to reach the water column, it could cause algae blooms, oxygen depletions and fish kills; however, in a natural salt marsh a large fraction is removed by the process of bacterial denitrification. The process only occurs in an environment of both low oxygen, e.g. waterlogged marsh peat, and high pH (low acidity). In contrast, current water management in Herring River results in aerated, low-pH soils.

If nitrogen is in fact high in Herring River, diking and drainage, and their disturbance to natural nitrogen cycling, may be a contributing factor. **References: 11, 14.**

9. *Do the mosquito ditches function as storm-water control mechanisms?*

The mosquito control ditches were not designed as storm-water control mechanisms; rather they were intended to drain the marshlands, lowering the local water table for

the purpose of reducing mosquito breeding sites. The ditches expedite the return of rainwater to the sea. However, the ditches have also effectively eliminated the marsh in areas where they have lowered the water table to the point where upland plants can encroach. Marshes act as buffer zones between the ocean and upland areas during storms. By changing the function of parts of the marsh, mosquito control ditches have reduced the ability of this low-lying area to absorb the energy of incoming storm waves, making upland areas potentially more susceptible to storm damage. Ditching and stream channelization are both intended to drain adjacent wetlands, a action that at Herring River causes peat oxidation, acid sulfate soil formation and fish kills.
References: 5, 9, 10, 14, 17.

10. *What is allowed by the existing Herring Run maintenance Order of Conditions? What was the logic behind the court's decision that established the gate's opening height?*

The dike was built in 1908/1909 and restricted the flow of seawater into the Herring River system while allowing the outflow of fresh water to Wellfleet Harbor. By the 1960s, the original culverts had deteriorated and was allowing seawater to re-enter the diked estuary. Consequently an estuarine community of shellfish, crustaceans, fishes and other species re-established itself upstream from the dike. Federal and State law protects established fisheries; therefore when the dike was re-built in the mid-1970s the Conservation Commission mandated enough tidal flow be preserved to protect the existing marine communities.

Rationale for tidal restoration

11. *What is the overall rationale for a salt marsh restoration effort here at Herring River?*

Many people agree that the Herring River is in trouble. Some are worried about the Herring Run; others miss the migratory birds that used to shelter in these marshlands. Shellfishermen are concerned about the quality of water washing out over their shellfish grants. Landowners are concerned about changes in the current system and what the future might bring. Mosquito control experts all agree that the status quo is a pest control nightmare. Most people involved feel that some decisive action should be taken. In response to all of these interests, a great deal of information has been collected and analyzed to help us understand the Herring River and make the best management decisions possible.

In light of these concerns, several fundamental issues have become clear. Perhaps most critical is the compromised water quality in the existing Herring River. Species decline and periodic die-offs have emphasized this problem, but they are only symptoms of the underlying condition. In fact, marsh surface subsidence, upland forest encroachment onto native open marshlands, and decreasing biodiversity are all problems which are intimately linked to the condition of the water column. Having first identified the problems and then discovered how these conditions evolved in the Herring River, we are now faced with the challenge of remediation. Many communities have struggled with these decisions, and several alternatives have been experimented with in the past.

Liming has been tried in ponds and even over small-scale watersheds in an effort to reduce the acidity of water. The advantage of this approach is that it quickly buffers pH in water. The disadvantages are that it initially kills much of the biota in the system, is non-permanent, and is terribly expensive. The acidified portion of the Herring River system encompasses roughly 300 acres. Liming on this scale is logistically, economically, and ecologically unsuitable. Under the present management regime, acid generation will continue indefinitely.

Wellfleet citizens have annually removed woody debris from the channels in the Herring River to ease river herring passage between Wellfleet Harbor and the headwater spawning ponds. It is important to realize that this action has only been necessary because of the nearly 100-year long program of diking that blocked the seawater which prevented the growth of salt-sensitive woody plants (shrubs and trees). Thus, until tides and salinity are restored, the woody vegetation will continue to invade and channel maintenance will become increasingly difficult and laborious.

Worldwide, most communities and agencies facing these issues have chosen to restore the tidal flow of salt water in an effort to remediate the negative conditions that develop in diked estuaries and marshes. Perhaps the main reason this approach is popular is because it is comparatively low-cost. Even in locations where the existing restricting structure has to be re-built (example: Hatches Harbor), the long-term costs of tidal restoration are ultimately lower than the alternatives. This method is considered advantageous because it treats the underlying problems in the marsh system, rather than just the symptoms. It will also create an environment which can be stable for hundreds, if not thousands of years, reducing the need to constantly monitor the system in the future after equilibrium has been reached.

In early salt marsh restoration efforts, mistakes were made. The rapid reintroduction of salt water to a system which has been primarily fresh causes a rapid and extensive death of salt-sensitive plants, for example following the breach of the railroad grade in the lower Pamet River about 1991. People are right to be concerned about this approach—it is difficult to successfully monitor and predict such a radical change. However, even these early attempts were ultimately successful. Within a decade the salt marsh community began to grow and prosper, eventually re-establishing a healthy ecosystem. Today, the pressures of human activities in and around the wetland areas make such rapid inundation impractical and irresponsible. Laboratory studies and successful salt marsh restoration efforts on Cape Cod and the world over have all demonstrated that gradually increasing the tidal range in a previously restricted marshland will effectively remediate most of the outstanding problems in the region, while allowing careful monitoring and more accurate prediction to guide the project. A carefully monitored, gradual re-introduction of salt water to the Herring River system is a responsible and feasible management option available to the town of Wellfleet. **References: 17, 19. Also see supplemental references.**

Effects of Tidal Restoration

12. *First, what is the goal from a long-term ecological restoration perspective in terms of tide heights, tidal range and salinity distribution?*

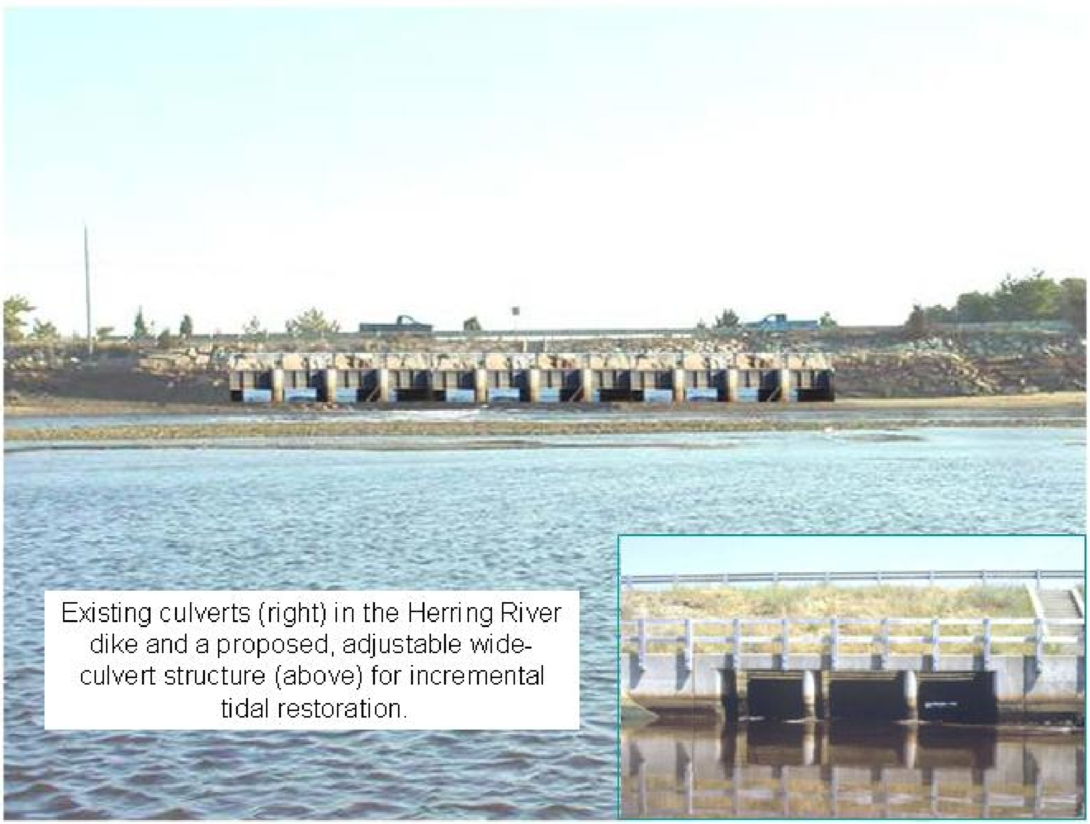
Ideally from this perspective the system would be managed so that it could sustain itself with minimal active human intervention and maximal ecological and social benefits. Given current sea-level rise, and a scientific consensus that the rate of sea-level rise will increase, one would choose to remove all restrictions on tidal and sediment exchange between the river and marine environment. However, the persistence of low-lying structures may make this goal unattainable for many decades. Short of full restoration, a relatively modest goal, but with potentially great benefits, would be to achieve average river tide heights that approximate current conditions in the salt marsh just seaward of the dike. This would bring biweekly spring high tides to about six feet above mean sea level (6-ft-MSL), which roughly defines the upper limit of salt marsh vegetation in Wellfleet Harbor. **References: 5, 22, 23.**

13. *How can the effects of increased tidal exchange on tide heights and salinity be predicted?*

Hydrologists from the United States Geological Survey, Rutgers University and the University of Rhode Island have constructed computer models to predict the influx of seawater into the Herring River valley and resulting tide heights for a range of tidal-restoration scenarios. In a computer model, mathematical equations are used to describe the flow of water from one side of the dike to the other. The "tidal forcing" (i.e. height of the water in the harbor seaward of the dike relative to diked river level throughout the tidal cycle) and size, shape and elevation of the opening in the dike control the volume of water that passes through the structure and into the river. Resulting tide heights are determined by the shape and, thus, volume capacity (bathymetry) of the flood plain. A global positioning system and standard surveying techniques were used both 1) to generate an accurate bathymetric model of the flood plain, for hydrodynamic modeling of tide heights, and 2) to identify critical elevations of potentially flooded structures including buildings and roads up to the 10-foot mean-sea-level contour, i.e. the 100-year flood plain. Results of similar modeling for tidal restoration at Hatches Harbor (Provincetown) have been highly predictive of actual measured tide heights since restoration began in 1999. **References: 19, 20, 22, 23.**

14. *What structural changes are contemplated to alter tidal flow at the river mouth and what are their likely effects on tide heights and tidal range?*

Hydrodynamic modeling has shown that opening the existing three culverts in the Chequesset Neck dike will cause a substantial increase in tide heights; however, modeling also shows that low-tide drainage is impeded; therefore, opening the existing structure actually decreases tidal range and flushing. A high tidal range drives salt-marsh productivity, and good flushing depresses nuisance mosquito production and dilutes contaminants like fecal coliform. In contrast with the poor performance of the existing culverts, modeling results for a low, but much wider culvert opening, as used at Hatches Harbor, were far superior in terms of tidal range and tidal flushing. The hydrodynamic work indicates that the Herring River opening should be at least 30 meters (~100 feet) wide to remove most restriction on tidal exchange. Such a wide culvert (more realistically: culverts) could be gated to allow adjustments and incremental restoration as has been done at Hatches Harbor. The illustration below shows existing culverts and a composite of Hatches Harbor style culverts of 100-foot width in the Herring River dike. **References: 19, 22, 23.**


Existing culverts (right) in the Herring River dike and a proposed, adjustable wide-culvert structure (above) for incremental tidal restoration.

15. *Would tidal restoration cause inundation of, or limit access to, town roads and other structures?*

Flooding to 6-ft-MSL would, at time of high tide, flood portions of High Toss, Bound Brook Island, Pole Dike and Old County Roads where they actually cross the flood plain; hese roads' surfaces are in places below 4.5 ft-MSL. A complete survey of potentially flood-prone structures, including homes, wells and septic systems, is under way. Obviously, alternatives for dealing with this flooding need to be developed prior to increasing tide heights. An in-depth study of potential impacts to the only year-round-occupied home seaward of High Toss Road, and within the flood plain, was recently completed (Reference 27).

It should be noted that, for both ecological and social reasons, the current conceptual plan is to restore tidal exchange, and increase high-tide heights, slowly and incrementally over years. In this way, conditions can be monitored and any problems corrected in a controlled fashion as habitat restoration proceeds.

Although, except for the low-lying roads mentioned above, public road access should not change, public access to the estuary itself should greatly increase. Shrubs, brambles and trees that presently cover the once-open marshlands and tidal creeks would die and be removed with tidal restoration, resulting in open salt marshes and creeks navigable by canoe, kayak and skiff as in unrestricted marshes like Blackfish Creek and the lower Pamet River. **References: 9, 19, 20, 22, 23, 27.**

16. *What is the potential of tidal restoration causing* ***saltwater intrusion into adjacent domestic wells****?*

In 1990, the US Geological Survey used geophysical soundings and well installation and sampling to determine that, with 20 meters of fresh water between domestic well screens and the salt/fresh ground water interface, there was no chance that tidal restoration in Herring River could affect those private wells installed in the adjacent upland. The wells of the two dwellings situated within the flood plain, however, could be affected by either surface seawater flow or a landward repositioning of the salt/fresh ground water boundary, which may be expected with tidal restoration.

This hydrologic work was expanded in 2003 to include the potential for salt water intrusion into supply wells around the Mill Creek tributary of Herring River, also including Chequesset Neck. The USGS Water Resources Division installed three additional observation wells through the fresh-salt groundwater interface, logged their water quality, and modeled the effects of tidal restoration. The investigators applied the tide heights and salinities predicted by the 2001 hydrodynamic model of the surface water system to a model of the local groundwater aquifer; they then ran the model for a virtual 300 years to assess the long-term effects on the interface. Results corroborated the above-mentioned 1990 study, indicating that re-opening the Herring River to tidal exchange should not affect well-water quality. Importantly, this analysis, and its conclusion of no impact, also included wells adjacent to Mill Creek , in the event that the golf course is able to relocate fairways and Mill Creek is kept open for salt marsh restoration. Besides establishing water quality in now six, deep observation wells around the flood plain, this study also summarizes domestic water quality from health records as a base line for future monitoring. **References: 6, 7, 8, 22.**

17. Would existing septic systems be affected by restored tidal flow?

Only septic systems already located inappropriately close to the water table would be affected, i.e. below 6 ft-MSL. An ongoing (December 2005) survey by Slade Associates has identified only two. Issues faced by individual landowners are unique and specific and must be solved on a case-by-case basis. **References: 22, 23.**

18. *How many undeveloped but buildable lots are located within the area that would be subject to inundation?*

There are no legally buildable lots located in the area that would be subject to inundation, because State and local laws prohibit building in the flood plain. Many lots that might otherwise be acceptable for houses are ineligible because their septic systems would have to be placed above ground due to the high water table in these lowlands. In the past, regulations were less strict and so some houses have been built in locations that today would not receive building permits. It is necessary that solutions be found regarding the few affected properties before any restoration effort can proceed.

19. *What are the potential impacts of an increased opening on the Chequesset Yacht and Country Club (CYCC) golf course and their irrigation water supply?*

The CYCC Executive Board has taken a proactive approach to this controversy and are actively seeking a solution that will allow them to move the affected holes to a more appropriate location on higher ground. In 2005, Wellfleet's Annual Town Meeting voted to contribute $1.2 million of Land Bank funds to acquire the low-lying fairways for Open Space, provided matching funds become available to complete the purchase. An additional $500,000 has been promised so far (November 2005) from the federal government, with another $100,000 from various public and private sources for golf course relocation planning. The drinking water at the CYCC will not be affected, although it may be necessary to seek an alternative water source for irrigation. **References: 8, 9.**

20. *Given the rationale for construction of the dike, what are the expected effects on the mosquito population? How does filling and maintenance of ditches play into this?*

Experts at the Cape Cod Mosquito Control Project agree that the Herring River is currently an exceptionally productive mosquito habitat, particularly between High Toss Road and Route 6. The dominant mosquito species caught in the Wellfleet area, *Ochlerotatus cantator*, breeds in fresh to brackish water, and its larvae can tolerate the acidified waters that keep its predators at bay. Restored tidal exchange should therefore decrease the population of this mosquito, as decreased acidity and increased salinity, oxygen, and predation would all have a negative impact on the reproduction of *Ochlerotatus cantator*. Eventually, salt marsh mosquitoes may recolonize the lower marsh, but the Cape Cod Mosquito Control Project reports greater success in controlling this species, so the net impact on the mosquito population of an increased opening in the dike should be to decrease it.

The filling and maintenance of the ditches is controversial. Ditching lowers the water table and begins the chain of events resulting in acidified water, which has negative ecological effects and, ironically, protects the mosquito larvae. Some scientists have argued that regular tidal flushing of a salt marsh washes mosquito larvae out to sea, helping to control populations as much as ditching might. Regardless of what management action is taken with the ditches, mosquito experts agree that tidal restoration, and its anticipated improvement of river water quality and flushing, would be a good thing relative to the current situation. **References: 10, 13, 15, 23.**

21. What impacts would tidal restoration have on the historically open inlets at Duck Harbor and Bound Brook?

An increased opening at the Herring River dike will have no impact on the barrier beaches at Duck Harbor and Bound Brook. The stability of these beaches is controlled by the sediment budget of Cape Cod Bay. Even if the barriers were to overwash during a storm, their back-barrier embayments have filled with sediment and have too little capacity to maintain a new inlet. Therefore, there is no reason to anticipate an opening at either of these locations under current sedimentation and erosion patterns. **Reference: 5.**

22. *What are the potential impacts to the shellfish industry? Will the fecal coliform contamination at the river mouth, which has caused shellfish-water closures since the 1980s, worsen with tidal restoration?*

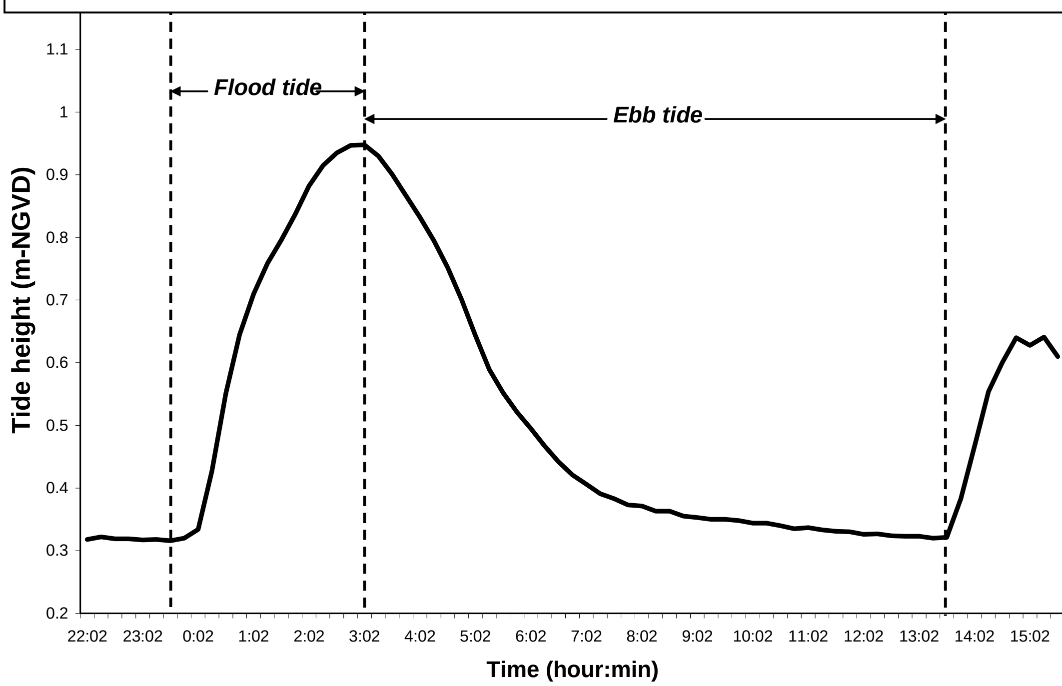
The source of fecal coliform bacteria, the standard indicator for shellfish-growing waters, in Herring River has always been a bit of a mystery: there is little development in the river flood plain and no major change in land use at least since the Seashore was established in 1961. It seems most likely that wildlife are the ultimate source of bacteria, and these microbes can survive and perhaps grow in the river sediment for some time. Recent (2005) research has shown that fecal coliform bacteria concentrations in Herring River are strongly associated with freshwater discharge, and greatly diminish once the fresh river water mixes with high-salinity Wellfleet Bay water en route to the sea. The extensive and productive shellfish-aquaculture beds of Egg Island are currently protected from high fecal coliform by the daily infusion of relatively clean Cape Cod Bay water, while the rich oyster beds in the river channel between Egg Island and the dike always have high bacteria counts during low tides, when river discharge predominates, and have been closed to shellfishing for about 20 years. With tidal restoration, the volume of clean seawater entering and leaving Herring River during each tidal cycle will increase by over 13 times. By simple dilution, this should reduce fecal coliform to concentrations that would allow the reopening of shellfish beds below the dike that have been closed for decades, and increase the high-salinity buffer between Egg Island aquaculture and river water. In addition, it is well known that coliform survival time is reduced in surface waters of high clarity, salinity, pH, and dissolved oxygen – the very water-quality factors that will increase most dramatically with restored tidal flow. Thus, the most effective and efficient way to reduce coliform levels in the Herring River system is to restore flushing by seawater.

According to George Heufelder of the Barnstable County Department of Health and Environment, Robert Duncanson of the Chatham Water Quality Laboratory and others with experience in managing bacterial contamination in coastal systems, increasing tidal exchange in Herring River should reduce coliform counts at and seaward of the dike. Operative factors include increased water clarity and UV penetration, improved aeration and survival of microbial predators, lower temperature and increased salinity; however, the overwhelming factor is increased dilution by the much increased tidal volume. Duncanson did caution that to the extent that high marsh pools develop and are not flushed daily by the tides, we could see episodic "coliform" release into surface waters after spring tides or storm events. Although this release is a potential in all of our salt marsh estuaries, we should plan to monitor it. **Reference: See Presentation 6.**

23. *Will increased tidal velocities carry fine sediments from above the dike to shellfish beds downstream?*

Regarding sediment transport, studies have shown that flood-tides will flow faster than ebb tides so that most sediment will be transported upstream with restored tidal flow. This is the mechanism in unaltered estuaries (see graph below for tide-restored Hatches Harbor): relatively strong flood-tide currents carry fine particles onto the marsh surface, and ebb currents are too weak to remove them. The accumulation of fine sediment (black muck) in the river channel today is a symptom of the interruption in this natural process of sediment transport; flood tides are blocked by the dike, so fine sediments fall short of the wetland, and settle in the channel. It's noteworthy in this respect to recall that shellfishermen complained about fine sediment accumulation both just above and below the dike structure <u>after the dike was rebuilt</u> in the mid-1970s, and not during its prior failure when shellfish actually proliferated for the first time since 1908 in the river above the dike. **Reference: 5, 22.**

Tide-restored Hatches Harbor, like other outer Cape salt-marsh estuaries, is flood-tide dominated, with a relatively brief and rapid flood tide and long and slow ebb. This kind of tidal asymmetry forces most sediment to move upstream, contributing to wetland sediment accretion.



24. *Will increased tidal flow increase the chances of a breach of The Gut barrier beach, and consequent change in the salinity and temperature of harbor water?*

The stability of The Gut barrier beach depends on the balance between sand transport and sea-level rise on the Cape Cod Bay shore, not on the hydrodynamics of Herring River. Old charts and aerial photos dating back to 1848, well before the river was even diked, make this very clear, with the river channel always in the same place, relative to The Gut, with or without the river diked. The Gut has always affected Herring River, and deflected it to the east and south, rather than the reverse. Of course, an overwash of the barrier beach is always possible during storms, but formation of a permanent breach is very unlikely. Permanent breaches happen where there are large differences in water level on either side of the barrier beach at times during the tidal cycle; this never happens at The Gut because water readily exchanges, and water levels equilibrate, between Cape Cod and Wellfleet Bays through the huge opening south of Jeremy Point – the path of least resistance.

According to Dr. Graham Giese, who has studied the coastal geology of the outer Cape for the past 40 years, the stability of The Gut is primarily dependent on littoral sediment transport along the Cape Cod Bay shore and aeolian (wind-borne) transport within the barrier dune system. The broad salt marshes behind The Gut barrier beach, which incidentally impose a formidable resistance to erosion in the case of storm overwash from the Bay, have been very stable for decades, as observable on aerial photographs. In addition, the occurrence of a broad mudflat of fine-grained sediments on the river side of this peat bank attest to low flow velocities under present conditions with no scouring. Increased flow from Herring River during the ebb will be accompanied by increased water velocities through the channel along this creek bank; however, flows are unlikely to be sufficient to resuspend sediment.

As a base line for future monitoring, AmeriCorps volunteers collected elevation profiles along four east-west transects across the Gut and also mapped the peat bank adjacent to Herring River in the winter of 2001-2002. As far as we know, this is the first such data set available and establishes a quantitative means of addressing changes to The Gut barrier beach and salt marsh system. **Reference: 5.**

25. *What are possible sources for funding if we agree that tidal exchange should be restored?*

There are many federal, state and even local sources for funding. Money can be used for research, monitoring, assessment, planning, permitting and actual implementation of all phases of a marsh restoration project. Massachusetts Coastal Zone Management's Wetland Restoration Program, Coastal America Foundation, Natural Resource Conservation Service, The Nature Conservancy, Conservation Law Foundation, Massachusetts Executive Office of Environmental Affairs, the US Army Corps of Engineers, Environmental Protection Agency, US Fish & Wildlife Service, National Oceanic and Atmospheric Administration, National Park Service and the

United States Geological Survey have all helped support projects of this nature, and several of these have already contributed funds and/or in-kind service to this project. A particularly useful contact for the Town of Wellfleet might be the Corporate Wetlands Restoration Partnership of the Massachusetts State Wetlands Restoration and Banking Program. This state agency specializes in finding matching grants for marsh restoration projects, and can generate three dollars for every dollar that comes from private or corporate funds. A small seed grant from Wellfleet or a private or corporate donor could therefore be used to secure significant federal and state funds.

26. *Are there contaminants stored in the sediments upstream of the dike, and, might increased flow lead to their activation?*

Because of the long history of diking and peat drainage, marsh sediments above High Toss Road are extremely acidic with porewater rich in dissolved aluminum and ferrous iron, explaining the depauperate aquatic fauna and past fish kills. Note however that these contaminants have not been introduced to the marsh (from the watershed or elsewhere) but have been generated within the marsh peat by diking, peat drainage and aeration. The production of these "acid sulfate soils", of which there are hundreds of acres north of High Toss Road, is a widely observed and studied problem associated with salt marsh drainage worldwide.

NPS and cooperating scientists at the Marine Biological Laboratory Ecosystems Center and Boston University conducted field and greenhouse experiments in the early 1990s to assess the effects of restored tidal flow and salinity on sediment and water quality and salt-marsh plant growth above the Herring River Dike. This work showed that restored high water levels and salinity reversed the chemical processes responsible for the release of acidity and toxic metals; pH rebounded within a few months. Salt marsh grasses thrived once pH had recovered. Importantly, the sulfide produced by sulfate reduction, a process that will occur with re-flooding of the marsh, strongly precipitates aluminum, ferrous iron and whatever other metals may be present (and whatever their origin), eliminating their potential toxicity to aquatic fauna. Thus, the return of regular seawater flooding both eliminates an existing problem and helps to protect the estuary and receiving shellfish waters from any future contamination by metals.

Regarding other contaminants recent (1999) sampling just above and below the Herring River Dike by Dr. James Quinn of URI revealed little to no contamination by synthetic organic compounds; this is expected because of the lack of commercial and industrial development. Even if isolated pockets of synthetic organic contaminants already occur within the flood plain (e,g. landfill leachate), it's important to realize that the dike presently restricts the inflow of relatively clean seawater, and not the discharge of freshwater and any potentially entrained contaminants. Increased seawater flow would at the least dilute any contamination from an upstream source. **References: 11, 13, 14, 24.**

27. *How would restoring tidal exchange in Herring River alter the salinity patterns of Wellfleet Harbor?*

Freshwater discharge from Herring River is about 0.1 m^3/sec (=3.5 cubic feet per second); Wellfleet Harbor's tidal flow is at least 100 times greater; expectedly, low-tide salinity rarely goes below 25 parts per thousand(ppt) at Egg Island. With tidal restoration, low-tide salinities at Egg Island channel would increase slightly, increasing protection from upstream coliform sources (see above); importantly, salinities within the tidal river proper will increase dramatically throughout the tidal cycle, extending habitat for marine bivalves at least to Old County Road.
References: 15, 22, 23 and Presentation 6.

28. *What changes would occur in both nutrient inputs and phytoplankton (food for shellfish) in the harbor should tidal exchange be restored?*

As mentioned (#27), the influence of Herring River discharge on harbor water quality is very small given the huge difference between their volumes. Thus there would be little change in nutrient flux, and dependent phytoplankton, <u>on the seaward side</u> with tidal restoration. In greenhouse microcosm experiments NPS did observe that re-salination of acid sulfate soils, typical of the drained wetlands above High Toss Road, mobilized ammonium-nitrogen; however, this should be a short-term phenomenon. The ammonium is presently adsorbed to clay particles. To the extent that seawater reaches these sediments, ammonium will desorb and will be available as a nitrogen source to primary producers, both phytoplankton and wetland vascular plants. However, with a incremental and slow restoration of tidal exchange, any increases in ammonium will be gradual, i.e. not a large pulse. Also, with the high flushing rate in Wellfleet Harbor proper, this nitrogen is not expected to cause excess algae blooms.
Reference: 11.

29. What will happen to the salt-sensitive plants and animals that presently inhabit those portions of the flood plain that will be affected by tidal restoration?

Woody vegetation, e.g. shrubs and tress, will die once saltwater encounters their root systems during the growing season. Many herbaceous plant species of the brackish and tidal-freshwater marsh (e.g. marsh mallow) have some salt tolerance and will shift farther upstream over time – a process that will occur over years to decades.

Use of the flood plain by larger mammals (e.g. coyotes, raccoons, deer) will change little. Small mammals like voles and mice will continue to be very abundant in marsh grasses.

As shrubs decrease and open marsh and tidal flats increase, waterfowl and shorebird use will increase. Songbirds will likely decline in the interior marsh but persist along shrubby upland borders.

It is important to realize that the restoration of tide heights and salinity can be managed to occur slowly over a time span that is much longer than the life span of most small mammals. Thus individual animals will be less affected than their species' ultimate distribution within the floodplain.

Special consideration must given to rare plants and animals. There are no federally listed threatened or endangered species within the Herring River flood plain; however, the Massachusetts Natural Heritage Program lists four rare animal species of concern: water-willow stem borer (a moth), four-toed salamander, northern harrier, and diamondback terrapin. The stem borer feeds on water willow, a shrub that has invaded the Herring River salt marshes since saltwater was excluded nearly 100 years ago. A recent survey has found this insect in many water willow stands that would be damaged or eliminated by tidal restoration. Four-toed salamanders have been found in the most inland portions of the flood plain, e.g. sphagnum swamps in Paradise Hollow and Prince Valley; these swamps would be the last to be affected by tidal restoration, if at all. Northern harrier nest sites may be affected by increased tide heights; a survey is under way. Terrapins would be benefited by restored tidal restoration because habitat for these salt-marsh turtles would increase greatly. For all of these species, project proponents will consult with the Conservation Commission and the Natural Heritage Program prior to any alterations in tidal exchange. **References: 15 and Presentation 8.**

30. How will dying and dead woody vegetation be managed during the restoration process and the transition back to herbaceous salt marsh cover?

Several alternatives can be considered and will be subject to management review. Dead woody vegetation is unsightly, shades the ground surface and thereby retards recolonization by salt-marsh grasses, and will likely topple and leave depressions for mosquito breeding. Woody debris that falls into the main stream can impede migratory fish passage. It could be cut, with stems less than six inches stacked and burned; larger logs may be made available to the public for firewood. Alternatively, there is low-ground-pressure equipment that is capable of chipping the above-ground portions of trees and shrubs in place. Chips could be burned or removed: however, because this woody material would decompose slowly and represent little oxygen demand, it could be left to rot on the wetland surface.

The dense stand of exotic and invasive *Phragmites* between the dike and High Toss Road are a special case that will take some careful planning to avoid its spread. Given its current position at low elevations and very near the river mouth, the current stand should be severely stressed by tidal restoration and increased salinity; however, active control will probably be necessary at its northern extent to prevent spread upstream of High Toss Road. **Reference: Presentation 8.**

Additional questions related to migratory fish

from Phil Brady, Division of Marine Fisheries

31. *Will access for all anadromous and catadromous fish species into and out of Herring River be improved with the new designed dike openings?*

Yes. With a new dike with a wide (at least 100-foot) culvert, which modeling showed was the minimum width to remove all restriction (assuming no vertical restriction), peak current velocity would be only 2 meters per second and negotiable for most strong swimmers. Flows through the existing dike reach 6 meters per second, a velocity that prevents all fish from entering or exiting the system. Further consultation with anadromous fish experts is required for an optimum culvert design and opening schedule. **References: 22, 23.**

32. *With tidal restoration, how much longer during the tidal cycle will fish have access through the dike structure, in both upstream and downstream directions?*

After restoration it is expected that the period of time during which fish can enter or exit the Herring River will increase. Depending on the species, the window of time for passage will differ. Each species uses particular cues to begin a feeding or spawning migration. Under the current configuration of the dike's culverts, many species are blocked or inhibited from entering or exiting the Herring River during most of the tidal cycle. Additionally, as the fish wait to pass the dike, they expose themselves to predation and sub-optimal environmental conditions that may impact vital future activities, like feeding or breeding. With restoration, the cross-sectional area of the dike opening available for passage will increase greatly, with a corresponding decrease in tidal velocities. This will substantially enlarge, over existing conditions, the time window for fish passage. **References: 22, 23.**

33. *Will the new dike openings have top or bottom control mechanisms?*

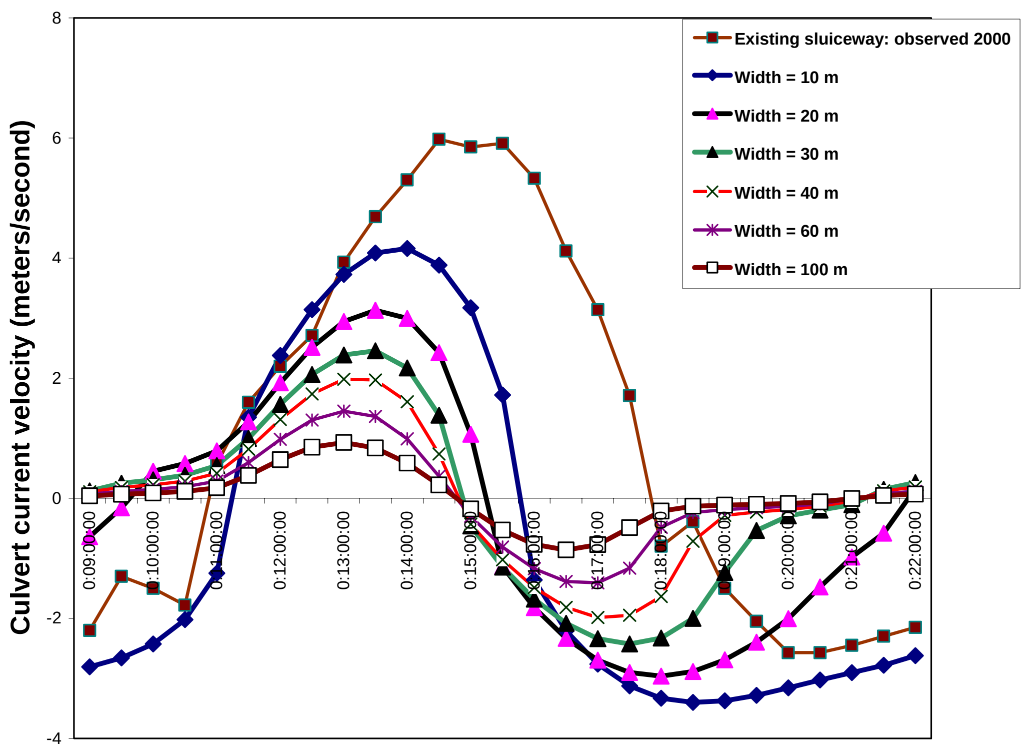
Decisions about actual design have not been finalized, but the Technical Committee has considered a structure similar to that installed at Hatches Harbor, where sluice gates are opened from the bottom up. The Hatches culverts are easily adjusted by a couple of people with manual house jacks. As mentioned above, additional consultation with anadromous fish experts is required to ensure improved fish passage.

34. *What will be the minimum water depth through the dike openings at low and high tides? As long as velocity criteria can be maintained, deeper and narrower is better than wider and shallower.*

The currently proposed openings will be shallow and wide: at dead low tide, water depth in the culverts would probably be about 0.9 ft; at high tide water depth would be about 3.7 ft, assuming a 30-m (100-ft) wide culvert. The objective here at the dike is to minimize restriction, and thereby simulate the geomtery and flow characteristics of the natural channel as much as possible. The increase in passage area through the structure, and decrease in tidal velocities will hopefully mitigate the impact of any sub-optimal passage conditions on all species, especially on species of interest, e.g., American eel and river herring. **References: 22, 23.**

35. *What will be the minimum and maximum water velocities through the new dike openings during period of potential fish passage?*

Although velocities acceptable for fish passage vary with fish species, age or size, the length of time that the tidal velocities are low (e.g. <0.5 meters per second) increases as the opening size increases. With the current culvert configuration the amount of time that the velocities are slow enough to allow passage for most weak swimmers (e.g., juvenile river herring) are very brief. Velocities under current conditions, and for a 100-foot wide culvert open to different heights, are depicted in the graph below for a normal 13-hour tidal cycle. **References: 22, 23.**



Comparison of water flow through the existing Herring River dike culverts versus a modeled wide culvert shows that flow velocity decreases with increasing culvert width. For the proposed 100-ft (30-m) wide culvert, peak velocity would be 1/3 of existing conditions.

36. *Will fish passage conditions be improved at the High Toss Road culvert?*

Yes. Modeling indicates that an opening 10 meters (about 33 feet) wide would remove all restriction on water movement here, assuming no restriction on tides at the mouth of the river, i.e. at the location of the existing dike. Essentially, the High Toss passage will allow the same tidal flow as the original tidal creek did through this part of the system, simulating original conditions. **Reference: 23.**

37. *If the High Toss Road culvert is not removed or replaced, what will be the minimum and maximum water velocities through that structure during the flood and ebb stages of flow?*

A significantly enlarged opening at High Toss is required for salt marsh restoration upstream; therefore, increasing tidal flow into the lower river without restoring original flow at High Toss is not a good option. **References: 22, 23.**

38. *At maximum restoration how much farther upstream will the salt wedge penetrate?*

Again, this depends on the which management alternative is selected. Modeling indicates that the 30-m wide culvert open only 0.4 meters (1.3 feet) high would bring the salt wedge to Old County Road; if this culvert were opened fully (e.g. 2 meters (6.6 feet) high), seawater could reach the wetlands just below Route 6 at high tide. **References: 22, 23.**

39. *Will any new hydraulic control points be established along the river's course from the upstream tidal intrusion?*

The town needs to decide on how to manage the 177 acres of the flood plain upstream of Pole Dike; if it's decided to exclude this from the restoration area, a clapper valve will be needed on the existing culvert. Elsewhere, an enlarged culvert would be needed at Bound Brook Island Road to minimize that restriction.

40. *Will any additional channelization or stream modifications of the river, upstream of High Toss road, occur during the restoration process?*

During the early 20th century, the river above High Toss Road was channelized and straightened, and the wetlands ditched for mosquito-control drainage. All involved, including the Cape Cod Mosquito Control Project, Division of Marine Fisheries, the National Park Service and the Town, need to consider and decide on the plan for restoring native hydrography. For example, should we restore cut-off meanders? Flexibility for adaptive management, acknowledging that we cannot foresee all possible outcomes, must be accommodated in the plan. For example at Hatches Harbor, during the restoration process it was found that original creeks had filled since 1930 diking and were not functioning to transport water, plant propagules and fish (mosquito predators) into the interior marsh. Mosquito Control and the Seashore responded to this problem by restoring (re-digging) Race Run and a tributary creek.

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Presentations

Summaries of above research presented to the Technical Committee, Oct-Dec 2005:

Presenters: John Portnoy, Evan Gwilliam and Steve Smith, Cape Cod National Seashore

Note that presentations are available on the Town of Wellfleet website: www.wellfleetma.org

1. Herring River tide heights and salinities under current and tide-restored conditions
2. Sediment transport and the stability of The Gut barrier beach with Herring River tidal restoration
3. Effects of tidal restoration on the freshwater aquifer and private water supplies adjacent to Herring River
4. Impacts of diking, drainage, and tidal restoration on Herring River water chemistry and aquatic habitat
5. Impacts of diking, drainage, and tidal restoration on Herring River nuisance mosquito production and control
6. An assessment of Herring River (Wellfleet, MA) microbiological (fecal coliform) water quality under existing tide-restricted and proposed tide-restored conditions (this 2005 research is in review and not yet published)
7. Herring River restoration: Fish and decapod crustacean monitoring 1984-2005 and response to restoration
8. Wellfleet's Herring River: History and future of the vegetation landscape

Responses Management Questions

Pursuant to the August 2005 MOU, the Herring River Technical Committee has considered Community and Stakeholder interests, as presented to the Committee by the Stakeholders Committee.

Technical Questions #1 and #17 (reassigned as Management Questions #31 and #32) and Management Questions #1 through #30 relate to the development of a restoration plan as required under the Technical Committee's charge, under Section Two (2), Part D of the MOU. These will be addressed pending acceptance of the Technical Committee's recommendation to the Wellfleet Board of Selectmen.

Management questions, included here, will be answered pursuant to the MOU, Section Two (2), Part D.

The Management Questions are as follows:

Management Questions

1. Have expenses and financing for culverts at Pole Dike & Old County Roads been identified, if not when will these be addressed?
2. Will the agreement to initiate restoration between the Town and the CCNS be subject to Town Meeting approval or referendum?
3. Have all federal permits been identified?
4. Have all state permits been identified?
5. Have all local permits been identified?
6. What is the procedure to include all permitting?
7. What oversight is proposed during the initial phases of restoration?
8. What oversight is proposed during the remaining phases of restoration?
9. Which agency will authorize any physical changes in elevation at the dike opening to adjust mean high water levels?
10. Which agency will implement these changes?
11. Who will authorize an operation and management agreement?
12. Who will implement a management agreement?
13. When will it be appropriate to recommend initializing an internal scoping process?
14. When will an environmental impact study be performed?
15. When will a fund be established to mitigate any damage caused by restoration to private property owners, businesses and shellfishermen?
16. When and how will federal, state, town or individual liability decisions be addressed?
17. Where will the funds come from?
18. Who will administer claims and issues?
19. When will a financial plan covering costs, funding, and assignment of liability be drafted?
20. Will the town and CCNS employ an administrator to manage certain aspects of this process?

21. Who would facilitate the emigration of fresh water aquatic life away from the restored area and when would it occur?
22. What will be done to monitor the integrity of the Gut after restoration?
23. If the Gut were to be eroded by the restoration, what impact would that have on continuing restoration?
24. Who will be responsible for monitoring changes in sediment in the harbor?
25. Will CCNS be allowed continued access after restoration?
26. Does an environmental impact study need to be done?
27. What will be done to compensate private individuals for damages resulting from restoration?
28. Can undesirable effects of restoration at the Country Club be resolved?
29. How will the costs of restoration affect the tax rate?
30. Would scrutiny by an independent agency (reviewing restoration plan) enhance credibility?
31. What is the proposed plan for the level of restoration?
32. How large an area would this take place over?

Suggested Additional Publications

1. Boumans, R.M.J., D. Burdick, M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10(3):543-555.
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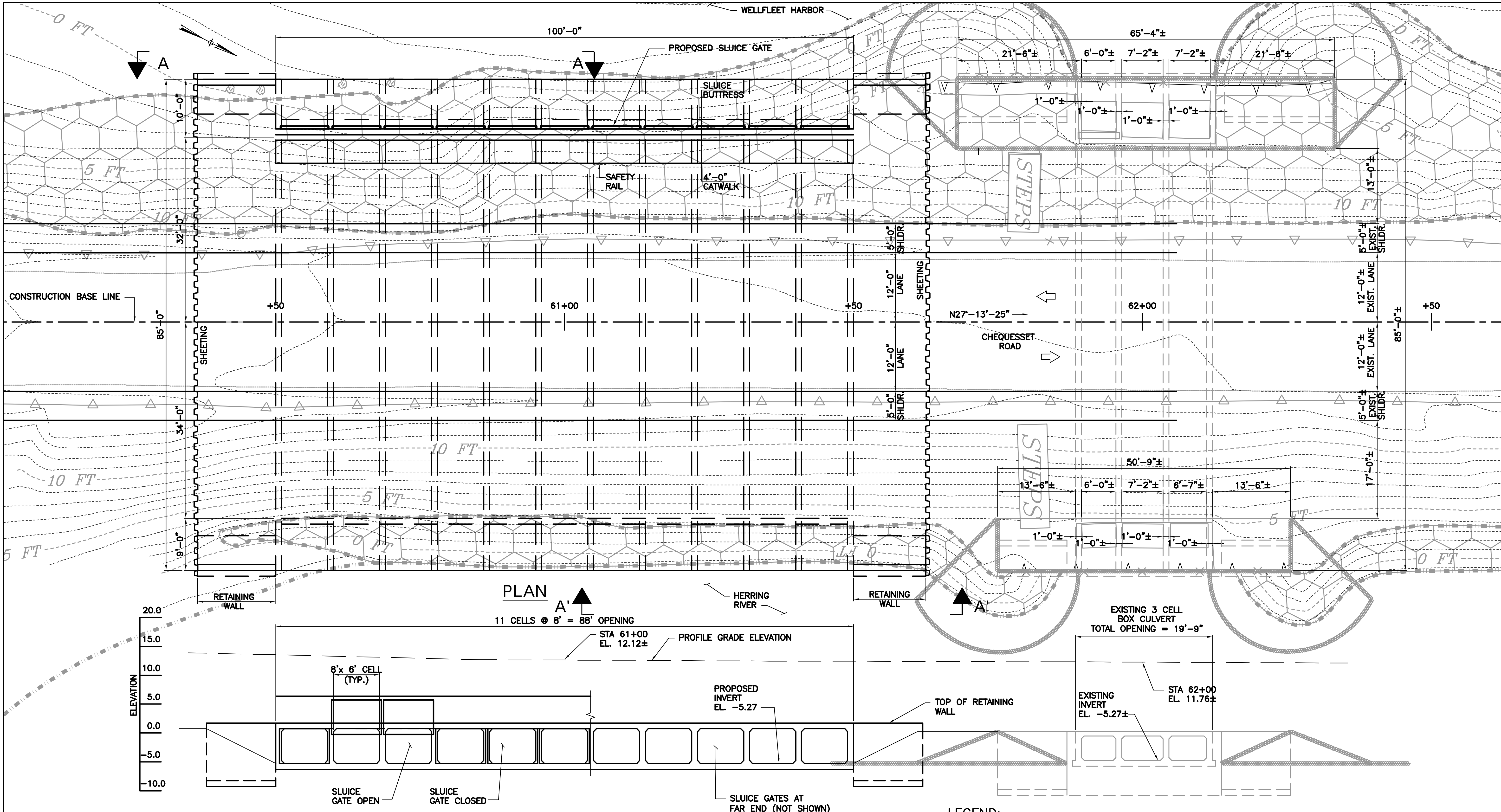
APPENDIX D

PRELIMINARY PLANS FROM DMJM HARRIS/AECOM MODIFIED TIDAL FLOODING CONTROL OPTIONS AT CHEQUESSET NECK ROAD DIKE

JUNE 2007

Note: all plans are in datum NAVD 88



STAGGERED ELEVATION
A-A & A'-A'

LEGEND:

△ GUARDRAIL

⬡ BOULDER

NOTES:

1. EXISTING TOPOGRAPHY IS SHOWN. TOPOGRAPHY WILL BE MODIFIED FOR PROPOSED CONDITION.

2. FINAL STRUCTURE DIMENSIONS WILL BE FINALIZED UPON COMPLETION OF HYDRAULIC ANALYSIS. TOTAL REQUIRED CLEAR OPENING WIDTH MAY INCREASE TO 130' OR MORE.

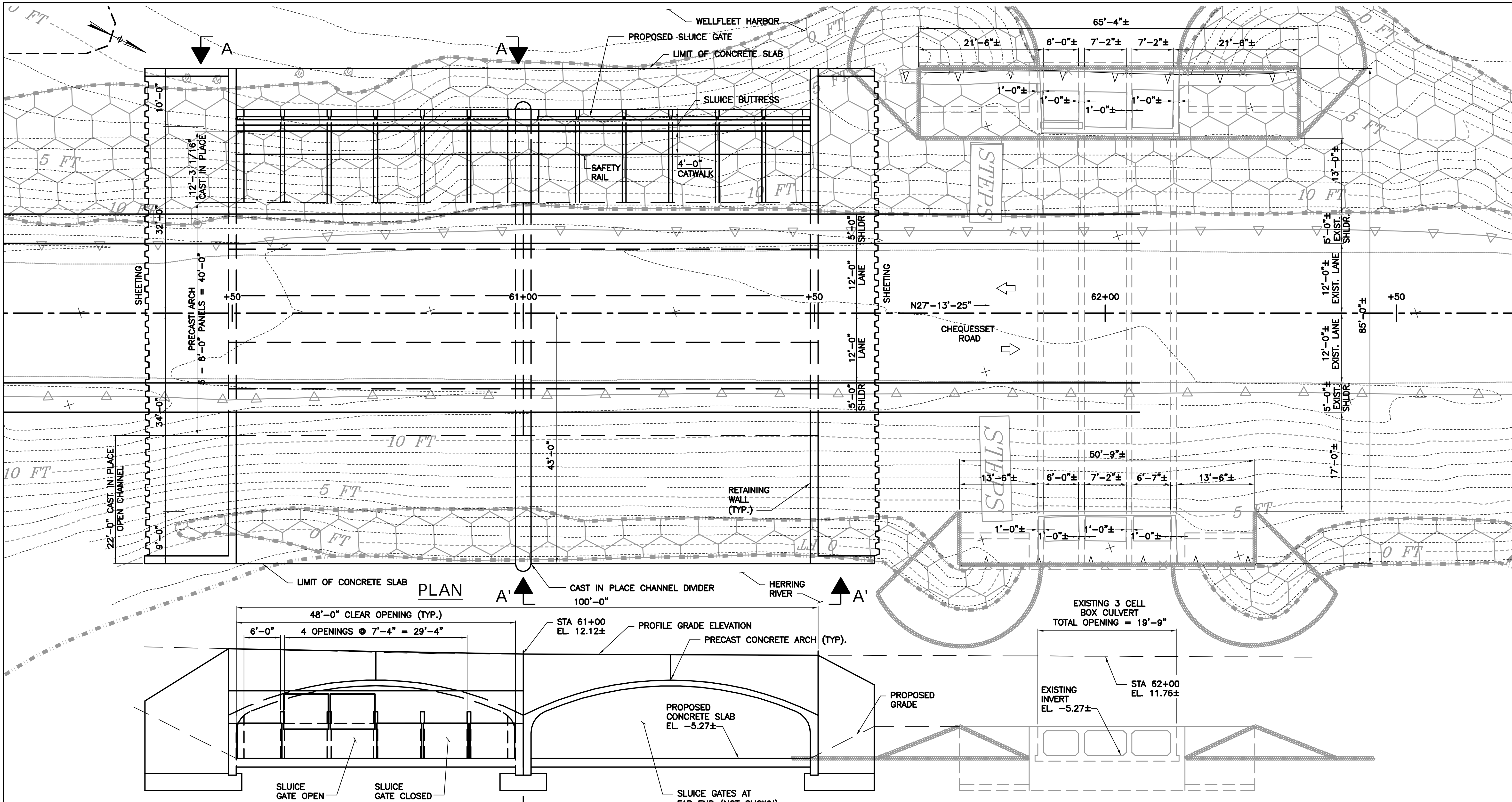
ENSR | AECOM

DMJM HARRIS | AECOM
ARCHITECTS - ENGINEERS - PLANNERS
66 LONG WHARF
BOSTON, MASSACHUSETTS 02110

ALT 1 - CAST-IN-PLACE BOX CULVERT

SCALE: 1/16" = 1'-0"

FIGURE 1



STAGGERED ELEVATION
A-A & A'-A'

LEGEND:
△ GUARDRAIL
⬡ BOULDER

NOTES:
1. EXISTING TOPOGRAPHY IS SHOWN. TOPOGRAPHY WILL BE MODIFIED FOR PROPOSED CONDITION.
2. FINAL STRUCTURE DIMENSIONS WILL BE FINALIZED UPON COMPLETION OF HYDRAULIC ANALYSIS. TOTAL REQUIRED CLEAR OPENING WIDTH MAY INCREASE TO 130' OR MORE.

ALT 2 - 2 SPAN PRECAST ARCH

SCALE: 1/16" = 1'-0"

FIGURE 2

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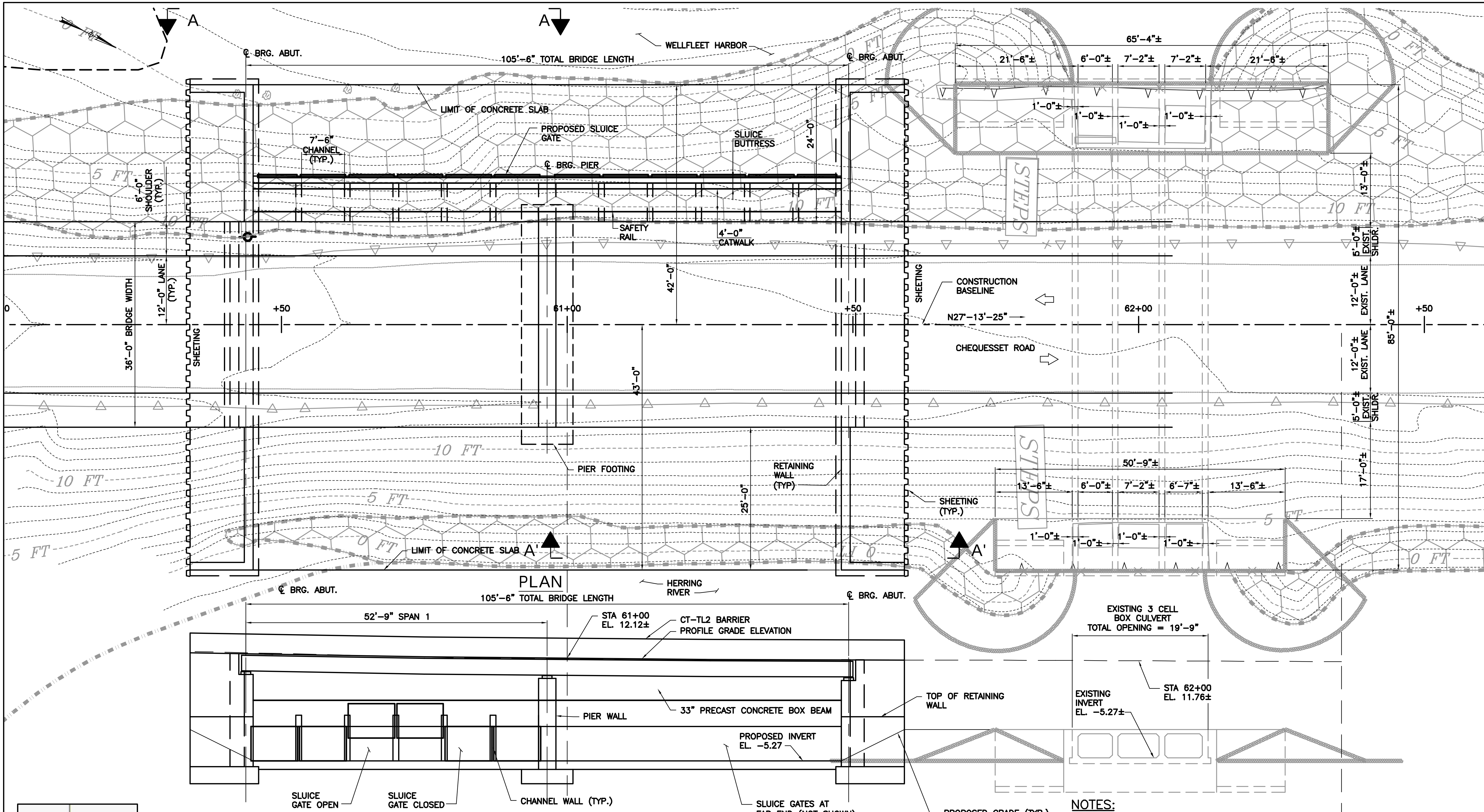

STAGGERED ELEVATION
A-A & A'-A'

ALT 3 - BRIDGE

SCALE: 1/16" = 1'-0"

LEGEND:

△ GUARDRAIL

⬡ BOULDER

NOTES:

1. EXISTING TOPOGRAPHY IS SHOWN. TOPOGRAPHY WILL BE MODIFIED FOR PROPOSED CONDITION.
2. FINAL STRUCTURE DIMENSIONS WILL BE FINALIZED UPON COMPLETION OF HYDRAULIC ANALYSIS. TOTAL REQUIRED CLEAR OPENING WIDTH MAY INCREASE TO 130' OR MORE.

FIGURE 3

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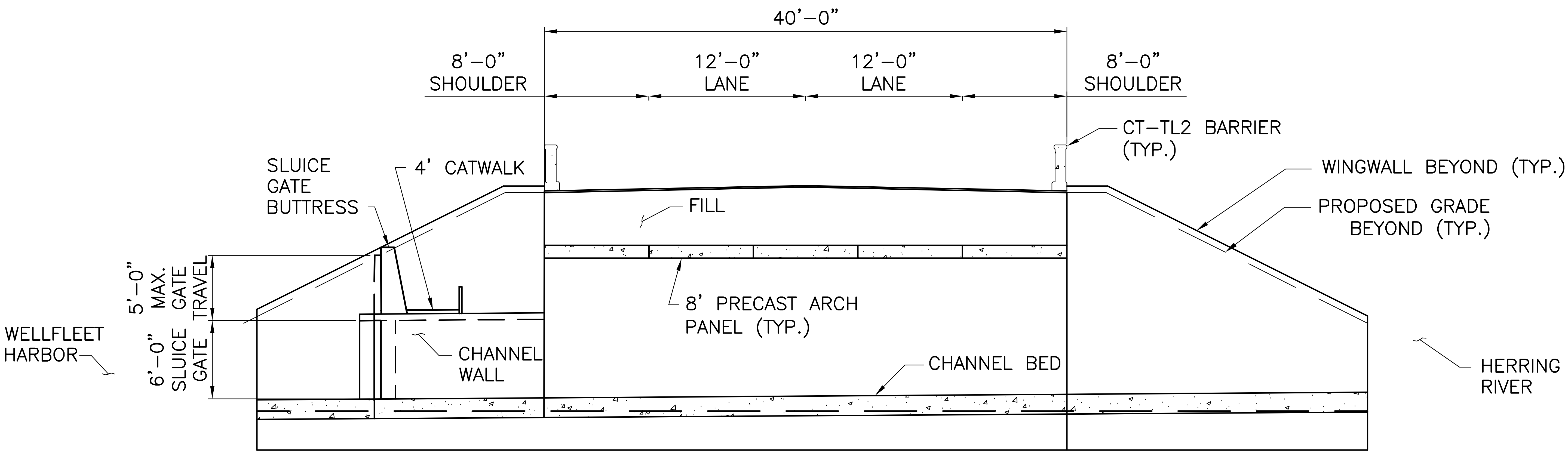

CROSS SECTION

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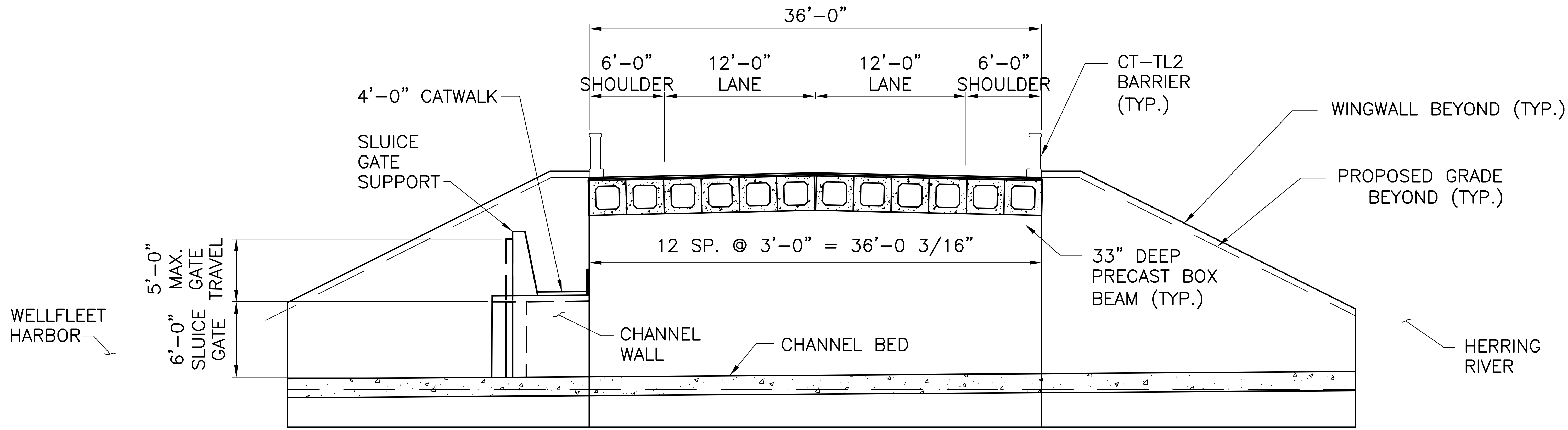
ALT 2 - 2 SPAN PRECAST ARCH

SCALE: 1/8" = 1'-0"

FIGURE 4



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ALT 3 - BRIDGE

SCALE: 1/8" = 1'-0"

FIGURE 5