Technical Report

Massachusetts Division of Marine Fisheries
Technical Report TR-56

The Acushnet River Restoration Project: Restoring Diadromous Populations to a Superfund Site in Southeastern Massachusetts

J.J. Sheppard[1], S. Block[2], H.L Becker[3], and D. Quinn[4]

[1]Massachusetts Division of Marine Fisheries
South Shore Field Station
1213 Purchase Street, 3rd Floor
New Bedford, MA 02740

[2]National Oceanic and Atmospheric Administration
Restoration Center
55 Great Republic Drive
Gloucester, MA 01930

[3]EA Engineering, Science, and Technology, Inc
221 Sun Valley Boulevard, Suite D
Lincoln, NE 68528

[4]DQ Engineering
11 Hickory Lane
Walpole, MA 02081

Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
Department of Fish and Game
Massachusetts Division of Marine Fisheries

March 2014

Massachusetts Division of Marine Fisheries Technical Report Series

Managing Editor: Michael P. Armstrong
Technical and Copy Editor: Elaine Brewer

The *Massachusetts Division of Marine Fisheries Technical Reports* present information and data pertinent to the management, biology and commercial and recreational fisheries of anadromous, estuarine, and marine organisms of the Commonwealth of Massachusetts and adjacent waters. The series presents information in a timely fashion that is of limited scope or is useful to a smaller, specific audience and therefore may not be appropriate for national or international journals. Included in this series are data summaries, reports of monitoring programs, and results of studies that are directed at specific management problems.

All Reports in the series are available for download in PDF format at:
http://www.mass.gov/eea/agencies/dfg/dmf/publications/technical.html or hard copies may be obtained from the Annisquam River Marine Fisheries Station, 30 Emerson Ave., Gloucester, MA 01930 USA (978-282-0308).

Recent publications in the Technical Report series:

TR-55 Nelson, G. 2012. **Massachusetts striped bass monitoring report for 2011.**
TR-54 Chase, B.C., A. Mansfield, and P. duBois. 2013. **River herring spawning and nursery habitat assessment.**
TR-53 Nelson, G.A. 2012. **Massachusetts striped bass monitoring report for 2011.**
TR-52 Camisa, M. and A. Wilbur. 2012. Buzzards Bay Disposal Site Fisheries Trawl Survey Report March 2001-March 2002.
TR-51 Wood, C. H., C. Enterline, K. Mills, B. C. Chase, G. Verreault, J. Fischer, and M. H. Ayer (editors). 2012. **Fourth North American Workshop on Rainbow Smelt: Extended Abstract Proceedings**.
TR-50 Hoffman, W. S., S. J. Correia, and D. E. Pierce. 2012. **Results of an industry-based survey for Gulf of Maine cod, May 2006-December 2007.**
TR-49 Hoffman, W. S., S. J. Correia, and D. E. Pierce. 2012. **Results of an industry-based survey for Gulf of Maine cod, November 2003—May 2005.**
TR-48 Nelson, G. A. 2011. **Massachusetts striped bass monitoring report for 2010.**
TR-47 Evans, N. T., K. H. Ford, B. C. Chase, and J. J. Sheppard. 2011. **Recommended time of year restrictions (TOYs) for coastal alteration projects to protect marine fisheries resources in Massachusetts.**
TR-46 Nelson, G. A., P. D. Brady, J. J. Sheppard, and M. P. Armstrong. 2011. **An assessment of river herring stocks in Massachusetts**.
TR-45 Ford, K. H., and S. Voss. 2010. **Seafloor sediment composition in Massachusetts determined through point data.**
TR-44 Chase, B. C., T. Callaghan, M. B. Dechant, P. Patel. 2010. **River herring spawning and nursery habitat assessment: Upper Mystic Lake, 2007-2008.**
TR-43 Evans, N. T., and A. S. Leschen. 2010. **Technical guidelines for the delineation, restoration, and monitoring of eelgrass (*Zostera marina*) in Massachusetts coastal waters.**
TR-42 Chase, B. C. 2010. **Quality assurance program plan (QAPP) for water quality measurements for diadromous fish monitoring 2008-2012, version 1.0.**
TR-41 Nelson, G. A. 2010. **Massachusetts striped bass monitoring report for 2009.**
TR-40 Pol, M., P. He, and P. Winger. 2010. **Proceedings of the international technical workshop on gadoid capture by pots (GACAPOT).**
TR-39 Dean, M. J. 2010. **Massachusetts lobster fishery statistics for 2006**.
TR-38 King, J. R., M. J. Camisa, V. M. Manfredi. 2010. **Massachusetts Division of Marine Fisheries trawl survey effort, list of species recorded, and bottom temperature trends, 1978-2007.**
TR-37 Leschen, A. S., R. K. Kessler, and B. T. Estrella. 2009. **Eelgrass restoration used as construction impact mitigation in Boston Harbor, Massachusetts.**
TR-36 Nelson, G. A. 2009. **Massachusetts striped bass monitoring report for 2008**.
TR-35 Barber, J. S., K. A. Whitmore, M. Rousseau, D. M. Chosid, and R. P. Glenn. 2009. **Boston Harbor artificial reef site selection and monitoring program.**
TR-34 Nelson, G. A. 2008. **2007 Massachusetts striped bass monitoring report**.
TR-33 Chase, B. C., Plouff, J. H., and M. Gabriel. 2007. **An evaluation of the use of egg transfers and habitat restoration to establish an anadromous rainbow smelt spawning population.**
TR-32 Nelson, G. A. 2007. **2006 Massachusetts striped bass monitoring report**.
TR-31 Dean, M.J., S. R. Reed, and T.B. Hoopes. 2007. **2005 Massachusetts lobster fishery statistics**.
TR-30 Chase, B. C. 2006. **Rainbow smelt (*Osmerus mordax*) spawning habitat on the Gulf of Maine coast of Massachusetts**.
TR-29 Glenn, R., T. Pugh, J. Barber, and D. Chosid. 2007. **2005 Massachusetts lobster monitoring and stock status report**.
TR-28 Nelson, G. A. 2006. **2005 Massachusetts striped bass monitoring report**.
TR-27 Estrella, B. T., and R. P. Glenn. 2006. **Lobster trap escape vent selectivity**.

Massachusetts Division of Marine Fisheries
Technical Report TR-56

The Acushnet River Restoration Project: Restoring Diadromous Populations to a Superfund Site in Southeastern Massachusetts

John J. Sheppard
Massachusetts Division of Marine Fisheries
1213 Purchase Street, 3rd Floor
New Bedford, MA 02740

Steve Block
National Oceanic and Atmospheric Administration
Restoration Center
55 Great Republic Drive
Gloucester, MA 01930

H. Lee Becker, P.E.
EA Engineering, Science, and Technology, Inc.
221 Sun Valley Blvd, Suite D
Lincoln, NE 68528

Dick Quinn
(formerly of the United States Fish & Wildlife Service—Retired)
DQ Engineering
11 Hickory Lane
Walpole, MA 02081

March 2014

Commonwealth of Massachusetts
Deval Patrick, Governor
Executive Office of Energy and Environmental Affairs
Richard K. Sullivan, Jr., Secretary
Department of Fish and Game
Mary B. Griffin, Commissioner
Massachusetts Division of Marine Fisheries
Paul Diodati, Director

Abstract: The Acushnet River has been the focus of a large-scale effort to restore river herring and American eel populations by improving access into the New Bedford Reservoir – the primary spawning and nursery habitat for these fishes. A cooperative effort between the Massachusetts Division of Marine Fisheries, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service focused on fish passage improvements to three main obstructions along the river. Fish passage improvements ran from 2002 to 2007 (the pre-construction period) and included: (1) the construction of a fishway at the New Bedford Reservoir Dam, and (2) improvement to fish passage at two downstream obstructions (the Acushnet Sawmill and the Hamlin Street dams), in which both sites were fitted with innovative, nature-like fishways, including a stone flow-constrictor/step pool system at the former and a stone step-weir system at the latter. Fish populations were monitored pre- and post-construction using census counting (river herring) and abundance estimation (American eel). Numbers of adult river herring returning to the reservoir during pre-construction were low, averaging less than 400 per year. Elver numbers also declined during this period and serve as a baseline to determine the effectiveness of the new fishways installed downstream. Post-construction monitoring commenced in spring of 2008. Results indicate an increasing trend of spawning adult river herring returning to the reservoir. According to counts in 2013, there has been an increase of 1870% over baseline conditions. There is also increased elver recruitment into the river, as well as in the upper watershed, which was mostly inaccessible prior to fishway installation. PCB testing, water quality analysis, and smelt monitoring were also conducted during this project to assess impacts to other resources as a result of fish passage improvements. Monitoring results suggest that the fish passage improvements to the three dams on the river have improved passage for both elvers and river herring; a step in restoring healthy populations of diadromous fish to the Acushnet River system.

Introduction

The Acushnet River was historically used as an industrial waterway during the 18th and early 19th centuries, in which dams were constructed to provide hydropower for mills (EAEST 2005). These dams have altered the habitat for resident aquatic life and significantly impaired the ability of the river to serve as a conduit for a variety of seasonally-transient diadromous species to and from the primary spawning and nursery habitats in the upper watershed.

The lower 4.4 miles of the Acushnet River system (and Upper New Bedford Harbor) is a tidally influenced estuarine and riverine habitat with no major impediments to fish passage. However, the lower watershed is located in a heavily industrialized area within the towns of Fairhaven and New Bedford, and was subjected to decades of contamination – primarily industrial discharges of heavy metals and polychlorinated byphenols (PCBs) into the harbor and nearby coastal areas of Buzzards Bay – from the 1940s through the 1970s[1].

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund," 42 U.S.C. §9601 et seq.) provides a mechanism for addressing the Nation's hazardous waste sites (NBHTC 2010). It allows states and the federal government to seek monetary compensation from polluters to recover the costs of clean-up and restoration of designated sites. In 1983, the U.S Environmental Protection Agency (EPA) designated the Acushnet River watershed and Upper New Bedford Harbor under the Superfund National Priorities List. Therefore, the area was subject to monetary compensation—a litigation settlement of $20,200,000 in 1992—for restoration projects that would restore the resources injured by the contamination.

Under the provisions of CERCLA, natural resource trustees (federal, state, or tribal authorities) are formed to represent the public interest in affected natural resources. In 1991, the New Bedford Harbor Trustee Council (NBHTC) – comprised of the Commonwealth of Massachusetts, the U.S. Department of Commerce (DOC), and the U.S. Department of the Interior (DOI) – was created and charged with the allocation of funds for natural resource restoration[2]. The National Oceanic and Atmospheric Administration

[1]A chronology of events detailing PCB contamination in the Acushnet River Estuary and New Bedford Harbor and measures taken to address this problem can be found in Appendix A.

[2]The designated representatives for the Commonwealth of Massachusetts, DOI, and DOC are the Executive Office of Energy and Environmental Affairs (EOEEA), US Fish and Wildlife Service (USFWS), and the National Oceanic and Atmospheric Administration (NOAA), respectively.

(NOAA) Restoration Center is the agency designated to serve as the lead agency responsible for restoration.

The NBHTC has undertaken environmental restoration in New Bedford Harbor and the surrounding area in order to: (1) restore natural resources injured by PCB releases; (2) restore the habitats of living resources and the ecological services that those resources provide; (3) restore human uses of natural resources, such as fisheries and public access; and (4) improve aspects of the human environment of New Bedford Harbor that have been degraded by the contamination (NBHTC 2001). The NBHTC has developed and published a final Restoration Plan and Environmental Impact Statement (RP/EIS) for the affected resources in the New Bedford Harbor Environment under CERCLA, 42 U.S.C. §9601 et seq., and NEPA, 42 U.S.C. §4321 et seq. (NBHTC 1998a). A Record of Decision (ROD) was issued on September 22, 1998 (NBHTC 1998b).

The Restoration Plan identified and prioritized the restoration of diadromous fisheries habitat and populations in the Acushnet River. In June of 1997, the NBHTC allocated funds for restoring and enhancing the diadromous populations in this watershed. The Massachusetts Division of Marine Fisheries (*MarineFisheries*), the agency under EOEEA responsible for the management of coastal diadromous resources in the Commonwealth, was assigned as the project proponent. This project was also advanced through the partnering sponsorship and participation of the NBHTC through NOAA, the Town of Acushnet, the Massachusetts Department of Fish and Game Division of Ecological Restoration (MADER), and the Buzzards Bay Coalition (BBC).

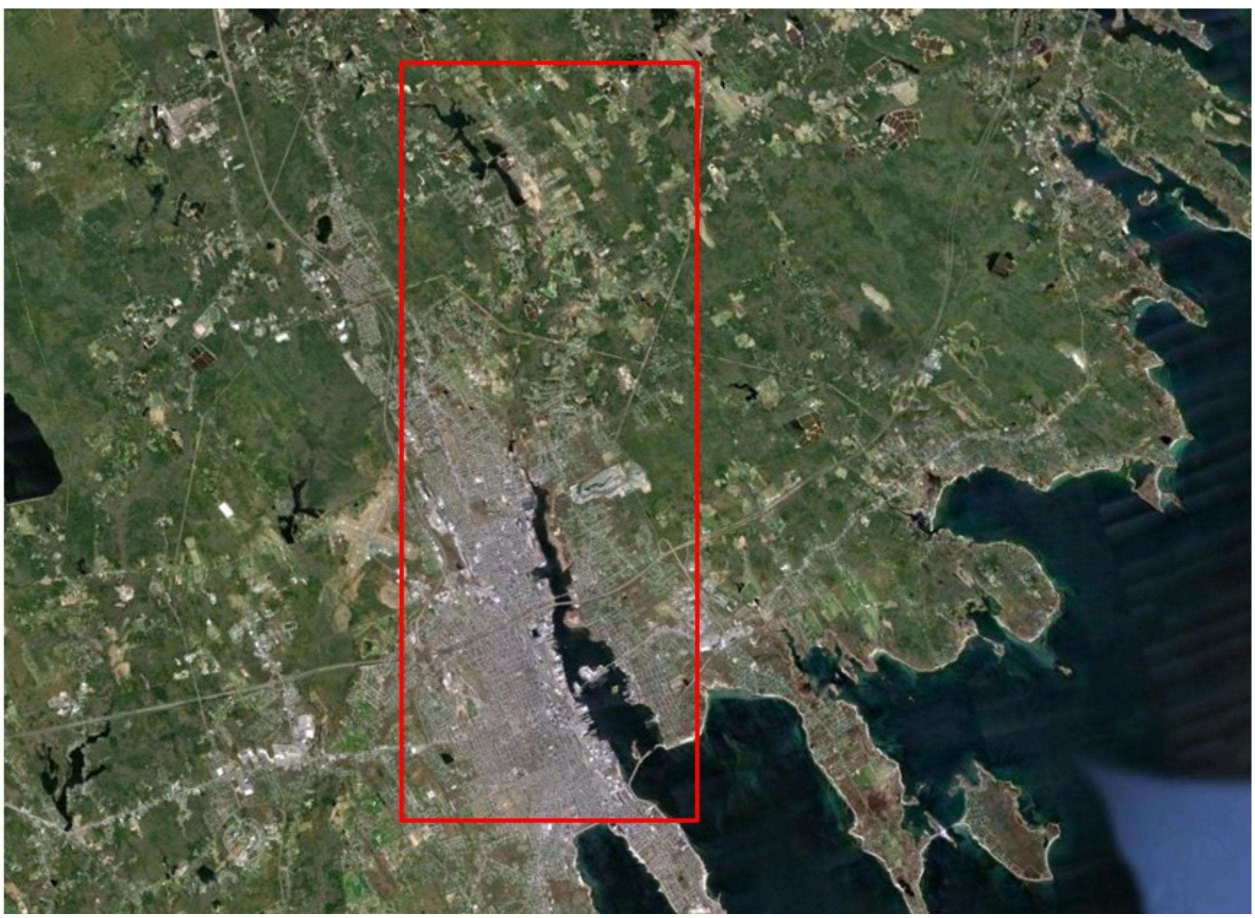


Figure 1: Satellite view of the Acushnet River watershed and New Bedford Harbor.

Figure 2: The Acushnet Sawmill Dam (left) and original weir-pool fish ladder (right) prior to construction in 2007.

Study Area

The Acushnet River is located in Bristol County, Massachusetts and encompasses an area of 18.8 mi^2 with a total stream length (including all tributaries) of 42.2 mi^2 and a mean annual flow (D50) of 19.0 ft^3/sec (USGS 2011). The headwaters of the Acushnet River are comprised of three root tributaries: (1) Roaring Brook originates in Freetown and flows southwesterly into the New Bedford Reservoir, an artificial reservoir created in 1869 as a water supply for the city of New Bedford; (2) Squin Brook rises in a swamp approximately 0.5 miles south of Little Quitticas Pond in Lakeville and flows south into the reservoir; and (3) Squam Brook flows out of Long Pond in Lakeville before emptying into the New Bedford Reservoir in the town of Acushnet. The connection to Long Pond had been severed, therefore the New Bedford Reservoir currently serves as the primary headwater impoundment for the system. The mainstem of the river flows approximately 8.6 mi south from the New Bedford Reservoir into New Bedford Harbor and empties into Buzzards Bay (Figure 1).

Using a water quality classification system developed by the Massachusetts Department of Environmental Protection (*MassDEP*) Division of Water Pollution Control (314 CMR 4.05 and 314 CMR 4.06; *MassDEP* 1996; Appendix B: Table B1, Figure B1), the watershed (including inner and outer New Bedford Harbor) is designated as category 5 (impaired waters) under section 303 (d) of the Clean Water Act (*MassDEP* 2007). Under regulation (40 CFR 130.7), existing conditions are not expected to meet surface water quality standards after the implementation of technology based controls, thereby requiring the development of total maximum daily loads (TMDLs) – the maximum amount of a pollutant that may be introduced into a waterbody and still ensure attainment and maintenance of water quality standards approved by the EPA (*MassDEP* 2012; Appendix B).

The Acushnet River historically supported several diadromous species including alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*), collectively called 'river herring', rainbow smelt (*Osmerus mordax*), white perch (*Morone americanus*), and American eel (*Anguilla rostrata*). An alewife fishery was established in 1863, subject to the rights of the City of New Bedford, which controlled the headwaters as a water supply (Belding 1921). Similar to many other coastal herring runs, this system experienced severe declines in alewife production during the industrial revolution. The creation of dams, water flow diversions, and the input of pollutants and manufacturing wastes into the river as a means of waste management were the main factors behind the collapse of the fishery. In 1920, it was believed that existing conditions were so poor, with lack of fish passage on several dams, and water quality severely degraded by factory wastes, that the herring fishery was not worth reclaiming (Belding 1921).

The production of diadromous populations (in particular, river herring) has been impacted by the presence of three barriers to passage: (1) Acushnet Sawmill Dam; (2) Hamlin Street Dam; and (3) New Bedford Reservoir Dam[3]. According to the EPA Index of Watershed indicators (Milone and MacBroom 2000; USEPA 2007), the dams are located within an area of moderate concern for contaminated sediments, moderate volumes of impounded water due to dams, and minor water quality problems. Using the *Mass-DEP* (1996) water quality classification system (Appendix B, Table B1), the upper watershed from river mile 4.5 to 8.2, including the New Bedford Reservoir, is designated as "Class B" with water suitable for fish and other aquatic life and for limited recreational use. The lower watershed from the Acushnet Sawmill Dam (river mile 4.4) downstream to Inner New Bedford Harbor is designated as "Class SB" and has shellfish harvest restrictions.

The Acushnet Sawmill Dam, at river mile 4.4 (Figure 2), was originally constructed in 1746 and used to power the sawmill there. Prior to this project, the earthen dam was unused and had a concrete spillway 118 feet in length and approximately 4.6 feet in height with heavy siltation both above (approximately 30 ft upstream) the dam and below in the tailrace. A 6.5 acre impoundment, Sawmill Pond, is located upstream of the dam. A functioning sluiceway bypassed a portion of the river around the main spillway, flowed below an existing building, and emptied downstream of the spillway. The main channel below the dam lied between stone walls for approximately 400 feet downstream of the spillway and exhibited a diffuse, dendritic flow pattern in low water conditions.

Figure 3: The Hamlin Street Dam prior to construction in 2007.

The Acushnet Sawmill Dam was equipped with a conventional weir-pool fish ladder and had seven pools averaging 42 inches in length, a pool drop of 9 inches, and weir board inverts situated below the level of the adjacent downstream pool. The entrance to the fishway was perpendicular to the main flow over the dam on the eastern side of the spillway. At high spring river flows, this configuration minimized and dissipated the attraction flow originating from the fishway and served to delay upstream migration. The fishway operated best at low flows, when the jet from the fishway better attracted fish (Dick Quinn, personal communication, 30 November 2012). However, the structure of the ladder had deteriorated over time and no longer provided efficient upstream passage. In addition, heavy vegetation growth at the base of the dam eliminated any defined stream channel and inhibited fish from finding the ladder entrance due to the reduced attraction flow.

The Hamlin Street Dam, at river mile 5.3, was originally built in 1746. According to the Massachusetts Department of Conservation and Recreation Office of Dam Safety, the existing dam was re-constructed in 1920, and used for irrigation for a local dairy farm (Milone & MacBroom 2003a). Pre-project, it was a 300-foot earthen dam that supported a town road (Hamlin Street) over the Acushnet River. The river flowed over the spillway (comprised of three concrete weirs 12 – 27 ft L x 0.5 – 1.5 ft. H) located approximately 15 feet upstream of the road and underneath Hamlin Street through three granite block culverts. The upstream impoundment (Hamlin

[3]A fourth obstruction, the Wheldon Mill Dam, was built in 1814 at river mile 7 and exists today as a porous stone rubble river ford that is passable by river herring.

Figure 4: Downstream (left) and upper (right) sections of the New Bedford Reservoir Dam prior to construction in 2007.

Pond, 12.5 acres) had filled with sediment and transitioned into a freshwater wetland system (6.5 acres) with few areas of open water (Milone & MacBroom 2000). Based upon measurements made at the Hamlin Street culvert (Quinn 1995), the estimated discharge was 10 cfs. Diadromous fish were able to pass upstream through the center and easternmost culverts via a stone ramp-like structure (Figure 3). However, passage through these culverts was possible only under limited optimum flow conditions and, even under those flow regimes, passage efficiency was poor.

The New Bedford Reservoir Dam at river mile 8.1, is an 11-foot earthen structure built in 1867 and is currently owned by the City of New Bedford (Figure 4). The reservoir historically served as a secondary water supply in water emergencies. It currently serves as an irrigation supply for a farm located on its eastern shore. The dam creates a large impoundment providing 220 acres of underutilized spawning and nursery habitat for river herring and eels.

The pre-project spillway at the New Bedford Dam was 50 feet in width, with three notched sections and a vertical drop of approximately 18 inches (Figure 4). Now, water levels at the spillway are regulated by the addition or removal of 2 x 10 inch boards, depending on water flow. The channel below the spillway has a gradient of 10 feet in 500 feet with a "V" shaped weir at the downstream end of the channel. Water velocity measurements (Quinn 1995) in the channel ranged from 1 fps to 8 fps. The spillway had functioned as a fishway for many years but was never intended for this purpose. Although the spillway has passed fish under ideal flow conditions (at high spring flows), this structure has hindered access to the spawning habitat in the reservoir. As a result, fish passage at this point was extremely inefficient and the structure was the limiting factor in reaching the production potential of the system. The remnant river herring population was sustained by the minimal number of adults able to ascend into the reservoir.

The potential for increasing the size of the existing river herring population was considerable based on the large amount of spawning and nursery habitat in the headwater impoundment. Recommendations from a state-wide assessment conducted by *MarineFisheries* (Reback et al. 2004) and the New Bedford Harbor Trustees Council (NBHTC 1998b) stated that further development of the Acushnet River was dependent on pollution abatement and provision of fish passage facilities to the New Bedford Reservoir. Over time, water conditions improved as mills closed, causing industrial waste run-off to decline.

Methods

Restoration activities for the Acushnet River occurred in two phases. The first phase included the design and construction of fishways at the three existing dams to enhance passage. The second phase focused on monitoring diadromous species abundance prior, and in response, to fishway improvements.

Phase One: Fish Passage Improvements (Conceptual Designs, Planning and Installation)

The NBHTC provided funds for *MarineFisheries* to (1) design and construct fish passage facilities at the New Bedford Reservoir and (2) study the feasibility of improving fish passage at both the Hamlin Street Dam and the unused industrial dam at the site of the former Acushnet Sawmill Company. NBHTC also provided funds to NOAA to design and construct the fishways at the lower two dams. The functional objective of these fishways was to improve upstream passage of adult river herring to the New Bedford Reservoir by 1000% by 2011 when compared to pre-project conditions.

<u>New Bedford Reservoir Fishway</u>

Prior to the development of a fishway plan at the New Bedford Reservoir, *MarineFisheries,* in conjunction with the USFWS and the town of Acushnet, developed a list of criteria the new fishway must meet:

(1) The ability to pass river herring (the target species) by establishing target velocities and depths under various

Figure 5: Upper Acushnet River watershed and New Bedford Reservoir with focus on the project area (*insert*).

Figure 6: Downstream section of the New Bedford Reservoir showing the location of the Denil ladder entrance (*left*) and exit upstream (*right*).

flow conditions expected to normally occur during the migration period

(2) The new fishway may not lower the headpond elevation

(3) Avoid and minimize impacts to wetland resource areas

(4) Meet safety standards established by the Massachusetts Department of Conservation and Recreation Office of Dam Safety

A Denil technical fishway was chosen over modifying the existing channel below the fishway or installing a nature-like bypass channel. This choice was based on initial measurements conducted by the USFWS (Quinn 1995) and water velocities within each section. Fishway design was based on a site evaluation of the exit channels, grades at the bottom of the spillway outlet channel, availability of river flows in this section of stream, and the ability of the design to regulate itself at varying water levels expected to occur during the fish passage season.

Hydrological modeling (Kleinschmidt 2001) and geometric analysis were used to ensure the fishway would have a wide flow range, thereby increasing the possibility for fish passage, minimizing instream impacts and adverse effects on the headwater pond elevation. (Appendix C, Figure C1). Because there are no stream gauges on the Acushnet River, data from five US Geological Survey (USGS) stream gauges in similar river systems in the region were evaluated and used to simulate flow frequencies at this site (see Appendix C, Table C2). Fishway entrance and exit flows, as well as channel flow distribution, were modeled over a 24-hour period during the fish passage season. During the expected operating conditions, the fishway passed a minimum of 5.5 cfs at minimum design level, 11—12 cfs during normal flow, and <20 cfs at maximum operating level when the spillway is passing excessive flows. Under these criteria, the velocity through the Denil baffles would have an average value of approximately 3.0 fps, which allows efficient passage for a wide range of fish species, specifically river herring (Odeh 2003).

Following the completion of the permitting process (Appendix C, Table C1), the fishway was built at the New Bedford Reservoir Dam and is located on the western edge of the river channel adjacent to the spillway (Figure 5). In accordance with design criteria, the fishway exit is located approximately 25 feet upstream of the centerline of the spillway structure and continues for approximately 240 feet along the bank of the stone lined channel. The entrance is located approximately 60 feet downstream of an existing channel crossing. The channel to the entrance was placed in a backwater pool created by an existing grade control structure. An existing partial barrier, consisting of boulders, was enhanced to act as a barrier dam guiding upstream migrants into the fishway entrance. After migrants enter the fishway, they must negotiate two Denil baffle sections (a maximum lift of approximately 5 feet) and three level sections before exiting the fishway above the upper spillway. Design plans can be found in Appendix C (Figure C2).

The fishway configuration (Figure 6) included a diversion of a portion of the flows from the existing channel to the exit of the new fishway. The fishway exit channel was placed above the spillway where the river channel width narrowed. Because the fishway exit elevation is below the headwater elevation, river flow was diverted entirely through the fishway during certain periods of the year – primarily during the migration season, April 15 to June 15. The fishway was designed to also accommodate the insertion of stop logs in the exit channel to close off flows through the fishway after the spring migration period and divert flows over the spillway for the juvenile herring outmigration during the summer and autumn months. If these flows were not diverted, safe passage for juveniles

Figure 7: (A) Acushnet Sawmill and (B) the Hamlin Street dams and fishways on the lower Acushnet River.

would not be ensured and massive die-offs could occur, undermining the restoration efforts.

Acushnet Sawmill and Hamlin Street Fishway Design Considerations

Restoration efforts then focused on improvements to fish passage along the 3.8-mile stretch of the Acushnet River from the head of tide to the reservoir (Figure 7). Various alternatives, including conventional fishway installation as well as full and partial dam removals, were examined to determine the most appropriate fish passage designs. These scenarios were considered due to the poor condition of the dam structures, the potential need for future road improvements at the Hamlin Street site, and the willingness of the dam owners to consider removal. The first task was to consider the various feasible alternatives that would enhance fish passage at the Sawmill and Hamlin Street Dams while meeting the following criteria:

(1) The ability to pass river herring and other migratory species by establishing target velocities and depths under various flow conditions

(2) The new fishways may not significantly impact upstream headpond elevations

(3) Impacts to wetland resource areas must be avoided or minimized

(4) Safety standards established by the Massachusetts Department of Conservation and Recreation Office of Dam Safety must be met

To determine if dam modification or removal would be more beneficial, a Dam Structure Topography Survey was conducted at both sites in accordance with requirements established by Massachusetts Regulations 250 CMR (Milone & MacBroom 2003a). In addition, a feasibility study was conducted to examine the potential benefits and impacts to river herring, as well as other species and habitats, that may result from removing a portion or all of the two lower dams (Milone & MacBroom 2003b). The study examined critical issues such as impoundment water surface levels, flow velocities, sediment quality, and transport. As a component to the feasibility study, bathymetric surveys were conducted at both sites to determine impoundment areas including adjacent wetlands within the shoreline limits of each impoundment.

Both the Sawmill and Hamlin Street Dams are located within Federal Emergency Management Agency (FEMA) regulated floodplain and floodway areas. Therefore, a hydraulic analysis model built by Milone & MacBroom (2003b) was used to predict water surface levels and velocity profiles as a result of full or partial dam removals at the Sawmill Dam (Appendix D) and the Hamlin Street Dam (Appendix E). The model used the Hydrologic Engineering Centers River Analysis System (HEC-RAS) to evaluate the potential increase in flood stage or velocity during the 100-year flood as a result of proposed project designs. The model also assesses the potential loss of impoundment surface area and adjacent wetlands upstream under the proposed designs. Using data from the FEMA Flood Insurance Study for Acushnet, Massachusetts for tidal and riverine reaches (Appendix D, Tables D2-D3; Appendix E, Table E2) of the area (FEMA 1982; EAEST 2007) and with additional calculations provided by the USFWS, the developed HEC-RAS model also determined the potential long-term changes in rates and volume of sediment transport as well as possible impacts on downstream areas, including New Bedford Harbor. Results of these studies were used to determine the areas and volumes of sediment that would require removal for constructing the preferred alternatives and resulting in hydro-dynamically stable conditions.

Results from hydraulic analyses, examination of preferred alternatives in the feasibility studies and the subsequent Expanded Environmental Notification Form (ENF) (Milone & MacBroom 2000; 2003b, 2003c; EAEST 2006a; 2006b) recommended modifications to existing structures at both sites. The incorporation of nature-like fishways was recommended to restore natural river continuity and morphology and enhance fish passage. As the preferred alternative to complete dam removal (mostly to maintain headponds), conceptual planning on partial dam removals fitting the existing sites with innovative nature-like fishways were developed in order to minimize impacts to wetlands and maintain the headpond water levels for adjacent cranberry operations.

As a component of nature-like fishway conceptual planning, the HEC-RAS model was used to determine: (1) the appropriate elevation of each step (weir) increase (as measured from the lowest notch of the previous weir) upstream; and (2) proper stone size for both weir and pool construction (Appendix D, E). Stone size selection is based on a standard channel design method as described by the US Army Corps of Engineers (USACOE 2012). Smaller stones used for riffle grade control were selected to provide compaction and stability while large boulders were chosen for step pools and weirs to prevent displacement during high-flow periods. The HEC-RAS model was used to find the highest shear stress in the stream (typically 100-year flood) and used for stone sizing of both fishways. One of the goals of the dam modification/removal (and subsequent nature-like fishway designs) was to minimize potential changes in the headpond elevation during springtime flow conditions, in order to preserve the existing upstream wetlands as much as possible. For the Acushnet Sawmill site (Sawmill Pond), the design targeted a springtime headpond elevation of approximately 10 to 10.5 feet in order to minimize impacts to wetlands. For the Hamlin Street Dam, the fishway was designed to maintain the upstream impoundment (Hamlin Pond) at ≥ 16.6 ft with flow of 75 cfs.

The Acushnet Sawmill Fishway

Work at the Sawmill site involved the construction of a flow constrictor-step pool structure that extends from the top of the Sawmill Dam spillway for a distance of approximately 200 ft downstream. Details of the technical design are summarized in Appendix D. Construction commenced in July 2007, outside of the critical migration period of adult spawning river herring and elvers (March 15 through June 30), after the required permits were obtained (Appendix D, Table D1). This was also a time of low flow periods, allowing for the effective diversion of river flows from construction areas through the existing sluiceway. This, in turn, allowed the construction site to be de-watered (impacting approximately 4,400 ft^2 of wetland resource areas) and work was conducted in dry conditions while safe passage for any outmigrating diadromous species was still provided. Fishway replacement (Appendix D, Figure D2a) involved breaching the dam through removal of a portion of the spillway in which the length of the

Figure 8: The Acushnet Sawmill dam and fishway prior to (April 2007, *left*), and after (July 2007, *right*) construction.

Figure 9: Completed construction (October 2007) of the rock weirs downstream of Hamilton Street.

dam was reduced (approximately 60 feet). The dam was further modified by demolishing a portion of the spillway in which the height of the dam was lowered about three feet and notched at the eastern end. This was done to facilitate passage upstream as the modified dam served as the final weir in the ladder.

Following spillway modification, the stream channel was re-defined through excavation of material within the existing channel boundary downstream (approximately 314 yd^3) of the spillway to allow for the construction of the step pools. Dredged material was combined with imported clean fill material (approximately 1,120 yd^3 of imported stone, boulders, and granular fill) to stabilize riverbanks downstream of the Sawmill Dam for the flow constrictor/step pool system. Results from the tractive shear stress method (EAEST 2007) or particle size indicated 4 - to 5-foot median axis diameter stones were required to construct the weirs. Large boulders (3,000 to 5,000 pounds, each) were placed side-by-side forming eleven weirs at different elevations to assist in navigation at most water flow levels (based on hydrology modeling) up to and upstream of the spillway (Appendix D, Figure D2b). Each step was designed with five elevations with baseflows directed through notches to promote fish passage (Appendix D, Figure D2c). Each notch has a minimum depth of 0.7 feet and a maximum design velocity of 2.5 fps. The re-configured spillway was tied into the grade from the uppermost flow constrictor-step pool to serve as the top elevation of the flow constrictor-step pool structure. In order to maintain a springtime headpond elevation between 10 and 10.5 feet, the uppermost weir elevation was set at approximately 9 feet with a predicted 90% exceedance flow of 10.31 feet at the spillway and 10.84 feet in the headpond.

Imbricated riprap walls were installed adjacent to the step pool structure to stabilize the re-defined stream channel. The re-defined riverbanks were fortified with native vegetation planted along the upper slopes and the top of banks. The plantings (seed mixes, branch layering, and live stakes) stabilize the re-deposited dredged material from flow levels above flood elevations. A biodegradable erosion control mat was used to provide immediate erosion control until the root systems of the plantings became established and provided long term bank stabilization.

Following the completion of the new fishway (Figure 8), approximately 20 yd^3 of sediment immediately upstream of the dam were excavated to create a stable channel connecting the newly constructed fishway with the upstream impoundment. After this connection was made, the existing underground sluiceway was permanently closed, directing all flow through the newly constructed fishway, providing more light and eliminating dry, no-flow periods in the restored reach of the river. The existing weir-pool fish ladder was decommissioned and filled in.

The Hamlin Street Fishway

Results from feasibility studies and the subsequent ENF (Milone & MacBroom 2000, 2003b, 2003c; EAEST 2006b) recommended the removal of the eastern sill of the Hamlin Street Dam and the construction of a graduated stone step-weir system. Details of the technical design are summarized in Appendix E. Construction commenced in August 2007, after the required permits were obtained (Appendix E, Table E1) and included the partial demolition of the existing concrete spillway and three associated concrete piers upstream of the eastern bridge under Hamlin Street. In addition, a 50 ft channel upstream of the removed spillway was stabilized by replacing the fine substrate with cobble.

A series of five rock weirs, to overcome a smaller elevation differential (two upstream of the existing eastern box culvert and three downstream), were constructed in the river channel to facilitate fish passage (Figure 9). The design utilizes weir elevations of ≤ 1 foot, and the uppermost step weir structure elevation was set at 14.97 feet (eastern culvert) and 16.75 feet (central culvert) to establish the headpond elevation at 16.6 feet at a flow of 75 cfs. The fishway is designed to direct flows ≤ 140 cfs to the eastern channel.

Under pre-construction conditions, the 2-foot retaining wall on the left bank of the river downstream of the eastern culvert was deteriorating and was unable to contain excess flow levels during high flow conditions. As part of the step weir construction, existing grades were raised one foot and boulders were placed along the retaining wall in order to stabilize the area for the new flow conditions. In addition, a retaining wall was constructed along the right bank to confine the channel to the desired width (20 feet) to allow excess flows (≥ 94 cfs) to spill over into the adjacent wetland area.

Phase Two: Biological Enhancement and Monitoring

The NBHTC provided funding for *MarineFisheries* to conduct seven years of biological monitoring of diadromous populations. Monitoring efforts focused primarily on river herring with a secondary focus on juvenile American eels and smelt. The purpose was to examine the status of these populations prior to fish passage improvements, as well as to assess the response of these populations to improvements in fish passage.

In anticipation of the fishway installations at the New Bedford Reservoir and Hamlin Street and Acushnet Sawmill dams, *MarineFisheries* initiated alewife augmentation stocking at the reservoir to accelerate the recovery of this population during construction efforts. Transplantation efforts were carried out for six years to supplement the remnant natural run. Over 22,000 pre-spawning adult alewives were transplanted into the New Bedford Reservoir from 1999 through 2005 (Table 1).

Table 1: Origin and number of pre-spawning adult alewives used to augment the Acushnet River spawning run.

Year	Donor System	Watershed	Number Stocked
2000	Monument River	South Coastal	4,500
2001	Monument River	South Coastal	4,500
2002	Monument River	South Coastal	3,473
2003	Agawam River/Gibbs Brook	Buzzards Bay	5,700
2004	Monument River	South Coastal	3,300
2005	Agawam River	Buzzards Bay	600
		Total Stocked	22,073

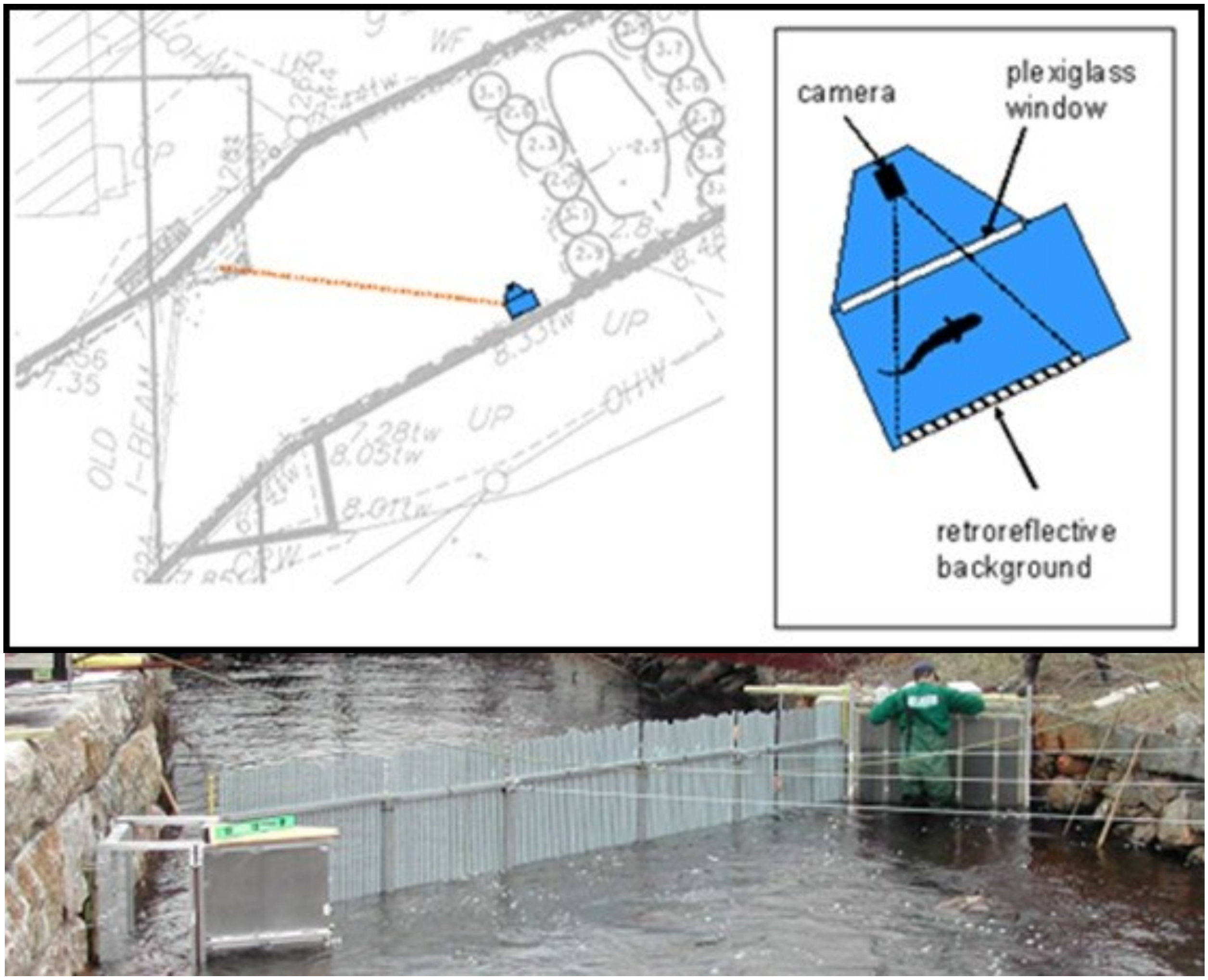


Figure 10: Above, USGS video monitoring system diagram detailing location and layout of the weir (left) and camera housing (right). Below, the lower-most rock weir (entrance) of the Sawmill Dam fishway. Photos courtesy of USGS (see Haro et. al. 2008).

Census monitoring of river herring commenced in Spring 2005 and continued for seven consecutive years, terminating in 2011. Total counts of river herring were recorded each year, and an average total count of the pre-construction years (2005 through 2007) was used as baseline conditions in order to establish the 1000% enumeration target level for 2011. Two additional years (2012-2013) of monitoring (funded by *MarineFisheries*) were conducted to monitor changes in herring run size beyond the original project scope. To census the river herring population and other species compositions, *MarineFisheries* constructed a locking box trap (118 inches overall; 2 feet W x 2 feet H x 46 feet L holding area) and installed it at the top of the fishway at the New Bedford Reservoir. The trap was constructed with 2-inch square wire mesh to capture all fish using the fishway. In addition, a Smith-Root (S-R 1100) electronic counter was fitted to the trap exit and activated on the weekends, when the trap was untended, to count fish passing. Due to increasing numbers of river herring observed in 2008, the first year of post-construction census monitoring, a larger box trap (8 feet x 10 feet L with mount; 5 feet x 6 feet L holding area, 3 feet W x 2 feet H) was constructed and deployed with a counting tube in Spring 2009 to minimize mortalities in anticipation of increasing numbers of migrating fish.

Figure 11: Transect locations (red) for monitoring smelt egg deposition in the lower Acushnet River.

Monitoring during the pre-construction years identified an approximate four-week period (the last two weeks of April and the first two weeks of May) as the peak migration period for river herring. The trap was tended seven days a week during this time. Outside the peak migration period, the trap was tended five days a week, (Monday-Friday), and left open on weekends for migrating animals to pass through. This was done to prevent mortalities; numbers between pre- and post-opening counts were recorded using the electronic counter. All individuals were identified to species, removed from the trap using a dip net, and released alive upstream.

Each spring, samples were collected from alewife mortalities found in the trap and were retained for biological information and subsequent PCB testing by *MassDEP*. During the pre-construction period, both mortalities and live herring were retained and sacrificed to meet the requirements of the *MassDEP* PCB testing program, therefore, percent removals were higher during this phase. All river herring mortalities were counted, sexed, measured (total length [TL] and fork length [FL] in millimeters), and weighed to the nearest gram. Scales were collected from each individual and aged using standard methodologies (Cating 1953; Rothschild 1963; Marcy 1969; Libby 1985). Tissue from the collected specimens was sampled for homogenization, lipid extraction, and analysis. The samples were analyzed by Alpha Woods Hole Laboratories in Mansfield, Massachusetts for four PCB Aroclors and 136 PCB congeners by GC/MS-SIM (gas chromatography/mass spectrometry-selective ion monitoring) based on EPA Methods 680 and 8270C (*MassDEP* and *MarineFisheries* 2012). Results from this analysis (Appendix F) were compared to the current Food and Drug Administration (FDA) level (2.0 ppm), and further comparisons were made to a site-specific threshold of 0.02 ppm PCBs as specified in the 1998 ROD.

The NBHTC funded a one-year study to evaluate the efficiency of the new fishway structures and migratory behavior of river herring, which was initiated in March 2008 by the USGS and the BBC (Haro et. al. 2008). In an effort to estimate total population size of river herring in the Acushnet River, a video counting system and diversion weir were installed above the head of tide and downstream of the first weir of the Sawmill fishway (Figure 10). The upstream end of the diversion weir led to an aluminum camera box similar to the design by Guimond (2006, 2007), which housed and protected a Delta Vision industrial grade color underwater video camera. The camera box also provided an 18 inch wide channel that fish going upstream passed through. Counts were conducted by passively monitoring fish passage through the camera box.

During the pre-construction monitoring period, a systematic search for adherent smelt eggs on benthic substrates was conducted bi-weekly below the Sawmill Dam. In 2006, monitoring was conducted by visual inspections of substrate along established transects from the base of the dam, extending downstream to the outlet into Upper New Bedford Harbor (Figure 11). In 2007, monitoring was conducted by placing wooden trays (18 inches L x 14 inches W x 1 inch H) containing sphagnum moss (for egg deposition) along the five transects extending from the base of the dam to the access bridge into the Acushnet Sawmill property. The trays were inspected bi-weekly for evidence of egg deposition. In addition to smelt egg deposition, data on location, substrate, total number of eggs (estimated), and range of egg densities (estimated) were recorded.

Two American eel traps, built following a *MarineFisheries* modified Sheldon design used for the Atlantic States Marine Fisheries Commission (ASMFC) compliance requirements (ASMFC 2000), were placed at two locations in the Acushnet River. One was placed in the lower river below the Sawmill Dam and the other was placed downstream to the ladder entrance of the New Bedford Reservoir Dam. All trapped elvers were separated by development stage (un-pigmented young-of-the-year (YOY) and larger pigmented age-1+) and counted four days per week (Tuesday – Friday), following protocols supplied by the *MarineFisheries* eel project and in compliance with the ASMFC fisheries management plan (see ASMFC 2000). Daily catches were counted and released into the New Bedford Reservoir. Traps were removed from the river each Friday and re-deployed each Monday. When possible, a weekly sub-sample of sixty elvers was collected and brought to the lab for processing; the rest were released in the reservoir. Sub-sampled elvers were anesthetized in a clove oil solution, measured to the nearest millimeter, and weighed to the nearest 0.01 gram. In addition, pigment stage was examined and recorded from YOY sub-samples based on the classification scheme from Haro and Krueger (1988). Elvers were subsequently released alive back to the reservoir.

A concurrent study by Sheppard and Block (2013) conducted during the primary funding period (2005 through 2011) examined changes in elver abundance prior to and after improvements to passage. Subsequently, catch data from 2012 and 2013 were added to the existing dataset and re-analyzed. In this study, catch-per-unit-effort (CPUE, N_{elvers}/hr/day) from elver catches at both stations were generated as daily catch rates. Mean CPUE indices were generated based on catch data during peak migration peri-

Table 2: Total counts and corresponding percentages of all species collected in the New Bedford Reservoir fishway fish trap.

	Total count and proportions of all species												
	*Alewife	*B. Herring	Bluegill	Brook Trout	B. Bullhead	Golden Shiner	Largemouth Bass	Pumpkinseed	Yellow Perch	Chain Pickerel	Sea Lamprey	B. Crappie	
Year	*(A. pseudoharengus)*	*(A. aestivalis)*	*(L. macrochirus)*	*(S. fontinalis)*	*(A. melas)*	*(N. crysoleucas)*	*(M. salmoides)*	*(L. gibossus)*	*(P. flavescens)*	*(E. niger)*	*(P. marinus)*	*(P. nigromaculatus)*	Totals
2005	395 (73%)	0 (0%)	114 (21%)	10 (2%)	10 (2%)	2 (0%)	9 (2%)	2 (0%)	1 (0%)	0 (0%)	0 (0%)	0 (0%)	543
2006	202 (57%)	0 (0%)	71 (20%)	11 (3%)	11 (3%)	1 (0%)	5 (1%)	4 (1%)	48 (14%)	0 (0%)	0 (0%)	0 (0%)	353
2007	371 (80%)	0 (0%)	33 (7%)	28 (6%)	2 (0%)	3 (1%)	5 (1%)	1 (0%)	21 (5%)	0 (0%)	0 (0%)	0 (0%)	464
2008	977 (87%)	1 (0%)	105 (11%)	12 (1%)	4 (0%)	3 (0%)	6 (1%)	5 (1%)	7 (1%)	0 (0%)	0 (0%)	0 (0%)	1,120
2009	1,695 (91%)	5 (0%)	97 (5%)	6 (0%)	0 (0%)	4 (0%)	3 (0%)	6 (0%)	49 (3%)	1 (0%)	0 (0%)	0 (0%)	1,866
2010	2,703 (91%)	7 (0%)	159 (5%)	9 (0%)	53 (2%)	1 (0%)	5 (0%)	14 (0%)	28 (1%)	1 (0%)	0 (0%)	0 (0%)	2,980
2011	3,608 (96%)	71 (2%)	29 (1%)	20 (1%)	4 (0%)	0 (0%)	3 (0%)	13 (0%)	10 (0%)	2 (0%)	1 (0%)	0 (0%)	3,761
2012	3,123 (92%)	97 (3%)	67 (2%)	6 (0%)	1 (0%)	3 (0%)	8 (0%)	14 (1%)	37 (1%)	0 (0%)	0 (0%)	21 (1%)	3,377
2013	6,012 (94%)	21 (1%)	142 (2%)	9 (0%)	41 (1%)	1 (0%)	24 (1%)	55 (1%)	4 (0%)	5 (0%)	0 (0%)	0 (0%)	6,314
Totals	19,086 (92%)	202 (1%)	817 (4%)	111 (1%)	126 (1%)	18 (0%)	68 (0%)	114 (1%)	205 (1%)	9 (0%)	1 (0%)	21 (0%)	20,778

* Includes mortalities

ods in April (as well as May in most (71%) years). Annual mean CPUE scores were generated as indices of juvenile abundance for annual comparisons. To determine if annual differences in CPUE exist, a generalized linear model was used where CPUE was the dependent variable and year was the categorical predictor. To select the appropriate distributional error form, annual mean CPUE scores and variances (σ) were calculated and the following equations were fitted.

The following formula was used for Poisson, gamma and inverse Gaussian error distributions:

$$\sigma = b(\mu)^{c}$$

The formula below was used for the negative binomial error distribution:

$$\sigma = \mu + b(\mu)^{c}$$

where μ is the mean CPUE value and *b* and *c* represent the slope and intercept parameters, respectively. If $c = 1$, a Poisson error distribution is used; if $c = 2$, a gamma or negative binomial distribution are suggested; if $c = 3$, then an inverse Gaussian distribution is suggested.

The *c* coefficient estimates were 2.1 (Acushnet Sawmill station) and 1.7 (Reservoir station) for both models, suggesting either the gamma or negative binomial error distributions were most appropriate. Given that CPUE is a continuous variable, the gamma distribution was used. Because the gamma distribution assumes non-zero observations, 0.01 was added to each CPUE score before the model was fitted and a log link function was used. Deviance residuals were used to assess model fit. Distribution of deviance residuals versus predictor (on link scale) showed no pattern of residuals indicating that the model fit the data well. Annual mean CPUE values were plotted and examined for trends in catch rates at both stations. If applicable, mean catch rates at the Reservoir station were grouped by monitoring period (pre- and post-construction) and tested to determine if catch rates differ by period. Catch rates by period and catch compositions at the Reservoir station were examined to determine the effectiveness of the fishways to facilitate access for elvers into the upper watershed.

Throughout the course of the run, routine water quality samples (dissolved oxygen, pH, conductivity, and salinity) were collected during monitoring at both the Sawmill and Reservoir sites using a YSI 556 MPS meter. In addition, air and water temperatures were collected daily using a mercury thermometer. A HOBO U22 water temperature probe was placed at the time of trap installation at the Sawmill Dam (and subsequent fishway). The probe was set to record temperature continuously at one-hour intervals and the data were downloaded after removal. The data were used to document water temperature at the time of the fish runs and also to track changes in the river temperature associated with passage improvement. The data were also compared to established water chemistry criteria in the *MarineFisheries* Quality Assurance Program Plan (QAPP) for diadromous fish habitat monitoring (Chase 2010; Appendix B, Table B2) as well as the Massachusetts Surface Water Quality Standards (*MassDEP* 1996, 2007, 2012) to determine if the measurements meet the criteria set by these standards.

Results

Results are focused primarily on the census monitoring of river herring accessing the New Bedford Reservoir as well as abundance estimation of elvers in the lower and upper watershed. Additional information concerning the census monitoring results of other freshwater and diadromous species, PCB testing and water chemistry monitoring are also provided.

Results of species monitoring

Monitoring results of all species (total number and proportions) collected in the trap are summarized in Table 2. A total of 20,778 individuals (12 species) were collected throughout the monitoring period in which alewives comprised themajority (*N* = 19,086; 92%) of species collected. Monitoring on April 20, 2011 observed a juvenile sea lamprey (*Petromyzon marinus*, 200mm TL). This species has not been observed in previous years of monitoring, although it is possible they may have been present. Furthermore, results from the USGS video monitoring study (Haro et al. 2008) confirmed the presence of rainbow smelt (*Osmerus mordax*), white perch (*Morone Americana*), and striped bass (*Morone saxatilis*) passing both upstream and downstream of the video counting station at the entrance to the Sawmill Dam. However, these species were not captured in the reservoir trap. It is therefore assumed that their range is con-

Table 3: Summary results of census counts, means and percent changes of river herring sampled from the New Bedford Reservoir fish trap throughout the monitoring period (2005 – 2013).

Year	Date Deployed	Date Removed	Alewife	Blueback Herring	River herring (Combined)	Peak Observations	Annual Difference	% Annual Difference
2005	4/1/05	6/10/05	395	0	395	5/3-5/6		
2006	3/29/06	6/6/06	202	0	202	4/25-4/28	-193	-48.9%
2007	3/28/07	6/15/07	371	0	371	4/23-4/27	169	183.7%
2008	4/1/08	6/6/08	977	1	978	4/10-5/1	607	263.6%
2009	3/30/09	6/5/09	1,695	5	1,700	4/19-5/2	722	173.8%
2010	4/1/10	6/10/10	2,703	7	2,710	4/6-5/4	1,010	159.4%
2011	3/28/11	6/3/11	3,608	71	***3,679***	4/8-5/2 *5/14-5/16	969	135.8%
2012	3/9/12	6/8/12	3,123	97	3,220	3/14-3/25 4/14-4/30 ** 5/10-5/20	-459	-12.5%
2013	3/11/13	6/7/13	6,012	21	6,033	4/2-5/2 5/8-5/15	2,813	187.4%
Totals (2005 - 2011)			9,951	84	10,035			**•1140%**
Totals (2005 - 2013)			19,086	202	19,288			**••1870%**
Pre-construction Means (2005 - 2007)			323	0	***323 (baseline)***		-12	67.4%
Post-construction Means (2008 - 2011)			2,246	21	2,267		827	183.2%
Post-construction Means (2008 - 2013)			3,020	34	3,053		944	151.2%

* Peak observation period for blueback herring

• Percent change in 2011 population size over baseline conditions (average N river herring observed during pre-construction phase)

•• Percent change in 2013 population size over baseline conditions (average N river herring observed during pre-construction phase) fined primarily to the freshwater impoundments and estuarine habitats in the lower watershed.

Results of river herring census monitoring

Monitoring results of total counts of river herring are summarized in Table 3 (percent change in total counts) and Figure 12 (peak observation periods). A total of 19,288 river herring (19,086 alewives; 202 blueback herring) were captured and released into the New Bedford Reservoir throughout the monitoring period. It is assumed, based on peak observations, that the entire run was captured each year. The data is grouped into two phases: the pre-construction phase period, 2005 through 2007; and post-construction period, 2008 through 2011. Total counts of alewives observed during pre-construction phase monitoring were low, amounting to less than 400 per year. No blueback herring were observed in the trap during this period. Peak migrations occurred within short temporal scales during the pre-

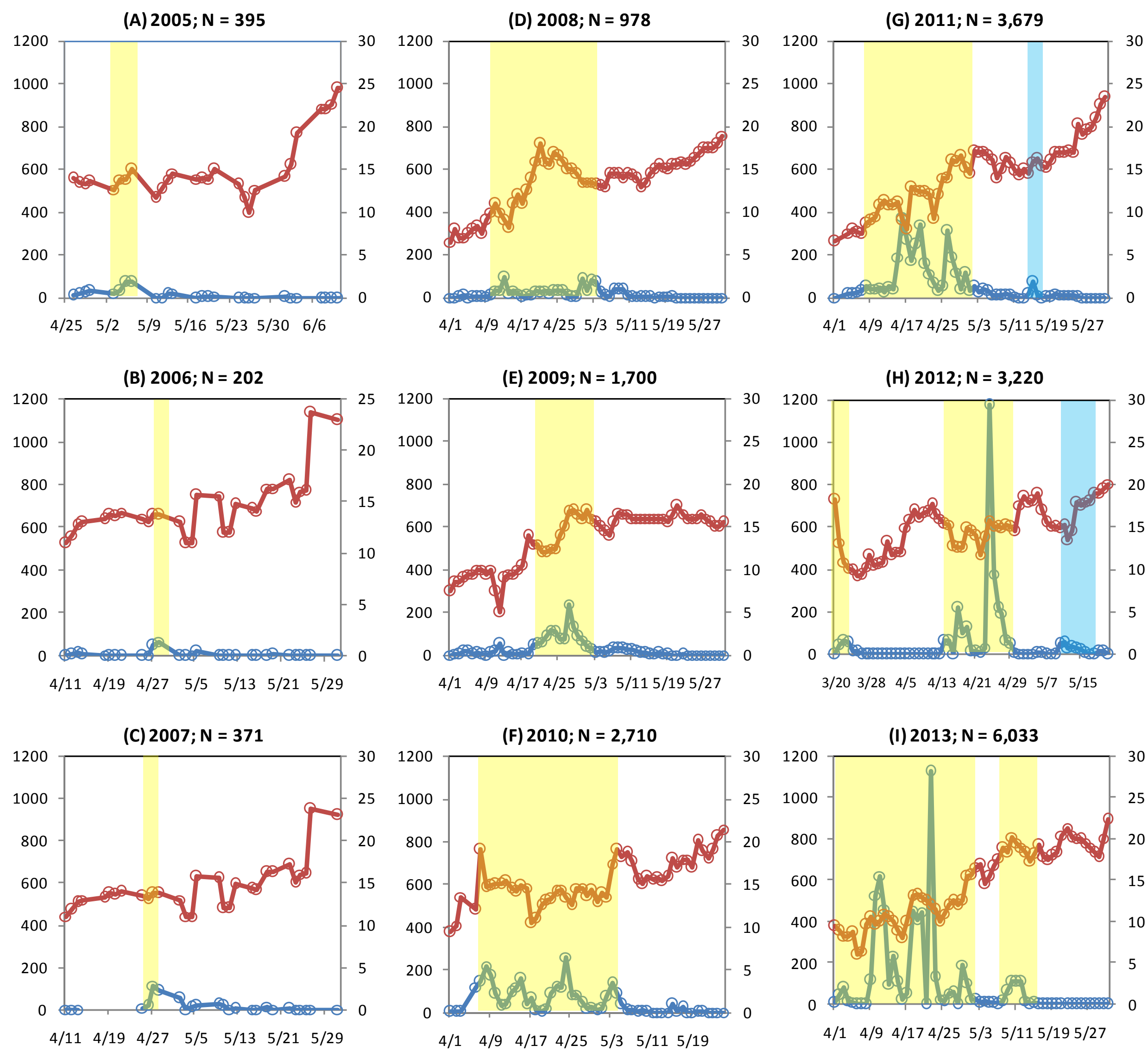


Figure 12a-i: Total number of river herring (primary y-axis, blue line) and water temperature (°C, secondary y-axis, red line) derived from catches at the New Bedford Reservoir trap. Shaded regions indicate peak observation periods for alewives (yellow) and blueback herring (blue).

Table 4: Numbers, percent removals, and biological information of alewife mortalities collected from the New Bedford Reservoir trap. Numbers and percent removals derived from mortalities in the trap (pre construction period only).

Year	N (male)	N (female)	N (total)	% Removal	Mean TL (mm)	Mean FL (mm)	Mean Wgt (g)	Mean Age
2005	18	22	40 (32)	10.1 (8)	272	242	196	4.7
2006	13	12	25 (3)	12.4 (1)	265	235	185	4.2
2007	11	20	31 (18)	8.4 (5)	277	245	208	3.8
2008	13	18	31	3.2	260	231	173	3.5
2009	10	19	29	1.7	267	237	188	4.0
2010	26	28	54	2.0	271	240	196	3.9
2011	48	66	114	3.2	271	238	195	3.7
2012	0	7	7	0.2	274	243	209	3.4
2013	9	14	23	0.4	271	239	187	3.3
Totals	148	206	354					
Means				2.7	270	239	193	3.8

construction period (Figures 12a-c) in which each year, the peak of the run was observed to occur within less than one week. The average total count for this period (N_{PRE} = 323) served as a baseline level to establish the 1000% enumeration target in 2011 ($N_{1000\%}$ = 3,230).

During the 2008 sampling season (the first year of post-construction phase monitoring), the total count of river herring (N_{2008} = 978) represented an increase of 264% over the total count in 2007 (Table 3). Count data from the USGS video counting system installed downstream of the Sawmill fishway estimated a net movement of 701 river herring – 1,142 passing upstream and 441 passing downstream. However, structural collapse of the weir caused by high waters occurred at the end of April, giving fish the opportunity to bypass the video system for a period of four days. Using both video counts and fish trap census counts, Haro, et al. (2008) conservatively estimated the run size between 1,000 and 1,500 river herring.

Total counts for both species increased each year of post-construction monitoring at an average rate of 183% per year. Peak observation periods increased during the post-construction phase from a two week migration period in 2009 to four week periods in 2010 and 2011. During the 2011 monitoring season, a second peak migration occurred (14-16 May) in which the majority of blueback herring were observed. The total number (N_{2011} = 3,679) of river herring captured and released into the reservoir in 2011, the final year of funded monitoring, represents an increase of 1140% over baseline conditions established during the pre-construction period.

Monitoring in 2012 indicated an overall decrease in the total number of river herring (N_{2012} = 3,220) captured and released into the reservoir. This represented an overall decrease of 12.5% compared to the 2011 results. However, while the number of alewives (N = 3,123) decreased in 2012, the number of blueback herring (N = 97) continued to increase. Monitoring in 2013 resulted in a large increase in the total number of river herring (N_{2013} = 6,033) captured and released into the reservoir. This represents an increase of 187% from 2012 and an increase of 1870% over baseline conditions established during the pre-construction period.

Census monitoring results indicate increasing numbers of river herring entering the New Bedford Reservoir throughout the post-construction phase monitoring period. The rate of increase (% annual difference, Table 3) was highest in 2008 where total counts doubled during the first year of post-construction monitoring. The annual rate of increase declined toward the end of post-construction phase monitoring. However, total counts maintained a positive trend in which the total counts in 2011 and 2013 exceeded the 1000% enumeration target level. Total count declined in 2012, in which no herring were observed in the trap from the last week of March through mid-April.

Results of alewife PCB analysis

Biological information (sex, size, weight, age, and percent removals) from retained river herring samples are presented in Table 4. A total of 354 alewives (148 males, 206 females) were retained for biological information and PCB analysis. Mortality rate constituted less than 10% of the run size in all years (mean removal rate of 2.7%).

In most years, samples were comprised mainly of age-4 fish (Figure 13), except in 2005 (age-5), and 2008 and 2010 (age-3). Samples were comprised mainly of virgin spawners with repeat spawning (RPS) detected in less than 10% of samples in each year.

Results from PCB testing of alewife tissue samples are described in Appendix F. At the time of this writing, results are available from samples collected throughout the funded monitoring period (2005 through 2011). Overall, the data set indicates levels of PCBs in alewives

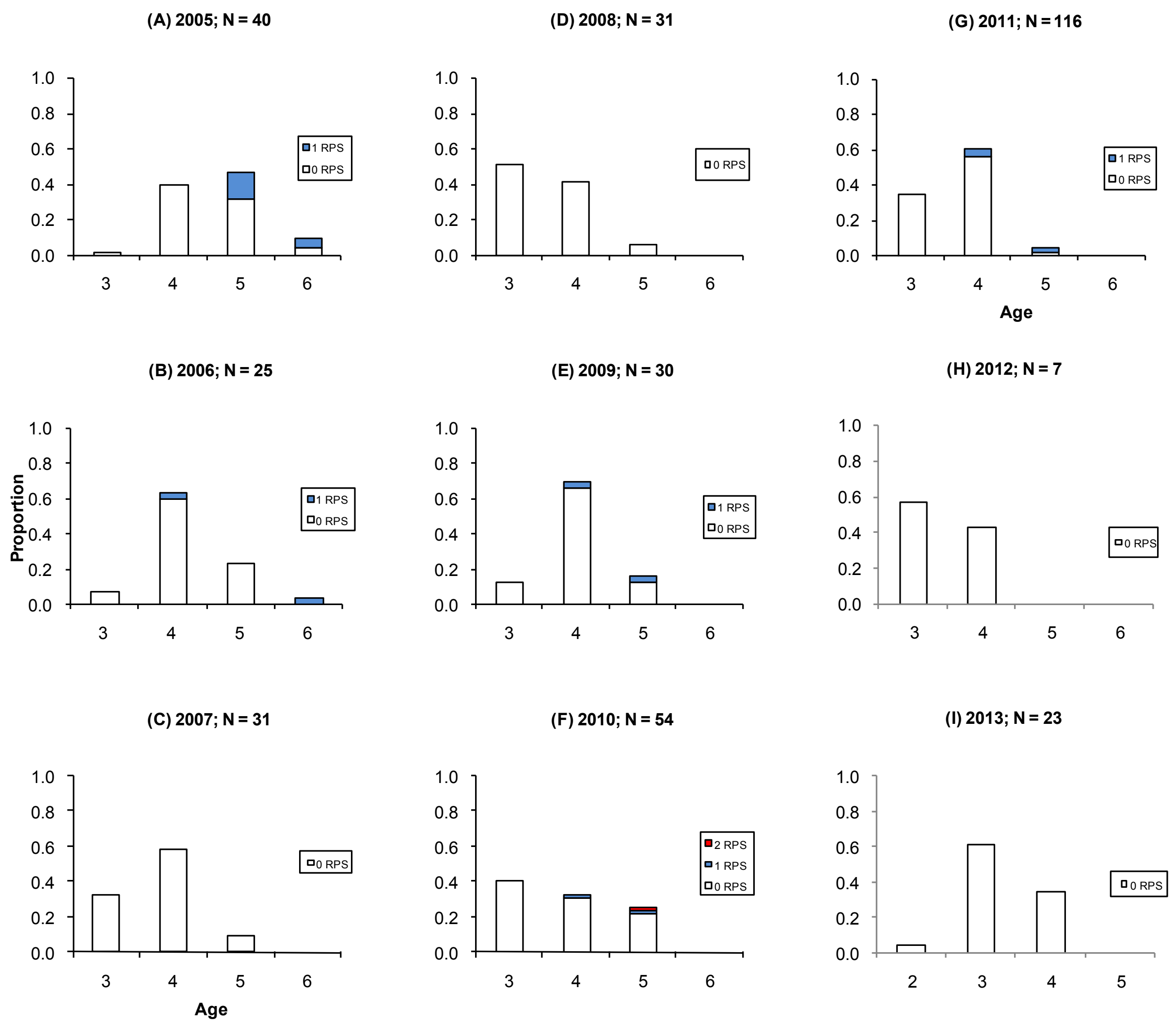


Figure 13a-i: Proportions at age and frequency of spawning (RPS) of alewives collected for PCB testing from the New Bedford Reservoir trap.

Table 5: Summary results (numbers, catch rates and peak observation periods) of juvenile American Eel (elver) sampling in the Acushnet River (2005 – 2013).

			Site: Acushnet Sawmill					Site: NB Reservoir					
Year	Start Date	End Date	$N_{(YOY)}$	$N_{(Age-1+)}$	April/May Mean CPUE	April/May Geometric CPUE	Peak Observation	$N_{(YOY)}$	$N_{(Age-1+)}$	April/May Mean CPUE	April/May Geometric CPUE	Peak Observation	Percent YOY
2005	4/1/05	6/10/05	1,284	0	1.67	1.55	4/20-4/29	0	1	0.002	1.00	N/A	0%
2006	3/29/06	6/6/06	427	0	0.64	1.50	4/26-5/5	5	43	0.07	1.06	N/A	10%
2007	3/28/07	6/15/07	180	0	0.16	1.14	N/A	0	12	0.01	1.01	N/A	0%
2008	4/1/08	6/6/08	4,635	2	5.69	2.51	4/9-4/18 5/2-5/9	719	65	0.88	1.47	4/25-5/9	92%
2009	3/30/09	6/5/09	5,904	3	7.95	4.91	4/10-4/30 5/5-5/28	104	64	0.23	1.17	4/28-5/6	61%
2010	4/1/10	6/10/10	3,330	4	3.61	2.43	4/7-4/23 4/30-5/4	0	54	0.06	1.05	5/1 - 5/9	0%
2011	3/28/11	6/3/11	8,365	3	8.23	3.44	3/30-4/28	85	89	0.17	1.15	5/2-5/5 5/26-5/31	49%
2012	3/10/12	5/18/12	2,158	0	2.88	1.83	3/14-3/23 4/4/-4/18	2	121	0.11	1.10	3/20-3/23 4/17-4/24	2%
2013	3/25/13	5/31/13	2,465	1	2.29	2.38	3/27-4/9 4/30-5/4 5/21-5/24	165	141	0.30	1.20	4/30-5/14 5/29-5/31	54%
Combined totals			28,748	13				1080	590				
Pre-construction Totals			1,891	0				5	56				
Pre-construction Means			630	0	0.82	1.40		2	19	0.03	1.02		3%
Post-construction Totals			26,857	13				1,075	534				
Post-construction Means			4,476	2	5.11	2.92		179	89	0.29	1.19		43%

above the 1998 ROD's site-specific goal of 0.02 ppm (USEPA 1998). PCB levels in alewives (Area I, congener basis = 2.0 ppm) were found to be elevated to the FDA level of 2.0 ppm. Tissue PCB levels decrease proportionally with the distance from the primary source of PCBs to the upper harbor, the former Aerovox facility. Highest PCB concentrations (total PCB cogeners) were detected in 2005 and 2006 from samples collected immediately upstream (Station A) and downstream (Station B) of the Sawmill Dam. PCB concentrations were lower from samples collected from 2007 through 2011. During which time, samples were collected further upstream at the New Bedford Reservoir fish trap. This is due to low abundance (2007) and the impossibility of procuring samples (2008-2013) because of site alterations from the construction.

Results from rainbow smelt monitoring

Results of smelt monitoring for egg deposition and habitat assessment data are shown in Appendix G. Visual inspection of substrate along established transects in 2006 and of sphagnum moss trays in 2007 did not reveal any evidence of egg deposition. The 2007 monitoring was confined to the upper habitat downstream of the Sawmill Dam due to lack of favorable spawning habitat downstream of the access bridge. Monitoring was discontinued after the replacement of fishways due to unsafe working conditions. However, the presence of smelt was confirmed in 2008, as a low number of individuals were observed migrating upstream and downstream through the USGS video counting array.

Results of elver monitoring

Results of elver catches, including catch rates and peak observation periods for both sampling sites, are shown in Table 5, Figure 14, and Figure 15 respectively. Elver traps were deployed and removed at the same time as the fish trap.

Based on peak observations, it is assumed that the monitoring periods encompassed the majority of the elver migration periods. A total of 30,431 elvers (N_{YOY} = 29,828; $N_{age\text{-}1+}$ = 603) were collected and transferred to the New Bedford Reservoir throughout the course of the monitoring period. The data is grouped into two phases: the pre-construction phase period, 2005 through 2007; and post-construction phase period, 2008 through 2013.

A total of 28,761 elvers (N_{YOY} = 28,748; $N_{age\text{-}1+}$ =

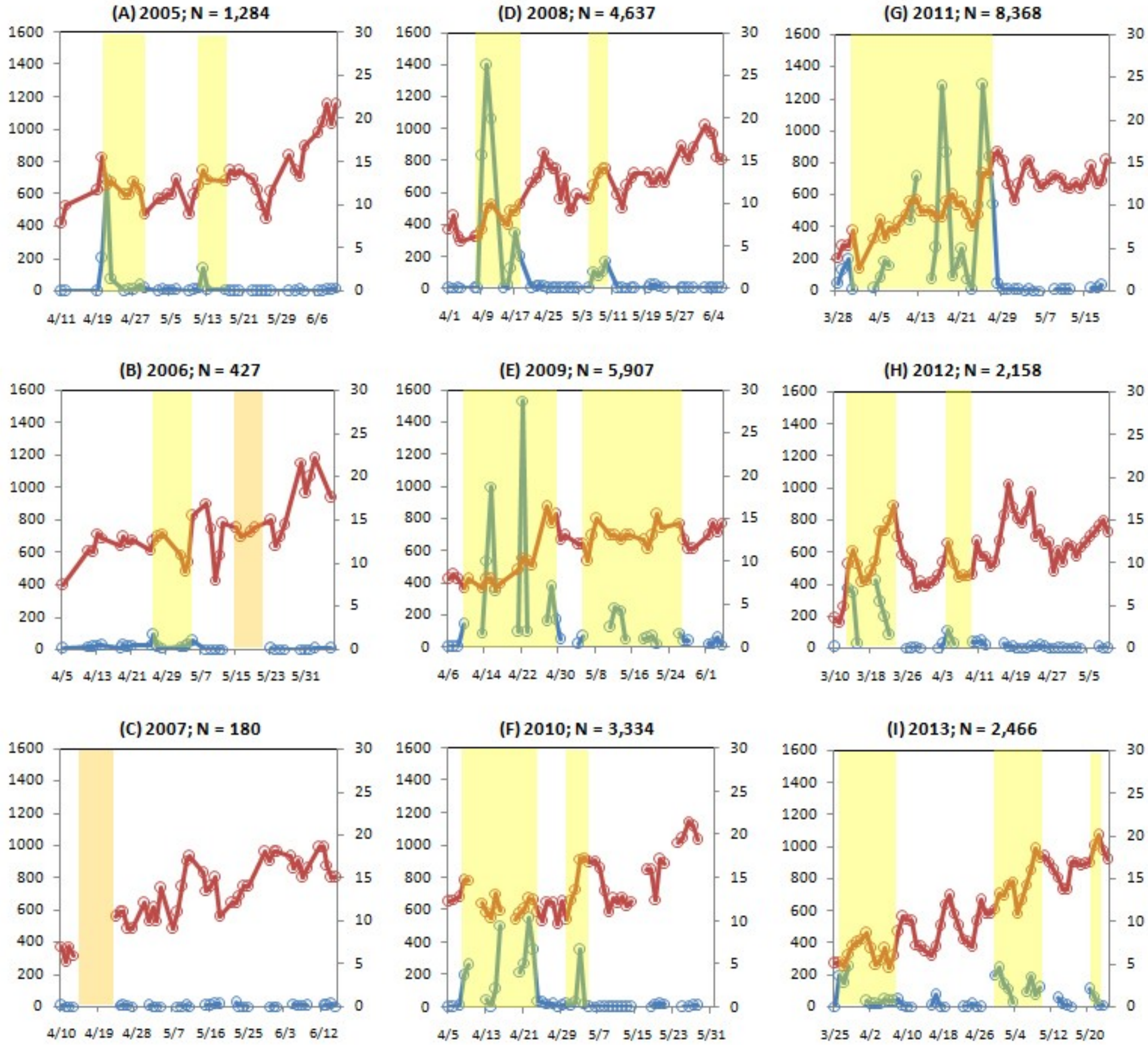


Figure 14a-i: Total number of elvers (primary y-axis, blue) and water temperature (°C, secondary y-axis, red) derived from catches at the Sawmill station. Shaded regions indicate peak observation periods for elvers (yellow) and periods of high water in which sampling was not possible (orange).

13) were collected at the Sawmill Dam throughout the entire monitoring period (Table 5). During the pre-construction phase, a total of 1,891 elvers were collected and were comprised of YOY. Age-1+ elvers were not observed. Peak observations occurred within ten-day periods (starting the last week of April) in 2005 and 2006, (Figures 14a and b). No discreet peak observation period could be identified in 2007 due to low catch levels. Results from post-construction phase monitoring indicated increased catch numbers at the Acushnet Sawmill station in which YOY comprised 99% of the catches each year. Migrations occurred over longer temporal scales with two discreet periods ranging between 10 – 20 days (occurring in April and May) in 2008-2010 and one period (lasting four weeks in April) in 2011 (Figures 14d-g). Peak migrations occurred in March, according to monitoring in 2012 and 2013 (Figures 14h and i), in one week intervals. A second migration period occurred in 2012 (April), lasting approxi-

mately two weeks. Two additional migration periods occurred in 2013 (April and May).

A total of 1,670 elvers (N_{YOY} = 1,080; $N_{age\text{-}1+}$ = 590) were collected at the entrance to the New Bedford Reservoir ladder throughout the monitoring period (Table 5). During the pre-construction phase, a total of 61 elvers (N_{YOY} = 5; $N_{age\text{-}1+}$ = 56) were collected, of which YOY comprised 8% of the total catch. No distinct peak observation periods could be identified. However, catches occurred toward the latter half of the spring monitoring season (late May into early June, Figures 15a-c). Results from post-construction phase monitoring (Figures 15d-i) indicated increased catch numbers (N_{YOY} = 1,075; $N_{age\text{-}1+}$ = 534) in which YOY comprised 67% of the total catch. In 2008 and 2009, peak migrations occurred over two-week periods (last week of April and first week of May), the first week of May in 2010, and two distinct periods (the first and last weeks of May) in 2011. Monitoring in 2012 indicated that elver movements occurred earlier (third week of March and April) com-

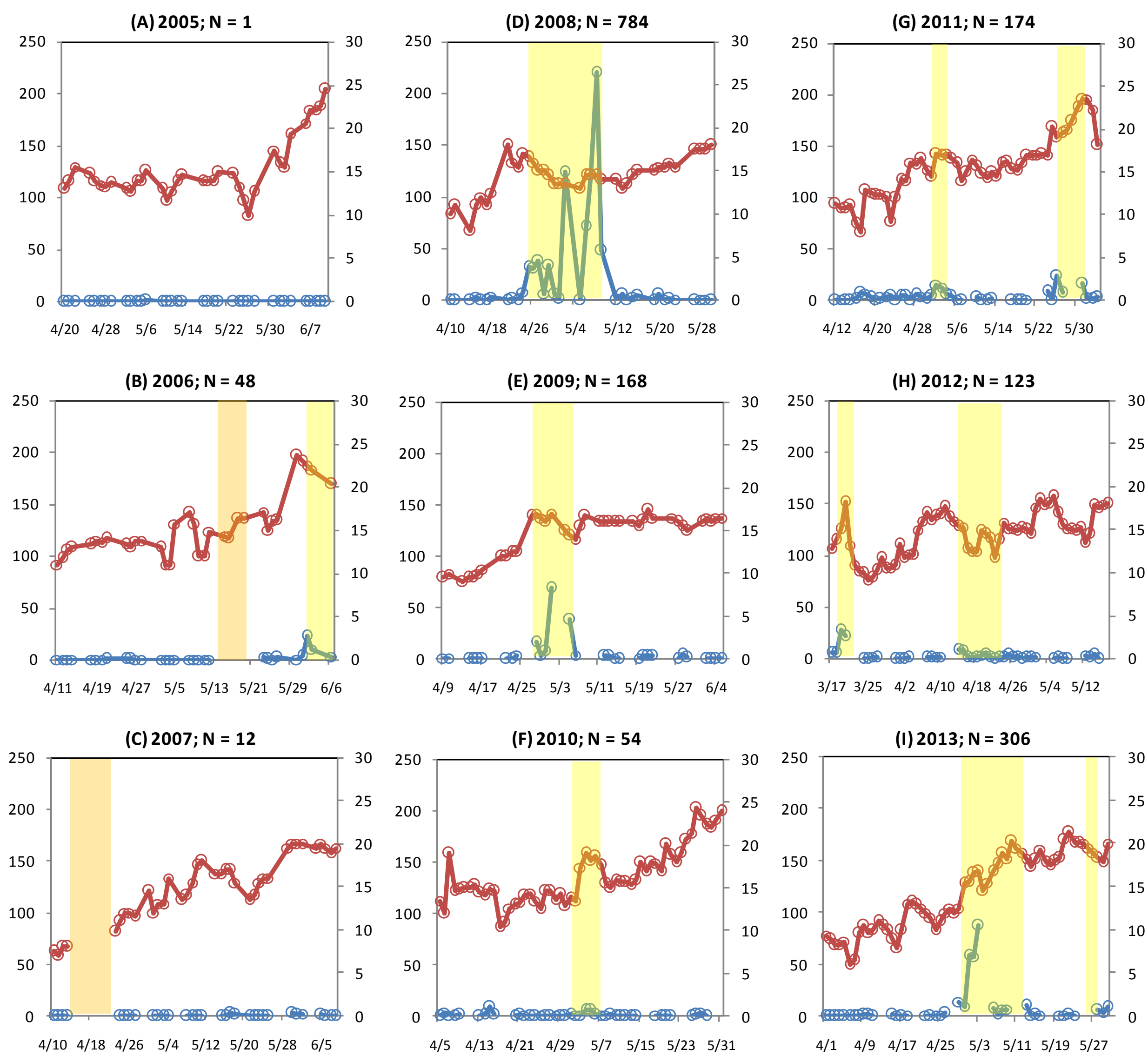


Figure 15a-i: Total number of elvers (primary y-axis, blue) and water temperature (°C, secondary y-axis, red) derived from catches at the Reservoir station. Shaded regions indicate peak observation periods for elvers (yellow) and periods of high water in which sampling was not possible (orange).

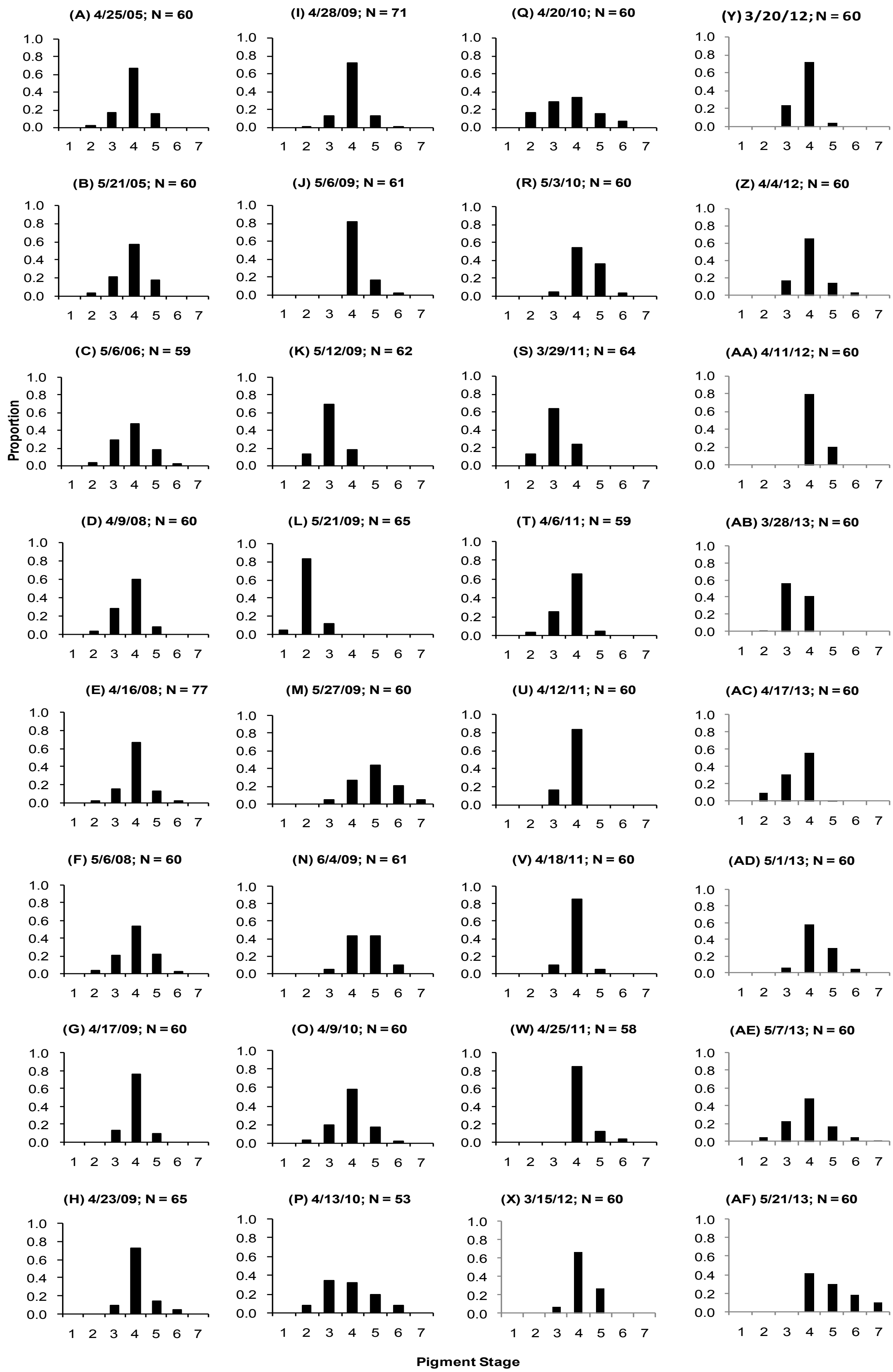


Figure 16a-af: Proportions by development stage of elvers entering the Acushnet River (based on samples collected from the Sawmill station).

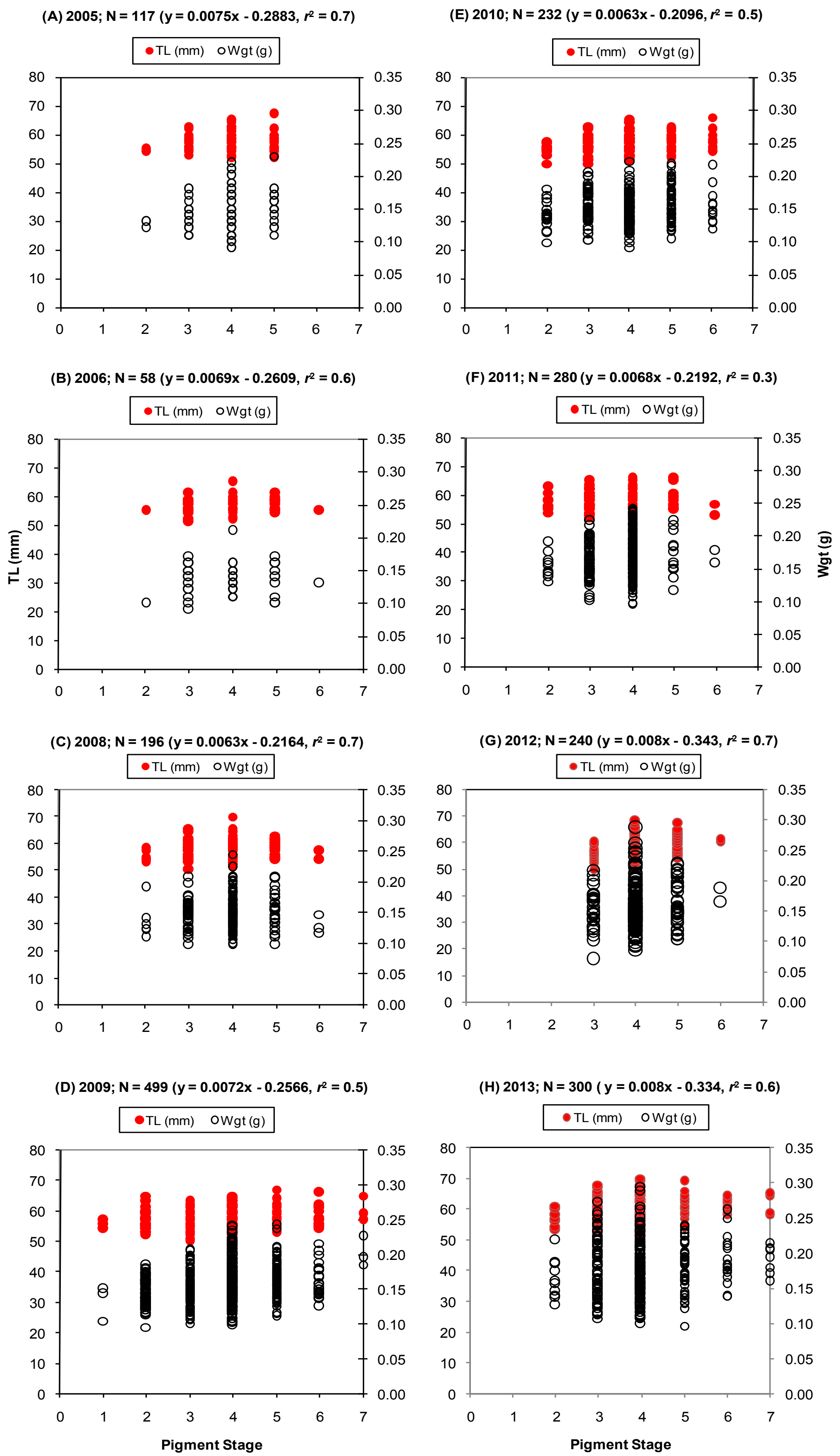


Figure 17a-h: Length-weight relationships (by development stage) of elvers derived from samples collected at the Sawmill station throughout the monitoring period.

pared to previous years. In contrast, monitoring in 2013 indicated that migration patterns were consistent with previous years of post-construction monitoring (2008-2011).

Elver sample sizes and relative proportions by pigment stage are shown in Figure 16. Samples were collected primarily from the Acushnet Sawmill station as adequate sample sizes were unavailable from the Reservoir station. There was difficulty in securing adequate sample sizes during the pre-construction phase due to insufficient numbers available for collection. Two samples were collected in 2005 and one sample was collected in 2006. Samples were comprised primarily of stage-4 (62% in 2005 and 47% in 2006) fish. No samples were collected in 2007 due to low catch numbers throughout the sampling season.

Stage-4 elvers constituted the majority of samples collected during the post-construction period comprising 60% (2008), 49% (2009), 45% (2010), 68% (2001), 71% (2012), and 49% in 2013. In addition, variations in weekly proportions of pigment stage were observed in 2009, 2010, 2011, and 2013. All weekly samples collected were comprised mostly of stage-4 elvers in 2008 and 2012.

Length-weight relationships of elver samples collected per annum are shown in Figure 17. Results suggest that as sample size increased over time, the correlation coefficient, relationship (r^2), decreased (r^2 = 0.5 in 2009 and 2010; r^2 = 0.3 in 2011). Smaller samples – those taken especially in 2005, 2006, and 2008 – had higher r^2 values. Relationship improved in samples collected in 2012 and 2013 (r^2 = 0.7 and r^2 = 0.6, respectively). Relationship is affected by the low sample sizes collected for the lower (stage-2) and upper (stage-6 and stage-7) limits.

Changes in elver abundance prior to and after improvements to passage are shown in Figure 18. Log-transformed annual mean CPUE scores of elver catches at the Acushnet Sawmill station are shown in Figure 18a. Analysis of deviance (F = 9.5, $p < 0.01$, df = 8) showed year was a significant factor, indicating annual differences in CPUE among years. Log-transformed annual mean CPUE scores of elver catches at the Reservoir station are shown in Figure 18b. Analysis of deviance (F = 15.9, $p < 0.01$, df = 8) showed that year was a significant factor, indicating annual differences in CPUE among years. Catch rates were grouped by monitoring period (pre-construction, 2005 – 2007; post-construction, 2008 – 2013) and tested to determine if catch rates differ between periods. Results (F = 2.1, p = 0.2, df = 1) indicated that variability in catch rates was too great to detect differences between the two periods.

Results from pre-construction phase monitoring indicated declines in catch rates at the Acushnet Sawmill station (Figure 18a). Low catch

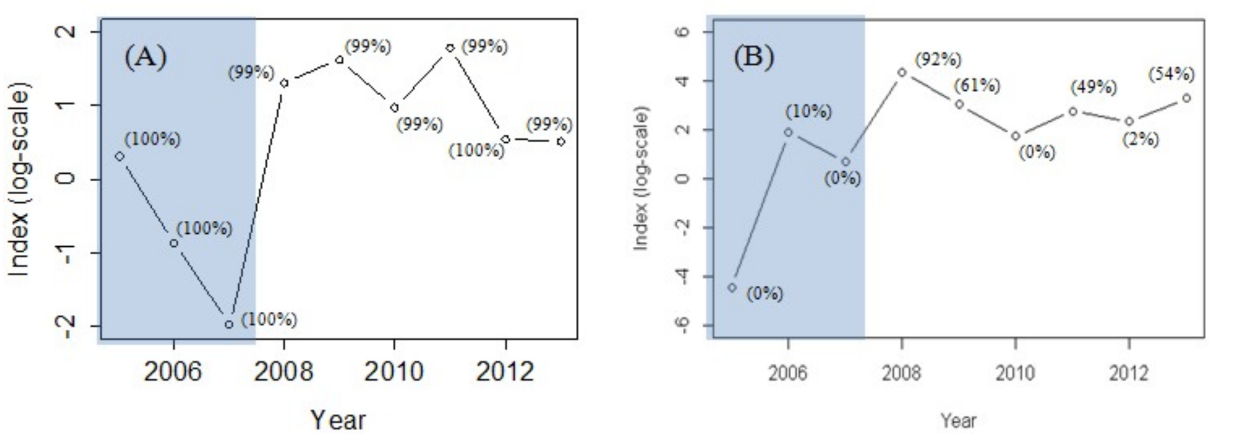


Figure 18a-b. Log-transformed annual mean catch-per-unit-effort (CPUE) indices of elver catches at the Acushnet Sawmill station (A) and the Reservoir station (B).

Table 6: Mean monthly water chemistry parameters collected from the Sawmill Station (A) and the Reservoir Station (B) throughout the monitoring period.

(A) Site: Sawmill							(B) Site: Reservoir						Temp.	Mean Temp.
			Sp. Conductivity	DO	Salinity	Water			Sp. Conductivity	DO	Salinity	Water	Start of Run	(Peak migration)
Year	Month	pH	(mS/Cm)	(mg/L)	(ppt)	Temp (°C)	Month	pH	(mS/Cm)	(mg/L)	(ppt)	Temp (°C)	(°C)	(°C)
2005	April	**5.6**	0.11	10.1	0	12.67	April	**6.0**	0.08	9.50	0.00	12.50	14.8 (4/25)	
	May	**5.8**	0.11	9.87	0.00	13.57	May	**6.0**	0.08	9.23	0.00	14.95		12.1 (5/3-5/6)
	June	**5.2**	0.12	7.88	0.00	**21.52**	June	**6.0**	0.08	7.86	0.00	**22.00**		
2006	April	**5.6**	0.11	10.35	0.00	11.38	April	**6.0**	0.10	10.40	0.00	12.64	11.0 (4/11)	12.6 (4/25-4/28)
	May	6.3	0.10	8.53	0.00	15.82	May	6.5	0.09	8.51	0.00	16.14		
	June	6.5	0.10	7.79	0.00	19.92	June	6.3	0.07	6.29	0.02	20.41		
2007	April	6.5	0.09	11.00	0.04	9.29	April	6.4	0.08	10.64	0.04	10.31	11.0 (4/23)	13.7 (4/23-4/27)
	May	6.9	0.10	8.99	0.05	17.19	May	6.7	0.08	8.63	0.04	17.36		
	June	7.0	0.11	6.00	0.05	20.19	June	6.9	0.09	6.51	0.04	**21.60**		
2008	April	6.9	0.13	9.79	0.06	11.95	April	6.7	0.12	9.76	0.06	12.75	8.6 (4/3)	13.2 (4/10-5/1)
	May	7.8	0.13	7.84	0.06	14.66	May	7.2	0.12	7.47	0.05	15.82		
	June	7.6	0.15	6.21	0.07	**21.54**	June	8.1	0.12	5.76	0.06	20.08		
2009	April	7.1	0.09	9.26	0.02	11.54	April	6.6	0.08	9.63	0.02	11.53	7.5 (3/31)	14.5 (4/19-5/2)
	May	6.5	0.10	7.30	0.00	15.69	May	6.0	0.08	6.97	0.00	17.45		
	June	6.7	0.11	8.98	0.00	17.88	June	7.2	0.16	6.72	0.00	20.40		
2010	April	6.3	0.10	8.95	0.05	14.35	April	6.2	0.08	8.46	0.04	14.52	9.1 (3/30)	13.7 (4/6-5/4)
	May	6.5	0.11	7.10	0.05	17.65	May	6.5	0.10	7.15	0.05	20.05		
	June	6.4	0.11	7.16	0.05	**21.74**	June	6.5	0.10	7.24	0.05	**22.36**		
2011	March	6.4	0.12	10.96	0.06	6.73	March	6.5	0.09	11.21	0.04	6.42	6.5 (3/30)	
	April	6.5	0.12	9.59	0.05	10.94	April	6.3	0.10	9.98	0.05	11.44		12.3 (4/8-5/2)
	May	6.4	0.12	8.01	0.06	16.23	May	6.4	0.10	7.62	0.05	17.21		*15.5 (5/14-5/16)
	June	6.6	0.13	6.08	0.06	19.99	June	6.5	0.10	5.73	0.05	**22.29**		
2012	March	6.0	0.12	9.65	0.06	10.24	March	6.7	0.10	10.01	0.05	11.66	10.09 (3/14)	12.7 (3/14-3/25)
	April	6.3	0.17	8.72	0.06	12.88	April	6.7	0.11	9.12	0.05	13.83		16.2 (4/14-4/30)
	May	6.0	0.11	8.46	0.05	14.21	May	6.4	0.10	7.59	0.05	17.07		*18.0 (5/10-5/22)
2013	April	6.3	0.13	10.35	0.06	8.87	April	6.6	0.11	11.12	0.05	10.54	7.6 (3/29)	11.5 (4/2-5/2)
	May	6.2	0.13	7.83	0.06	16.59	May	6.5	0.2	8.89	0.06	18.69		18.6 (5/8-5/15)

* Mean water temperature during peak blueback herring migration

numbers were observed at the Reservoir station (Figure 18b) during this period in which age-1+ elvers constituted the majority of those captured. The average annual proportion of YOY during the pre-construction period was low (3%; Table 5). YOY were observed at the Reservoir station in 2006 (comprising 10% of the total catch) and were absent in catches in 2005 and 2007.

Although catch rates were not greatly different from the pre-construction monitoring period, increased elver catches were observed at the Reservoir station (Figure 18b) during the post-construction period. Higher proportions of YOY were observed in the catches in comparison to pre-construction phase monitoring (post-construction mean: 43%; Table 5). However, the proportions of YOY were variable from year to year comprising 92% (2008), 61% (2009), and 49% (2011) of the catches. YOY were not present in the 2010 catche). Proportions of YOY decreased in 2012 (2%), then increased in 2013 (54%).

Results of water chemistry monitoring

Summary results of basic water chemistry parameters (monthly mean water temperature, dissolved oxygen, pH, and specific conductivity) for all years are listed in Table 6. Annual water temperature profiles, recorded using the HOBO U22 water temperature probe at the Sawmill station, are shown in Figure 19 and weekly mean water temperatures are summarized in Table 7. In general, weekly temperature range remained within acceptable limits of the *MassDEP* Class B criteria throughout the primary spawning migration period (April - May). Weekly water temperatures approached – and in some cases exceeded the recommended daily and 7-day mean water temperature limits. Water temperature data (Figure 19a) indicated large daily fluctuations during the latter part of the (end of) May through June monitoring period (these fluctuations may be due to probe exposure to air). Daily water temperatures at the Sawmill station appeared to stabilize during the post-construction period.

At the Reservoir station, monthly mean water temperature ranges remained within acceptable limits of the *MassDEP* Class B criteria throughout the primary spawning migration period (April – May, Table 6b). In June, weekly water temperatures approached – and in some years exceeded – the recommended daily and 7-day mean water temperature limits for Class B waters. Mean water temperatures during peak migrations occurred in the range of 12.1 ºC (2005) and 18.6 ºC (2013). Mean water temperature recorded during the peak blueback herring migration in 2011 and 2012 was 15.5 ºC and 18.0 ºC, respectively.

Mean monthly pH readings were below the Class B lower limit of 6.5 during the first two years of monitoring (2005 and 2006) for both sites (Table 6). Mean pH levels recorded at the Sawmill station increased in 2007 and monthly readings fluctuated between 2007 and 2009 (ranging between 6.5 and 7.8). Mean pH levels recorded at the Sawmill station decreased and stabilized between 2010 and 2013 (ranging between 6.2 and 6.6). Mean pH readings recorded at the Reservoir station (range: 6.0 - 8.1) were within the Class B classification limits in most months between 2007 and 2013. Toward the

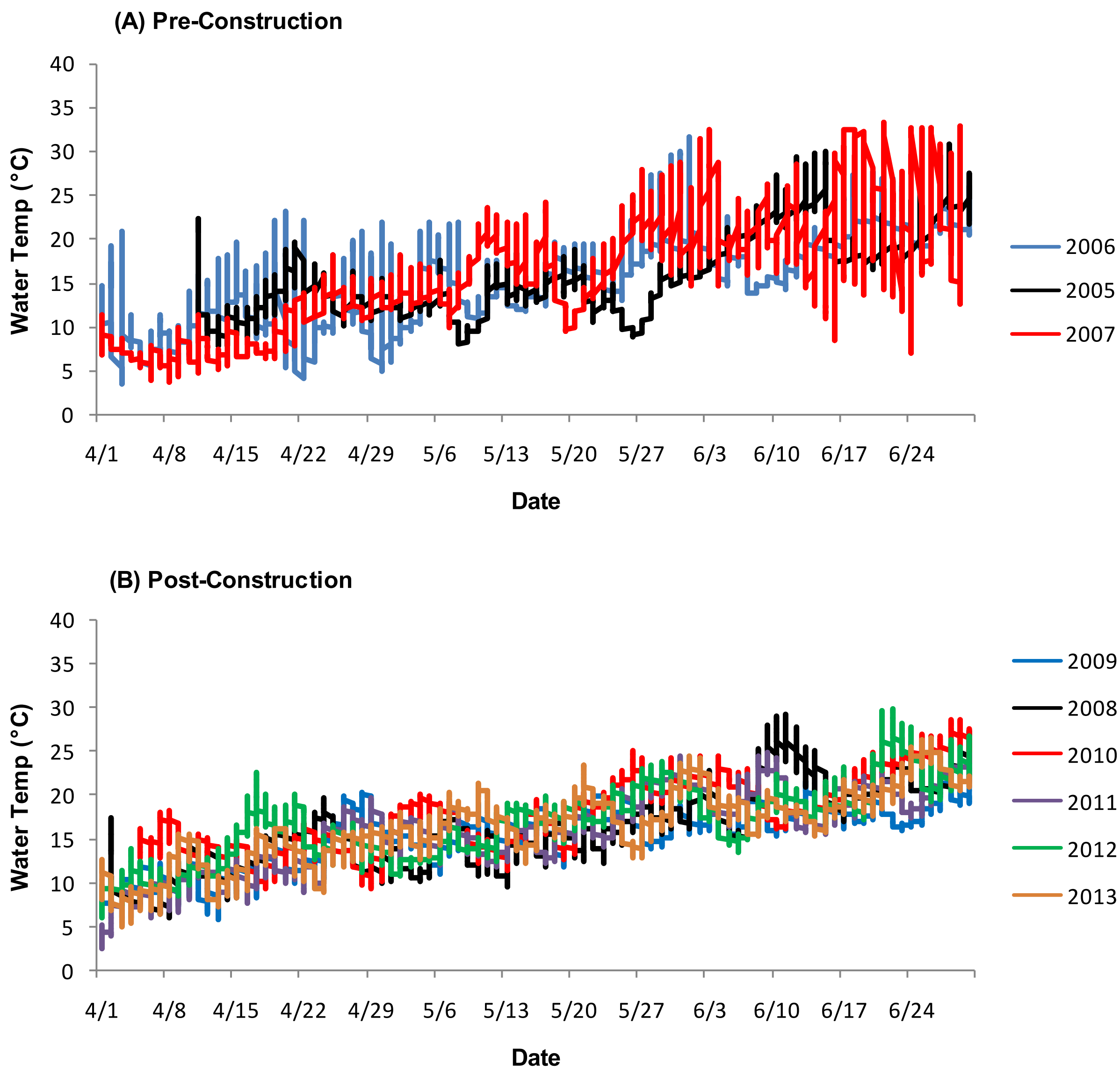


Figure 19a-b: Water temperature readings recorded at the Sawmill Dam throughout the spring spawning migration period (April – June).

Table 7: Mean weekly water temperatures recorded at the Acushnet River Sawmill using HOBO water temp logger. Numbers in bold are mean temperatures during peak migration periods. Numbers in italics are mean temperatures exceeding 7-day mean limit for Class B waters (≤ 20°C). Numbers in bold italics indicate mean temperatures exceeding the maximum spawning threshold (≤ 26°C) for Class B waters.

	Pre-construction				Post-construction						
Week	2005	2006	2007	Mean	2008	2009	2010	2011	2012	2013	Mean
4/1-4/8	9.25	9.18	6.88	8.44	7.94	9.11	**8.20**	**7.29**	9.72	**8.29**	8.42
4/9-4/16	10.74	11.96	7.32	10.01	**10.94**	9.68	**13.06**	**10.06**	**12.72**	**11.24**	11.28
4/17-4/24	14.08	11.65	10.62	12.12	**14.85**	**11.95**	**12.75**	**11.50**	**16.41**	**12.91**	13.39
4/25-5/2	12.95	**12.63**	**13.70**	13.09	**13.11**	**16.24**	**13.37**	**15.80**	**13.54**	**14.71**	14.46
5/3-5/10	**12.05**	14.62	15.37	14.01	13.37	14.50	17.04	15.27	13.74	**16.79**	15.12
5/11-5/18	15.23	14.03	17.51	15.59	13.71	15.38	15.28	**14.19**	16.56	**16.18**	15.22
5/19-5/26	12.52	16.34	16.82	15.23	15.39	17.26	18.54	16.60	18.01	17.77	17.26
5/27-6/3	16.26	*21.59*	*21.26*	19.70	18.72	16.34	*21.62*	*20.91*	*20.81*	19.23	19.61
6/4-6/11	*22.26*	16.17	19.58	19.34	20.93	17.23	19.83	20.41	17.38	18.16	18.99
6/12-6/19	*21.19*	20.14	19.18	*20.17*	*21.24*	18.08	19.37	18.26	18.95	18.33	19.04
6/20-6/27	*21.77*	*22.07*	20.72	*21.52*	*21.94*	17.85	*24.25*	19.94	*23.69*	*22.35*	*21.67*
6/28-6/30	*23.55*	*22.34*	*22.01*	*22.63*	*24.53*	20.00	***26.18***	*22.99*	*23.42*	*21.42*	*23.09*

end of the monitoring period, pH recordings at both sites stabilized within acceptable limits for Class B waters.

Monthly dissolved oxygen (DO) readings decreased throughout the course of each monitoring season (March through June of each year). DO levels decreased with increasing mean water temperature. Monthly mean DO levels (Table 6) ranged within the Class B criteria (range: 6.0 – 11.0mg/L (Sawmill); range: 5.7 – 11.2 mg/L (Reservoir)) and did not decrease below the recommended minimum limit (5.0 mg/L).

Discussion

The project was successful in re-establishing river continuity and improving fish passage along a 3.8-mile stretch of the Acushnet River from the head of tide to the New Bedford Reservoir, 0.9 river miles from the Acushnet Sawmill Dam to Hamlin Street Dam, and 2.8 river miles from the Hamlin Street Dam to the New Bedford Reservoir Dam. The Denil fish ladder installed at the New Bedford Reservoir Dam re-opened the final 0.1 river miles to enable access to primary spawning and nursery habitat.

Phase One: Fish Passage Improvements

Various options for providing fish passage at the New Bedford Reservoir were evaluated, including full and partial dam removal options, and nature-like and technical fishways. After extensive review of each alternative, the Denil fishway design was selected. The existing conditions at the site were important in determining the appropriate fishway design. There is a long distance between the spillway and the tailwater below the dam with a narrow outlet channel below the dam. In addition, the fishway could not take up a large amount of the flow carrying capacity of the channel without affecting headpond levels which necessitated a passage device that was located in the riverbank area and a concrete wall for structural support. The Denil fishway does not greatly affect surface water levels of the reservoir, thereby maintaining its function as an irrigation supply, allowing for fish passage over the widest flow range with minimal in stream impact. The Denil fishway does not impede flood capacity within the channel and the reservoir, and impacts to shoreline spawning habitat are minimized.

Another important consideration in fishway design is the capacity of the fishway to pass the maximum number of fish during the peak time of day during the peak migration period. While steeppass fishways (another technical fishway) have passed significant numbers of fish in some sites in the Northeast, the capacity numbers that the USFWS uses place a maximum capacity of 40,000 fish (Dick Quinn, personal communication, 30 November 2012). In addition, since concrete walls are needed, the Denil fishway was determined to be a better choice than a steep-pass at minimal additional cost.

Nature-like fishway designs were preferred for both the Acushnet Sawmill and Hamlin Street dams to restore a nature-like reach of the river system. These fishways incorporate design features that reduce modifications to existing dams while maintaining annual flood elevations within the upstream impoundments and associated wetlands at their pre-construction levels. In particular, the wetland system upstream of the Hamlin Street Dam was identified as having significant wildlife habitat (Milone & MacBroom, 2000). Limiting impacts to this system was a priority for all passage alternatives considered. Data collected from rain gauges and pressure transducers (EAEST 2007) indicate that the river flow peaks approximately 0.5 – 1 day after the peak of rainfall. It then takes 2 – 3 days for the peak discharge to return to pre-rain conditions. This suggests that when a river discharge is less than designed for the Sawmill (105 cfs) and Hamlin (95 cfs), a storm flow event will pass through the structures quickly. This is a short enough window so that river herring can hold downstream before ascending. These designs meet the USFWS requirement of periods of non-passage should not exceed three days during critical migratory periods (EAEST 2007).

Pool depths and water levels flowing through the ladder during the summer and autumn months of the first year following construction were insufficient, preventing downstream passage. This was likely due to low flow conditions in conjunction with inadequate filling in of the interstitial spaces of fill material for the pools which reduced the ability of the ladder to retain water as it leaked through the substrate. In order to protect juvenile river herring and other species from becoming stranded in the pools and dying from increased water temperatures and reduced oxygen levels, *MarineFisheries* installed nets upstream of the ladder exit to prevent downstream migration. The nets were removed once adequate flow levels were achieved during rain events. This problem was not evident from 2009 onward and was likely due to the ladder's ability to restore natural sediment transport processes in which sediment from upstream settled into the pools, thereby filling in the interstitial spaces and improving water retention.

Phase Two: Biological Monitoring

River Herring

River herring have an iteroparous life history in which maturation occurs at sea and spawning occurs in freshwater three to four years later. This may be the reason why Sheppard and Block (2013) noted there is a delay in observing increased numbers associated with improvements to passage. The short-term results from census monitoring are encouraging and it is anticipated that numbers will increase in future years, given an entire generation (starting with the 2008 year class) and successive generations were spawned and reared in the New Bedford Reservoir.

Increases in peak migration periods can be due to the improved design characteristics of the Acushnet Sawmill and Hamlin Street fishways, which enable herring to pass upstream at various flow levels without significant delay. Although access to the upper watershed has improved, it is possible that river herring may also be utilizing habitats downstream of the reservoir for spawning. Based on census counts in 2008 (N = 978) and results from Haro et al. (2008), it is assumed that between 65% and 98% of the run entered the New Bedford Reservoir in 2008, with the remaining proportion of the run utilizing downstream riverine habitats. In particular, alewives can utilize spawning habitat in the shallow impoundments created upstream of the dams (Sawmill Pond, 9.5 acres; Hamlins Pond, 6.5 acres). Complete removal of the dams at Acushnet Sawmill and Hamlin Street would have resulted in a decrease in impoundment water levels, potentially eliminated these spawning habitats as well as impacting the surrounding riparian wetland habitat.

The presence of blueback herring in the reservoir trap during post-construction monitoring was an unexpected result. The primary objective of this restoration effort focused on enhancing the existing alewife population as evidenced by alewife stocking operations performed prior to project construction. The Denil ladder installed at the New Bedford Reservoir Dam was designed primarily to facilitate access for alewives to the reservoir. While both alewives and blueback herring are capable of spawning in both riverine and lacustrine environments, alewives prefer spawning in lentic (lucastrine) habitats – such as ponds and lakes – while blueback herring prefer spawning in lotic (riverine) environments. It is not known whether blueback herring reaching the reservoir will utilize this impoundment for spawning, or migrate upstream to root tributaries or downstream to the riverine sections. The increase in blueback herring in the trap catches suggest that fish passage improvements in the lower obstructions may facilitate improved access for blueback herring to spawning habitat available in the upper watershed (including the New Bedford Reservoir) and is an additional benefit to this population and to this restoration effort.

Results from PCB testing indicate elevated PCB concentrations in river herring above recommended consumption safety limits. The threshold levels recommended by the FDA and USEPA (1998) were developed to ensure the protection of local residents and recreational anglers whose seafood consumption might include seafood caught mostly, if not entirely, from New Bedford Harbor. Improving access into the upper watershed and reservoir reduces residence time and exposure to areas in the lower watershed where PCB concentrations are higher. This and the continued remediation of PCBs in New Bedford harbor may continue to decrease PCB concentrations in alewives over time. Further sampling and testing is recommended to determine if PCB levels in river herring decrease to levels acceptable for human consumption.

Other Species

Results from census monitoring at the New Bedford Reservoir and the video monitoring conducted by the USGS (Haro et al. 2008) were used to identify and confirm the presence of other diadromous species. Census monitoring during the 2011 spring season confirmed the first known record of the sea lamprey in the system. No lamprey species have been recorded before in *MarineFisheries* surveys (Reback et al. 2004; Evans et al. 2011). Sea lampreys may have entered the river and avoided detection in the past by (1) passing through the openings in the fish trap mesh as juveniles and/or (2) by attaching to an adult alewife – a host species for sea lampreys – en route to the reservoir. Monitoring should be continued in the future to determine if lamprey observations increase. To do so would require modifications to the existing trap (smaller wire mesh size) in order to retain smaller individuals.

Results from the USGS video monitoring study (Haro et al. 2008) confirmed the presence of rainbow smelt, white perch, and striped bass immediately below the Sawmill Dam fishway. Striped bass are a seasonal visitor to the lower watershed and their presence has been noted near the entrance to the Sawmill Fishway during the latter stages of monitoring in late spring. Based on accounts from local residents and anglers, smelt historically comprised a viable fishery in the Acushnet River. However, it was believed that the population had since been extirpated from the system. *MarineFisheries* surveys (Reback et al. 2004; Evans et al. 2011) have not currently or historically identified the presence of white perch in this system, although it is possible they may have been present in the lower watershed; census monitoring did not detect white perch ascending the reservoir fishway. Despite the confirmation of the presence of these two species, white perch colonization and rainbow smelt re-colonization are undeterminable. The rainbow smelt population is likely a remnant that may utilize potential spawning habitat at the freshwater-saltwater interface. Despite confirming their presence, however, there is no evidence of spawning at this time.

Elver sampling from the Acushnet Sawmill station during post-construction phase monitoring indicated increased catch rates in the lower river. Given the location of the Acushnet Sawmill elver trap (at the head of tide), it serves as an indicator of the abundance of elvers entering the system. Increasing CPUE scores at this location may suggest an increase in juvenile recruitment into the system. Sheppard and Block (2013) observed a significant increase in recruitment in the four years following the Sawmill fishway installation. Abundance indices in 2012 and 2013 suggest a stabilizing trend in recruitment. However, the mechanism behind these dynamics is currently unknown.

Catch data from pre-construction phase monitoring indicated that few elvers (comprised mainly of age-1+) were reaching the entrance to the reservoir ladder. Catches increased moderately during post-construction phase monitoring and suggest that eels have improved access to the upper reaches of the river due to fish passage improvements at the downstream obstructions. In particular, greater proportions of YOY were present at the reservoir station in comparison to pre-construction years. However, the increase in catch rates did not exhibit the same trend as river herring. Results indicated catch rates and YOY proportions were highly variable and are consistent with Sheppard and Block (2013). YOY were not present in the catches during post-construction phase monitoring, nor were they observed at the reservoir station during the 2010 monitoring season). This suggests that elvers may be residing in the impoundments downstream of the reservoir, with only a portion of the population migrating upstream to the reservoir. Residence time in downstream impoundments is unknown at this time. YOY may be migrating upstream outside of the monitoring period, as suggested by the catch data at the reservoir station, which were observed toward the latter part of the monitoring periods (late May to early June). With increased recruitment into the system, it is anticipated that greater proportions of YOY will utilize nursery habitat in sections of the upper watershed including the reservoir.

Water Chemistry Monitoring

Mean weekly readings indicate that water temperatures remained within acceptable ranges for spawning and survival for river herring throughout the majority of the spawning migration period and during the peak migration periods (April and May). Dissolved oxygen concentrations generally decrease as water temperatures increase, however, mean monthly readings did not decline below acceptable limits. Initial observations suggest there is potential for concern regarding temperature patterns toward the end of the monitoring period where weekly water temperatures in June approach, and in some cases exceed, the recommended daily and 7-day mean water temperature limits.

Studies such as Rounsefell and Stringer (1943) and Carlander (1969) indicate alewife spawning has been reported to occur at temperatures ranging from 10 ºC to 22 ºC with the majority of alewife spawning in the Gulf of Maine occurring with the temperature range between 12 ºC and 15 ºC (Bigelow and Schroeder 1953). Additional studies (Cianci 1969; Marcy 1976; Klauda et al. 1991) indicate that optimal spawning temperatures for blueback herring range between 21º and 25 ºC. Since the Sawmill station is located at the head of tide, it is unlikely that blueback herring spawn in this location. The presence of blueback herring in the reservoir trap during the post-construction period suggests that spawning occurs upstream of the Sawmill fishway. During this study, the run terminated (the last river herring observed in the fish trap) during the first week of June in 2005, and between 20 May (2008) and 27 May (2011). This suggests that, in general, the run terminates before water temperatures rise above acceptable limits for reproductive success.

PH levels were below (≤ 6.5) the recommended limit for suitable habitat for Class B waters in 2005. In particular, mean monthly pH levels recorded at the reservoir (6.0) and Sawmill (<6.0) stations were particularly low. Low pH (< 6.5) increase metal toxicity and disrupt ion-oregulation at gill tissues. Levels below 4.0 can be lethal whereas higher pH (≥ 8.3) can be a threat to the development of fish eggs and larvae. Studies conducted by Klauda and Palmer (1986) and Klauda et al. (1987) of blueback herring egg survival indicate that mortality rates were low (7%) in a pH range of 5.7 to 6.5. The *MarineFisheries* QAPP (Chase 2010; Chase et al. 2010) adopted the *MassDEP* criterion of ≥6.5 to ≤8.3 for suitable pH to support aquatic life. Under these criteria, the pH conditions within the two riverine sections monitored gradually improved throughout the monitoring period and can provide suitable future spawning conditions for blueback herring.

Conclusions and Recommendations

The fish passage enhancements to the three dams on the Acushnet River have successfully improved passage for river herring and juvenile American eel. Alterations to the lower two obstructions (Acushnet Sawmill Dam and Hamlin Street Dam) using nature-like fishway designs have facilitated access to the upper watershed for both species and installation of a technical Denil fishway has enabled passage for river herring into their primary spawning habitat in the New Bedford Reservoir. Basic water chemistry parameters remained within acceptable surface water quality standards for Class B waters with some improvement observed in pH levels. Continued recording of basic water chemistry as well as water temperature profiles is recommended to monitor long-term stability or changes in these essential habitat parameters. It is anticipated that the numbers of spawning adult river herring and elvers reaching the New Bedford Reservoir will continue to increase. Monitoring and testing should continue in successive years to examine changes in these populations and further document the success of the fish passage improvements as well as to determine if public consumption of river herring is allowable, should this fishery be opened in the future.

Acknowledgements

We wish to thank former *MarineFisheries* biologist Phillips Brady who was involved in this restoration project from inception to planning and design of the fish passage improvements to stock enhancement and initiation of biological monitoring. Thanks to Ed Clark and Luis Carmo of *MarineFisheries* for their efforts in stocking as well as construction, installation, removal and maintenance of the fish and elver traps. We also wish to thank various *MarineFisheries* staff including John Boardman, Derek Perry, David Kowalske, Joe Fascendola, Dan Syriala, Josh Black, Talia Bigelow, Andrea Petrella, Jeff Devine, Kelly Kleister, Ray Jarvis and Mananjo Jonahson for their efforts in monitoring, sample collection, processing and data entry. Additional thanks to Tony Williams and staff of the Coalition for Buzzards Bay for monitoring and recording counts from the electronic counter at the New Bedford Reservoir. Special thanks to Dr. Alex Haro and Abigail Franklin of the USGS for conducting biological monitoring of diadromous resources using video counting system during the 2008 spring season. And special thanks to the New Bedford Harbor Trustee Council for funding the fish passage restoration projects and associated monitoring efforts.

References

ASMFC (Atlantic States Marine Fisheries Commission). 2000. Interstate Fishery Management Plan for American Eel (*Anguilla rostrata*). Fish management Report No. 36. 93p.

Belding, D.L. 1921. Report upon the alewife fisheries of Massachusetts. Marine Fisheries Series No. 1. Massachusetts Division of Marine Fisheries. 135p.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fishery Bulletin 74, Fishery

Bulletin of the Fish and Wildlife Service 53. 1-577.

Carlander, K.D. 1969. Life history data on freshwater fishes of the United States and Canada, exclusive of the Perciformes. In Handbook of Freshwater Biology, Volume 1. The Iova State University Press, Ames. 27-169p.

Cating, J.P. 1953. Determining age of Atlantic shad from their scales. US Fish and Wildlife Service, Fishery Bulletin No. 85, Vol 54, 187-199.

Chase, B.C. 2010. Quality assurance program plan (QAPP) for water quality measurements conducted for diadromous fish habitat monitoring version 1.0, 2008-2012. Massachusetts Division of Marine Fisheries Technical Report 42. 63p.

Chase, BC., T. Callaghan, M.B. Dechant, and P. Patel. 2010. River herring spawning and nursery habitat assessment: Upper Mystic Lake, 2007-2008. Massachusetts Division of Marine Fisheries Technical Report 44. 15p.

Cianci, J.M. 1969. Larval development of the alewife, *Alosa pseudohargengus* Wilson, and the glut herring, *Alosa aestivalis* Mitchell. M.S. thesis, University of Connecticut, Storrs. 62p.

EAEST (EA Engineering, Science, and Technology, Inc.). 2005. Environmental monitoring program: Acushnet River fish passage restoration project, Acushnet, Massachusetts. Project No. 61905.11. 16p.

EAEST. 2006a. Section 404 Permit Acushnet River fish passage restoration project: Phase II—sawmill Dam, Acushnet, Massachusetts. Final Report. Project No. 61905.11. 29p.

EAEST. 2006b. Single environmental impact report, Acushnet River fish passage restoration project: Phase II—Sawmill Dam, Acushnet, Massachusetts. Prepared for the National Oceanic and Atmospheric Administration (NOAA) Restoration Center. EOEA No. 13074.

EAEST. 2007. Basis of design: Acushnet River fish passage restoration project, Acushnet, Massachusetts. Prepared for the NOAA Northeast Restoration Center.

Evans, N.T., K.H. Ford, B.C. Chase, and J.J. Sheppard. 2011. Recommended time of year restrictions (TOYs) for coastal alteration projects to protect marine fisheries resources in Massachusetts. Massachusetts Division of Marine Fisheries Technical Report 47. 69p.

FEMA (Federal Emergency Management Agency). 1982. Flood Insurance Study, town of Acushnet, Massachusetts, Bristol County. 19 January 1982. 17p.

Guimond. 2006. Puntledge River impoundment and diversion dam fishway assessment 2005. Report prepared for Fisheries and Oceans Canada. British Columbia, Canada. 19p.

Guimond. 2007. Puntledge River impoundment and diversion dam fishway assessment 2006. Report prepared for Comox Vallet Project Watershed Society. British Columbia, Canada. 22p.

Haro, A., A. Franklin, and T. Williams. 2008. Evaluation of fish migration in the Acushnet River system, 2008. Report submitted to NOAA National Marine Fisheries Service Office of Habitat Conservation. 14p.

Haro, A. and W.M. Krueger. 1988. Pigmentation, size, and migration of elvers (*Anguilla rostrata* (Lesuer)) in a coastal Rhode Island stream. 66 (11): 2528-2533.

Klauda, R.J., S.A. Fischer, L.W. Hall, Jr., and J.A. Sullivan. 1991. Alewife and blueback herring: *Alosa pseudohargengus* and *Alosa aestivalis*. In S.L. Funderburk, J.A. Mihursky, S.J. Jordan, and D. Riley (eds). Habitat requirements for Chesapeake Bay living resources, 2nd edition. Chesapeake Bay Program, Living Resources Subcommittee, Annapolis, Maryland.

Klauda, R.J. and R.E. Palmer. 1986. Laboratory and field bioassay experiments on blueback herring (*Alosa aestivalis*) from Maryland coastal plain streams. Applied Physics Laboratory, The Johns Hopkins University. PPSP-AD-15. 228p.

Klauda, R.J., R.E. Palmer, and M.J. Lenkevich. 1987. Sensitivity of early life stages of blueback herring to moderate acidity and aluminum in soft freshwater. Estuaries 10 (1): 44-53.

Kleinschmidt Associates. 2001. New Bedford reservoir fishway - Acushnet River preliminary site evaluation report. 24p.

Libby, D.A. 1985. A comparison of scale and otolith aging methods for the alewife, *Alosa pseudoharengus*. US National Marine Fisheries Service Fishery Bulletin 83: 696-701.

Marcy, B.C. Jr. 1969. Age determination from scales of *Alosa pseudoharengus* (Wilson) and *Alosa aestivalis* (Mitchill) in Connecticut waters. Transactions of the American fisheries Society 98: 622-630.

Marcy, B.C., Jr. 1976. Planktonic fish eggs and larvae of the lower Connecticut River and effects of the Connecticut Yankee plank including entrainment. In D. Merriman and L.M. Thorpe (eds.). The Connecticut River Ecological Study: The Impact of a Nuclear Power Plant. American Fisheries Society Monograph 1: 115-139.

MassDEP (Massachusetts Department of Environmental Protection). 1996. Massachusetts surface water quality standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA. Revision of 314 CMR 4.00, effective 23 June 1996.

MassDEP. 2007. Massachusetts surface water quality standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA. Revision of 314 CMR 4.00, effective January 2007.

MassDEP. 2012. Massachusetts Year 2012 Integrated List of Waters. Proposed Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314, and 303(d) of the Clean Water Act. 260p.

MassDEP and *MarineFisheries* (Massachusetts Division of Marine Fisheries). 2012. Contaminated monitoring report for seafood harvested in 2011. New Bedford Harbor Superfund Site, 2011 annual report. 157p.

Milone & MacBroom. 2000. Acushnet River anadromous fish restoration project, Acushnet, Massachusetts. Proposal. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts.

Milone & MacBroom. 2003a. Project notification form: Acushnet River fish restoration, Hamlin Street dam, Acushnet, Massachusetts. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts. MMI #2214-01-7

Milone & MacBroom. 2003b. Dam removal feasibility study: Sawmill and Hamlin Street dams, Acushnet River, Acushnet, Massachusetts. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts.

Milone & MacBroom. 2003c. Project notification form: Acushnet River fish restoration, Sawmill Dam, Acushnet, Massachusetts. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts. MMI #2214-01-7.

NBHTC (New Bedford Harbor Trustee Council). 1998a. New Bedford Harbor Trustee Council: Final restoration plan/Environmental impact statement for the New Bedford Harbor environment. 28 April. Gloucester, MA.

NBHTC. 1998b. New Bedford Harbor Trustee council Restoration Plan Environmental Impact Statement. Record of Decision. 7p.

NBHTC. 2001. New Bedford Harbor Trustee Council: Environmental assessment—New Bedford harbor restoration round II. Final report submitted to the Commonwealth of Massachusetts, US Department of Commerce, and US Department of the Interior. 137p.

Odeh, M. 2003. Discharge rating equation and hydraulic characteristics of standard Denil fishways. Journal of Hydraulic Engineering. 129(5): 341-348.

Quinn, R. 1995. Acushnet River preliminary site survey. US Department of the Interior. 8p.

Reback, K.E., P.D. Brady, K.D. McLaughlin, and C.G. Milliken. 2004. A survey of anadromous fish passage in coastal Massachusetts: Part 1. Southeastern Massachusetts. Massachusetts Division of Marine Fisheries Technical Report 15. 134p.

Rothschild, B.J. 1963. A critique of the scale method for determining the age of the alewife, *Alosa pseudohargengus* (Wilson). Transactions of the American Fisheries Society. 92(4): 409-413.

Rounsefell, G.A. and L.D. Stringer. 1943. Restoration and management of the New England alewife fisheries with special references to Maine. Transactions of the American Fisheries Society 73: 394-424.

Sheppard, J., and S. Block. 2013. Monitoring response of diadromous populations to fish passage improvements on a Massachusetts coastal stream. Journal of Environmental Science and Engineering A. 2:71-79.

USACOE (US Army Corps of Engineers). 2012. Compensatory stream mitigation standard operating prodecures and guidelines. Department of the Army Mobile Distric Corps of Engineers. SAM -2011-317-MBM. 47p.

USEPA (U.S. Envirnmental Protection Agency). 1998. Record of decision for the upper and lower harbor operable unit, New Bedford Harbor Superfun site, New Bedford, Massachusetts. U.S. EPA—Region 1 New England. September.

USEPA. 2007. National Estuary Program Coastal Condition Report. Office of Waterr/Office of Research and Development. Washington, D.C. EPA 842-F-06-001. 486p.

USGS (United States Geological Survey). 2011. StreamStats. http://streamstatsags.cr.usgs.gov/ma_ss/default/aspx?stabbr=ma&dt=1316199203967. Accessed: 16 September 2011.

Appendices

Appendix A

Chronology of the Polychlorinated Biphenyl (PCB) contamination in the Acushnet River Estuary and New Bedford Harbor.

Year	Event
1941	Cornell Dubilier begins production of electronic capacitors containing PCBs.
1947	Aerovox Corporation uses PCBs in electronic capacitors.
1950-70	Capacitor manufacturing continues. Total use of PCBs estimated to be approximately 32 million lbs. or 1.5 million kg. Estimates of 1% loss to discharges would yield 150 tons.
1971	Arcolor 1016 substituted for Arcolor 1242.
1974-75	PCB contamination evident in birds and sediments of New Bedford Harbor and Buzzards Bay.
1976	U.S. EPA samples wastewater effluents of Cornell Dubilier, Aerovox and New Bedford sewage treatment plants. Significant levels of PCBs reported. High levels of PCBs reported in sediments and marine life. Scientists from Massachusetts Audubon and Woods Hole Oceanographic Institution Express concern over perceived lack of official action by state and state and federal agencies. The Governor and Secretary for Environmental Affairs instruct state agencies to investigate severity of problem. Intensive sampling and analyses of marine life and harbor sediments conducted by academic scientists, state and federal agency laboratories, and consulting companies.
1977	Monsanto Co. voluntarily ceases production of PCBs due to accumulating evidence of environmental and health effects. Massachusetts department of Public Health issues warnings against consumption of lobsters and bottom feeding finfish from the Acushnet River Estuary and New Bedford Harbor because concentrations of 5 ppm (wet weight) or greater are detected in edible tissues. Aerovox and Cornell Dubilier cease production of capacitors containing PCBs.
1979	Massachusetts Department of Public Health enacts fishery closures in New Bedford Harbor as a result of PCB contamination. An ad hoc committee is formed to assess the PCB contamination problem.
1980	Massachusetts Department of Environmental Quality Engineering designates New Bedford Harbor PCB problem as priority issue in state EPA agreement.
1981	Secretary of Environmental Affairs establishes an interagency PCB task force.

Small-scale epidemiology study of New Bedford residents reveals very high concentrations of PCBs in blood samples compared to other U.S. regions. Based on this and other evidence of high environmental levels, Department of Public Health ban is fully enacted.

1982 Coastal Zone Management, DEQE, and U.S. Coast Guard identify "hot spot" areas of sediment in the Acushnet River estuary with several hundred to several thousand parts per million PCB concentrations.

Acushnet River Estuary and New Bedford Harbor designated as a U.S. Superfund hazardous waste site under the Comprehensive Environmental Response Compensation and Liabilities Act (CERCLA) and remedial action planning begins.

1982-Present Investigations on the biogeochemistry, bioavailability and biological effects of PCBs are conducted in New Bedford Harbor and Buzzards Bay.

1985 Fishery closures in New Bedford Harbor administered by the Massachusetts Division of Marine Fisheries.

Food and Drug Administration (FDA) action level for PCBs reduced from 5 ppm to 2 ppm.

1990 Dredging feasibility study conducted.

1991 The New Bedford Harbor Trustees Council was created and charged with allocation of funds for natural resource remediation and restoration.

1992 A litigation settlement of $20,200,000 was awarded for damage assessment, mitigation and restoration projects for the Acushnet River Estuary and New Bedford Harbor.

Superfund clean-up proposed.

1998 A Final Restoration Plan and EIS developed by the NBHTC.

Appendix B

Water quality classifications and standards outlined by the Massachusetts Department of Water Pollution Control under 314 CMR 4.05 and 314 CMR 4.06. Source: Massachusetts Department of Environmental Protection (*MassDEP* 1996, 2007, and 2012)

Table B1: 314 CMR: Division of Water Pollution Control 4.06: Acushnet River watershed.

Region	Mile	Class	Other Restrictions	DO (mg/L)	H20 Temp (ºC)	pH Range	Fecal Coliform
New Bedford Reservoir (source to outlet)	8.2 +	B	Warm water High quality water	≥ 6.0 (CWF) ≤ 5.0 (WWF)	≤ 20 (*CWF) ≤ 28.3 (**WWF)	6.5 – 8.3	≤ 200 organisms per 100ml
Outlet of New Bedford Reservoir	8.2 – 4.5	B	Warm water High quality water	≥ 6.0 (CWF) ≤ 5.0 (WWF)	≤ 20 (CWF) ≤ 28.3 (WWF)	6.5 – 8.3	≤ 200 organisms per 100ml
Main St. to Route 6	4.5 – 1.2	SB	Shellfishing (R) CSO	≤ 5.0 (≤ 60% sat.)	≤ 29.4 OR ≤ 26.7 max. daily mean	6.5 – 8.5	≤ 88 organisms per 100ml (restricted shellfishing areas) ≤ 200 organisms per 100ml (non-shellfish)
Inner New Bedford HBR	4.5 – 1.2	SB	Shellfishing (R) CSO	≤ 5.0 (≤ 60% sat.)	≤ 29.4 OR ≤ 26.7 max. daily mean	6.5 – 8.5	≤ 88 organisms per 100ml (restricted shellfishing areas) ≤ 200 organisms per 100ml (non-shellfish)

*CWF – Cold water fisheries
**WWF – Warm water fisheries

314 CMR 4.05 and 4.06 (*MassDEP* 1996)

Class B. These waters are designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. Where designated in 314 CMR 4.06, they shall be suitable as a source of public water supply with appropriate treatment ("Treated Water Supply"). Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value.

1. Dissolved Oxygen.

a. Shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries. Where natural background conditions are lower, DO shall not be less than natural background conditions. Natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained.

2. Temperature.

a. Shall not exceed 68°F (20°C) based on the mean of the daily maximum temperature over a seven day period in cold water fisheries, unless naturally occurring. Where a reproducing cold water aquatic community exists at a naturally occurring higher temperature, the temperature necessary to protect the community shall not be exceeded and the natural daily and seasonal temperature fluctuations necessary to protect the community shall be maintained. Temperature shall not exceed 83°F (28.3°C) in warm water fisheries. The rise in temperature due to a discharge shall not exceed 3°F (1.7°0C) in rivers and streams designated as cold water fisheries nor 5°F (2.8°C) in rivers and streams designated as warm water fisheries (based on the minimum expected flow for the month); in lakes and ponds the rise shall not exceed 3°F (1.7°0C) in the epilimnion (based on the monthly average of maximum daily temperature);

b. natural seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained. There shall be no changes from natural background conditions that would impair any use assigned to this Class, including those conditions necessary to protect normal species diversity, successful migration, reproductive functions or growth of aquatic organisms;

c. alternative effluent limitations established in connection with a variance for a thermal discharge issued under 33 U.S.C. § 1251 (FWPCA, § 316(a)) and 314 CMR 3.00 are in compliance with 314 CMR 4.00. As required by 33 U.S.C.§1251 (FWPCA, § 316(a)) and 314 CMR 3.00, for permit and variance renewal, the applicant must demonstrate that alternative effluent limitations continue to comply with the variance standard for thermal discharges; and

d. in the case of a cooling water intake structure (CWIS) regulated by EPA under 314 33 U.S.C. §1251 (FWPCA § 316(b)), the Department has the authority under 33 U.S.C. §1251 (FWPCA §401), M.G.L. c. 21, §§ 26 through 53 and 314 CMR 3.00 to condition the CWIS to assure compliance of the withdrawal activity with 314 CMR 4.00, including, but not limited to, compliance with narrative and numerical criteria and protection of existing and designated uses.

3. pH.
Shall be in the range of 6.5 through 8.3 standard units and not more than 0.5 units outside of the natural background range. There shall be no change from natural background conditions that would impair any use assigned to this Class.

4. Bacteria.

a. At bathing beaches as defined by the Massachusetts Department of Public Health in 105 CMR 445.010: where E. coli is the chosen indicator, the geometric mean of the five most recent samples taken during the same bathing season shall not exceed 126 colonies per 100 ml and no single sample taken during the bathing season shall exceed 235 colonies per 100 ml; alternatively, where enterococci are the chosen indicator, the geometric mean of the five most recent samples taken during the same bathing season shall not exceed 33 colonies per 100 ml and no single sample taken during the bathing season shall exceed 61 colonies per 100 ml;

b. for other waters and, during the non bathing season, for waters at bathing beaches as defined by the Massachusetts Department of Public Health in 105 CMR 445.010: the geometric mean of all E. coli samples taken within the most recent six months shall not exceed 126 colonies per 100 ml typically based on a minimum of five samples and no single sample shall exceed 235 colonies per 100 ml; alternatively, the geometric mean of all enterococci samples taken within the most recent six months shall not exceed 33 colonies per 100 ml typically based on a minimum of five samples and no single sample shall exceed 61 colonies per 100 ml. These criteria may be applied on a seasonal basis at the discretion of the Department; and

c. consistent with Massachusetts Department of Public Health regulations for bathing beaches, the single sample maximum values in the primary contact bacteria criteria in 314 CMR 4.05(3)(b)4.a. and 4.05 (3)(b)4.b. also are for use in the context of notification and closure decisions.

5. Solids.

These waters shall be free from floating, suspended and settleable solids in concentrations and combinations that would impair any use assigned to this Class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom.

6. Color and Turbidity.

These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this Class.

7. Oil and Grease.

These waters shall be free from oil, grease and petrochemicals that produce a visible film on the surface of the water, impart an oily taste to the water or an oily or other undesirable taste to the edible portions of aquatic life, coat the banks or bottom of the water course, or are deleterious or become toxic to aquatic life.

8. Taste and Odor.

None in such concentrations or combinations that are aesthetically objectionable, that would impair any use assigned to this Class, or that would cause tainting or undesirable flavors in the edible portions of aquatic life.

Class SB. These waters are designated as a habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. In certain waters, habitat for fish, other aquatic life and wildlife may include, but is not limited to, seagrass. Where designated in the tables to 314 CMR 4.00 for shellfishing, these waters shall be suitable for shellfish harvesting with depuration (Restricted and Conditionally Restricted Shellfish Areas). These waters shall have consistently good aesthetic value. In the case of a water intake structure (IS) at a desalination facility, the Department has the authority under 33 U.S.C. § 1251 (FWPCA § 401), M.G.L. c. 21, §§ 26 through 53 and 314 CMR 3.00 to condition the IS to assure compliance of the withdrawal activity with 314 CMR 4.00, including, but not limited to, compliance with the narrative and numerical criteria and protection of existing and designated uses.

1. Dissolved Oxygen.

Shall not be less than 5.0 mg/l. Seasonal and daily variations that are necessary to protect existing and designated uses shall be maintained. Where natural background conditions are lower, DO shall not be less than natural background.

2. Temperature.

a. Shall not exceed 85°F (29.4°C) nor a maximum daily mean of 80°0F (26.7°C), and the rise in temperature due to a discharge shall not exceed 1.5°F (0.8°C) during the summer months (July through September) nor 4°0F (2.2°0C) during the winter months (October through June);

b. there shall be no changes from natural background that would impair any uses assigned to this class including those conditions necessary to protect normal species diversity, successful migration, reproductive functions or growth of aquatic organisms;

c. alternative effluent limitations established in connection with a variance for a thermal discharge issued under 33 U.S.C. § 1251 (FWPCA, § 316(a)) and 314 CMR 3.00 are in compliance with 314 CMR 4.00. As required by 33 U.S.C. § 1251 (FWPCA, § 316(a)) and 314 CMR 3.00, for permit and variance renewal, the applicant must demonstrate that alternative effluent limitations continue to comply with the variance standard for thermal discharges; and

d. in the case of a cooling water intake structure (CWIS) regulated by EPA under 33 U.S.C. § 1251 (FWPCA § 316(b)), the Department has the authority under 33 U.S.C. § 1251 (FWPCA § 401), M.G..L. c. 21, §§ 26 through 53 and 314 CMR 3.00 to condition the CWIS to assure compliance of the withdrawal activity with 314 CMR 4.00, including, but not limited to, compliance with narrative and numerical criteria and protection of existing and designated uses.

3. pH.

Shall be in the range of 6.5 through 8.5 standard units and not more than 0.2 units outside of the natural background range. There shall be no change from natural background conditions that would impair any use assigned to this Class.

4. Bacteria.

a. Waters designated for shellfishing shall not exceed a fecal coliform median or geometric mean MPN of 88 organisms per 100 ml, nor shall more than 10% of the samples exceed an MPN of 260 per 100 ml or other values of equivalent protection based on sampling and analytical methods used by the Massachusetts Division of Marine Fisheries and approved by the National Shellfish Sanitation Program in the latest revision of the Guide For The Control of Molluscan Shellfish (more stringent regulations may apply, see 314 CMR 4.06(1)(d)(5));

b. at bathing beaches as defined by the Massachusetts Department of Public Health in 105 CMR 445.010, no single enterococci sample taken during the bathing season shall exceed 104 colonies per 100 ml and the geometric mean of the five most recent samples taken within the same bathing season shall not exceed 35 enterococci colonies per 100 ml. In non bathing beach waters and bathing beach waters during the non bathing season, no single enterococci sample shall exceed 104 colonies per 100 ml and the geometric mean of all of the samples taken during the most recent six months typically based on a minimum of five samples shall not exceed 35 enterococci colonies per 100 ml. These criteria may be applied on a seasonal basis at the discretion of the Department; and

c. consistent with Massachusetts Department of Public Health regulations for bathing beaches, the single sample maximum values in the primary contact recreation bacteria criteria in 314 CMR 4.05(4)(b) 4.b. also are for use in the context of notification and closure decisions.

5. Solids.

These waters shall be free from floating, suspended and settleable solids in concentrations or combinations that would impair any use assigned to this class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom.

6. Color and Turbidity.

These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.

7. Oil and Grease.

These waters shall be free from oil, grease and petrochemicals that produce a visible film on the surface of the water, impart an oily taste to the water or an oily or other undesirable taste to the edible portions of aquatic life, coat the banks or bottom of the water course, or are deleterious or become toxic to aquatic life.

8. Taste and Odor.

None in such concentrations or combinations that are aesthetically objectionable, that would impair any use assigned to this class, or that would cause tainting or undesirable flavors in the edible portions of aquatic life.

Table B.2: Chemical criteria used for reference conditions of river herring spawning and nursery habitat. The water chemistry parameters relate to Massachusetts Class B SWQS for aquatic life (*MassDEP* 2007), and US EPA reference conditions for the Northeast Coastal Zone sub-ecoregions 59 and 84 (source: Chase 2010).

Variables	Suitable (SWQC or BPJ)	Minimally Impacted (25th percentile)	Notes/Source
Temperature (˚C) (July - October: nursery)	≤ 28.3		Maximum limit (*MassDEP* 2007)
Temperature (˚C) (May - June: spawning)	≤ 26.0		Scientific literature & BPJ
Temperature (˚C) (May - June: spawning)	≤ 20.0 (7-day mean)		7-day mean of daily max. from logger data (MassDEP 2007)
pH	≥ 6.5 to ≤ 8.3		(*MassDEP* 2007)
DO (mg/L)	≥ 5.0		(*MassDEP* 2007)
Secchi Disc (m)		≤ 2.0	75th percentile; EPA Ecoregion 14, sub-84 (US EPA 2000a)
Turbidity (NTU)		≤ 1.7 (rivers only)	EPA Ecoregion 14, sub-59 (US EPA, 2000b)
TN (mg/L)		≤ 0.32	EPA Ecoregion 14, sub-59 (US EPA, 2000a)
TP (μg/L)		≤ 8.0	EPA Ecoregion 14, sub-59 (US EPA, 2000a)
Chlorophyll a (μg/L) Flourometric		≤ 4.2	EPA Ecoregion 14, sub-59 (US EPA, 2000a)

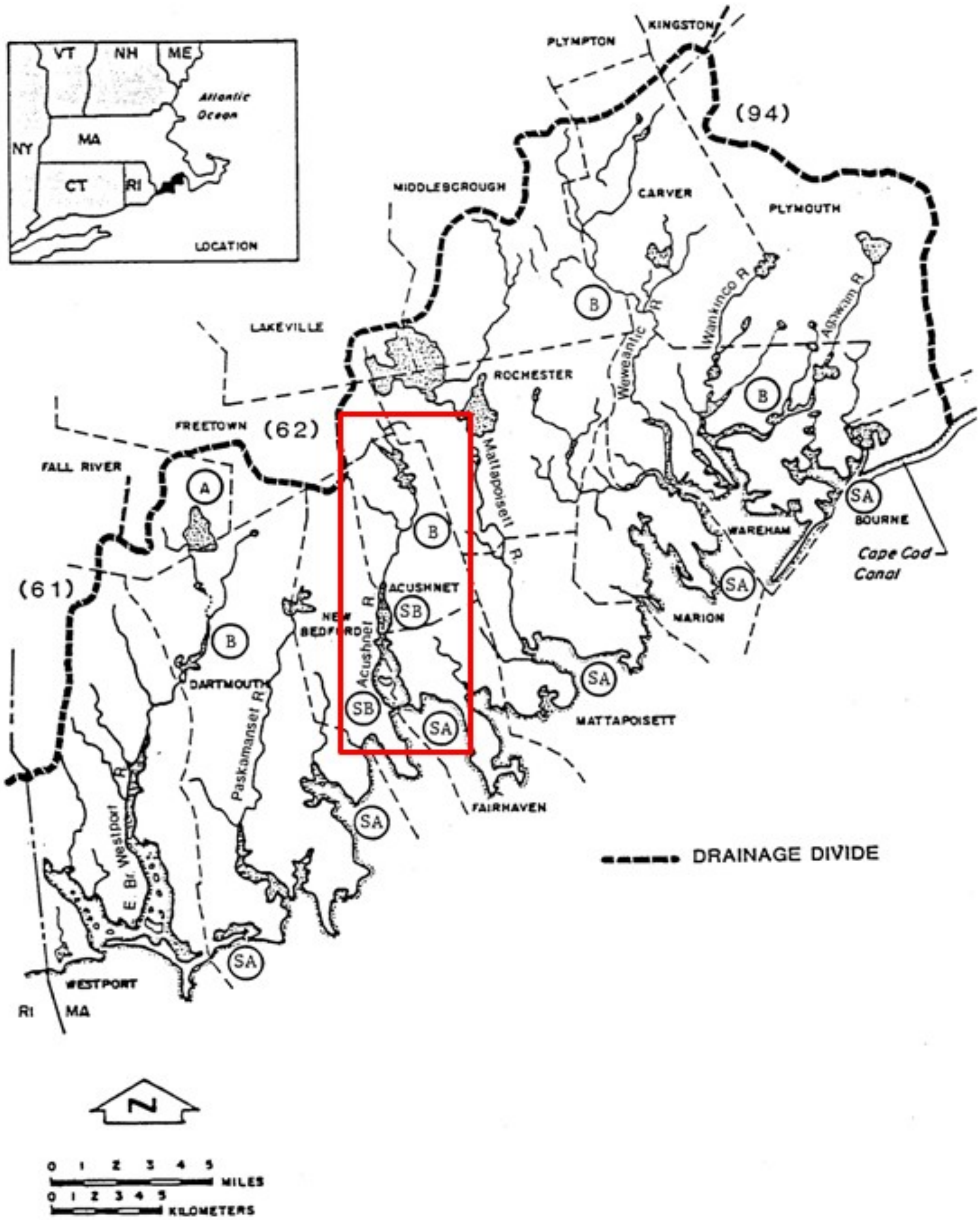


Figure B1: Water quality classifications of the Buzzards Bay watershed conducted by the Massachusetts Department of Water Pollution Control (314 CMR 4.06). Source: Massachusetts Department of Environmental Protection (Source: *MassDEP* 1996).

Appendix C

Preliminary site survey, conceptual design and planning for the New Bedford Reservoir Fishway. Information was obtained from the New Bedford Reservoir Fishway Preliminary Site Evaluation Report (Kleinschmidt 2001) with additional information provided by the USFWS (Dick Quinn, personal communication, 30 November 2012).

Table C1. Permitting process (permit types) required to initiate construction of the New Bedford Reservoir fishway.

Code	Permit Type	Issuer	Date
DEP SE 1-297	Order of Conditions 401 Certification & Wetlands Permit	MA Dept. Environmental Protection	10/01
	Final Project Approval	Town of Acushnet	9/01
01-9130	Rare Species Information Request Form	MA Dept. Fish & Game – Natural Heritage Endangered Species Program	8/01
R.C. 17682	950 CMR 275 Archaeological Survey Prehistoric Archaeological Sites	MA Historical Commission	7/01
199800811	General Permit	US Army Corps Engineers	6/01
MA 01014 6-3-3-3-3	Municipally Owned Dam Inspection/ Evaluation Report	MA Dept. Environmental Management – Office of Dam Safety	6/93

C.1: New Bedford Reservoir Dam Preliminary Site Survey

Prior to construction of the new fishway at the New Bedford Reservoir, a preliminary site survey was conducted to evaluate existing conditions to determine any constraints to the proposed fishway conceptual design drawings by the USFWS. A hydrology analysis was conducted by Kleinschmidt (2001) to provide a range of flow levels likely to occur at the proposed New Bedford Reservoir Dam fishway. In particular, the analysis focused on the frequency at which total discharge at the dam could be expected to exceed the capacity of the fishway (approximately 10 cfs).

Because there are no stream gauges on the Acushnet River, data from five USGS gauges in the vicinity of the dam were evaluated and used to simulate flow frequencies at the New Bedford Reservoir Dam site (Table C2). Of the five gauges evaluated, only one of the gauges (Paskamanset River, South Dartmouth) was located in the same major drainage area (Buzzards Bay). The gauges were evaluated

Table C2: Locations and characteristics of USGS stream gauges in the vicinity of the New Bedford Reservoir Dam.

Station No.	Station Name	Watershed	Drainage Area (mi^2)	Record
01105933	Paskamanset River, S. Dartmouth	Buzzards Bay	26.2	10/01/1995 – 9/30/1999
01108000	Taunton River, Bridgewater	Taunton	258.0	10/1/1929 – 4/23/1976 4/19/1985 – 5/31/1988 10/1/1996 – 9/30/1999
01109000	Wading River, Norton	Taunton	43.3	6/01/1925 – 9/30/1999
01109060	Threemile River, N. Dighton	Taunton	84.3	7/01/1966 – 9/30/1999
01109070	Segreganset River, Dighton	Taunton	10.6	7/01/1966 – 2/15/1992 7/23/1992 – 9/30/1999

and compared and flow data was summarized monthly to calculate values of discharge vs. drainage area. Results indicated similar patterns in monthly discharge among the five gauges and therefore, all five stations were included in the analysis.

The five flow records were then synthesized for the New Bedford Reservoir Dam site by summarizing the data in the form of a flow duration curve examining the rate of discharge vs. exceedance. Flow duration curves were also created based on a subset of each flow record covering the period from 15 April to 15 June, which coincides with upstream passage of river herring. Based on hydrological analysis (Kleinschmidt 2001) flows will be below 10 cfs during the migration season approximately 40% of the time with exceedance values (i.e. flows ≥ 10 cfs) ranging from 45 to 49 percent on an annual basis and from 52 to 67 percent for the 15 April to 15 June time period.

Table C.3: Estimates of flood flow levels for the New Bedford Reservoir Dam based on flow data collected from four USGS stream flow gauges in the vicinity.

Return Interval	Unit Runoff (cfs/mi^2)	Peak Reservoir Outflow (cfs)
10 years	61	440
25 years	77	560
50 years	90	660
100 years	105	760
500 years	143	1,030

Estimates of flood flow levels for the site were generated based on values reported by the USGS for four of the five gauges (the Paskamanset River gauge did not have computed values, and was excluded). Results of estimated flood flow levels for the site are shown in Table C3. Specific drainage basin characteristics or storage effects of the reservoir were not taken into consideration and therefore, these estimates as applied to the New Bedford Reservoir Dam site, are considered preliminary. It was assumed that the New Bedford Reservoir site would produce a high unit of runoff due to a relatively small drainage area (7.26 mi^2).

C.2: Conceptual Planning for the New Bedford Reservoir Fishway

Conceptual design drawings for the New Bedford Reservoir fishway are based on initial measurements of channel sections and water velocities made by Quinn (1995). Using geometric data for the USFWS conceptual design for this site (1:6 bottom slope, 3 ft channel width, 22-inch baffle open width), a fishway flow of 10 cfs (minimum 5.5 cfs) will require a depth over the baffles of approximately 1.5 feet (Kleinschmidt 2001). Using a relationship of discharge as a function of flow depth (Figure C1), the USFWS plans required the channel invert at the fishway exit located at an elevation of 92.16 feet. The exit location would establish the water level of approximately 94.37’ and passing approximately 8.0 cfs of water through the fishway while maintaining existing impoundment surface water levels.

The design plans (Figure C2) indicate that after migrants enter the fishway, they must negotiate five sections before exiting the fishway above the upper spillway. Passage consists of approximately 30 ft of level channel, then 30 ft (16 baffles) of sloped floor, a level intermediate channel approximately 44 ft in length, then 18 ft (10 baffles) of sloped channel (Figure C2b), followed by 4 custom baffles placed in a 7 ft channel (Figure C2b and Figure C2c), and an exit channel of approximately 136 ft in length. The cus-

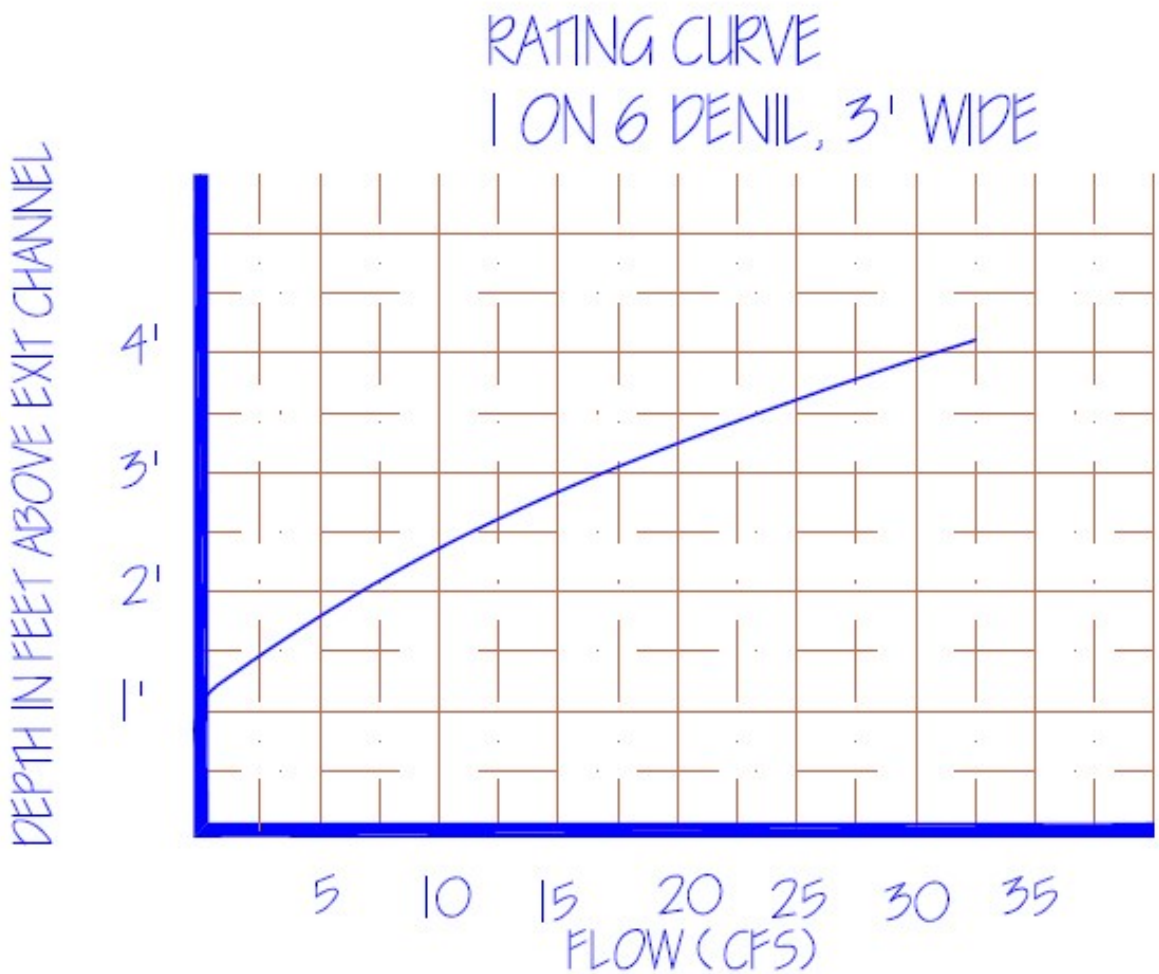


Figure C1: Discharge as a function of flow depth for a standard Denil fishway (1:6 bottom slope, 3 ft channel width, 22-inch baffle open width (relationship constructed by D. Quinn based on criteria by Odeh (2003)).

tom baffles were added after the project was completed due to a minor design error that placed the exit channel at a slight slope rather than at a constant slope as described by the preliminary design plans. This error resulted in the uppermost baffle (the hydraulic control for all flows down the fishway) passing almost 4.0 ft of water rather than 3.0 ft as recommended in the preliminary design plans (thus resulting in excessive flows and velocities (> 30 cfs) through the fishway). The error was due to a slight slope placed in the level sections of the fishway, which over the course of the 136 foot exit channel equated to approximately 1.5 feet lower than the exit channel elevation recommended by the USFWS conceptual design plans. The *MarineFisheries* fishway crew with assistance from the USFWS added the four custom baffles to correct this problem.

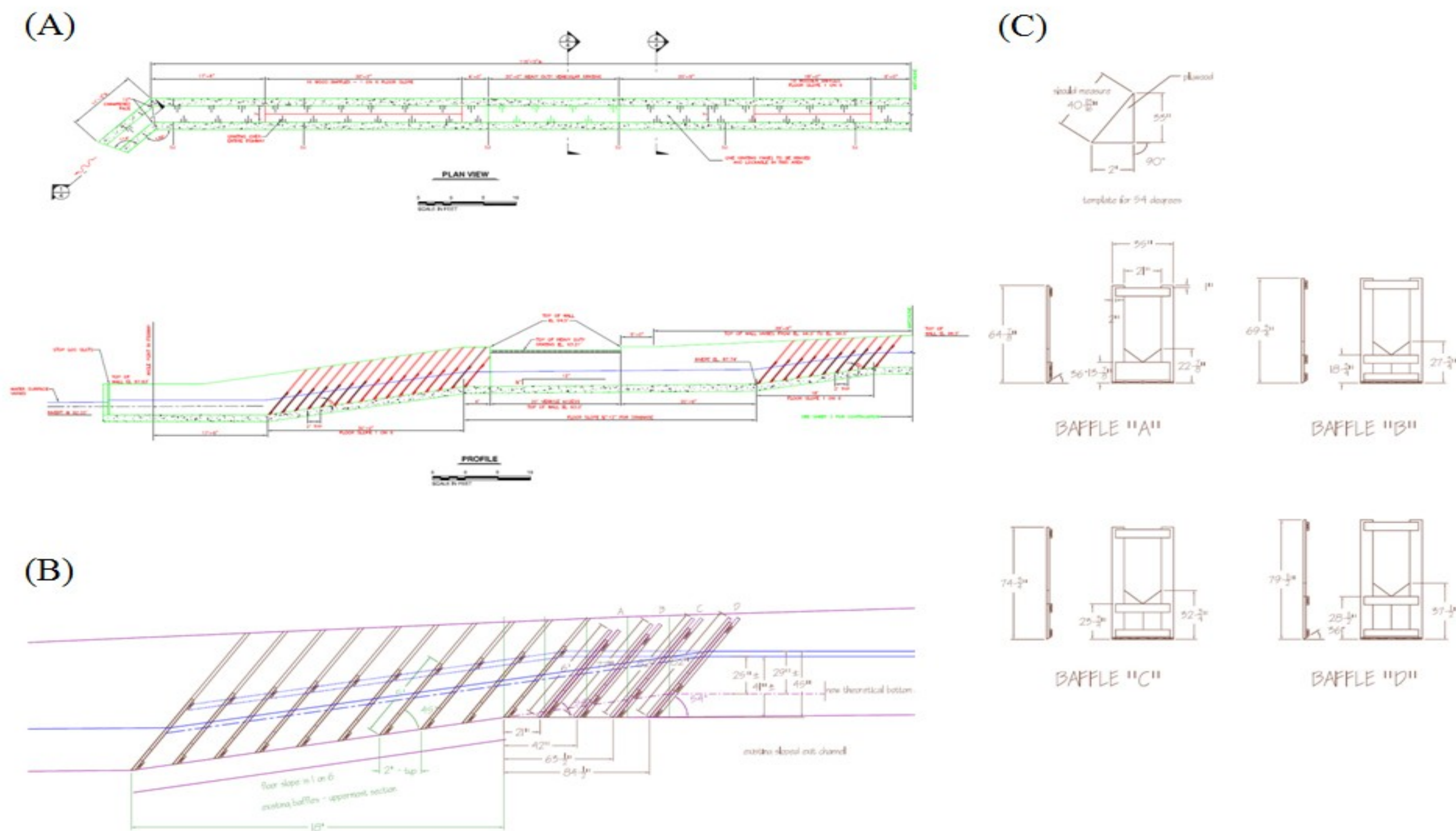


Figure C2a-c: Conceptual design plans for the New Bedford Reservoir fishway detailing (A) full profile and top view; (B) profile of the upper fishway with custom baffles; and (C) designs of for each custom baffle (Source: Dick Quinn, personal communication, 30 November 2012).

Appendix D

Preliminary site survey, conceptual design and planning for the Acushnet Sawmill Fishway. Information was obtained from the Acushnet River Restoration Project 95% Basis of Design by EA Engineering, Science, and Technology (EAEST 2007).

Table D1. Permitting process (permit type and timeline) required prior to construction of the fishway at the Sawmill Dam.

Agency	Type of Approval	Date Applied	Date Approved
Executive Office of Environmental Affairs, MEPA Unit	Secretary's Certificate of Acceptance Single Environmental Impact Report	3/30/06	5/17/06
MA Dept. Environmental Protection	Chapter 91 License	6/6/06	10/30/06
Acushnet Conservation Commission	Notice of Intent (NOI) and Order of Conditions	6/14/06	7/26/06
US Army Corps of Engineers, NE District	Section 404 Permit	8/4/06	11/16/06
MA Dept. Environmental Protection	Section 401 Water Quality Certificate	8/4/06	10/24/06
MA Dept. Conservation and Recreation, Office of Dam Safety	Chapter 253 Dam Safety Permit (#07-001)	8/16/06	1/26/07
MA Division Marine Fisheries	322 CMR 7.01(4)(f) Special Permit		2/14/07
National Environmental Policy Act	NEPA Environmental Assessment	10/17/06	10/27/06

Prior to fish passage design and construction, a hydrologic evaluation was conducted at the Acushnet Sawmill Dam to assess trends in baseflow and floodflow water levels. Initial measurements at the site were conducted by Milone and MacBroom (2003b) to predict water surface levels and velocity profiles using the Hydrologic Engineering Centers River Analysis System (HEC-RAS). Data collected from the HEC-RAS model was incorporated into development plans for fishway design including (1) baseflow velocities; (2) floodflow velocities; (3) step pool design; and (4) stone size selection.

D.1. Calculating baseflow velocities

In the initial feasibility study conducted by Milone and MacBroom (2003a), flood insurance data for the tidal reaches downstream of the Sawmill Dam was obtained from FEMA (1982) and summarized in Table D2.

Table D.2. Federal Emergency Management Agency (FEMA) flood insurance study data in tidal reaches of the Acushnet River watershed (downstream of the Acushnet Sawmill Dam).

Return Frequency (years)	Flow Rate (cfs)	Tidal Flood Elevation (ft NGVD)*
10	280	5.2
50	475	5.5
100	620	5.7
500	935	16.0**

Table D3. Federal Emergency Management Agency (FEMA) flood insurance study data in riverine reaches of the Acushnet River watershed (at or above the Acushnet Sawmill Dam).

Return Frequency (years)	Flow Rate (cfs)	Tidal Flood Elevation (ft NGVD)*
10	280	11.4
50	475	11.75
100	620	12.0
500	935	16.0**

*ft NVGD - feet above the National Geodetic Vertical Datum

** For the 500-year flood, the Flood Insurance Study for the Town of Acushnet, Massachusetts (FEMA 1982) as-

The hydraulic design for the Sawmill Dam was based on three baseflow conditions (9%, 50%, and 90% flow of annual non-exceedance values). With 9% and 90% values representing minimum and maximum flow conditions, respectively, the 50% value was used as an average flow condition for fish passage. Each of the flow conditions was generated using the baseflow separation method of fixed interval developed by Pettyjohn and Henning (1979) to calculate duration of surface run-off using the following relationship:

$$N = A^{0.2}$$

where N is the number of days after which surface run-off ceases, and A is the watershed area, in square miles, draining the site. Two time periods (1 April – 15 May; and September – December) were used to calculate baseflow conditions at the Sawmill site as they encompass the adult spawning migration and juvenile out-migration periods in the system, respectively. The months of June through August were excluded from the analysis due to low flow conditions during this period (which is outside the migration periods). Results from baseflow calculations for the Sawmill Dam and regional watersheds is shown in Table D4. Fifteen years of staff gauge records provided flow ranges that would be necessary for the Sawmill Dam design to pass fish upstream. Baseflows ranged from 7.91 to 43.3 mi^2, which encompasses the project area size at 18.7 mi^2 for the Sawmill Dam.

Table D4. Gauge and regional watershed information for baseflow estimation at the Acushnet River.

	Adamsville Brook	Paskamanset River	Wading River	Hamlin Street Dam	Acushnet Sawmill Dam
USGS Gauge No.	01106000	01105933	01109000	N/A	N/A
Area (mi^2)	7.91	26.2	43.3	16.4	18.7
Fixed Interval	3	3	5	3	3

Each of the fixed interval baseflow values were used in an exceedance probability analysis by ranking the baseflow values (by watershed and by migration period) then calculating the probabilities using the Weibull equation:

$$P_i = i/(n + 1)$$

where *n* is the number of baseflows ranked, and *i* is the rank of each baseflow. Values of 9, 50, and 90 percent exceedance were found by averaging all baseflow values with the associated exceedance value. The results for non-exceedance baseflows for the critical migration period are shown in Table D5.

Table D5. Calculated flows at the Acushnet Sawmill Dam.

% Non-Exceedance	March-June	September-December
90	83.61	52.49
50	33.95	13.02
9	10.91	2.82

D.2. Calculating floodflow velocities

The 9, 50, and 90 percent baseflow values were then plotted against the watershed area. Regression lines were drawn through the values to generate linear equations and associated r^2 values. These equations along with those generated during the 50% Basis of Design (EA/KCI 2005) were then used with the known watershed area of the Sawmill Dam to find the expected 9, 50, and 90 percent exceedance flows for this watershed. Estimated maximum design flows for the Sawmill fishway is shown in Figure

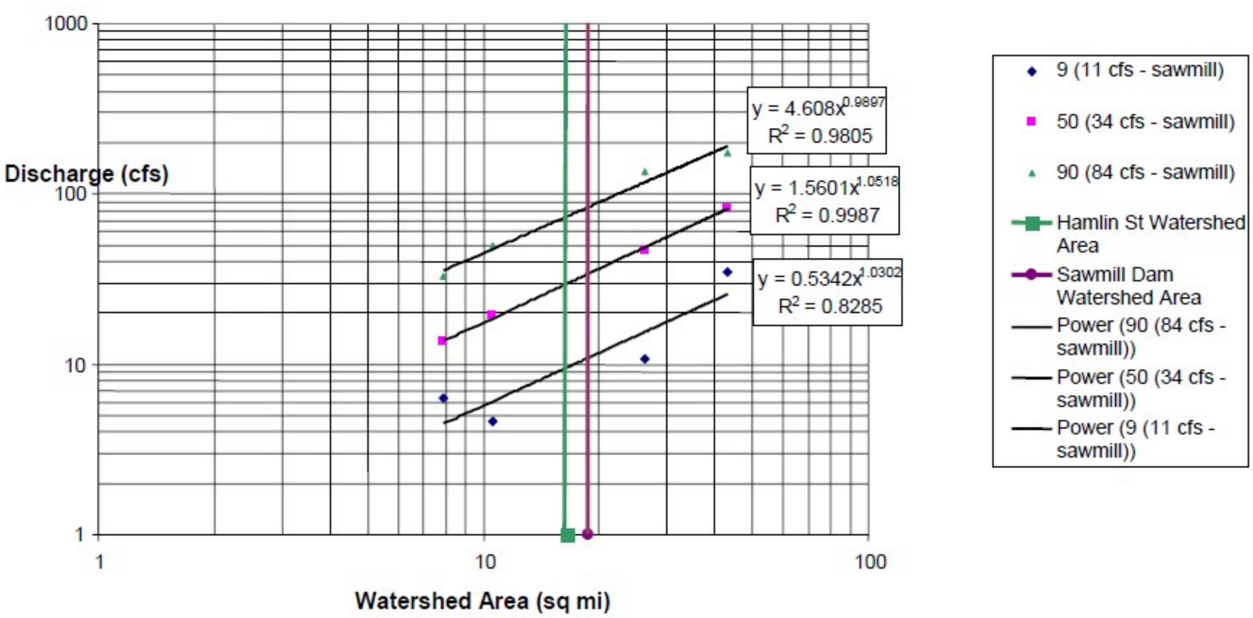


Figure D1. Non-exceedance curves for discharge based on watershed area for March-June at three gauging stations (source: EAEST 2007).

D1. Results indicated maximum flows for 9, 50, and 90 percent exceedance flows are 11 cfs, 34 cfs, and 84 cfs, respectively.

Additional calculations for determining maximum design flows for the Sawmill fishway were provided by the USFWS. These estimates were based on flow records from four gauging stations from watersheds within the region and included stormflow conditions (> 90% exceedance flows). The flow level required to pass fish through the Sawmill fishway was determined from these records. In order to measure flow levels at these sites, a rain gauge and pressure transducer was installed at the Sawmill Dam to record rainfall and water depth. The USFWS recommended a maximum design flow of 140 cfs in order to ensure no periods of non-passage for fish greater than three days. A comparative analysis conducted in a 2005 technical memorandum (EA/KCI 2005) indicated that the maximum design flow tested in the 50% Basis of Design (105 cfs) provides the optimal flow for passage based on the existing design plans, work area constraints as well as results from data collected from the rain gauge and pressure transducers installed at the site.

D.3. Step pool design criteria

The baseflow and floodflow velocities estimated by the HEC-RAS model (Milone and MacBroom 2003b) were utilized as initial downstream conditions for step pool design. For the design of each weir in the fishway, several conditions were expected. The first condition was that each step would increase by 0.8 ft, as measured from the lowest weir notch. For the Sawmill fishway, each weir was designed with five elevations. The flows established during the baseflow separation are directed through the notches to promote fish passage. This is accomplished by establishing a minimum depth of 0.7 ft, and a maximum design velocity of 2.5 fps through the notches. The design velocity was set below the maximum target velocity set by various fisheries biologists (3.0 fps) in order to compensate for nature-like fishway variations in rock shape, weir shape, roughness, elevation changes, and changes in pool size and depths due to natural sediment transport and deposition.

Another criteria of the step pool design is to determine the appropriate pool size downstream of each weir. Pool size was determined using the following equation to establish a maximum energy dissipation factor (EDF) of 4.0 lb/sec-ft^2 for the Sawmill fishway (based on typical EDF values used for structural fishways (EA/KCI 2005):

$$EDF = \gamma \frac{Q \times Drop}{Volume}$$

$$\gamma = 62.4 \ _{lb/cf}$$

where Q is the discharge (cfs), and *Drop* (ft) is the difference between the upstream water surface to the downstream water surface on the rock step. The design of the pool depths were based on the EDF and the length to the next pool (10ft maximum), and volume was determined based on maximum values selected for each fishway. Velocity and depth were modeled over a variety of flow ranges and the results are presented in Table D6.

D.4. Stone size selection

Stone size selection for use in constructing nature-like fishways is based on a standard channel design method. The tractive force, or tractive shear stress method is used to determine the size particle that corresponds to the shear stress associated with the flood stage of highest impact on the structure. The HEC-RAS model developed by Milone & MacBroom (2003b) was used to find the highest shear stress in the stream (typically 100-year flood). This value is used for stone sizing after critical shear stress values are calculated, using the Modified Andrew's relationship (Hey 2001):

$$\tau^*_{ci} = 0.0375(d_i/d_{s50})^{-0.872}$$

where τ^*_{ci} is the dimensionless critical shear (Pa), d_i is equivalent to d_{30} which is the intermediate diameter of the rock (m), and d_{s50} is the mean size of the surface gradation. The τ^*_{ci} is found utilizing the relationship $d_{30} = 0.3\ d_{50}$. The d_{30} is found using the dimensionless critical shear stress formula:

$$\tau_{ci} = \tau^*_{ci}\ (\rho_s\text{-}\rho)\ gd_i$$

where ρ_s is the bulk density of sediment (approximately 2,600 kg/m^3) and ρ is the density of water (approximately 1,000 kg/m^3). The value found through the HEC-RAS model is multiplied by 1.25 for a factor of safety and used as the τ_{ci} value. The d_{50} value is determined by the above relationship to d_{30}. The calculated d_{50} is the medium axis value for stone sizing. Calculations for the Sawmill Dam weirs established the need for 4- to 5-ft median axis diameter stones.

Tables D6a-c: Variation in velocity and depth for results of Sawmill Dam step pool design at 105 cfs design criteria used (Maximum velocity set at 105 cfs, weir lifts set at 0.8 inches, minimum depth set at 0.7 feet, Maximum EDF set at 4 with pool lengths set at variable distances).

Table D6a: Velocity values for each notch and station for each flow

Station	Weir Length	13 cfs					65 cfs					85 cfs					105 cfs					140 cfs				
1	29.0	2.5	2.2	1.3	0.7	0.1	3.4	3.3	3.1	2.6	2.1	3.6	3.5	3.3	2.9	2.6	3.8	3.7	3.5	3.1	2.9	4.2	4.0	3.9	3.5	3.2
2	29.0	2.8	2.2	1.3	1.5	0.1	3.2	3.0	3.0	2.6	2.1	3.3	3.2	3.0	2.9	2.6	3.4	3.3	3.2	3.0	2.9	3.6	3.5	3.3	3.2	3.1
3	30.0	2.8	2.2	0.9	1.6	0.1	3.1	3.0	2.9	2.5	1.6	3.2	3.1	3.0	2.8	2.2	3.3	3.2	3.0	2.9	2.7	3.4	3.3	3.2	3.0	2.9
4	30.0	2.7	2.2	1.2	1.6	0.1	2.9	2.8	2.7	2.6	2.0	2.9	2.9	2.8	2.7	2.5	3.0	2.9	2.8	2.8	2.7	3.2	3.1	3.0	2.9	2.8
5	30.0	2.7	2.2	1.2	1.6	0.1	3.1	2.9	2.9	2.6	1.7	3.1	3.0	2.9	2.8	4.5	3.2	3.1	3.0	2.9	5.3	3.3	3.2	3.1	2.9	6.7
6	30.0	2.8	2.3	1.0	1.6	0.1	3.2	3.1	3.0	2.5	1.7	3.3	3.2	3.0	2.9	2.3	3.3	3.2	3.1	2.9	2.7	3.4	3.3	3.2	3.0	2.9
7	30.0	2.7	2.2	1.3	1.6	0.1	3.0	2.9	2.8	2.6	1.6	3.1	3.0	2.9	2.8	2.3	3.1	3.0	3.0	2.8	2.7	3.3	3.2	3.1	2.9	2.8
8	30.0	2.8	2.2	1.3	0.9	0.1	3.0	2.9	2.8	2.7	1.6	3.1	3.0	2.9	2.8	2.3	3.2	3.0	3.0	2.8	2.7	3.3	3.2	3.1	2.9	2.8
9	31.0	2.8	2.2	0.9	0.9	0.1	3.0	2.9	2.8	2.6	1.8	3.0	2.9	2.8	2.7	4.6	3.1	3.0	2.9	2.8	5.4	3.2	3.1	3.0	2.9	6.8
10	31.0	2.9	4.2	1.7	0.9	0.1	3.2	3.1	3.0	2.4	1.5	3.3	3.2	3.0	2.8	2.1	3.4	3.2	3.0	2.9	2.6	3.5	3.3	3.1	3.0	2.9
11	31.0	2.7	4.3	0.9	0.9	0.1	2.9	2.8	2.8	2.5	1.7	3.0	2.9	2.8	2.7	4.4	3.1	3.0	2.9	2.8	5.2	3.3	3.1	3.0	2.9	6.6

Table D6b: Water depth for each weir notch and station for each flow

Station	Weir Length	13 cfs					65 cfs					85 cfs					105 cfs					140 cfs				
1	29.0	0.7	0.4	0.2	0.0	0.0	1.4	1.1	0.8	0.6	0.4	1.5	1.3	1.0	0.7	0.5	1.7	1.4	1.1	0.9	0.7	1.9	1.6	1.3	1.1	0.9
2	29.0	0.7	0.4	0.2	0.0	0.0	1.5	1.2	0.9	0.5	0.4	1.7	1.4	1.1	0.7	0.6	1.9	1.6	1.3	0.9	0.7	2.2	1.9	1.6	1.2	1.0
3	30.0	0.7	0.4	0.1	0.0	0.0	1.6	1.3	0.9	0.5	0.3	1.8	1.5	1.1	0.7	0.4	1.9	1.7	1.3	0.9	0.6	2.3	2.0	1.6	1.2	0.9
4	30.0	0.7	0.4	0.2	0.0	0.0	1.5	1.2	0.9	0.6	0.4	1.7	1.4	1.1	0.8	0.5	1.9	1.6	1.3	1.0	0.7	2.2	2.0	1.7	1.4	1.1
5	30.0	0.7	0.4	0.2	0.0	0.0	1.5	1.2	0.9	0.5	0.3	1.7	1.4	1.1	0.7	0.3	1.9	1.6	1.3	0.9	0.3	2.2	2.0	1.7	1.3	0.4
6	30.0	0.7	0.5	0.1	0.0	0.0	1.6	1.3	0.9	0.5	0.3	1.8	1.5	1.1	0.7	0.5	2.0	1.7	1.3	0.9	0.6	2.3	2.0	1.6	1.2	1.0
7	30.0	0.7	0.4	0.2	0.0	0.0	1.6	1.3	1.0	0.6	0.3	1.8	1.5	1.2	0.8	0.4	2.0	1.7	1.4	1.0	0.6	2.3	2.0	1.7	1.3	1.0
8	30.0	0.7	0.4	0.2	0.0	0.0	1.6	1.3	1.0	0.6	0.3	1.8	1.5	1.2	0.8	0.4	2.0	1.7	1.4	1.0	0.6	2.3	2.0	1.6	1.3	0.4
9	31.0	0.7	0.4	0.1	0.0	0.0	1.5	1.2	0.9	0.6	0.3	1.7	1.5	1.1	0.8	0.3	1.9	1.7	1.3	1.0	0.3	2.3	1.9	1.6	1.2	0.9
10	31.0	0.7	0.2	0.0	0.0	0.0	1.6	1.2	0.8	0.5	0.2	1.8	1.4	1.0	0.7	0.4	2.0	1.6	1.2	0.8	0.6	2.3	1.9	1.6	1.2	0.9
11	31.0	0.7	0.2	0.1	0.0	0.0	1.6	1.3	0.9	0.5	0.3	1.8	1.5	1.1	0.7	0.2	2.0	1.7	1.3	0.9	0.3	2.3	2.0	1.6	1.3	0.4

Table D6c: Pool Depth required for EDF at 4 lb/ft^2

Station	85 cfs					105 cfs					140 cfs				
1	6.3	5.0	3.7	2.4	1.6	8.0	6.4	4.9	3.3	2.4	11.6	9.5	7.5	5.5	4.3
2	4.6	3.7	2.9	1.8	1.2	5.5	4.5	3.5	2.4	1.8	7.2	6.0	4.9	3.6	2.9
3	6.4	5.2	3.6	2.2	1.1	7.3	6.0	4.4	2.9	1.9	9.1	7.6	5.9	4.2	3.1
4	4.7	3.8	2.9	2.1	1.3	5.5	4.5	3.6	2.7	1.9	7.0	5.9	4.9	3.9	3.0
5	4.4	3.6	2.7	1.7	0.9	5.0	4.1	3.3	2.2	1.5	6.1	5.2	4.2	3.1	2.4
6	5.9	4.8	3.4	2.1	1.1	6.6	5.5	4.0	2.7	1.7	7.9	6.7	5.2	3.8	2.8
7	5.5	4.5	3.5	2.3	1.0	6.3	5.2	4.2	2.9	1.7	7.8	6.6	5.5	4.1	2.8
8	4.9	4.0	3.1	2.0	0.9	5.6	4.6	3.7	2.6	1.5	6.9	5.8	4.8	3.6	2.4
9	3.6	3.0	2.1	1.5	0.8	4.2	3.4	2.5	1.9	1.3	5.1	4.3	3.3	2.6	2.0
10	5.0	3.8	2.6	1.5	0.7	5.5	4.2	3.1	2.0	1.2	6.4	5.1	3.9	2.8	2.1
11	3.7	3.0	2.2	1.4	0.7	4.3	3.5	2.6	1.8	1.2	5.3	4.5	3.5	2.5	1.9

Table 6 key.

Green	within acceptable range - good fish passage
Yellow	borderline of acceptable range - moderate to questionable fish passage
Red	outside acceptable range - unlikely for any fish passage

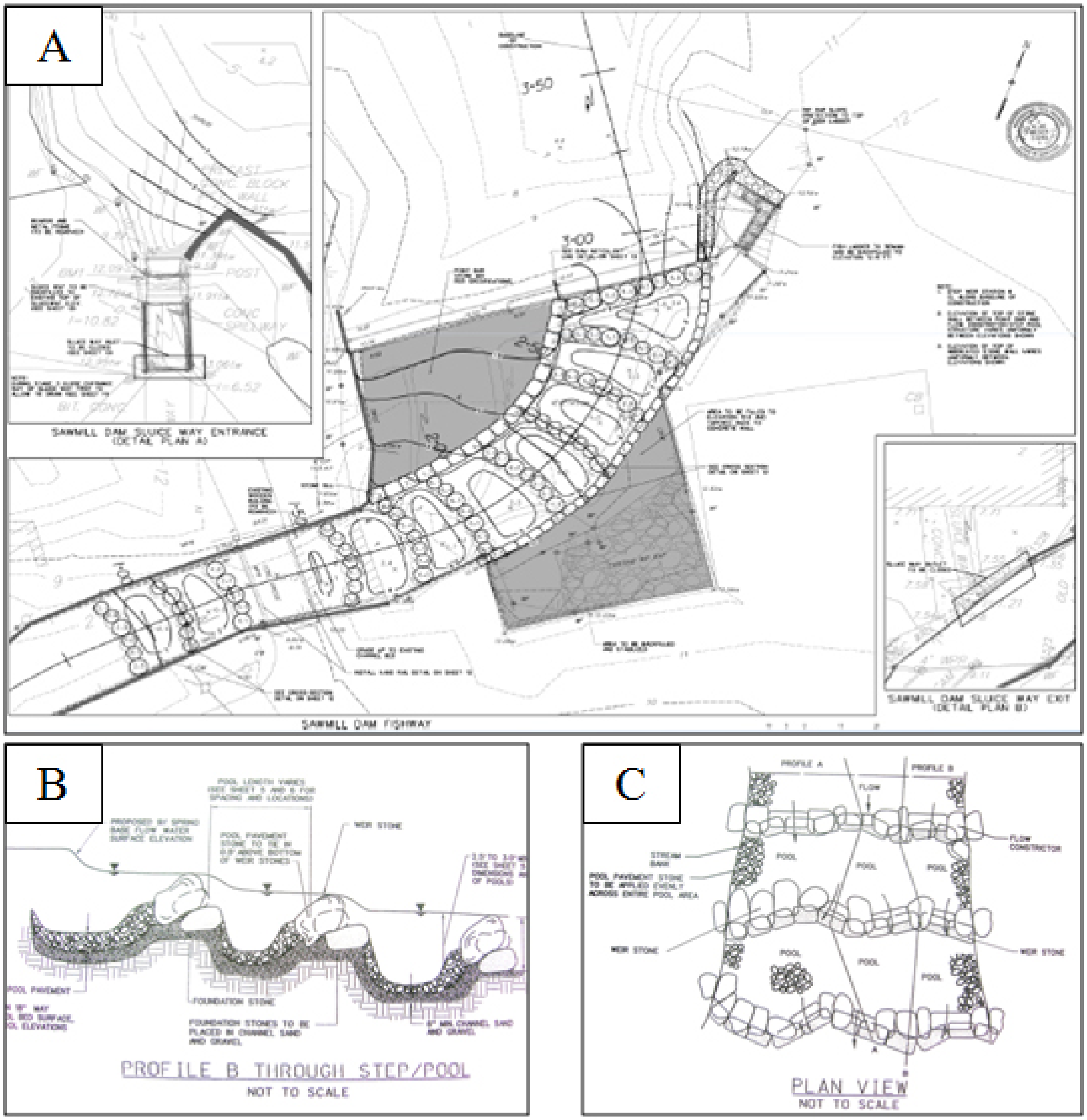


Figure D2a-c: Conceptual design plans for the Sawmill fishway detailing (A) aerial view of fishway; (B) profile of weir and pool design; and (C) aerial view of weir and pool design detailing weir stone elevations and water flow through notches (Source: EA Engineering Science and Technology).

Appendix E

Preliminary site survey, conceptual design and planning for the Hamlin Street Fishway. Information was obtained from the Acushnet River Restoration Project 95% Basis of Design by EA Engineering, Science, and Technology (EAEST 2007).

Prior to fish passage design and construction, a hydrologic evaluation was conducted at the Hamlin Street Dam to assess trends in baseflow and floodflow water levels. Initial measurements at the site were conducted by Milone and MacBroom (2003b) to predict water surface levels and velocity profiles using the Hydrologic Engineering Centers River Analysis System (HEC-RAS). Data collected from the HEC-RAS model was incorporated into development plans for fishway design including (1) baseflow velocities; (2) floodflow velocities; (3) step pool design; and (4) stone size selection.

Table E1. Permitting process (permit type and timeline) required prior to construction of the fishway at the Hamlin Street Dam.

Agency	Type of Approval	Date Applied	Date Approved
Executive Office of Environmental Affairs, MEPA Unit	Secretary's Certificate of Phase I Waiver of Single Environmental Impact Report (SEIR)		
MA Dept. Environmental Protection	N/A	6/6/06	10/30/06
Acushnet Conservation Commission	Notice of Intent (NOI) and Order of Conditions	6/14/06	7/26/06
US Army Corps of Engineers, NE District	Section 404 Permit	8/4/06	11/16/06
MA Dept. Environmental Protection	N/A	8/4/06	10/24/06
MA Dept. Conservation and Recreation, Office of Dam Safety	Chapter 253 Dam Safety Permit (#07-002)	8/16/06	1/26/07
MA Division Marine Fisheries	322 CMR 7.01(4)(f) Special Permit		2/14/07
National Environmental Policy Act	NEPA Environmental Assessment	10/17/06	10/27/06

E.1. Calculating baseflow velocities

In the initial feasibility study conducted by Milone and MacBroom (2003a), flood insurance data for riverine sections of the watershed (at or above both the Sawmill Dam and Hamlin Street Dam) were obtained from FEMA (1982) and summarized in Table E2. Flood insurance data from upstream and downstream reaches in the watershed were used in the HEC-RAS to model storm conditions and predicted flood flow levels for fishway design considerations.

The hydraulic design for the Hamlin Street Dam was based on three baseflow conditions (9%, 50% and 90% flow of annual non-exceedance values). With 9% and 90% values representing minimum and maximum flow conditions, respectively, the 50% value was used as an average flow condition for fish passage. Each of the flow conditions was generated using the baseflow separation method of fixed interval developed by Pettyjohn and Henning (1979) to calculate duration of surface run-off using the following relationship:

$$N = A^{0.2}$$

where N is the number of days after which surface run-off ceases, and A is the watershed area, in square miles, draining the site. Two time periods (April 1 – May 15; and September – December) were used to calculate baseflow conditions at the Hamlin Street site as they encompass the adult spawning migration and juvenile out-migration periods in the system, respectively. The months of June through August were excluded from the analysis due to low flow conditions during this period (which is outside the migration periods). Results from baseflow calculations for the Hamlin Street Dam and regional watersheds is shown in Table E3. The baseflows provided from staff gauge records to pass fish upstream of the Hamlin Street Dam ranged from 7.91 to 43.3 mi^2, which encompasses the project area size at 16.4 mi^2.

Table E2. Federal Emergency Management Agency (FEMA) flood insurance study data in riverine reaches of the Acushnet River (at or above the Acushnet Sawmill Dam and Hamlin Street Dam).

Return Frequency (years)	Sawmill Dam		Hamlin Street Dam	
	Flow Rate (cfs)	Flood elevation above the dam (ft NVGD)*	Flow Rate (cfs)	Flood elevation above the dam (ft NVGD)
10	280	11.4	220	19.2
50	475	11.75	380	20.2
100	620	12.0	505	20.6
500	935	16.0**	760	21.4

*ft NVGD - feet above the National Geodetic Vertical Datum
** For the 500-year flood, the Flood Insurance Study for the Town of Acushnet, Massachusetts (FEMA 1982) assumes that the New Bedford-Fairhaven Hurricane Barrier is overtopped.

Each of the fixed interval baseflow values were used in an exceedance probability analysis by ranking the baseflow values (by watershed and by migration period) then calculating the probabilities using the Weibull equation:

$$P_i = i/(n + 1)$$

where n is the number of baseflows ranked, and i is the rank of each baseflow. Values of 9, 50, and 90 percent exceedance were found by averaging all baseflow values with the associated exceedance value. The results for non-exceedance baseflows for the critical migration period are shown in Table E4.

Table E3. Gauge and regional watershed information for baseflow estimation at the Acushnet River.

	Adamsville Brook	Paskamanset River	Wading River	Sawmill Dam	Hamlin Street Dam
USGS Gauge No.	01106000	01105933	01109000	N/A	N/A
Area (mi^2)	7.91	26.2	43.3	18.7	16.4
Fixed Interval	3	3	5	3	3

.

Table E4. Calculated flows at the Hamlin Street Dam.

% Non-Exceedance	March – June
90	73
50	30
9	9.5

E.2. Calculating floodflow velocities

The 9, 50, and 90 percent baseflow values were then plotted against the watershed area. Regression lines were drawn through the values to generate linear equations and associated r^2 values. These equations were then used with the known watershed area of the Hamlin Street Dam to find the expected 9, 50, and 90 percent exceedance flows at each of the two watersheds. Estimated maximum design flows for the Hamlin Street fishway is shown in Figure E1. Results indicated maximum flows for 9, 50, and 90 percent exceedance flows are 9.5, 30, and 73 cfs, respectively.

Additional calculations for determining maximum design flows for the Hamlin Street fishway were provided by the USFWS. These estimates were based on flow records from four gauging stations from watersheds within the region and included stormflow conditions (> 90% exceedance flows). The flow level required to pass fish through the Hamlin Street fishway was determined from these records. In order to measure flow levels at these sites, a pressure transducer was installed at the Hamlin Street Dam to record rainfall and water depth. The USFWS recommended a higher maximum design flow than the levels calculated above, in order to ensure there are no periods of non-passage for fish greater than three days. Meetings and subsequent agreement between NOAA, the USFWS and the project team targeted 9, 50, and 90 percent exceedance flows of 11 cfs, 56 cfs, and 95 cfs, respectively. Subse-

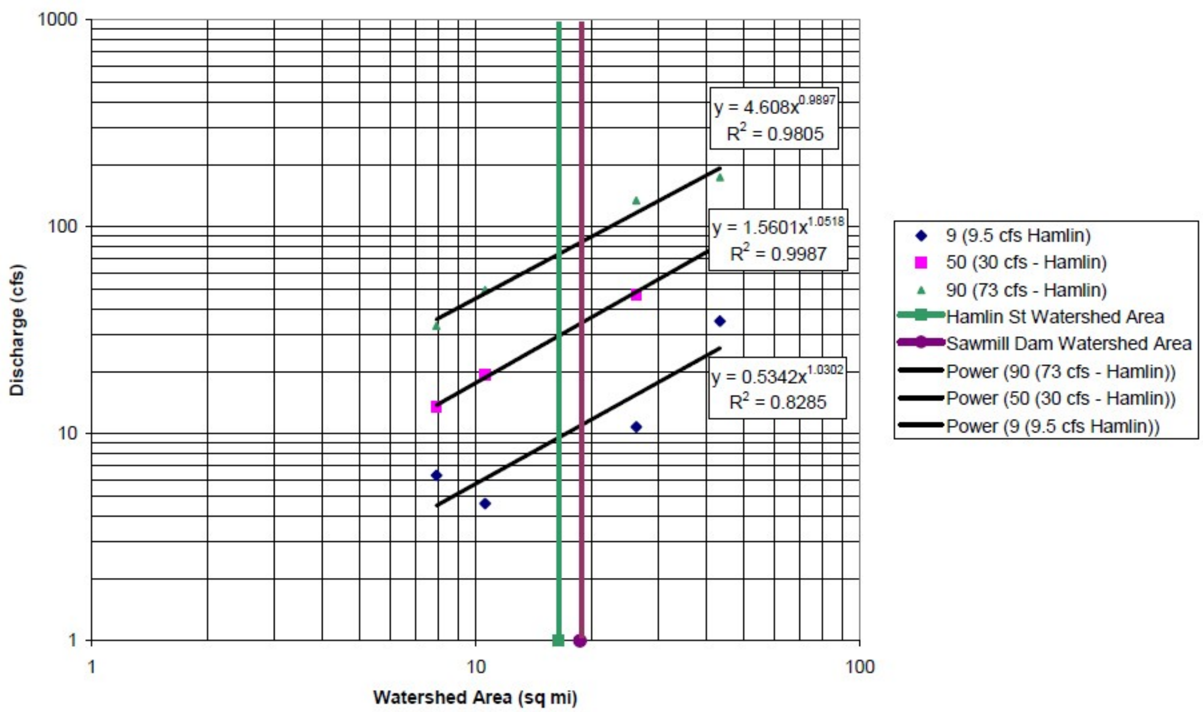


Figure E1. Non-exceedance curves for discharge based on watershed area for March-June at three gauging stations (source: EAEST 2007).

quent discussions with the Project Team in February 2006 provided guidance that headpond elevation upstream of Hamlin Street (Hamlin Pond) should be maintained at ≥ 16.3 ft with flow of 75 cfs and that the eastern channel should be utilized for primary fish passage.

E.3. Step weir design criteria

The baseflow and floodflow velocities estimated by the HEC-RAS model (Milone and MacBroom 2003b) were utilized as initial downstream conditions for step weir design. For the design of each weir in the fishway, several conditions were expected. The first condition was that each step would increase by ≤ 1.0 ft, as measured from the lowest weir stone surface elevation with flows established during baseflow separation directed through the notches to promote fish passage. This is accomplished by establishing a minimum depth of 0.6 ft and a maximum design velocity of 3.0 fps through the notches. Achieving the desired flow velocity required variations in rock shape, weir shape, roughness, elevation changes, and changes in pool size and depths due to natural sediment transport and deposition to ensure conditions acceptable for fish passage.

Another criteria of the step weir design is to determine the appropriate pool size downstream of each weir. Pool size was determined using the following equation to establish a maximum energy dissipation factor (EDF) of 3.0 lb/sec-ft^2 for the Hamlin Street fishway (based on typical EDF values used for structural fishways (EA/KCI 2005):

$$EDF = \gamma \frac{Q \times Drop}{Volume}$$

$$\gamma = 62.4\ _{lb/cf}$$

where Q is the discharge (cfs), and *Drop* (ft) is the difference between the upstream water surface to the downstream water surface on the rock step. The design of the pool depths were based on the EDF and the length to the next pool (10 ft maximum), and volume was determined based on maximum values selected for each fishway. Weir lengths and elevations were adjusted at each location until the desired design considerations were achieved.

E.4. Stone size selection

Existing stone and boulder features located within the eastern culvert structure were incorporated into the HEC-RAS model and fishway design (Figure E2). The selection of the stone for use in constructing the Step Weir structures is based on a standard channel design method. Rectangular stone with uniform surface were selected to maintain weir shape and minimize variations in roughness and head change under design flow considerations. Stone for Step Weirs should also be large enough to remain stationary during flood flow conditions.

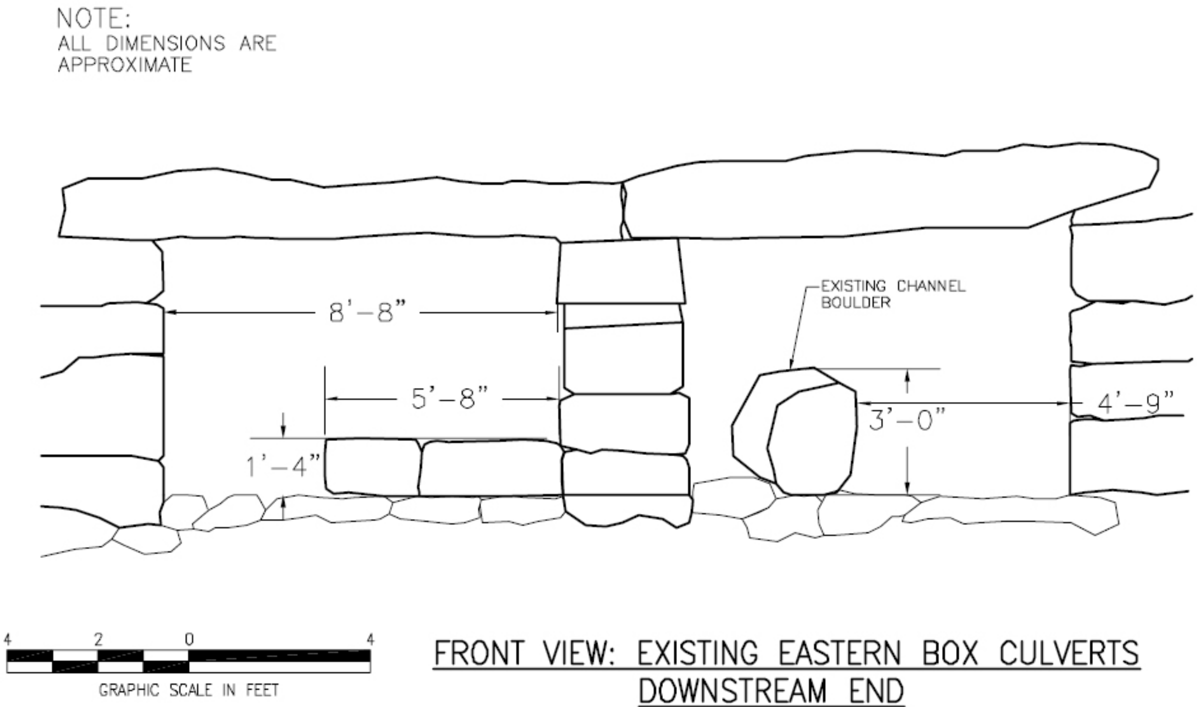
Hamlin Street Fishway Design

For the Hamlin Street fishway, a HEC-RAS model (Milone & MacBroom 2003b) was developed for the eastern channel and box culverts for weir design to achieve the desired EDF. The spillway length at the Hamlin Street Dam is a limiting factor in passing fish under high flow conditions with the current configuration sending up to the annual flow of 140 cfs through the eastern culvert. Under the proposed fishway design, flows greater than the annual flow will be directed through both the eastern and central culverts.

A series of five rock weirs to overcome a smaller elevation differential (two upstream of the existing eastern box culvert and three downstream) were constructed in the river channel downstream and under Hamlin Street to facilitate fish passage (Figure E.3a). Each weir was designed with five elevations and the flows established during the baseflow separation directed through the notches to promote fish passage (Figure E3b,c). This is accomplished by establishing a minimum depth of 0.6 ft and a maximum design velocity of approximately 3.0 fps through each notch. Utilizing weir elevations of ≤ 1 ft, the uppermost step weir structure (40 ft in length) elevation was set at approximately 14.97 ft at the eastern culvert and 16.75 ft at the central (second) culvert to establish the headpond elevation at 16.6 ft at a flow of 75 cfs and to direct annual flows (≤ 140 cfs) to the eastern channel (Table E5). Flows greater than 140 cfs will be directed to both the eastern and central culverts. The second weir step structure (32 ft in length) was set immediately upstream of Hamlin Street and the three weirs downstream of Hamlin Street are each 20 ft in length. The western (third) culvert of the dam was left unmodified and will remain as a flood overflow channel.

Table E5. Weir length and elevations based on HEC-RAS model results for the Hamlin Street Fishway.

Weir No. (Downstream to Upstream)	Total Length (ft)	No. Sections	Section 1		Section 2	
			Length (ft)	Elevation (ft)	Length (ft)	Elevation (ft)
1	20	2	16	11.56	4	10.70
2	20	2	16	12.65	4	11.65
3	20	2	16	13.68	4	12.56
4	32	2	28	14.90	4	14.17
5	40	2	36	15.86	4	14.97



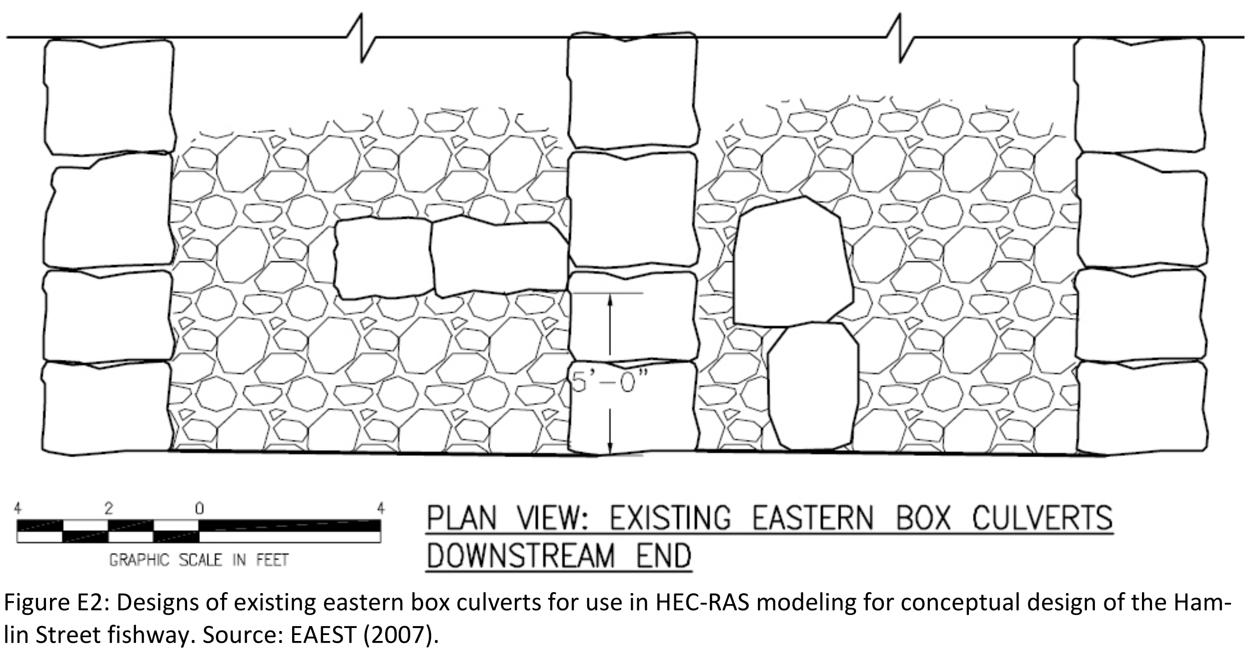


Figure E2: Designs of existing eastern box culverts for use in HEC-RAS modeling for conceptual design of the Hamlin Street fishway. Source: EAEST (2007).

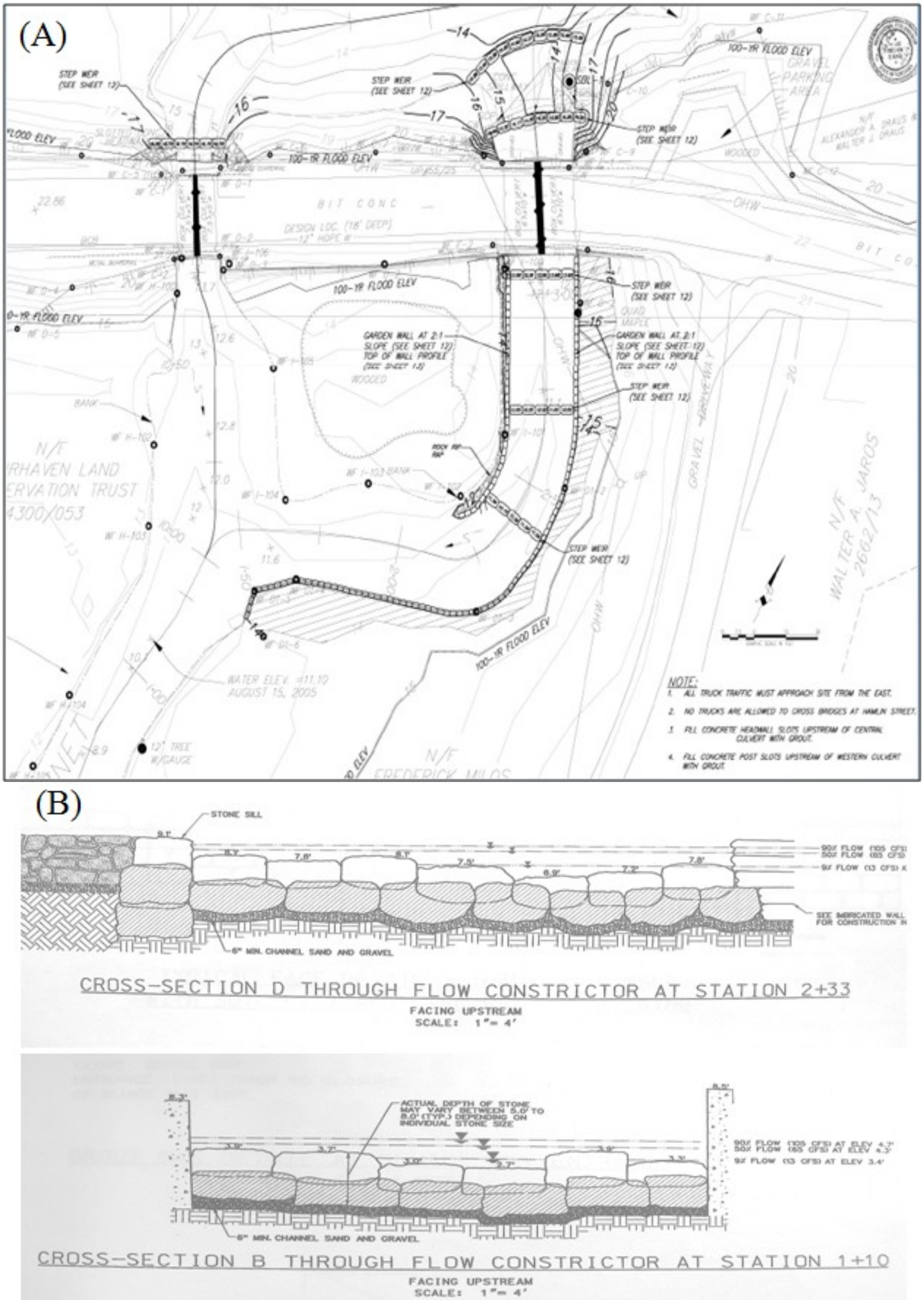


Figure E3a-b: Conceptual design plans for the Hamlin Street fishway detailing (A) aerial view of fishway; and (B) front view of weir and pool design detailing weir stone elevations and water flow through notches (Source: EA Engineering Science and Technology).

Appendix F

Summary results of PCB testing of river herring samples collected from the Acushnet River watershed

Table F1. Summary results of PCB testing of river herring samples collected from the Acushnet River watershed (Source: *MassDEP* and *Marine-Fisheries* 2008; 2009; 2010a, b, c; 2011; 2012).

Parameter Species	Year	Area	Station Units	Lipids Percent	Total PCB Cogeners[1] MG/KG	Total PCB Cogeners Hits[2] MG/KG	Total NOAA Cogeners[3] MG/KG	Total WHO Cogeners[4] MG/KG	Total NOAA/WHO Cogeners[5] MG/KG	Total Aroclors[6] MG/KG
Alewife	2005	I	A	1.6	4.9 (J4)	4.9	2.2 (J4)	0.17 (J4)	2.2 (J4)	0.00047 (U)
Alewife	2005	I	B	2.6	9.9 (J4)	9.9	4.3 (J4)	0.22 (J4)	4.4 (J4)	0.00047 (U)
Mean				2.1	7.4	7.4	3.3	0.20	3.3	0.00047 (U)
Alewife	2006	I	A	3.1	11 (J4)	11	4.9 (J4)	0.18 (J4)	5.0 (J4)	10 (J4)
Alewife	2006	I	B	4.4	7.8 (J4)	7.8	3.4 (J4)	0.14 (J4)	3.4 (J4)	6.5 (J4)
Mean				3.8	9.5 (J4)	9.5	4.1 (J4)	0.16 (J4)	4.2 (J4)	8.4 (J4)
Alewife	2007	I	C-1	2.0	5.0 (J4)	5.0	2.2 (J4)	0.15 (J4)	2.2 (J4)	5.8 (J4)
Alewife	2008	1	C-1	2.0	4.6 (J4)	4.6	2.0 (J4)	0.090 (J4)	2.0 (J4)	4.2 (J4)
Alewife	2009	1	C-1	2.2	2.0 (J4)	2.0	0.84 (J4)	0.044 (J3)	0.84 (J4)	1.9 (J4)
Alewife	2010	1	C-1	2.6	0.18 (J3)	0.17	0.079 (J4)	0.010 (J2)	0.082 (J3)	0.22 (J3)
Alewife	2011	1	A (C-1)	1.6	0.62 (J3)	0.61	0.26 (J4)	0.020 (J3)	0.27 (J4)	0.73 (J3)

Table F1. continued.

Station	Location (Lat./Lon.)	Description
A	041° 40.900'/ 070° 55.125	Dam NBH Area 1 (Sawmill)
B	041° 40.900'/ 070° 55.125	Dam NBH Area 1 (Sawmill)
C-1	041° 43.724'/ 070° 53.915	Dam NBH Area 1 (Reservoir)

Notes and Footnotes for Tables:
1 = summation of 136 PCB congener results (1/2 Sample Quantitation Limit [SQL] used for non-detected results)
2 = summation of detected 136 PCB congeners
3 = summation of 18 NOAA PCB congener results (1/2 SQL used for non-detected results)
4 = summation of 12 WHO PCB congener results (1/2 SQL used for non-detected results)
5 = summation of 18 NOAA & 12 WHO PCB congener results (1/2 SQL used for nondetected results); duplicative congeners (BZ# 105, #118, #167/128) subtracted from total for one data set
6 = summation of 5 Aroclor results (1/2 SQL used for non-detected results); if all Aroclor results are not detected, then total value represets SQL for each individual Aroclor
U = not detected; value represents SQL
J1 = concentration of detected congeners contributes < 50% of total congener result
J2 = concentration of detected congeners contributes 50% to 90% of total congener result
J3 = concentration of detected congeners contributes 90% to 99% of total congener result
J4 = concentration of detected congeners contributes > 99% of total congener result

Results reported in milligrams per kilogram (mg/kg) wet weight, unless otherwise noted. PCB Congeners and Aroclors analyzed by GC/MS-SIM.

Appendix G

Results from smelt sampling in the lower Acushnet River watershed (from the base of the Acushnet Sawmill dam downstream to the entrance to Upper New Bedford Harbor).

Table G1. Results from smelt sampling in the lower Acushnet River watershed (from the base of the Acushnet Sawmill dam downstream to the entrance to Upper New Bedford Harbor).

Date	Transect No.	Time Low Tide	Start Time	End Time	Stream Width (ft)	Start Distance (Coordinates)	End Distance (Coordinates)	Presence (Y/N) LB	1/4	1/2	3/4	RB	Substrate Type LB	1/4	1/2	3/4	RB	Percent Vegetation
3/1/06	1	1431	1342	1358	100	41°41.03/70°55.08	41°41.03/70°55.07	N	N	N	N	N	4	4,5	4,5	4,5	3,4	75
3/1/06	2	1431	1409	1417	66	41°41.03/70°55.07	41°41.03/70°55.06	N	N	N	N	N	3,4	3,5	3,5	3,4	3,4	80
3/1/06	3	1431	1425	1435	25	41°41.02/70°55.07	41°41.02/70°55.07	N	N	N	N	N	3	3,4	3,4	3,4	4,5	50
3/1/06	4	1431	1440	1455	21	41°41.02/70°55.09	41°41.02/70°55.09	N	N	N	N	N	4,3	4,3	3,4	3	4,5	50
3/1/06	5	1431	1503	1515	23	41°41.02/70°55.10	41°41.02/70°55.10	N	N	N	N	N	4	4	3	3,2	3,4	60
3/1/06	6	1431	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3/1/06	7	1431	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3/1/06	8	1431	1538	1550	22	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4	3,4	3,4	3,4	3,4	10
3/1/06	9	1431	1600	1615	23	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1,3,5	4	4	4	4	10
3/1/06	10	1431	1625	1635	58	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	1,3,5	1,3,5	4	1,4,3	1,2,4	< 5
3/8/06	7	0942	0958	1006	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	< 5
3/8/06	8	0942	1011	1018	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	1
3/8/06	9	0942	1027	1031	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	< 1
3/8/06	10	0942	1036	1043	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	< 1
3/13/06	7	1251	1231	1239	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	20
3/13/06	8	1251	1241	1252	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	5
3/13/06	9	1251	1254	1258	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	3
3/13/06	10	1251	1301	1311	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	1
3/23/06	7	0723	0715	0724	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	20
3/23/06	8	0723	0726	0730	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	5
3/23/06	9	0723	0733	0737	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	< 5
3/23/06	10	0723	0740	0745	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	< 5
3/29/06	7	1320	1348	1354	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	30
3/29/06	8	1320	1357	1400	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	25
3/29/06	9	1320	1403	1406	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	10
3/29/06	10	1320	1410	1415	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	<1
4/5/06	7	0819	0855	0900	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	15
4/5/06	8	0819	0901	0905	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	< 5
4/5/06	9	0819	0906	0909	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	1
4/5/06	10	0819	0910	0915	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	1
4/11/06	7	1308	1315	1320	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	40
4/11/06	8	1308	1322	1326	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	30
4/11/06	9	1308	1328	1333	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	10
4/11/06	10	1308	1335	1338	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	< 5
4/21/06	7	0806	0850	0856	28	41°41.004/70°55.095	41°41.006/70°55.091	N	N	N	N	N	1,5,3	1,3,4	3,4	3,4,1	3,4,1	75
4/21/06	8	0806	0858	0903	60	41°40.588/70°55.090	41°40.591/70°55.082	N	N	N	N	N	3,4,1	1,3	1,3,4	1,3,4	1,3	20
4/21/06	9	0806	0904	0908	38	41°40.574/70°55.093	41°40.574/70°55.083	N	N	N	N	N	1	1,3,4	1,3,4	1,3	1,3	40
4/21/06	10	0806	0910	0912	45	41°40.558/70°55.083	41°40.555/70°55.088	N	N	N	N	N	6	1,3	1,3,4	1,3,4	1,3,4	5

Table G2. Results from smelt sampling in the lower Acushnet River watershed (from the base of the Acushnet Sawmill dam downstream to the entrance to Upper New Bedford Harbor). Key is on the next page.

Date	Transect No.	Water Temp (ºC)	Salinity (ppt)	DO (mg/L)	pH	Conductivity mS/Cm	Air Temp (ºC)	Weather Code	Water Depth (cm) LB	1/4	1/2	3/4	RB
3/1/06	1	2.4	0.0	11.42	6.48	0.116	6	1	8	35	20	32	20
3/1/06	2	2.4	0.0	11.57	6.55	0.115	6	1	14.5	N/A	15	12.5	12
3/1/06	3	2.4	0.0	11.54	6.74	0.115	6	1	23	27	15	17.5	27
3/1/06	4	2.4	0.0	11.69	6.64	0.117	5	1	34	43.5	45	27.5	31
3/1/06	5	2.4	0.0	12.5	6.5	0.111	5	1	43	55	56	63	47.5
3/1/06	6	-	-	-	-	-	-	-	-	-	-	-	-
3/1/06	7	-	-	-	-	-	-	-	-	-	-	-	-
3/1/06	8	2.3	0.0	12.54	6.77	0.123	5	1	21	29	23	22	24
3/1/06	9	2.3	0.0				5	1	19.5	23	14	30	25.5
3/1/06	10	2.3	0.0	11.13	6.99	0.127	5	1	14	21	28.5	19	35
3/8/06	D1	2.8	0.0	13.23	8.48	0.104	4	3	25.5	52.5	40.5	31	27.5
3/8/06	D2	2.7	0.0	12.18	8.1	0.118	5	3	36	22	16.5	26	18
									30	43	41	40.5	28
									16.5	46	50	25.5	14
3/13/06	D1	7.4	0.0	12.98	8.08	0.103	14	5	33	51.5	48.5	31	28.5
3/13/06	D2	6.8	0.0	11.76	7.84	0.103	14	5	23	13	30	22	33.5
3/13/06	D3	6.8	0.0	11.84	7.72	0.129	14	5	27	40	43	48	33
									14	26	41	51	27
3/23/06	D6	5.5	0.0	13.15	5.09	0.104	4.0	1	20.5	26	26	43.5	26
3/23/06	D7	5.3	0.0	11.79	5.51	0.117	4.0	1	15	23	10	14	28
									24.5	27	37	39.5	30
									0	17.5	42.5	48.5	21.5
3/29/06	D1	10.6	0.0	11.23	5.51	0.128	14	1	25	46	27	17	20.5
3/29/06	D2	10.1	0.0	11.47	5.88	0.122	14	1	25	13	10	19	11.5
3/29/06									27	35	34	29	19.5
3/29/06									16	49	42.5	14	0
4/5/06	YSI 1	7.4	0.1	12.50		121.8	6.7	5	32	45	29	29.5	28.5
4/5/06	YSI 2	7.0	0.1	12.54		130.9	3.0	5	28	21	19	19	20
4/5/06									32	46	41	35.5	28.5
4/5/06									23	56	42.5	25	4
4/11/06	D2	11.5	0.0	12.68	5.33	0.099	8.3	3	31.5	29	34	48	25
4/11/06	D3	11.0	0.0	12.31	6.13	0.108	8.5	3	38	20.5	22	26	22.5
4/11/06									36	43.5	39	37	29
4/11/06									19	59	51	27	3
4/21/06								1	NO MEASUREMENTS MADE				
4/21/06								1	NO MEASUREMENTS MADE				
4/21/06									NO MEASUREMENTS MADE				
4/21/06									NO MEASUREMENTS MADE				

Table G2 Key:

Substrate Type:		Substrate Type:	
1 = Sand	(< 0.2 in.)	4 = Cobbles	(2.5 - 9.5 in.)
2 = Clay	(< 0.2 in. congealed)	5 = Boulders	(10 - 160 in.)
3 = Gravel	(0.2 - 2.5 in.)	6 = Bedrock	(Bottom is rock slab)

Table G3. Results from smelt sampling in the lower Acushnet River watershed (from the base of the Acushnet Sawmill dam downstream to the access bridge of the Acushnet Sawmill property.

Date	Site	H_20 Temp(C^0)	Cond(mS/cm)	Sp Cond(mS/cm)	TDS (g/L)	Salinity	DO%	DO(mg/L)	pH
3/12/2007	Dam	3.15	0.06	0.102	0.066	0.05	98.9	13.26	7.19
3/12/2007	Bridge	no wq							
3/14/2007	Dam	5.6	0.062	0.099	0.064	0.05	94.3	11.86	6.82
3/14/2007	Bridge	5.9	0.079	0.124	0.08	0.06	92.9	11.59	6.75
3/15/2007	Dam	7.6	0.067	0.096	0.062	0.04	95.1	11.37	8.08
3/15/2007	Bridge	7.63	0.078	0.116	0.076	0.05	94.4	11.29	7.69
3/20/2007	Dam	5.96	0.093	12.9	7.18	0.059	103.6	0.04	0.06
3/20/2007	Bridge	6.17	0.114	12.33	7.02	0.073	99.5	0.05	0.074
3/26/2007	Dam	6.58	0.116	11.42	7.15	0.075	93.1	0.05	0.076
3/26/2007	Bridge	6.59	0.117	11.41	7.14	0.076	93.1	0.06	0.076
4/2/2007	Dam	7.77	0.104	11.32	6.65	0.07	95.1	0.05	0.068
4/2/2007	Bridge	7.91	0.132	10.87	6.66	0.089	91.6	0.06	0.086
4/11/2007	Dam	5.49	0.101	11.95	6.53	0.064	94.7	0.05	0.066
4/11/2007	Bridge	5.87	0.124	11.7	6.64	0.079	93.7	0.06	0.081
4/20/2007	Dam	7.1	0.085	11.61	6.31	0.056	95.9	0.04	0.055
4/20/2007	Bridge	7.5	0.118	11.14	6.31	0.079	92.9	0.06	0.077
4/23/2007	Dam	10.73	0.092	10.19	6.7	0.067	91.9	0.04	0.06
4/23/2007	Bridge	10.62	0.136	9.97	6.53	0.099	89.6	0.06	0.089
4/30/2007	Dam	12	0.089	9.95	6.26	0.067	92.4	0.04	0.058
5/4/2007	Bridge	13.86	0.098	10.3	7.2	0.077	99.6	0.05	0.064
5/7/2007	Dam	10.35	0.101	10.21	6.63	0.073	91.3	0.05	0.066
5/14/2007	Bridge	15.47	0.108	8.65	7.2	0.088	86.7	0.05	0.07
5/22/2007	Dam	13.16	0.089	9.55	6.23	0.069	91	0.04	0.058
5/29/2007	Bridge	19.11	0.108	6.25	7.18	0.096	67.6	0.05	0.07
6/12/2007	Dam	19.98	0.107	5.9	6.89	0.097	64.9	0.05	0.07

Appendices References

Appendices References

Chase, B.C. 2010. Quality assurance program plan (QAPP) for water quality measurements conducted for diadromous fish abitat monitoring verion 1.0, 2008-2012. Massachusetts Division of Marine Fisheries Technical Report 42. 63p.

EAEST (EA Engineering, Science, and Technology, Inc.) 2007. Basis of design: Acushnet River fish passage restoration project, Acushnet, Massachusetts. Prepared for the NOAA Northeast Restoration Center.

EA/KCI (EAEST/KCI Technologies, Inc). 2005. Technical memorandum: Evaluation of changes in design parameters for the 50% design - Sawmill Dam, Acushnett River fish passage project, Acushnett, Massachusetts. 21 November.

FEMA (Federal Emergency Management Agency). 1982. Flood Insurance Study, town of Acushnet, Massachusetts, Bristol County. 19 January 1982. 17p.

Kleinschmidt Associates. 2001. New Bedford reservoir fishway - Acushnet River preliminary site evaluation report. 24p.

MassDEP (Massachusetts Department of Environmental Protection). 1996. Massachusetts surface water quality standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA. Revision of 314 CMF 4.00, effective 23 June 1996.

MassDEP. 2007. Massachusetts surface water quality standards. Massachusetts Department of Environmental Protection, Division of Water Pollution Control, Technical Services Branch. Westborough, MA. Revision of 314 CMF 4.00, effective January 2007.

MassDEP. 2012. Massachusetts Year 2012 Integrated List of Waters. Proposed Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314, and 303(d) of the Clean Water Act. 260p.

MassDEP and *MarineFisheries* (Massachusetts Division of Marine Fisheries). 2008. Contaminated Monitoring Report for Seafood Harvested in 2005 from the New Bedford harbor Superfund Site. 2005 Annual Report. 105p.

MassDEP and *MarineFisheries.* 2009. Contaminated Monitoring Report for Seafood Harvested in 2007 from the New Bedford harbor Superfund Site. 2007 Annual Report. 93p.

MassDEP and *MarineFisheries.* 2010a. Contaminated Monitoring Report for Seafood Harvested in 2009 from the New Bedford harbor Superfund Site. 2009 Annual Report. 72p.

MassDEP and *MarineFisheries.* 2010b. Contaminated Monitoring Report for Seafood Harvested in 2008 from the New Bedford harbor Superfund Site. 2008 Annual Report. 64p.

MassDEP and *MarineFisheries.* 2010c. Contaminated Monitoring Report for Seafood Harvested in 2006 from the New Bedford harbor Superfund Site. 2006 Annual Report. 92p.

MassDEP and *MarineFisheries.* 2011. Contaminated Monitoring Report for Seafood Harvested in 2010 from the New Bedford harbor Superfund Site. 2010 Annual Report. 125p.

MassDEP and *MarineFisheries*. 2012. Contaminated Monitoring Report for Seafood Harvested in 2011 from the New Bedford harbor Superfund Site. 2011 Annual Report. 157p.

Milone & MacBroom. 2003a. Project notification form: Acushnet River fish restoration, Hamlin Street dam, Acushnet, Massachusetts. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts. MMI #2214-01-7.

Milone & MacBroom. 2003b. Dam removal feasibility study: Sawmill and Hamlin Street dams, Acushnet River, Acushnet, Massachusetts. Prepared for the Division of Marine Fisheries, Commonwealth of Massachusetts.

Odeh, M. 2003. Discharge rating equation and hydraulic characteristics of standard Denil fishways. Journal of Hydraulic Engineering. 129(5): 341-348.

Pettyjohn, W.A. and R. Henning. 1979. Preliminary estimate of regional effective groundwater recharge rates, related streamflow and water quality in Ohio. Water Resources Center, Ohio State University. Project Completion Report 552. 323p.

Quinn, R. 1995. Acushnet River preliminary site survey. US Department of the Interior. 8p.