Concord River Diadromous Fish Restoration

FEASIBILITY STUDY

Concord River, Massachusetts

DRAFT REPORT

FEBRUARY 2016

Prepared for:

Commonwealth of Massachusetts Division of Marine Fisheries

In partnership with:

NOAA, U.S. Fish & Wildlife Service, MassDEP

Prepared by:

Gomez and Sullivan Engineers

This page intentionally left blank.

Concord River Diadromous Fish Restoration

FEASIBILITY STUDY – DRAFT REPORT

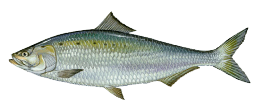
EXECUTIVE SUMMARY

Project Purpose

The purpose of this project is to evaluate the feasibility of restoring populations of diadromous fish to the Concord, Sudbury, and Assabet Rivers, collectively known as the SuAsCo Watershed. The primary impediment to fish passage in the Concord River is the Talbot Mills Dam in Billerica, Massachusetts. Prior to reaching the dam, fish must first navigate potential obstacles at the Essex Dam (an active hydro dam with a fish elevator and an eel ladder) on the Merrimack River in Lawrence, Middlesex Falls (a natural bedrock falls and remnants of a breached dam) on the Concord River in Lowell, and Centennial Falls Dam (a hydropower dam with a fish ladder), also on the Concord River in Lowell.


Blueback herring


Alewife


American shad


American eel

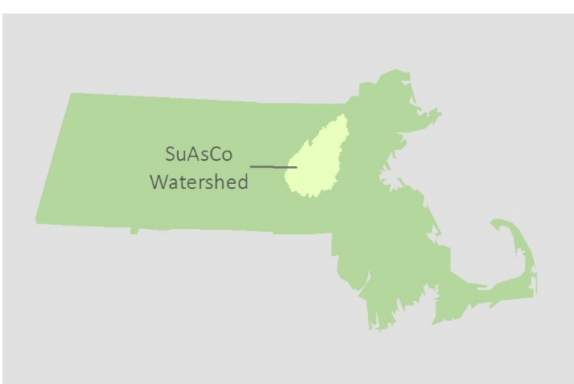

Sea lamprey

Species targeted for restoration include both species of river herring (blueback herring and alewife), American shad, American eel, and sea lamprey, all of which are diadromous fish that depend upon passage between marine and freshwater habitats to complete their life cycle. Reasons for pursuing fish passage restoration in the Concord River watershed include the importance and historical presence of the target species, the connectivity of and significant potential habitat within the watershed, and active public input and support.

The impact of diadromous fish species extends far beyond the scope of a single restoration project, as they have a broad migratory range along the Atlantic coast and benefit commercial and recreational fisheries of other species.

Project Support & Outreach

This project has been led by the Massachusetts Department of Fish and Game (DFG), Division of Marine Fisheries (*MarineFisheries*) with support from the National Oceanic and Atmospheric Administration (NOAA) Restoration Center, the US Fish and Wildlife Service (USFWS), and the Massachusetts Department of Environmental Protection (MassDEP). Gomez and Sullivan Engineers, DPC (Gomez and Sullivan) was contracted to conduct the study, which involved a review of existing information, hydrologic and hydraulic analyses, structural assessment, evaluation of impounded sediments, conceptual design of fish passage options, this feasibility report, and final public meeting. The Public Archaeology Laboratory (PAL) was subcontracted to conduct a cultural resources analysis.



Public involvement is paramount in the process of restoring diadromous fish to the Concord River. Public input has been or will be actively solicited at the following stages in the timeline of the broader restoration effort surrounding this feasibility study: planning phase, feasibility phase (this study), additional feasibility and consultation phase, design phase, and permitting.

Feasibility Study Overview

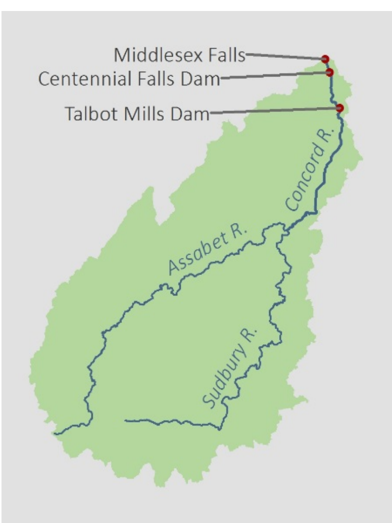
The first step in this project involved an extensive review of available existing information to compile data from previous studies and research, including information about the watershed, fish passage obstacles, infrastructure, and diadromous fishery resources. Various technical assessments—including a topographic survey and sediment, hydrologic, hydraulic, and cultural resources analyses—were then conducted to provide additional information for the alternatives analysis. Alternatives to restore diadromous fish passage in the Concord River were developed for each of the three sites of interest: Middlesex Falls, Centennial Falls Dam, and Talbot Mills Dam. The following alternatives that were determined to be most feasible for each site were analyzed:

- Middlesex Falls
  - No Action
  - Channel Improvements (1A)
- Centennial Falls Dam
  - No Action
  - Fishway Improvements (2A)
  - Volunteer Coordination (2B)
- Talbot Mills Dam
  - No Action
  - Technical Fishway (3A)
  - Partial Dam Removal (3B)

Obstacles to fish passage in the Concord River include Middlesex Falls (a natural bedrock falls and remnants of a breached dam), Centennial Falls Dam (a hydro dam with a fish ladder), and Talbot Mills Dam (a former mill dam that currently has no fish passage facilities).

Each alternative analysis included a discussion of its conceptual design, ability to meet target fish passage thresholds, potential benefits and impacts, recommendations for additional studies, and budgetary opinion of cost where applicable.

Site Background



The lowest potential obstacle to fish passage in the Concord River is Middlesex Falls at river mile 0.44 in Lowell, where the former Middlesex Dam was breached in the early 1980s. The site now consists of a large island flanked by a main channel defined by the remains of the concrete dam abutments and a minor channel defined by the remains of the former mill race/power canal. The natural bedrock ledge of the falls creates turbulence, making it hard for fish to pass upstream. Previous studies have suggested that during low flow conditions in spring, fish passage could be impeded, particularly for river herring and American shad.

The next obstacle is the Centennial Falls Dam at river mile 1.55 in Lowell, which contributes to hydraulic head for the Centennial Island Hydroelectric Project, a run-of-river facility owned and operated by Centennial Island Hydroelectric Company. The circa 1900, irregularly

shaped dam is approximately 8 feet high and 320 feet long. Fish passage structures added to the dam in 1990 include an upstream fish ladder and a downstream bypass sluice. The fishway has a history of deficiencies and passage efficiency is unknown. However, river herring have been observed using the fish ladder—a success due in part to recent active management of the fishway by the dam owner.

The third and primary obstacle to fish passage in the Concord River is the Talbot Mills Dam at river mile 4.76 in Billerica, a former mill dam that currently has no fish passage facilities. The dam is privately owned by CRT Development Realty, LLC. Its broad-crested stone masonry primary spillway is about 127 feet long and 10.2 feet high. It is classified as an Intermediate sized, Significant (Class II) Hazard potential structure. According to the most recent (2015) dam safety inspection, the dam was found to be in "fair" condition. Noted deficiencies include the lack of an operation and maintenance plan, lack of routine oversight of the dam (particularly during storm events), lack of working controls, lack of an operable low level outlet and emergency bypass in the event of flooding, seepage in the spillway abutments (particularly the left abutment), and trees located just downstream of the primary spillway and on the upstream face of the left embankment near the former intake gates to the Talbot Mills complex. Significant remedial measures were recommended to bring the dam into compliance with dam safety regulations, including repair or replacement of the left abutment, low level outlets, and sluiceway and stilling basin gates, totaling (at a minimum) over $100,000.

The Talbot Mills Dam does not meet dam safety regulations and increases upstream flooding.

Additionally, as part of this study, the dam was found to not meet dam safety regulations to be able to pass the 100-year spillway design flow without overtopping. As such, spillway capacity would need to be added, and recommended dam safety repairs would need to be made if the dam is maintained as is or modified in any way (e.g., to add a fishway). Although described in the dam safety report as a flood control dam, it is important to note that an overflow or "run-of-river" type of dam such as the Talbot Mills Dam provides no flood control. In fact, the hydraulic analysis conducted for this study found that the dam increases upstream water surface elevations—by at least 3.5 feet upstream of the dam and 0.8 feet at the upstream extent of the Concord River for the 100- and 500-year floods. The lack of any operable low level outlet or emergency bypass system at the Talbot Mills Dam further decreases its ability to provide any sort of flood control.

The Talbot Mills Dam is a historic property listed in the National Register of Historic Places. The site of the current dam has a long and controversial past. Prior to the damming of the Concord River in North Billerica, the area was used by generations of Native Americans as an encampment and fishing grounds. The first dam was erected at the site over 300 years ago in 1711. Over the course of the next nearly 150 years and incremental raising of the dam height, various legal disputes between multiple generations of farmers and dam owners resulted in the dam being removed and rebuilt several times. Both the current dam, built in 1828, and its predecessor, built in 1798, reportedly included a fishway, which was likely a simple opening in the spillway abutment through which fish could pass under suitable flow conditions with unknown effectiveness. The fishway was filled with concrete sometime after the 1960s. If a fish passage restoration alternative is selected for implementation at the Talbot Mills Dam (e.g., a technical fishway or partial dam removal), the lead federal agency for this project (NOAA) would consult with interested parties on ways to avoid, minimize, or mitigate any adverse effects to historic and archaeological resources that may result.

Feasibility Study Findings

Diadromous fish passage restoration in the Concord River is feasible.

This study has demonstrated that diadromous fish passage restoration in the Concord River is feasible. Alternatives at the two most downstream sites—Middlesex Falls and Centennial Falls Dam—are relatively straightforward and inexpensive and could be implemented fairly quickly if pursued. Channel improvements at Middlesex Falls (Alternative 1A) may help reduce flow turbulence to more acceptable ranges for upstream passage, or this project could be deferred to a later phase after additional monitoring to confirm whether or not fish can navigate the falls at a satisfactory rate. Minor fishway and operational modifications could be made at Centennial Falls Dam (Alternative 2A) to improve fish passage, and the opportunity for continued stewardship and public education at that site and throughout the watershed (Alternative 2B) would help ensure the lasting effectiveness.

Although more complex than options at the other sites, each of the alternatives at Talbot Mills Dam—a technical fishway or partial dam removal—has been demonstrated to be technically feasible. Installation of a fishway (Alternative 3A)—including a Denil ladder, eel ramp, and downstream bypass notch—would provide effective passage for target species. Passage of other aquatic species and overall connectivity of the river would be limited, but would represent an improvement over existing conditions. With the exception of cultural resources and aesthetics, little to no impacts to other resources are anticipated. The obligation to bring the dam into compliance with dam safety regulations as well as the continued responsibility for ongoing operation, maintenance, and liability associated with the dam would impact the cost effectiveness of this alternative. Still, a fishway at Talbot Mills Dam is a viable alternative for restoring diadromous fish in the Concord River that could advance to the next phase of this project for further study.


Conceptual rendering of a fish ladder at Talbot Mills dam

The proposed partial removal of the Talbot Mills Dam (Alternative 3B) would provide effective passage for target species as well as significant benefits for other resources. Water quality, aquatic habitat connectivity, and natural riverine sediment and flow regimes would be restored. Increased upstream flooding resulting from the dam would be reduced. Aging and unsafe infrastructure would be decommissioned, eliminating ongoing operation, maintenance, and liability costs and concerns. Recreation and aesthetic resources may improve as well, although these benefits are subject to individual preferences of the members of the public using the resources. With the exception of cultural resources, few impacts to other resources are anticipated. As such, partial removal of the Talbot Mills Dam is a feasible alternative for restoring diadromous fish in the Concord River that could be further evaluated in future phases of this project.

Conceptual rendering of the partial removal of the Talbot Mills dam

Providing fish passage at the Talbot Mills Dam and addressing any potential obstacles at Middlesex Falls and Centennial Falls Dam would restore over 35 miles of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams). The possibility of combining two or more alternatives together, implemented simultaneously or in several phases, provides the flexibility to develop a watershed-wide restoration plan that has both immediate and long-lasting benefits.

Providing fish passage at the Talbot Mills Dam would restore over 35 miles of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries.

Next Steps

This feasibility study is not intended to identify a preferred alternative, but rather provides a critical foundation for ongoing and future restoration activities as well as a framework for continued communication between project partners and the public to determine how best to reconcile project goals with other interests. If preferred alternative(s) can be agreed upon, the project will advance to future phases of securing funding, additional feasibility work, consultation with interested parties, design, and construction to ultimately restore diadromous fish passage to the Concord, Sudbury, and Assabet Rivers.

Please send written comments on the feasibility study by April 6, 2016.

At this juncture, the next step is to solicit input from the public on the draft feasibility report. The findings of the study will be presented to the public at a meeting to be held on February 23, 2016, which will be followed by a six-week-long formal public comment period ending April 6, 2016. During the comment period, electronic copies of the full feasibility report and appendices will be available for viewing or downloading at http://tinyurl.com/ConcordRiverFishStudy. Hardcopies of the report will also be available in the reference section at the Billerica Public Library at 15 Concord Road in Billerica (978-671-0948). Written comments are welcome and encouraged. Please send any comments on the draft report, the public presentation, or the overall project by April 6, 2016 to:

Jill Griffiths, PE | Gomez and Sullivan Engineers
PO Box 2179 | Henniker, NH 03242 | 603-428-4960 | jgriffiths@gomezandsullivan.com

This page intentionally left blank.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ACEC	Area of Critical Environmental Concern
APE	Area of Potential Effects
AUL	Activity and Use Limitation
BVW	bordering vegetated wetlands
cfs	cubic feet per second
CLOMR	Conditional Letter of Map Revision
CRT	CRT Development Realty, LLC
CY	cubic yards
D/S	downstream
DCR	Massachusetts Department of Conservation and Recreation
DER	Massachusetts Division of Ecological Restoration
DFG	Massachusetts Department of Fish and Game
DFW	Massachusetts Division of Fisheries and Wildlife
DOT	Massachusetts Department of Transportation
DPW	Department of Public Works
EEA	Massachusetts Executive Office of Energy and Environmental Affairs
el/elev	elevation
ENF/EENF	Expanded Environmental Notification Form
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
ft	feet
ft/s	feet per second
Gomez and Sullivan	Gomez and Sullivan Engineers, DPC
GPR	ground-penetrating radar
HEC-RAS	Hydraulic Engineering Center River Analysis System
LiDAR	Light Detection and Ranging
LPCT	Lowell Parks and Conservation Trust
MAHW	mean annual high water
MarineFisheries	Massachusetts Division of Marine Fisheries
MassDEP	Massachusetts Department of Environmental Protection
MassGIS	Massachusetts Office of Geographic Information
MCA	Middlesex Canal Association
MCC	Middlesex Canal Commission
MCP	Massachusetts Contingency Plan
MEPA	Massachusetts Environmental Policy Act
MGD	million gallons per day
MHC	Massachusetts Historical Commission
NAVD 88	North American Vertical Datum of 1988 (datum used in this report)
NEFO	USFWS New England Field Office
NGVD 29	National Geodetic Vertical Datum of 1929
NHESP	Natural Heritage & Endangered Species Program
NID	National Inventory of Dams
NMCOG	Northern Middlesex Council of Governments

NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRD	Natural Resource Damages
NWR	National Wildlife Refuge
Nyanza Restoration Plan	Restoration Plan and Environmental Assessment for the Nyanza Chemical Waste Dump Superfund Site
Nyanza Site	Nyanza Chemical Waste Dump Superfund Site
OARS	OARS for the Assabet, Sudbury, and Concord Rivers
ODS	Office of Dam Safety
OED	Olson Electric Development Co., Inc.
OHW	ordinary high water
ORW	Outstanding Resource Water
PAH	polycyclic aromatic hydrocarbon
PAL	Public Archaeology Laboratory
PEC	Probable Effects Concentration
PNF	Project Notification Form
RTK	real-time kinematic
STARR	Strategic Alliance for Risk Reduction
SuAsCo	Sudbury, Assabet, and Concord Rivers
TEC	Threshold Effects Concentration
TMDL	total maximum daily load
U/S	upstream
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
WMA	Water Management Act

LIST OF PROJECT CONTACTS

Lead Project Partners

Ben Gahagan
Massachusetts Division of Marine Fisheries
ben.gahagan@state.ma.us
978-282-0308 ext. 140

Michael Bailey, PhD
US Fish and Wildlife Service
michael_bailey@fws.gov
603-595-0957

Nyanza Site Natural Resource Damages Trustee Council

Eric Hutchins
NOAA Restoration Center
eric.hutchins@noaa.gov
978-281-9313

Rose Knox
Massachusetts Department of Environmental Protection
rosemary.knox@state.ma.us
617-556-1026

Molly Sperduto
US Fish and Wildlife Service
molly_sperduto@fws.gov
603-223-2541

Karen Pelto
Massachusetts Department of Environmental Protection
karen.pelto@state.ma.us
617-292-5785

Consultant

Jill Griffiths, PE
Gomez and Sullivan Engineers
jgriffiths@gomezandsullivan.com
603-428-4960

1. Introduction

1.1 Project Purpose

The purpose of this report is to evaluate the feasibility of restoring populations of diadromous fish to the Concord, Sudbury, and Assabet Rivers.

Currently, the primary impediment to fish passage in the Concord River is the Talbot Mills Dam[1] in Billerica, Massachusetts. Prior to reaching the dam, fish must first navigate potential obstacles at the Essex Dam[2] (an active hydropower dam with a fish elevator and an eel ladder) on the Merrimack River in Lawrence, Middlesex Falls (a natural bedrock falls and remnants of a breached dam) on the Concord River in Lowell, and Centennial Falls Dam[3] (a hydropower dam with a fish ladder), also on the Concord River in Lowell. Species targeted for restoration include both species of river herring (blueback herring and alewife), American shad, American eel, and sea lamprey, all of which are diadromous fish that depend upon passage between marine and freshwater habitats to complete their life cycle.

Reasons for pursuing fish passage restoration include the following:

- **Ecosystem Functions –** The target species are important forage species for many types of fish and wildlife (e.g., striped bass, trout, cod, bluefish, tuna, ospreys, herons, cormorants, otters, seals, whales, etc.) and facilitate the transport of nutrients between marine and freshwater environments.
- **Fisheries** – Because they are forage species, diadromous fish are important for commercial and recreational fisheries of other species.
- **Cultural Values –** Anadromous fish provide cultural benefits to citizens who value fish runs for food, bait, and as a sign of a healthy river. Many towns celebrate their arrival each spring with festivals.
- **Range –** The impact of these species extends far beyond the site of a single restoration project, as the target species have a broad migratory range and are distributed along the entire Atlantic coast from Newfoundland (alewife) to Florida (blueback herring), from Greenland to South America (American eel), and even the European coast (sea lamprey).
- **History** – The historical presence of river herring and other diadromous target species in the Concord River is well documented.
- **Legal Statute** – Massachusetts General Law Chapter 130, Section 19 allows for the requirement of dam owners to provide fish passage at dams.
- **Habitat** – Significant lacustrine and riverine spawning and rearing habitat exists upstream of the Talbot Mills Dam—over 35 miles or 740 acres on the mainstem Concord, Assabet, and Sudbury Rivers, 100 miles of tributaries to these rivers, and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams).

---

[1] Also known as Faulkner Mills Dam, Billerica Dam, Billerica Falls Dam, Mill Pond Dam, or Middlesex Canal Dam and Locks. Talbot Mills Dam is used in this report as it is the name on file in the National Inventory of Dams (NID).
[2] Also known as the Great Stone Dam.
[3] Also known as Centennial Island Hydroelectric Dam, Lawrence Street Dam, Wamesit Falls Dam, or Wamesit Power Company Dam.

- **Connectivity** – The Concord River is low in the Merrimack River watershed and fish must only navigate past one dam—the Essex Dam in Lawrence—before reaching the mouth of the Concord River.
- **Support** – Active and involved watershed associations, volunteer organizations, community members, and state and federal agencies support restoration.
- **Public Input** – This project is one of 12 projects identified in the *Restoration Plan and Environmental Assessment for the Nyanza Chemical Waste Dump Superfund Site* (Nyanza Restoration Plan), which resulted from public input process (Stratus Consulting, 2012).

Fish passage restoration alternatives considered in this feasibility study include the following[4]:

- Middlesex Falls
  - No action
  - Channel modifications to improve fish passage efficiency
- Centennial Falls Dam
  - No action
  - Fishway improvements
  - Volunteer coordination
- Talbot Mills Dam
  - No action
  - Dam repair with upstream and downstream fish passage facilities
  - Dam repair with nature-like fishway
  - Partial dam removal[5]
  - Full dam removal

This phase of the project is not intended to result in a decision document or action at the Talbot Mills Dam; rather, it is an initial study to evaluate whether diadromous fish restoration in the Concord River may be feasible.

1.2 Project Support

This project has been led by the Massachusetts Department of Fish and Game (DFG) Division of Marine Fisheries (*MarineFisheries*) with support from the National Oceanic and Atmospheric Administration (NOAA) Restoration Center, the US Fish and Wildlife Service (USFWS), and the Massachusetts Department of Environmental Protection (MassDEP). Gomez and Sullivan Engineers, DPC (Gomez and Sullivan) was contracted to conduct the study, which involved a review of existing information, hydrologic and hydraulic analyses, structural assessment, evaluation of impounded sediments, conceptual design of fish passage options, this feasibility report, and final public meeting. The Public Archaeology Laboratory (PAL) was subcontracted to conduct a cultural resources analysis.

This project was approved for implementation by the Nyanza Chemical Waste Dump Superfund Site (Nyanza Site) Natural Resource Damages (NRD) Trustee Council in the 2011 Nyanza Restoration Plan, and received funding from the Nyanza Site NRD Settlement. The Trustee Council—composed of the

[4] Note that conceptual designs were only developed for the most feasible alternatives.

[5] Also referred to as "dam breach." In this case, partial dam removal would consist of removing the primary spillway and possibly one or both spillway abutments. Although not a full removal of the entire dam embankment, this scenario is sometimes referred to as "dam removal" in this report for simplicity.

Massachusetts Executive Office of Energy and Environmental Affairs (EEA), represented by the MassDEP, USFWS, and NOAA—is responsible for planning, implementing, and overseeing the restoration, replacement, and acquisition of the equivalent of natural resources and natural resource services that were harmed when hazardous substances and materials, primarily mercury, were released from the Nyanza Site located south of the Sudbury River in Ashland, Massachusetts between 1917 and 1978. To compensate for natural resources and natural resource services injured as a result of contamination, the Trustees seek to restore wetland, floodplain, and riverine habitats and species that utilize or historically utilized these habitats, particularly birds and riverine fish (Stratus Consulting, 2012).

1.3 Public Outreach

Public involvement is paramount in the process of restoring diadromous fish to the Concord River. All documents have been made publically available and stakeholders have been consulted throughout this project, and this will continue to be the case. Public input has been or will be actively solicited at the following stages in the timeline of the broader restoration effort surrounding this feasibility study:

- **Planning phase** – As noted above, this project was initiated by the public input process that resulted in the recommendations contained in the Nyanza Restoration Plan (Stratus Consulting, 2012).
- **Feasibility phase** (this study) – A public info session was held at the Middlesex Canal Museum on August 7, 2014 to kick off the project. Meeting invitees included owners of properties abutting the lower Talbot Mills Dam impoundment, Conservation Commissions of towns along the extent of the impoundment, watershed and other environmental organizations, historical associations/commissions, regional planning agencies, state and federal agencies, members of the public, and other stakeholders. Another public meeting will be held February 23, 2016, also at the Middlesex Canal Museum, to present the findings of the study. Comments received on the draft report during the six-week public comment period ending April 6, 2016 will be incorporated into the final report where appropriate and attached as an appendix. During the comment period, copies of the draft report will be publically available online and in hardcopy at the Billerica Public Library.
- **Additional feasibility/consultation phase** – Public input from the feasibility phase will be used to identify and collect any additional information needed to advance the feasibility study and select preferred alternative(s) in consultation with interested parties.
- **Design phase** – Consultation with interested parties will continue to inform the design process for preferred alternative(s). Additional public meetings will be held to present both preliminary and final designs for any recommended restoration measures.
- **Permitting phase** – Public comments will be solicited and public hearings will be held as part of a number of local, state, and federal permitting processes for the design.

Stakeholders for this project include, but are not limited to:

- Interested members of the public
- Landowners abutting the river
- Dam owners (CRT Development Realty, LLC, Olson Electric Development Co., Inc.)
- Mill owners (Leggett & Platt, Inc., Faulkner Mills Corp.)
- Municipal government officials (Boards of Selectmen/City Councils, Conservation Commissions, Historical Commissions, etc.) of affected municipalities along the Concord River (Concord, Bedford, Carlisle, Billerica, Chelmsford, and Lowell)
- Billerica Water Supply
- Lowell Parks and Conservation Trust (LPCT)
- Concord River Environmental Stream Team
- SuAsCo Watershed Community Council
- OARS for the Assabet, Sudbury, and Concord Rivers (OARS)
- Merrimack River Watershed Council
- Sudbury Valley Trustees
- Middlesex Canal Association (MCA)
- Middlesex Canal Commission (MCC)
- Billerica Historic Districts Commission
- Billerica Historical Commission
- Billerica Historical Society
- Northern Middlesex Council of Governments (NMCOG)
- Massachusetts Department of Environmental Protection (MassDEP)
- DFG Division of Marine Fisheries (*MarineFisheries*)
- DFG Division of Fisheries & Wildlife (DFW)
- DFG Division of Ecological Restoration (DER)
- Massachusetts Department of Conservation & Recreation (DCR), Office of Dam Safety (ODS)
- Massachusetts Historical Commission (MHC)
- Massachusetts Environmental Policy Act (MEPA) Office
- USFWS Central New England Fish and Wildlife Conservation Office (formerly Central New England Fishery Resources Office)
- USFWS New England Field Office (NEFO)
- USFWS – Great Meadows National Wildlife Refuge
- NOAA Restoration Center
- National Marine Fisheries Service (NMFS)
- National Park Service (NPS) – Sudbury, Assabet, and Concord Wild and Scenic Rivers Stewardship Council
- NPS – Minute Man National Historical Park
- US Environmental Protection Agency (USEPA) Region 1
- US Army Corps of Engineers (USACE)

1.4 Report Overview

The remainder of this report is laid out in four main sections:

- **Section 2. Existing Environment** – This section presents a summary of available existing information collected from previous studies and background research, including information about the watershed, fish passage obstacles, infrastructure, and diadromous fishery resources.

- **Section 3. Technical Assessment** – This section describes the various analyses conducted during the course of this project to provide additional information for the alternatives analysis, including a topographic survey and sediment, hydrologic, hydraulic, and cultural resources analyses.

- **Section 4. Restoration Alternatives Analysis** – This section discusses the restoration alternatives considered for each site (Middlesex Falls, Centennial Falls Dam, and Talbot Mills Dam), including their conceptual design, ability to meet target fish passage thresholds, potential benefits or impacts, recommendations for additional studies, and budgetary cost opinions, where applicable.

- **Section 5. Summary and Next Steps –** This section presents a summary of feasible alternatives—including a list of potential permitting requirements and a decision matrix for options at the Talbot Mills Dam—as well as an overview of the next steps for the project.

All figures and tables referenced in this report can be found in **Appendix A**. Photographs are included in **Appendix B**. **Appendix C** presents a set of eight aerial photographs of the Talbot Mills Dam area taken between 1938 and 2006, which were compiled for the 2009 dam safety inspection report (Geotechnical Consultants, 2015). Conceptual plans for alternatives at Middlesex Falls and Talbot Mills Dam are included in **Appendix D**. Conceptual photographic renderings for Talbot Mills Dam alternatives are provided in **Appendix E**. **Appendix F** contains tabular output from the hydraulic model. Correspondence with MHC regarding the cultural analysis is provided in **Appendix G**. In the final version of the report, an additional appendix will contain public comments received on the draft report.

This page intentionally left blank.

2. Existing Environment

This section presents a summary of available existing information collected from previous studies and background research, including information about the watershed, fish passage obstacles, infrastructure, and diadromous fishery resources.

2.1 Watershed

2.1.1 General Description

The Concord River is part of the Merrimack River watershed. It joins the Merrimack River downstream of the Pawtucket Dam[6] in Lowell, Massachusetts, making it an ideal candidate for fish passage restoration. Fish migrating upstream from the ocean must only navigate the fish passage facilities at the Essex Dam in Lawrence, Massachusetts—which include a fish elevator, a downstream fish bypass, and an eel ladder—before reaching the Concord River. **Figure 2.1.1-1**[7] shows the location of the Concord River drainage within the Merrimack River watershed.

The Concord River originates at the confluence of the Assabet and Sudbury Rivers near historic Egg Rock in the town of Concord, Massachusetts. The three rivers collectively drain an approximately 400-square-mile area known as the Sudbury-Assabet-Concord (SuAsCo) watershed, which is shown in **Figure 2.1.1-2**.

The Sudbury River is 41 miles long and drains 169 square miles. It begins in Westborough, flows eastward to Framingham, then north through Sudbury, Wayland, Lincoln, and into Concord. It has three distinct sections: a narrow, rapid reach upstream of Framingham, a middle section consisting of two large impoundments (one of which is created by the Saxonville Dam[8] in Framingham), followed by a 12-mile-long section that changes elevation by only one foot and has been compared to an elongated lake. The Assabet River is 31 miles long, and drains 175 square miles. It starts in Westborough, and flows northeast through many impoundments in the urban centers of Northborough, Hudson, Maynard, and Concord interspersed with rural and undeveloped watersheds (USFWS, 2005).

The Concord River retains the slow-moving characteristics of the third section of the Sudbury River for the first approximately 11 miles through Concord, Bedford, and Carlisle to the Pollard Street Bridge in Billerica, then drops nearly 65 feet over the last 5 miles through Chelmsford and Lowell before emptying into the Merrimack River and ultimately into the ocean at Plum Island. Tributaries include River Meadow Brook and Marginal Brook in Lowell, Mill Brook in Billerica, and Sawmill Brook and Mill Brook in Concord, which are also shown in **Figure 2.1.1-2**.

A total of 29 free-flowing miles of the Sudbury (16.6 miles), Assabet (4.4 miles), and Concord (8 miles) Rivers were designated as Wild and Scenic in 1999, recognizing the recreational, ecological, scenic, and historical/cultural resources of the rivers. A map of the designated Wild and Scenic area is shown in **Figure 2.1.1-3**. The designated reach on the Concord River extends from Egg Rock down to the Route 3 Bridge in Billerica. The SuAsCo watershed also encompasses two National Wildlife Refuges (NWRs)—the Great Meadows NWR, located in Sudbury and Concord (shown in **Figure 2.1.1-4**), and the Assabet NWR, located

[6] Fish passage has been provided at the first three dams on the Merrimack River, although fish have difficulty navigating the fish passage facility at the Pawtucket Dam. Only about 10% of fish that successfully navigate the Essex Dam downstream make it above the Pawtucket Dam (NH FGD, 2015).

[7] All numbered figures and tables referenced in this report are provided in **Appendix A**.

[8] Also known as the Central Street Dam.

primarily in Stow. Additionally, Massachusetts' first designated Area of Critical Environmental Concern (ACEC)—the Great Cedar Swamp—is located in Westborough on the Sudbury River. The Great Meadows NWR and the Great Cedar Swamp represent the two of the largest wetlands in central Massachusetts (MassDEP, 2015).

The Assabet, Sudbury, and Concord rivers have all been impounded by dams, creating systems with rapidly moving headwaters and slow moving impounded sections. There are eight dams along the Assabet River mainstem, six on the Sudbury River mainstem, and two on the Concord River mainstem—Talbot Mills Dam in Billerica and Centennial Falls Dam in Lowell. A third dam on the Concord River, the Middlesex Dam in Lowell, has been breached; only the abutments and remnants remain. **Figure 2.1.1-5** shows the locations of these three obstacles to fish passage on the Concord River. There are also three sets of waterfalls within a one-mile-long reach on the Concord River in Lowell that provide Class III and IV whitewater for rafting (Stratus Consulting, 2012).

Upstream of the Talbot Mills Dam, there are no obstructions to fish passage on the remaining 11.6 miles of the Concord River or beyond until the Saxonville Dam on the Sudbury River in Framingham (17 miles above its confluence with the Assabet River) and a small hydroelectric dam known as High Street Dam on the Assabet River in Acton (6.4 miles above its confluence with the Sudbury River) [9]. Providing fish passage at the Talbot Mills Dam and addressing any potential obstacles at Middlesex Falls and Centennial Falls Dam would restore over 35 miles or 740 acres of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams) [10]. A map of these potential habitat areas is provided in **Figure 2.1.1-6**.

2.1.2 River Flowage and the History of the Great Meadows

Although the Assabet is a relatively swift river, the Sudbury and Concord Rivers form a sluggish stretch of some 22 miles, from the Route20/Boston Post Road bridge in Wayland to the Pollard Street bridge in Billerica (approximately a half of a mile upstream of Talbot Mills Dam), where the channel bottom drops only two feet—about an inch per mile. Along much of this reach, the river is flanked by broad marshes (traditionally called "meadows," and in this case referred to as the Great Meadows) that stretch as wide as a mile in some places (Donahue, 1989). A historical plan and profile of the Concord and Sudbury Rivers along a 22.15-mile-long section through the Great Meadows in shown in **Figure 2.1.2-1**. Today, these wetlands are preserved along 12 miles of the Concord and Sudbury Rivers as part of the Great Meadows NWR.

[9] The Damonmill Dam (also known as the Damondale Dam), which is located approximately 1.8 miles downstream of the High Street Dam in Concord, was not considered to be the upstream barrier to fish passage on the Assabet River as it is breached. However, the ability of target species to successfully pass through the approximately 30-foot-wide breached dam section is unknown. A Notice of Intent filed with the MassDEP in June 2015 indicates that the property owner, Damonmill Square Properties, LLC, seeks to make necessary repairs to the breached dam to increase safety during high flows, remove restrictions during low flows, and close the headrace and tailrace.

[10] These numbers were derived from an analysis conducted with the USGS National Hydrography Dataset (NHD), considering available habitat between the Talbot Mills Dam and the next upstream dam on the Assabet River (High Street Dam), Sudbury River (Saxonville Dam), and tributaries. It did not consider other potential barriers to fish passage such as culverts. Of the target species for this project, American eel are most likely to utilize the tributaries, and it is assumed that they can pass through most road crossings.

History of the Great Meadows

Historically, when colonists settled the area in the 1630s, the native grasses of the meadows were farmed for hay. Because the meadows were wet and prone to flooding, various measures were taken to improve drainage, including digging ditches, diverting upland seepage, and cutting weeds and dredging bars in the river. When the river was first dammed in North Billerica at the site of the present-day Talbot Mills Dam over 300 years ago in 1711, farmers complained that the dam caused increased flooding of their meadow lands. Over the course of the next nearly 150 years and incremental raising of the dam height, various legal disputes between multiple generations of farmers and dam owners resulted in the dam being removed and rebuilt several times (see **Section 2.2.3**, **History**).

Finally, in 1859, the state legislature appointed a Joint Special Commission to investigate whether or not the dam was in fact the cause of increased flooding of the meadows. The commission's report (MA House of Representatives, 1860) largely consisted of testimony and anecdotal evidence of the dam's effect from dozens of aggrieved farmers. The commission concluded that the dam was a cause of the flooding, leading the legislature to issue the Act of 1860 which ordered that the dam be lowered by 33 inches to its original 1711 height. When the dam owner filed to repeal the decision, a new legislature appointed a Scientific Commission to conduct a more technical study of the effect of the dam on the upstream flooding in 1861. The study involved a survey[11] of the river, incremental lowering of the dam up to 33 inches, and more than 35,000 measurements of the resulting water levels in the Concord and Sudbury rivers and adjacent meadows at varying river flows from late July through mid-October. The results of the study showed that the top of the dam was higher than any point on the river bottom for 25 miles upstream, but that lowering the dam produced only a negligible drop of the water level in the upstream meadows. The commission's report (Alvord et al., 1862) concluded that the dam was not the primary cause of upstream flooding and doesn't substantially affect water levels above a natural high point known as the Fordway Bar (described below). It has been suggested that the study period (about 4 weeks with the dam lowered) may not have been long enough for the river to reach a new equilibrium with groundwater levels due to the constant influx of runoff from higher in the watershed, and that deforestation for a growing farming industry and upstream basin regulation were simultaneously contributing to increased flooding in the meadows, magnifying the dam's perceived impact (Donahue, 1989). Regardless, the legislature accepted the commission's report and, in 1862, repealed the Act of 1860's order to lower the dam (Yerrinton and Bacheler, 1862).

For restoration alternatives that would potentially remove or change the height of the Talbot Mills Dam, it is important to understand how it and other dynamics influence water levels in the Concord River. The 1861 study reported that, independent of the dam, the river is affected in its flow and condition by several factors, including:

- **Channel sinuosity** – Sinuosity is a measure of the curvature of a river's bends compared to the straight-line distance. A particularly sinuous channel is referred to as "meandering." The 1861

[11] The 1861 survey used a zero datum 10.00 feet below the top of an iron bolt that had been placed in 1825 at an elevation equal to the top of the flashboards at the dam. In the 1861 study, the elevation of the bolt top was reported as 115.35 feet above the Boston base datum (or mean low water in Boston Harbor), which is 5.65 feet above NVGD 29 and 6.477 feet above NAVD 88, which would make it 108.87 feet NAVD 88. The bolt still exists today and in 2013 its top elevation was re-measured as 108.81 feet NAVD 88 from a temporary benchmark set in 2000 from the 1965 US monument MY0308 (Breen, 2013).

study found that parts of the river are especially sinuous, with bends so short and frequent that they obstruct the flow of the water to some extent (Alvord et al., 1862).

- **Natural bars** – The river has various natural bar formations, or high points in the channel bottom profile, several of which are named (e.g., Fordway Bar, Pollard's Bar, Barrett's Bar, Assabet Bar). According to the 1861 study, the elevations of these bars do not change significantly over time (Alvord et al., 1862).

- **Weeds** – During the summer months, various weeds grow on some of the bars and in other places of the river, creating resistance for the flow of the river and adding to its sluggish nature. The 1861 study reported that the dense weed growth has a significant effect on upstream water levels. Historically, weeds have been cut from the bars by farmers to relieve upstream flooding of their meadow lands (Alvord et al., 1862).

- **Basin regulation** – The 1861 study reported that flow in the river was artificially affected by operation of some 24 ponds and 58 mill ponds on the Assabet and Sudbury Rivers at that time (Alvord et al., 1862). Today, flows are still regulated for various uses, as discussed in **Section 2.1.3** below.

Of these factors, the most important consideration for water levels upstream of the dam is the natural bars, specifically the first bar upstream of the dam known as the Fordway Bar. It is a natural bar of hard gravel that is about 700 feet in length and was formerly used as a ford to cross the river. According to the 1861 survey, the Fordway Bar lies between points approximately 2,700 to 3,400 feet upstream of the dam, passing through the location of the present-day Pollard Street bridge (which is 2,935 feet upstream of the dam). About 400 feet below the downstream end of the bar, the river flows swiftly through an approximately 500-foot-long section of narrow, rocky channel formed by broken ledge and obstructed by boulders and small islands (Alvord et al., 1862). This bedrock formation likely serves as the hydraulic control for the bar and may have led to its formation. **Figure 2.1.2-2** is a historical plan of the Billerica Mills area depicting the locations and cross-sections[12] of the Fordway Bar and the section of rapids and islands downstream.

Figure 2.1.2-3 shows a portion of the river bottom profile upstream of the dam as surveyed in 1861. The elevation of the top of the Fordway Bar measured from the profile is approximately 107.2 feet relative to the North American Vertical Datum of 1988 (NAVD 88)[13], which is about a foot below the spillway crest of the Talbot Mills Dam (Alvord et al., 1862). If the dam were removed or lowered by more than a foot, this feature would likely serve as the new hydraulic control for the river upstream.

In 1894, the State Board of Health was directed by the legislature to dredge sediment from the various bars in the river that impeded its flow. Over 31 thousand cubic yards (CY) of sediment were removed from more than 2 ½ miles of bars in the upper Concord and lower Sudbury Rivers. The channels dredged through the bars were generally 5 feet deep and 20 to 30 feet wide. Most of the sediment was disposed of in deeper sections of the channel, with some also being spread on the meadows. The proposed plan

---

[12] Unfortunately, Detail [B] showing the cross-section through the Fordway Bar was omitted from the copy of the plan obtained for this report.

[13] Unless otherwise specified, all elevations in this report are given in feet and referenced to the North American Vertical Datum of 1988 (NAVD 88). The datum shift to convert to the National Geodetic Vertical Datum of 1929 (NGVD 29) for the coordinates at Talbot Mills Dam (the conversion is location specific) is 0.827 feet (with NGVD 29 being the higher elevation).

also called for lowering the Fordway Bar and other bars closer to the dam in North Billerica, but these bars were found to be composed of hard material which would have been more difficult and expensive to move. The work was completed in 1897, and reportedly resulted in improving the flow of the river and lowering the water table in the meadows (State Board of Health, 1896; MA Senate, 1918).

In 1902, the legislature voted down a bill that would have authorized the Harbor and Land Commissioners to cut out and remove the Fordway Bar. The bar is still intact today (Sudbury, Assabet and Concord Wild & Scenic River Stewardship Council, n.d.).

Present-Day Water Levels and Flooding

In spite of the historical flood studies and subsequent dredging of the rivers, flooding is still issue in the watershed. The Talbot Mills Dam in Billerica affects flooding on the Concord and Sudbury Rivers, and the Damonmill Dam in West Concord and the old High Street Dam (Powder Mill Dam) in Acton increase flood elevations on the Assabet River. Bridges also play a key role. According to the flood profiles in the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS), a number of bridges upstream of the dam appear to be undersized, acting as a hydraulic control and causing a backwater effect and higher water surface elevations upstream. The center pier of the former Bridge Street bridge below the Boston Road/Route 3A bridge in Billerica is a hydraulic restriction that could be removed from the floodway. The abutment remains of the former Old Middlesex Turnpike bridge is also a constriction to flow (FEMA, 2014).

The duration of flooding for most of the Concord River is generally sustained due to the large drainage area, shallow channel slopes, low, undefined banks, and wide, meadow flood storage areas. Records indicate that the 1936 flood remained higher than an elevation of 117.2 feet NAVD 88 at the Carlisle Road bridge for more than 11 days. Hurricane Diane occurred on August 19 and 20, 1955, but the Concord River did not crest until late on August 22 with water levels remaining above an elevation of 117.2 feet NAVD 88 for over three days (FEMA, 2014).

The maximum peak flow recorded at the US Geological Survey (USGS) streamflow gage on the Concord River in Lowell (Gage No. 01099500) was 5,840 cubic feet per second (cfs) on March 17, 2010 during a series of widespread, large, low-pressure systems that affected southern New England in late February through late March of 2010 and resulted in record or near record rainfall and runoff. The total rainfall in the region during this period ranged from about 17 to 25 inches, which, coupled with seasonal low evaporation, resulted in record or near record peak flows at 13 of 37 streamgages in central and eastern Massachusetts. High water marks recorded on the Concord River above the Talbot Mills Dam ranged from 117.2 feet NAVD 88 above the Boston Road/Route 3A bridge (1.5 miles upstream of the dam) to 118.1 feet NAVD 88 above the Route 225 bridge (6.7 miles upstream of the dam) (USGS, 2015b and Zarriello and Bent, 2011).

Conversely, August 2002 produced some of the lowest water levels on the Concord River. In addition to the low flows, the sluice gate at Talbot Mills Dam was opened, causing the water to nearly stop flowing over the dam spillway. Some water was observed leaking past two inoperable low level outlet structures at the dam. Water levels approached 108 feet NAVD 88 at Pinewood Avenue in Billerica, located approximately 2.4 miles upstream from the dam. The sluice gate was subsequently closed and rainfall raised water levels above the dam spillway (E. Reiner, personal communication, February 5, 2016).

The USGS recorded high water marks observed during the 2010 flooding event at 7 locations on the Concord River, 18 on the Sudbury River, and 11 on the Assabet River (Zarriello and Bent, 2011). The USACE recorded high water marks associated with the flood of January 1979 on the Concord and Sudbury Rivers

(Boston Survey Consultants, 1979a and 1979b). Additionally, Billerica resident Ed Reiner has recorded water surface elevations during both high and low flows on a concrete wall with a surveyed benchmark at Pinewood Avenue, located approximately 2.4 miles upstream of the Talbot Mills Dam (E. Reiner, personal communication, February 8, 2016).

2.1.3 Basin Regulation

Flows in the SuAsCo watershed are regulated for various uses, including water supply, wildlife management, flood control, and small hydropower. In order to ensure successful fish passage restoration, it is important to assess whether flows are adequate for fish passage during key life cycle events (see **Section 2.4.2**).

The watershed is heavily used for water supply. A study of water use in the SuAsCo watershed conducted by the US Geological Survey (USGS) from 1996-2000 reported that 17 municipal supply systems withdrew water during that period, in total averaging 10.1 billion gallons per year or 27.7 million gallons per day (MGD). Water withdrawals were mostly (75 percent) from groundwater. Water use and management in the basin resulted in a net transfer of water from groundwater to surface water, discharged as wastewater, of about 4,000 million gallons per year (11.0 MGD) (Barlow et al., 2009). The Concord River serves as a treated water supply for the Town of Billerica (see **Section 2.3.2**) and receives discharges from four municipal wastewater treatment plants, as well as several industrial users (MassDEP, 2005).

The waters of the SuAsCo watershed have historically been used as water supplies for metropolitan Boston. Between 1872 and 1898, seven reservoirs were constructed on the north and south branches of the Sudbury River, four of which are still part of the present-day Sudbury System. However, limited yield, urbanization of the watersheds, and unsatisfactory water quality led to an investigation for additional water supply of adequate quantity and quality. The creation of the Wachusett and Quabbin Reservoirs meant that increasingly substandard source waters from many of the reservoirs in the Sudbury System could be discontinued. The entire Sudbury System was officially removed from active use and classified as an emergency water supply in 1976[14] (MassDEP, 2005).

Flows in the Concord River are also regulated for wildlife management. The Concord Unit of the Great Meadows NWR includes two 100-acre manmade impoundments, referred to as the Concord Impoundments, located adjacent to the Concord River. Since 2000, the USFWS has been actively manipulating water levels in the two impoundments to provide wildlife habitat, primarily for migratory birds, by gradually drawing down and refilling[15] the impoundments throughout the year. Despite the variation in timing of drawdown and filling of the impoundments, one impoundment typically has some water during most of the spring, summer, and fall (though which impoundment contains water varies within a season). Each year, both impoundments are flooded before winter freeze, and remain flooded until the following spring (USFWS, 2009).

The Great Meadows NWR Comprehensive Conservation Plan identifies a goal of restoring historical runs of fish in the herring family to the Concord River (USFWS, 2005). Additionally, the *Sudbury, Assabet, and*

[14] Interestingly, the USGS, in its remarks relative to the streamflow gage on the Concord River in Lowell, still notes that although the physical drainage area at the gage is 400 square miles, the net drainage area is actually 307 square miles, due to a water supply diversion from approximately 93 square miles in the Sudbury River basin and Lake Cochituate for use by the Boston metropolitan district, but this was discontinued in 1976 (USGS, 2015b).

[15] The impoundments are filled using a pump placed in the Concord River.

Concord Wild and Scenic River Study: River Conservation Plan notes the need to promote projects that support anadromous fish restoration (NPS, 1995).

Flood flows in the watershed are also regulated. Nine flood control dams—located in the towns of Berlin, Bolton, Harvard, Northborough, Marlborough, Shrewsbury, Stow, and Westborough—act as a system to control a drainage area of nearly 50 square miles and provide available flood storage of more than four billion gallons. The dams were built between 1962 and 1987 by the US Department of Agriculture's Natural Resources Conservation Service (NRCS) and the DCR. The DCR owns, operates, and maintains the dams, and, with NRCS assistance, monitors the dams to ensure that they provide flood protection. They provide an estimated $1.7 million in annual flood damage reduction benefits. Significant upstream urban development has generated the need for rehabilitation of the dams, which is currently in progress (NRCS, 2015). Additionally, the USACE has constructed flood protection dikes and walls along a portion of the Sudbury River, which minimizes flooding in much of the area of Saxonville (FEMA, 2014).

Additionally, the Great Meadows NWR protects an extensive portion of the floodplains of the Concord and Sudbury Rivers from development and provides a natural storage area for floodwaters, which helps to mitigate peak flows and the severity of flooding along the rivers. Similarly, Cedar Swamp provides natural floodplain storage and flood reduction benefits for the Sudbury River in the Towns of Sudbury and Wayland. The Sudbury Reservoir and the Framingham Reservoir system also provide significant storage volume which reduces peak flood flows on the Sudbury River (FEMA, 2014).

2.1.4 Water Quality & Aquatic Habitat

It is also important to assess whether the watershed can presently provide adequate water quality and aquatic habitat for target species prior to pursuing restoration alternatives. Under the federal Clean Water Act, states are required to evaluate the condition of surface and ground waters with respect to their ability to support designated uses (such as aquatic life) as defined in state-specific surface water quality standards. Every two years, states identify all impaired stream/river segments and lakes and prioritize the development of pollutant loading, or Total Maximum Daily Load (TMDL), studies based on the severity of the pollution and the sensitivity of the uses.

The resulting Massachusetts Integrated List of Waters (MassDEP, 2014) classifies all sections of the Assabet and Concord Rivers and a segment of the Sudbury River as Category 5 impaired waters. The main impairments caused by pollutants are: eutrophication (Assabet), dissolved oxygen (Assabet), bacteria (Assabet and Concord), phosphorus (Assabet and Concord), algae (Assabet and Concord), and mercury in fish (Sudbury and Concord). Invasive plants are a problem for all three rivers. Many ponds and lakes in the watershed are also listed. A TMDL study has been completed for the Assabet River (MassDEP, 2014).

A natural streamflow regime (i.e., range, duration, and timing of streamflow) throughout the year is critical to supporting fish and other aquatic life. Baseflow—the flow of groundwater into streams—is particularly important during the summer and is essential to diluting effluent discharged to the river. For the nutrient load reductions proposed in the state's TMDL for the Assabet River to be effective in restoring water quality in the mainstem, the existing baseflow in the river and its tributaries must be preserved and, if possible, augmented. The water resources of the area are under the strain of an increasing demand for water supply and centralized wastewater treatment, which results in the net loss of water from many sub-basins and reduced baseflow in the mainstem and tributaries (OARS, 2015).

Invasive aquatic plants are also a problem throughout the watershed. The Sudbury River has a long history of invasive water chestnut (*Trapa natans*) problems and efforts to remediate those problems. Significant

water chestnut infestations are also on the Concord River, particularly in the Talbot Mills Dam impoundment, and the Assabet River. Other invasive aquatic plants include Eurasian milfoil, fanwort, curlyleaf pondweed, and European water clover (OARS, 2015).

OARS (formerly the Organization for the Assabet River) conducts annual water quality, streamflow, and aquatic plant biomass monitoring on the mainstems and large tributaries of the Assabet (since 1992), Sudbury (since 2009), and Concord (since 2004) rivers. A map of sampling sites is shown in **Figure 2.1.4-1**. Water quality data collected under OARS' *Quality Assurance Project Plan for OARS' Water Quality and Quantity Monitoring Program* and previous Quality Assurance Project Plans may be used by the EPA and MassDEP in making regulatory decisions (OARS, 2015).

The data collected are also used to characterize fish habitat conditions in the main tributary sub-basins. Streamflow and habitat availability data have been collected at seven tributary sites to calculate OARS' "Stream Health Index" for those streams. An index brings information from multiple data sources together into a single number that can be understood at a glance, and thus is a useful tool in assessing spatial and temporal trends in water quality, habitat, and streamflow data. OARS' "Water Quality Index" (a sub-index of the overall Stream Health Index) is also used to assess water quality at selected mainstem and tributary sites (OARS, 2015). Stream Health Indices and Water Quality Indices for the 2014 monitoring season can be found in **Tables 2.1.4-1** and **2.1.4-2**, respectively.

Table 2.1.4-1 shows that all tributaries received "excellent" or "good" scores for water quality, flow, habitat, and stream health in the May and June sampling events, while most had some "fair," "poor," or "very poor" scores in the months of July, August, and September when streamflows were lower, particularly in the flow category. **Table 2.1.4-2** indicates that the lowest scoring water quality parameters included nitrates at the Assabet River sites, nitrates and total suspended solids at the Concord River sites, total phosphorus and total suspended solids at the Sudbury River site, and dissolved oxygen at the Hop Brook site.

The Concord River is designated as a Class B warm water fishery, with portions also designated as a treated drinking water supply and combined sewer overflow (CSO). Class B 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. A warm water fishery is a water in which the maximum mean monthly temperature generally exceeds 68°F during the summer months and is not capable of sustaining a year-round population of cold water aquatic life (e.g., brook trout). Water quality designations for all segments of the SuAsCo mainstem rivers is provided in **Table 2.1.4-3** (MassDEP, 2013). The DFW lists 34 tributary streams in the basin as Coldwater Fish Resources and the MassDEP designates two tributary streams (an unnamed tributary of the Assabet River and the upper portion of Jackstraw Brook) as cold water fisheries (OARS, 2015).

Table 2.1.4-4 lists acceptable ranges for various physical, chemical, and biotic criteria with regards to spawning and nursery habitat two of the target species—alewife and blueback herring. These thresholds were compiled by *MarineFisheries* from various sources, including the MassDEP's Surface Water Quality Standards (SWQS) (MassDEP, 2013), the EPA's Ambient Water Quality Criteria Recommendations (2001), scientific literature, and Best Professional Judgment (BPJ). These thresholds can be used in conjunction with the data presented in the water quality reports to identify sites in the SuAsCo watershed with characteristics suitable for juvenile herring production.

2.1.5 Potential for Sediment Contamination

Many contaminants released into rivers and streams in the form of industrial wastes, accidental spills, or urban runoff commonly adhere to solids suspended in the water column of a stream and ultimately accumulate in slow moving environments, such as impoundments behind dams. Some fish passage restoration alternatives, particularly dam removal, can have unintended effects on the downstream environment, if not carefully planned and implemented, due to the potential for the release of toxic contaminants by mobilization and downstream redeposition of impounded sediment (Breault et al., 2013).

Although less obvious, sediment contamination should also be a consideration for restoration alternatives that leave a dam intact, including the "no action" alternative. Contaminants trapped in sediment behind dams are often considered buried, but they cannot be assumed to be immobile. Some contaminants are easily exchanged between bottom sediment and the overlying water column, allowing them to become biologically available under certain environmental conditions. Sediment-bound contaminants can also be scoured, re-suspended, transported downstream, and redeposited during storm events, potentially affecting aquatic organisms, including fish, far from the original source. Additionally, benthic organisms, which live on or within the bottom sediment, may be directly exposed to hazardous levels of these contaminants and, in turn, indirectly expose fish and other wildlife to the contaminants through food-web magnification. Humans may be exposed through ingestion of affected wildlife or by direct physical contact (Breault et al., 2013).

Additionally, sediment quantity and quality should be factored into the overall hazard associated with a dam along with its structural integrity and downstream risks, although dam safety inspections required by the ODS do not currently consider this information. An accidental dam failure would cause all the same impacts on the downstream environment as a purposeful dam breach or removal, without the advance planning to minimize those impacts to the greatest extent possible.

This section includes a due diligence review of existing information relating to the potential for sediment contamination in the Talbot Mills Dam impoundment.

Oil and Hazardous Material Sites

Releases of oil and/or hazardous material to the environment are required to be reported to the MassDEP's Bureau of Waste Site Cleanup, in accordance with M.G.L. Chapter 21E and procedures established within the Massachusetts Contingency Plan (MCP) (310 CMR 40.0000). All reported releases are given a period of one year to either be cleaned up or be classified as either Tier I (indicating groundwater contamination in a current drinking water resource area, presence of an imminent hazard or Critical Exposure Pathway, or ongoing Immediate Response Action that involves remedial action) or Tier II (all other sites) in order to undergo a comprehensive assessment and cleanup program. Failure to comply with cleanup or "tier classify" in the one year timeframe results in the site being automatically classified as a Tier ID (Default) site. In cases where cleanup cannot be achieved to the most protective use, a Notice of Activity and Use Limitation (AUL) must be attached to the deed of the contaminated property to document the location of residual contamination and specify restricted and permitted activities and uses of the property in this location (AUL area).

The MassDEP maintains a searchable online database of waste sites and reportable releases, as well as a file viewer that can be used to access electronic reports and forms for those sites (MassDEP, 2016). The Massachusetts Office of Geographic Information (MassGIS) periodically publishes the MassDEP waste

sites database in a spatial format that can be used to identify potential sources of sediment contamination in a particular watershed. According to the most recent (January 2016) MassGIS publication of the MassDEP waste site data, there are currently 68 tier classified sites in the Talbot Mills Dam watershed for which a Permanent Solution (permanent site closure) has not yet been achieved (i.e., “active sites”). Of these, 23 are classified as Tier I, 31 as Tier II, and 14 as Tier ID. Of the sites with a Permanent Solution (i.e., “closed sites”) [16] in the Talbot Mills Dam watershed, 127 have AULs. **Figure 2.1.5-1** shows a map of oil and/or hazardous material sites in the SuAsCo watershed.

There are three primary oil and hazardous waste sites located upstream of the Talbot Mills Dam within 1,000 feet from the Concord River bank (two of these sites also have secondary Release Tracking Numbers, or RTNs, associated with them). **Table 2.1.5** provides a summary of information about these sites. The closest of the three is a Tier II site (RTN 3-0026097) located at 12 Phiney Street in Billerica (adjacent to the VFW Solomon Post No. 8819). This site is situated about 450 feet from the Concord River’s east bank just upstream of the Boston Road/Route 3A Bridge, or about 1.6 miles upstream of the dam. In 2006, waste oil was released from damaged 55-gallon drums at the site, and unrelated PCB and arsenic releases were discovered during site investigations (ENPRO, 2007).

There are also eight active Superfund Sites located within the SuAsCo watershed: four in the Assabet River watershed, two in the Sudbury River watershed (including the Nyanza Site), and two in the Concord River watershed, one of which is located downstream of the Talbot Mills Dam in Lowell (MassDEP, 2005). The other Concord River watershed site is located approximately one mile southeast (upstream) of the Talbot Mills Dam at Iron Horse Park off High Street in North Billerica, which is hydrologically connected to the dam’s impoundment by a wetted section (Segment 24) of the old Middlesex Canal (see **Section 2.3.1** for a description of the Middlesex Canal). The site is a 553-acre industrial complex that includes manufacturing and rail yard maintenance facilities, open storage areas, landfills, and wastewater lagoons. A long history of industrial activities, beginning in 1913, has resulted in the contamination of the site’s soil, groundwater, and surface water. Site cleanup, operation and maintenance activities, and environmental monitoring are ongoing. The USEPA identified no significant risk from migration of vapors from groundwater, and the only potential risk to human health from groundwater is associated with the scenario of a potential future on-site resident using groundwater. No human health risk was identified for exposure to either sediment or surface water. Moderate ecological risk was identified for benthic invertebrates (bottom-dwelling organisms) exposed to contaminated sediments, but those sediments were confined to a small pond and unnamed brook on the site (USEPA, 2010).

Sediment Quantity and Quality

This section presents historical sediment quantity and quality data collected prior to this feasibility study. Sediment data collected during the course of this study is presented in Section3.2.

The USGS and the MA DER collaborated in 2004 and 2005 to collect baseline information on the quantity and quality of sediment impounded behind selected dams in Massachusetts, including the Talbot Mills Dam. The thicknesses of impounded sediments were measured and cores of sediment were analyzed for contaminants potentially toxic to benthic organisms (Breault et al., 2013).

The Talbot Mills Dam impoundment was sampled on November 3, 2005. Twelve sediment thickness measurements were collected (mostly concentrated in the large backwater area on the river right side

[16] The total number closed sites (including those with AULs and those without) is not included in the MassGIS database, but can be found in the MassDEP database, which is searchable by town/city.

just upstream of the dam) and three sediment cores were composited and analyzed for contaminants—two from the backwater area on the right, and one from the smaller backwater area on river left about 150 feet upstream of the dam. **Figure 2.1.5-2** shows the locations of these sediment probes and cores. Sediment thickness measurements ranged from 0 to 8 feet and averaged 3.7 feet; water depths ranged from 4 to 15 feet and averaged 9.4 feet[17]. Glacial or peat materials at the base of the sediment cores were considered "pre-dam" and were not included in the chemical analysis (Breault et al., 2013).

Table 2.1.5-1 presents reported concentrations for selected contaminants tested in the 2005 sediment samples. Results are compared to screening criteria including the MCP Method 1 Standards (Category GW-1/SW-1) and the Threshold Effects Concentration (TEC) and Probable Effects Concentration (PEC) for Freshwater Ecosystems where applicable (MacDonald et al., 2000). In general, sediment chemistry suggests the presence of limited pollutant concentrations. As expected in a developed watershed, about half of the parameters were detected in the impoundment at levels above the TECs; however, concentrations were well below the PEC and MCP Method 1 Standards.

Chromium was the maximum single contributor to total estimated toxicity (contributing 24% to the total toxicity). The likelihood of toxicity of bottom-sediment cores collected in the Talbot Mills Dam impoundment was estimated as 26%, which was close to the average (28%) of the 32 sites sampled, falling at 19 out of 32. The likelihood value serves as an indicator of the potential risk posed by the sediment to local and downstream receptors (Breault et al., 2013).

Significant correlations were found between the number of factories operating in each drainage basin in the 1830s and the concentrations of several inorganic elements (cadmium, chromium, copper, lead, and zinc) as well as total polycyclic aromatic hydrocarbon (PAH) concentrations. At least 40 factories were operated within the drainage area to the Talbot Mills Dam during that era (Breault et al., 2013).

Sediment cores have been collected and analyzed at many sites throughout the SuAsCo watershed as part of various other studies. Additional information is provided in the 2001 SuAsCo watershed water quality assessment report (MassDEP, 2005, "Sources of Information, pages 21-33), as well as in reports by the USGS (Zimmerman and Sorenson, 2005) and the USACE (2010). An updated sediment analysis was conducted as part of this feasibility study (**Section 3.2**).

2.2 Fish Passage Obstacles

2.2.1 Middlesex Falls

The lowest potential obstacle to fish passage in the Concord River is Middlesex Falls at river mile 0.44 in Lowell. The drainage area at this location is approximately 400 square miles[18]. This is the site of the former Middlesex Dam, which was breached in the early 1980s. The site now consists of a large island flanked by a main channel on river left[19], defined by the remains of the concrete dam abutments, and a

[17] In the USGS report, the average sediment thickness and water depth was extrapolated across the entire estimated impoundment surface area, for which a previously published value of 505 acres was used (from the NID, developed by the USACE), to calculate a total sediment volume of 81 million cubic feet. However, this value is believed to be a significant overestimate. A surface area of 505 acres would extend all the way up the Concord River and possibly into the Sudbury and Assabet Rivers, depending on the flow. Due to the numerous grade controls in the river, it is not likely that sediment upstream of the Fordway Bar is either attributable to the Talbot Mills Dam or would mobilize if the dam were removed. An updated analysis of total and mobile sediment volume can be found in **Section 3.2.1**.
[18] Estimated using the USGS StreamStats program.
[19] "River left" and "river right" refer to the direction when facing downstream.

minor channel on river right, defined by the remains of the former mill race/power canal. **Figure 2.2.1-1** shows an aerial image of the site with key features labeled. Photographs of the site can be found in **Appendix B**.

*Middlesex Falls (looking upstream), showing major (river left) and minor (river right) channels. See **Figure 2.2.1-1** for a labeled version of this aerial image (Bing, 2015).*

Former mill race/power canal in minor channel on river right (looking downstream).

Main channel on river left showing proposed passage route along remaining abutment (looking toward island) (McKeon, 2002).

In 2000, the NRCS worked with the USFWS to conduct a survey of the main channel at Middlesex Falls. Existing plan and profile drawings of the site developed from this survey are provided in **Figures 2.2.1-2** and **2.2.1-3**. The survey found no remnants of timber crib or stone/concrete footings in the channel. However, the natural bedrock ledge of the falls creates turbulence, making it hard for fish to pass upstream. A preliminary hydraulic assessment indicated that during low flow (approximately 650 cfs) conditions in spring, fish passage could be impeded, particularly for river herring and American shad (McKeon, 2002).

The NRCS determined that the best potential passage route lies along the island side dam abutment and adjacent ledge in the main channel. Recommended modifications to improve fish passage involve the creation of a channel of less turbulent flow along the island side abutment. It was proposed that sections of ledge in the river channel (indicated by the dashed lines in the drawings) that result in turbulence along the island side bank be removed using a combination of mechanical equipment, explosives, and manual labor (McKeon, 2002). Approximately five major ledge outcrops would need to be removed (D. Quinn, personal communication, March 20, 2001).

The project had received $25,000 in USFWS National Fish Passage Program funds for dam remnant removal to improve fish passage at the site. It had progressed to the permitting stage and was scheduled to be implemented in the summer or fall of 2002 (McKeon, 2002). However, it was unclear whether or not most flows at the site would present a severe impediment to fish passage, and the funds were subsequently used for other activities (Smithwood, 2012).

Additionally, the possibility of fish navigating the old raceway channel on river right was discussed (J. McKeon, personal communication, August 4, 2014). However, no fish passage improvements have been implemented at the site to date. It is known that American eel and at least some river herring can migrate through Middlesex Falls, as they have been observed at upstream locations.

2.2.2 Centennial Falls Dam

The next obstacle to fish passage in the Concord River is the Centennial Falls Dam (National Inventory of Dams (NID) ID MA01190) at river mile 1.55 in Lowell. The drainage area at this location is approximately 373 square miles[20]. The dam provides hydraulic head for the Centennial Island Hydroelectric Project (Federal Energy Regulatory Commission (FERC) Project No. 2998), a run-of-river facility owned and operated by Centennial Island Hydroelectric Company (a subsidiary of Olson Electric Development Co. (OED)). The project was granted an exemption from licensing by the FERC in 1981 and commercial operation commenced in 1990 (OED, 2011). **Figure 2.2.2-1** shows an aerial image of the site with key features labeled. Photographs of the site can be found in **Appendix B**.

The circa 1900, irregularly shaped Centennial Falls Dam is approximately 8 feet high by 320 feet long and is constructed of granite slabs topped with 8-inch-high plywood flashboards. It impounds an area of about 20 acres and is classified as a “Low Hazard” dam. The dam diverts water into the 2,300-foot-long Wamesit Canal to achieve an average net head of approximately 22 feet at the powerhouse, which contains a 640-kW vertical Kaplan turbine with a hydraulic capacity of 450 cfs (OED, 2011).

Fish passage structures were added to the dam in 1990, including an upstream fish ladder and a downstream bypass sluice located between the river left side of the dam and the power canal. The upstream fishway is a 4-foot-wide, approximately 80-foot-long concrete Denil ladder with wooden baffles

[20] Estimated using the USGS StreamStats program.

(Brady et al., 2005). The fishways are regulated by stoplogs and also operate as the structures for the release of minimum flows. The upstream fish ladder typically begins operating one week after migrating fish are first observed in the Lawrence Hydroelectric Project fish lift on the Merrimack River, and closes July 31. The downstream fishway is operated to pass out-migrating adults starting two weeks after the upstream fish ladder opens and closing July 31, and then again to pass juveniles from September 1 through November 15 (OED, 2011).

Centennial Falls Dam (looking downstream), showing the power canal and gatehouse on the left, spillway and bypass reach below on the right, and fish passage structures adjacent to the river left side of the dam. See ***Figure 2.2.2-1*** *for a labeled version of this aerial image (Bing, 2015).*

Centennial Falls Dam (looking upstream). Fishway is out of view to the right side of picture (Smithwood, 2013).

Centennial Island fish passage structures, showing downstream bypass entrance on the left and Denil fish ladder exit on the right (Brady et al., 2005).

The LPCT, whose volunteers have performed fish counts in the past, has reported that fish are utilizing the fishway. However, the NMFS and the DFW report that fish may be attracted to the base of the dam rather than to the entrance of the fishway due to differences in attraction flows (Stratus Consulting, 2012).

Per the FERC exemption, the project is required to maintain a minimum flow of 57 cfs (or the natural inflow to the project, if it is less than 57 cfs), in the bypass reach and also to provide suitable fish passage facilities for anadromous fish. The FERC exemption does not include a requirement for American eel passage. It appears that eel are able to pass above the leaky, relatively low Centennial Falls Dam, but passage efficiency is unknown. Based on the project's approved Streamflow Monitoring Plan, minimum flows are to be provided through the fishways and through leakage at the dam. However, the USFWS has reported that, on several occasions, no water was observed flowing through the fish ladder outside of the passage season (USFWS, 2004).

The Centennial Island fishways have a long history of deficiencies documented in various inspection letters submitted by the USFWS to the Centennial Island Hydroelectric Company and/or the FERC, beginning with the fact that they were not constructed in accordance with the final plans approved by the USFWS. Subsequent issues have included missing or inadequate stoplogs, stoplogs in exit channel, missing or misaligned baffles, holes in the fishway, broken V-gate, missing tailrace screen, failure of the non-overflow section, debris clogs, excessive dam leakage, crumbled rock barrier dam, lack of legible staff gages, and others (USFWS, 2004).

On December 27, 2004, the Centennial Island Hydroelectric Company filed a fishway operations plan and schedule of repairs for the operation and maintenance of the fish passage facilities in response to concerns raised by the USFWS, which was approved with modifications by the FERC on February 23, 2005 (FERC, 2005). The plan includes the following measures:

- By March 20 of each year, an inspection of all fish passage facilities and flow monitoring devices will be conducted (including the barrier dam, non-overflow section, and tailrace screen) to assess their condition and need for repairs.

- By March 30 of each year, a schedule of repairs will be developed for the facilities, which will accommodate normal[21] maintenance and repair of the facilities prior to May 1 of each year.

- By March 30 of each year, the operator of the Lawrence Hydroelectric Project (FERC No. 2800) at the Essex Dam will be contacted in order to coordinate the commencement of the project's fish ladder.

- For each year of the project's operation, the commencement of operation of the fish ladder will be initiated by the removal of all stop logs and installation and alignment of baffles in a state of good repair. The tailrace screen will be installed and maintained in operable condition for the duration of each upstream fish passage season.

[21] The project owner defines normal repairs as those that can be accomplished without dewatering any area other than temporary closure of the Denil fish ladder. Repairs requiring dewatering or other extraordinary actions will have a separate schedule and proposal for action with notification given to state and federal agencies.

- At the start of upstream operation, stoplogs will be placed in the entrance and lower end of the fish ladder sufficient to create a 4- to 6-inch head difference between the tailwater and water surface inside the entrance, as measured at the upstream and downstream faces of the stoplogs.

- Upstream fish passage operations will be terminated on August 1 each year and any adjustments to stoplogs, baffles, and other facilities will be made.

- The downstream fish passage facilities will be operated 14 days after commencement of the fish ladder operation and continue through November 15 each year.

- Flow in the downstream bypass facility shall be controlled with stoplogs at the lower control weir set to elevation 96.5 feet with no stoplogs in the upper weir.

During the most recent inspection conducted by the USFWS on May 19, 2015, the following outstanding issues were identified (USFWS, 2015, June 23):

- **Fish ladder entrance drop** – The low tailwater level during the time of the site visit caused an excessive drop from the water surface within the entrance channel as well as negative hydraulics (e.g., turbulence, aeration) just downstream of the lowermost baffle. The USFWS recommends that the fishway be operable through a range of flows equivalent to the 95% exceedence flow (low flow) to the 5% exceedence flow (high flow), which corresponds to approximately 100 cfs and 1800 cfs according to a flow duration curve provided by the project owner. However, during the site visit in which the river flow was about 300 cfs, the fishway was not conducive to fish passage. The project owner was advised to work with USFWS engineering personnel to implement additional weir boards to appropriately backwater the lowermost baffle. The boards would be cut as v-notch weirs and could be affixed to the concrete via angle iron. Boulders could also be configured downstream of the entrance to provide additional backwatering.

- **Tailwater staff gage –** The USFWS recommended that a tailwater staff gage be placed on the downstream face of the fish ladder entrance wall or other convenient location that could be easily tied into the fish ladder elevations in order to collect tailwater data. Tailwater elevations should be recorded at flows within the full range of fish passage flows and sent to USFWS affiliates. This information would be utilized to develop a tailwater rating curve and assist in the design of entrance channel weirs.

- **Trash rack –** A trash rack did not exist at the exit of the fish ladder. Debris within a Denil fish ladder can cause the entire system to be non-functional. The USFWS recommended that a trash rack with 8-inch clear spacing be implemented at the exit to prevent coarse debris from entering the fish ladder. Additionally, the fish ladder should be inspected for debris on a daily basis during the upstream migratory season.

Additionally, the 2015 inspection report noted that lower flows, such as during the site visit that day (approximately 300 cfs), seem to be more conducive to fish passage through the bypass reach than higher flows. This further validates the need to have the fishway fully functional at lower flows (USFWS, 2015, June 23). OED has been actively coordinating with the USFWS to address the items noted in the most recent inspection report in what has been a mutually positive working experience.

The recent inspection also noted that 2015 was the first year in which river herring were observed using the fish ladder (USFWS, 2015, June 23). This success is in part due to the continued cooperation and active management of the fishways by OED.

2.2.3 Talbot Mills Dam

The third and primary obstacle to fish passage in the Concord River is the Talbot Mills Dam (NID ID MA00774) at river mile 4.76 in Billerica, a former mill dam that currently has no fish passage facilities. The drainage area at this location is approximately 370 square miles[22]. The dam is privately owned by CRT Development Realty, LLC (CRT). It is approximately 316 feet long[23] with a maximum height of about 15 feet, and is comprised of stone masonry, concrete, and (presumably) earthen materials (Geotechnical Consultants, 2015). The three major components of the dam are:

- Primary spillway and abutments
- Non-overflow section and intake structure to the Talbot Mills complex (river left side)
- Sluiceway and intake structure to the Faulkner Mills complex (river right side)

Figure 2.2.3-1 shows an aerial image of the site with key features labeled. **Figures 2.2.3-2** and **2.2.3-3** show schematic and survey plans of dam features, respectively. Photographs of the site can be found in **Appendix B**.

The primary spillway is a broad-crested stone masonry structure of mortared square-cut granite block construction with a near-vertical downstream face (Geotechnical Consultants, 2015). It is approximately 127 feet long with a height of about 10.2 feet and a crest elevation of approximately 108.2 feet NAVD 88[24]. The spillway is trapezoidal in cross-section with an 8-foot wide base and 7-foot wide crest. It has a curving footprint and a narrow capstone across the downstream lip of the crest. The spillway crest reportedly dips slightly lower toward the middle of the structure, as shown in historical dam plans (see

---

[22] As reported in the Flood Insurance Study (FIS) (FEMA, 2014).

[23] This reported length excludes a training wall on the left and a sluiceway on the right, but does include an approximately 150-foot-long embankment section to the left of the primary spillway that supports Faulkner Street and forms part of the impoundment shoreline. It is unknown whether this embankment was constructed to serve as part of the dam or was a pre-existing natural landform that was later bisected by an intake structure and armored with retaining walls to prevent scouring.

[24] The spillway crest elevation of 108.2 feet NAVD 88 reported here was determined by a survey conducted on October 6, 2014 by Gomez and Sullivan using RTK GPS with a vertical accuracy of 0.05-0.2 feet. Several points were taken at each edge of the spillway (the reported dip in the center of the spillway was not measured). The points on the left edge were 108.0 feet NAVD 88 and the points on the right edge were 108.4 feet NAVD 88, for an average of 108.2 feet NAVD 88. This elevation corresponds exactly with that reported in the text of the effective (2014) FIS and in both the report text and flood profiles of earlier (2010 and 1985) publications of the FIS. However, in the hydraulic model used to develop the 2014 FIS, the spillway crest elevation is modeled 2.5 feet higher at 110.67 feet NAVD 88. Consequently, the regulatory (100-year) flood elevation at the dam is almost 2 feet higher in the 2014 FIS (115.9 feet NAVD 88 vs. 114.0 feet NAVD 88 in the 2010 and 1985 publications), a difference that propagates upstream and is still over a half of a foot in magnitude at the upstream extent of the Concord River model. The STARR team has confirmed that the elevation used in the model was an error, and their survey found the dam to be approximately 108.1 feet NAVD 88. The FIS is currently undergoing revisions and a preliminary version was been published on April 29, 2015 (which also contains the dam elevation error). Now that the STARR team is aware of the error, it is assumed that the preliminary FIS will be revised.

Figure 2.2.3-4) and evidenced by photographs taken during low flow events (see **Appendix B**) (MA House of Representatives, 1860).

The spillway is flanked by small granite block masonry abutments that tie into retaining/training walls for the river and impoundment. Both abutments are topped with a large granite capstone adjacent to the spillway. At flood stages, the abutments serve as auxiliary spillways to provide additional discharge capacity (Geotechnical Consultants, 2015). The left and right abutments have lengths of approximately 17 and 20 feet and average crest elevations of 110.5 and 110.8 feet NAVD 88[25], respectively. The left abutment contains two small low level outlets with downstream inverts at approximately 99.8 feet NAVD 88 (Geotechnical Consultants, 2015). The outlets are blocked, although discharge has been observed at their downstream end. There is no operational low level outlet for the dam. Numerous anchor holes in the top of the left abutment are likely related to a pair of former waste gates, which, after several replacements, were removed around 1950. Portions of the top course of the right abutment are braced with an iron strap. A section of the right abutment is constructed of cast-in-place concrete and is reportedly the location of a former wooden fish ladder that was filled with concrete sometime after the 1960s (Ingraham, 1995).

The embankment or non-overflow section of the dam extends from the left spillway abutment approximately to an 1880s brick former cloth warehouse for the Talbot Mill, supporting Faulkner Street and separating the impoundment from the Talbot Mills complex located on the left bank of the river just downstream from the dam. The top of dam (road) elevation is approximately 113.8 feet NAVD 88 (Geotechnical Consultants, 2015; FEMA, 2014). Remnants of the Old Middlesex Canal alignment (Segment 24) are located to the south of the old Talbot cloth warehouse building.

A 60-foot-long vertical concrete wall at the southernmost end of the embankment section of the dam contains five intake gates which formerly provided water to the Talbot Mills complex. The gates are no longer functional and the intake tunnels upstream of the Talbot Mills complex have been filled with concrete (Geotechnical Consultants, 2015).

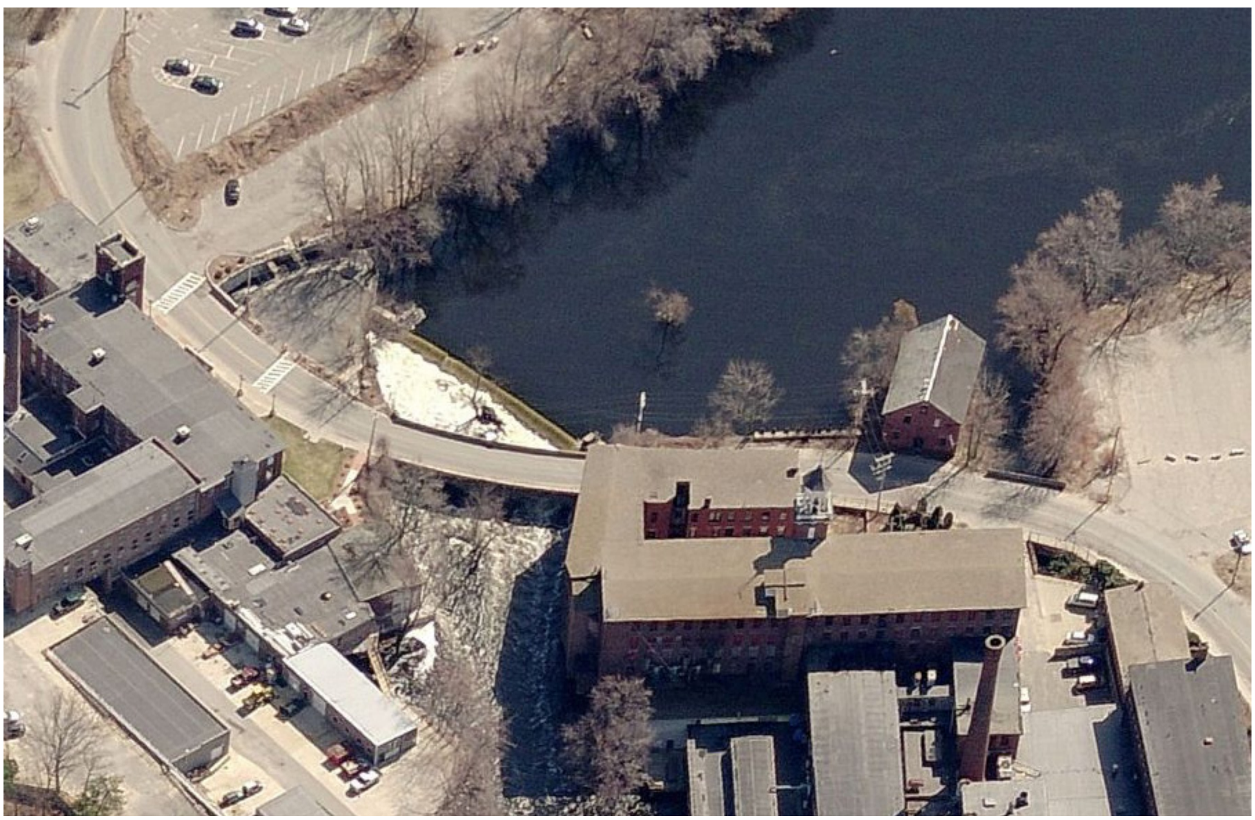
An approximately 12-foot-wide, mortared stone masonry and concrete sluiceway just east of the right spillway abutment diverts water to the Faulkner Mill complex located on the right bank of the river just downstream from the dam. The sluiceway contains a concrete weir with a movable sluice gate. The gate is in poor condition and leaks through large gaps in the wood. Water in the sluiceway passes under a small bridge supporting Faulkner Street and into a stilling basin located between the road and the Faulkner Mill complex. From the stilling basin, water flows through an outlet gate locked in the open position to a turbine under the mill, which reportedly has not been in service since 1972 (Geotechnical Consultants, 2015). Water from the sluiceway is discharged back to the river approximately 150 feet downstream of the Faulkner Street bridge. The outlet channel is shared with a sewer pipe that services Faulkner Mills.

Numerous bedrock outcrops are visible at the toe of the spillway and form the downstream channel bed. Although channel elevations in this area vary due to the jagged rock profile, the estimated elevation of the channel downstream of the spillway ranges from approximately 95.5 feet to 98.9 feet NAVD 88 (FEMA, 2014).

[25] Average elevations exclude the additional 2- to 3-foot height of the right and left abutment granite capstones, respectively.

The lower portion of the impoundment backwatering from the Talbot Mills Dam up to the Pollard Street bridge is referred to in this study as the "lower impoundment" and is also known as the Mill Pond[26]. It is approximately 30 acres in surface area during the 2-year (i.e., "bankfull") flood[27]. Key features of the lower impoundment are shown in **Figure 2.2.3-5**. The influence of the dam extends upstream beyond the Mill Pond into the riverine section of the Concord River. As part of this study, an analysis was conducted to determine the approximate upstream extent of the dam's impoundment (**Section 3.4**). **Appendix C** presents a set of eight aerial photographs of the Talbot Mills Dam area taken between 1938 and 2006 and compiled for the 2009 dam safety inspection report (Geotechnical Consultants, 2015). The photographs show that the pond shoreline has remained relatively unchanged throughout the 68-year period.

A small park is located adjacent to the right abutment of the spillway. The park contains a gazebo, benches, and a historic marker dedicated to the employees of the Faulkner Mills. Access to the park is available from a paved parking lot just east of the river and south of Faulkner Street by crossing a pedestrian bridge over the sluiceway. The Faulkner Mills complex currently houses the Middlesex Canal Museum and Visitor Center. In 2014, the MCA acquired the old Talbot cloth warehouse building adjacent to the dam, which it plans to restore and transform into a new home for the museum in the future (Breen, 2014).



*Talbot Mills Dam (looking upstream), showing the Faulkner Mills complex on the left and the Talbot Mills complex on the right. See **Figure 2.2.3-1** for a labeled version of this aerial image (Bing, 2015).*

[26] Also referred to as the Millpond, the millpond or the mill pond.

[27] The surface area was estimated by mapping the inundation area of the 2-year flood elevation determined by the hydraulic model developed for this study (discussed in **Section 3.4**).

Talbot Mills Dam (looking upstream), showing the bedrock channel downstream of the dam.

Dam Purpose

Historically, the Talbot Mills Dam and its predecessors were used to impound water for power and fire protection purposes for the adjacent mills, and to divert water into the old Middlesex Canal that flowed to Boston. The most recent dam safety inspection report (Geotechnical Consultants, 2015) states that the dam is currently used for recreational and flood control purposes. However, it is important to note that an overflow or "run-of-river" type of dam such as the Talbot Mills Dam does not provide flood control. Dams can be divided into two groups based on their style of operations: storage and run-of-river. A storage dam typically has a large hydraulic head and storage volume, long hydraulic residence time, and control over the rate at which water is released from the impoundment, thereby lending it useful for flood control purposes. By contrast, a run-of-river dam usually has a small hydraulic head and storage volume, short residence time, and little or no control over the water-release rate (Poff and Hart, 2002). As such, run-of-river dams are usually not beneficial for flood control, and actually may exacerbate upstream flooding by raising water surface elevations. In fact, in the 1700s and 1800s, the higher water levels created by the Talbot Mills Dam flooded upstream meadows and led to tension among local farmers and legal action (see **Section 2.1.2**). The hydraulic analysis conducted for this study (**Section 3.4**) found that the dam increases upstream water surface elevations—by at least 3.5 feet upstream of the dam and 0.8 feet at the upstream extent of the Concord River for the 100- and 500-year floods[28]. The lack of any operable low level outlet or emergency bypass system at the Talbot Mills Dam further decreases its ability to provide any sort of flood control.

[28] These hydraulic modeling results are based on the conceptual removal of the primary spillway and abutments and associated mobilization of impounded sediment that would be expected to occur (discussed in **Section 4.3.3**). Due to the lack of detailed drawings showing the bedrock profile underneath the dam, elevations under the spillway were assumed from sediment probing data conducted just upstream (**Section 3.2.1**). Flooding impacts of the dam could be more significant if the bedrock profile under the dam is lower than the sediment probing data suggest.

Dam Safety

The Talbot Mills Dam is classified as an Intermediate sized[29], Significant (Class II) Hazard[30,31] potential structure. Significant hazard potential dams must be inspected every five years (DCR, 2005). The most recent Phase I dam safety inspection was conducted on October 28, 2015 and November 6, 2015 by Geotechnical Consultants, Inc. Previous inspections on file with the ODS were conducted in 2009 by Geotechnical Consultants, Inc. and in 1999 by Weston & Sampson Engineers, Inc. According to the 2015 inspection, the Talbot Mills Dam was found to be in "fair" condition. The following deficiencies were noted:

- Lack of an operation and maintenance plan
- Lack of routine oversight of the dam, particularly during storm events
- Lack of working controls
- Lack of an operable low level outlet and emergency bypass in the event of flooding
- Seepage in the spillway abutments, particularly the left abutment
- Trees located just downstream of the primary spillway and on the upstream face of the left embankment near the former intake gates to the Talbot Mills complex

The following remedial measures were recommended in the inspection report:

- Prepare and implement routine inspection and maintenance plans
- Inspect the interior of the of the Talbot Mills complex, particularly the downstream end of the former intake structures
- Repair/replace the sluiceway and stilling basin gates so that the gates are operational and can provide emergency bypass control
- Repair/replace the left spillway abutment to provide an operational low level outlet and emergency bypass control
- Remove trees located just downstream of the primary spillway and on the upstream face of the left embankment near the former intake gates to the Talbot Mills complex

The inspection report estimated conceptual opinions of probable construction costs for several of the recommendations, including tree removal ($5,000), repair/replacement of the sluiceway and stilling basin gates ($60,000) and repair replacement of the left spillway abutment ($40,000), for a total repair cost of approximately $105,000 (Geotechnical Consultants, 2015). However, these estimates are much lower than expected and may not include all costs associated with implementing these measures, such as engineering, permitting, water control, etc. Particularly if the left abutment or any of the gates must be replaced rather than just repaired, estimated costs would likely be more on the order of several hundred thousand dollars.

---

[29] An Intermediate sized dam is one that has a storage volume between 50 and 1,000 acre-feet and is between 15 and 40 feet tall (DCR, 2005).

[30] A Significant (Class II) Hazard potential dam is one located where failure may cause loss of life and damage home(s), industrial or commercial facilities, secondary highway(s), or railroad(s), or cause interruption of use or service of relatively important facilities (DCR, 2005).

[31] Talbot Mills Dam was previously classified as High (Class III) Hazard potential, but was reclassified in 2009 (Geotechnical Consultants, 2015).

Existing significant hazard potential dams of intermediate size are required to have the capacity to pass a spillway design flood equivalent to the 100-year flood (DCR, 2005). The dam safety report noted that, according to the FEMA FIS of 1985, the 100-year flood would produce a flow of 5,675 cfs and a water surface elevation of 113.9 feet NAVD 88 at the Talbot Mills Dam. Given this water surface elevation, the inspection report estimated the spillway capacity to be approximately 6,650 cfs[32], which is greater than the flood flow, and thus concluded that the spillway is adequate to pass the design flood (Geotechnical Consultants, 2015). However, at this elevation, floodwaters would overtop both spillway abutments and the dam crest, which lies at elevation 113.8 feet NAVD 88 according to both the dam safety report and 2014 FIS (Geotechnical Consultants, 2015; FEMA, 2014). ODS regulations do not explicitly prohibit the overtopping of spillway abutments or embankment sections in analyzing whether the dam can pass the spillway design flood. However, ODS recommends that engineers use their best professional judgement to evaluate whether the abutments and/or embankments are structurally sound enough and designed for overtopping. Due to leakage through both abutments and the fact that the embankment section is a public road, Gomez and Sullivan does not recommend that these structures be overtopped in the spillway design flood. As part of this study, a hydraulic analysis was conducted to confirm whether or not the dam meets spillway capacity requirements (**Section 3.4.3**).

As a follow-up to the 2009 dam safety inspection, a dam break analysis was performed to determine the incremental increase in flooding downstream of the dam and evaluate the severity of any potential damage, with the intent of reclassifying the dam from High (Class III) to Significant (Class II) Hazard potential if appropriate[33]. A dam break model was developed using the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) software. The resulting unsteady flow analysis showed only a small (0.2 foot) increase in flood height in the areas downstream of the dam due to a dam breach. Based on this information, the request to reclassify the dam as Significant (Class II) Hazard potential was approved (Geotechnical Consultants, 2015). A dam break model was not developed for this study to be able to confirm this finding. However, reconnaissance-level observations downstream of the dam suggest that the reclassification is appropriate.

History

The Talbot Mills Dam is a historic property listed in the National Register of Historic Places as a contributing resource to the Middlesex Canal Historic and Archaeological District, and is a potential contributing resource to the Billerica Mills Historic District. The dam is also within the North Billerica Mills Local Historic District. The site of the current Talbot Mills Dam has a long and controversial past, with multiple dams being constructed, removed, and rebuilt throughout the years. A timeline of historical events at the dam site is provided in **Figure 2.2.3-6**. A cultural analysis was conducted as part of this feasibility study and additional details are provided in **Section 3.5**.

---

[32] The estimated spillway capacity of 6,650 cfs includes approximately 620 cfs attributed to the auxiliary capacity of the spillway abutments.

[33] Hazard classifications are based only on conditions downstream of the dam (e.g., the potential for property damage and/or loss of life) and do not consider the condition of the dam itself. A Significant (Class II) Hazard potential dam is defined as a dam where "failure *may* cause loss of life and damage home(s), industrial or commercial facilities, [or] secondary highway(s) or railroad(s), or cause interruption of use or service of relatively important facilities," whereas a High (Class III) Hazard potential dam is defined as a dam where "failure *will likely* cause loss of life and serious damage to home(s), industrial or commercial facilities, important public utilities, main highway(s) or railroad(s)" (emphasis added) (DCR, 2005).

To understand the history of human occupation of the Concord drainage area, it is necessary to understand the regional long-term human settlement, technology, and subsistence practices in the pre-contact[34] through modern periods. Archaeologists have documented nearly 12,000 years of pre-contact Native American occupation of the region, and oral traditions of some contemporary tribes tell of a 50,000-year cultural legacy. Prior to 7,000 years ago, Native American peoples focused primarily on inland-based resources and on hunting and collecting along the Northeast's waterways. After 7,000 years ago, settlement became more concentrated within the region's major river drainages. By 3,000 years ago, concurrent with a focus on coastal and riverine settlement, large populations lived in nucleated settlements and developed complex social ties. During the centuries before European contact, these groups began to coalesce into the peoples known as Pocumtuck, Nipmuck, Massachusett, Wampanoag, Pokanoket, Mohegan, Pequot, and Narragansett (PAL, 2016).

Prior to the damming of the Concord River in North Billerica, the area was used by generations of Native Americans as an encampment and fishing grounds (Hazen, 1883). A 1700 map of Billerica (shown in **Figure 2.2.3-7**) documents the existence of a series of falls in the Concord River between the present day Pollard Street and Faulkner Street bridges (Ingraham, 1995). A large Native American village is reported to have been located along the Concord River in proximity to the Talbot Mills Dam. The Native American occupation in the area of the dam was focused on a natural falls, which would have afforded an abundance of diadromous fish resources and wildlife (PAL, 2016). Early colonists settled Billerica in 1653 and continued to use the river's fisheries (Wildman, 2013).

The first dam was erected at the location of the current Talbot Mills Dam in 1710-11 by Charles Osgood. It was built in three sections of wood frame with gravel fill, was likely between 5 and 7 feet in height, followed a "zigzag" course across the bedrock outcroppings in the river, and was situated upstream from the current dam. Since its construction, dam owners have faced many complaints and legal battles from local residents about blocked fish passage and elevated upstream water levels leading to flooding of adjacent meadow lands farmed for hay (see **Section 2.1.2**). In 1711, the dam owner was ordered to pay restitution to a flooded upstream landowner. In 1721, the dam was removed by order of the court, but was quickly rebuilt by 1722. That same year, the dam was forcefully removed by the aggrieved landowners whose properties had been flooded[35], damaging the gristmill in the process. Subsequent lawsuits ended in favor of the dam owner, and the dam was rebuilt for the second time shortly thereafter[36] (Ingraham, 1995).

In 1794, the dam was sold to agents acting for the Proprietors of the Middlesex Canal. In 1798, the dam was rebuilt for the third time to address leaks, an increased demand for water power, and the need for water to fill the lengthening canal. The new structure was a "figure" dam of wood frame built with 2 ¾-inch-thick planks and filled and tightened with sand and gravel. It was approximately 150 feet long and 8 feet high. Records indicate the presence of flashboards attached to the cap sill, ranging in height from 20 to 33 inches in various reports (Ingraham, 1995 and MA House of Representatives, 1860). The dam may have been referred to as the "Richardson Dam" (MA House of Representatives, 1860, pages 169 and 272).

---

34 An archaeological property may be pre-contact, post-contact, or contain components from both periods. Pre-contact (sometimes referred to as "prehistoric") archaeology focuses on the remains of indigenous American societies as they existed before substantial contact with Europeans and the resulting written records. There is no single year that marks the transition from pre-contact to post-contact (PAL, 2016).

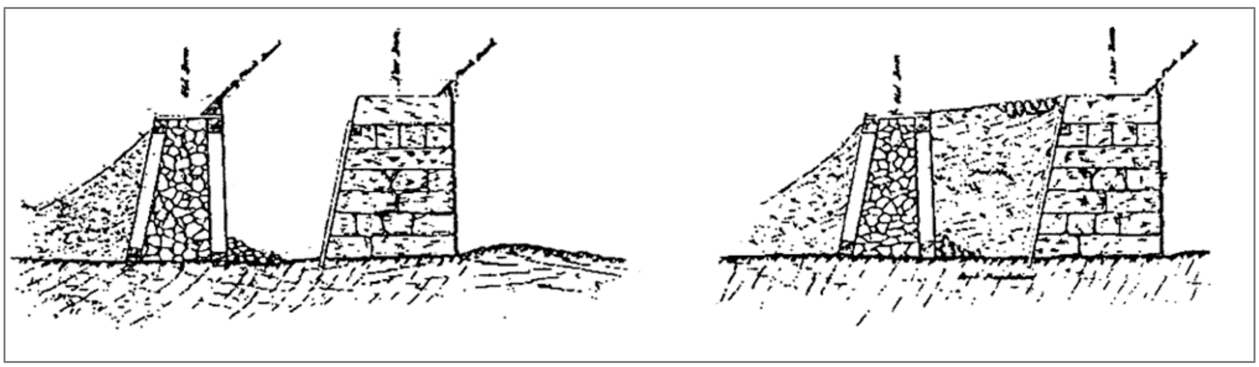
35 Donahue (1989) reported that blocked fish runs were the reason for the 1722 forceful dam removal by farmers.

36 An exact year for the construction of the third dam is not known, but it was prior to Osgood's death in 1739 (Ingraham, 1995).

An 1860 account noted the following about the dam's construction (MA House of Representatives, 1860, page 266):

> *The old Dam was a rolling-dam—a box-dam, filled with stone, planked over on the top, and flash boards on top of that. The planking we called a figure-4—fixed up with joists. They put solid timber, sawed in two, on the Dam, in 1820 or '21. We took timber twelve or fourteen inches square, and split it corner-wise, and trunneled it on, with the biggest way up, so that it would be 12 or 14 inches above the Dam. We trunneled it on with 2-inch trunnels, and then a plank of 2-inch planking, which we trunneled on with spikes, and then a board nailed on that, making about 30 inches above the planking of the Dam.*

In 1828-29, the canal proprietors built the current (fifth) masonry dam to replace the deteriorating and insufficient 1798 structure. Rather than removing the earlier dam, the new dam was built just downstream (approximately 8 to 12 feet) and the space between them was filled with rock and gravel, as shown in the figure below. During this era, antiquated dams were commonly left in place to be submerged by the new, usually taller dams that replaced them, in part to save on demolition costs and provide water control during construction of the new dam. The submerged dam is often referred to as a "legacy dam." The new dam crest was set about 12 to 14 inches higher than the cap sill of the old dam, but its flashboards were lower than those of the old dam (with reported flashboard heights ranging from 9 to 11 inches for the 1828 dam and 20 to 33 inches for the 1798 dam) (MA House of Representatives, 1860).



An 1829 detail showing the relative positions of the current Talbot Mills Dam (on the right / downstream in each detail) and the legacy dam that was submerged when the current dam was built (on the left / upstream in each detail). The legacy and current dams were the fourth and fifth dams built at the Talbot Mills site, respectively (Ingraham, 2009).

In 1975, the Cambridge Tool and Manufacturing Co., Inc. purchased the complete Talbot Mills complex, including the dam, the water rights, and property around the mill pond. The impoundment was used for process water until town water became available. Cambridge Tool and Manufacturing Co., Inc. was later sold to Pace Industries, who was in turn were sold to Leggett & Platt, excluding the dam and water rights, but including the property around the mill pond. In 2011, Leggett & Platt then granted a 50-foot-wide strip of land that borders the mill pond up to Pollard Street, including the floating towpath peninsula, to the MCC[37]. The dam and water rights are still held by the original owners of Cambridge Tool and Manufacturing Co. Inc., doing business as CRT Development Realty, LLC (T. Raphael, personal

[37] The granter's title deed is recorded in Book 22265, Page 216, and the grantee's title deed is recorded in Book 24911, Page 61 at the Middlesex North Registry of Deeds

communication, November 17, 2014). A map of properties abutting the Talbot Mills Dam and lower impoundment is provided in **Figure 2.2.3-8**.

Fish Passage

There is a long history of fish passage being provided and repealed/removed at the Talbot Mills Dam and throughout coastal Massachusetts. Shortly after the first dam was erected across the Concord River in North Billerica in 1710-11, local residents complained about it blocking fish passage. Following the forceful removal and subsequent rebuilding of the dam in 1721-22, disputes about blocked fish runs were temporarily assuaged by opening up the spillway every spring for two months to facilitate upstream passage of fish (Donahue, 1989). A fishway was later added to the dam to fulfill a 1791 agreement between a dam owner and neighboring landowner. Both the 1798 and 1828 dam structures reportedly included a fishway at the northeast (river right) end of the spillway. Maintaining a fishway at the dam was required by an act of the Legislature as early as 1820, which ordered the following (MA Senate and House of Representatives, 1820):

> *…so long as there shall be kept and upheld, a dam across Concord River, in the Town of Billerica, where the mill dam of the proprietors of the Middlesex Canal now is situated, there shall be kept open at the usual place in said dam, a sluice or passage way for fish to pass up and down the river through said dam, from the first day of April to the twentieth day of May in each year; which sluice or passage way shall be constructed with a permanent mud sill, to be placed upon the bottom of the natural channel of said river, with permanent abutments and a cross timber at the top, not less than thirty inches above the mud sill, and shall not be less than fifteen feet in breadth, except only, when by reason of the falling of the water in said river, there shall not be more than twenty four inches of water above said mud sill, the said passageway, with the advice and consent of the Fish Wardens of Billerica, given in writing, may be diminished in proportion to the depth of the water; provided, however, that it shall never be reduced to a less breadth than six feet.*

Historical plans of the dam showing evidence of the former fishway are shown in **Figures 2.1.2-2**, **2.2.3-9** and **2.2.3-10**. The fishway was reportedly filled with concrete sometime after the 1960s, rendering it useless and obscuring its original appearance (Ingraham, 1995). However, based on the historic plans and reports, it is likely that the former fishway was simply an opening in the dam through which fish could swim under suitable flow conditions. The most probable location is the portion of the right spillway abutment currently comprised of concrete (pictured at right). The granite capstones under the concrete "plug" likely formed the sill over which fish swam. The concrete plug (and the assumed former fishway opening) is about 16 feet wide by 6.5 feet high with a bottom elevation (top of the granite sill under the concrete plug) of approximately 104.3 feet NAVD 88. The opening was probably fitted with wooden stoplogs or a gate structure (as suggested by the wood line across the fishway opening in **Figure 2.2.3-10**) so that it could be closed at times of the year outside of the mandated fish migration period (which was noted in the Act of 1820 above as April 1st through May 20th). The small notch in the bottom of the concrete plug may have been formed by a remnant of a wooden structure associated with the fishway that has since rotted away. The fishway opening could have also been used to draw down the impoundment (e.g., to inspect or repair the dam) or help reduce

upstream flooding, as noted in historical accounts, such as: "The fish-way was used to keep the water down, before and after the new [1828] Dam" (MA House of Representatives, 1860, page 272). It is unknown how effective the former fishway was at providing for upstream fish passage under the range of flows experienced during the migration period.

The fishway obligation was repealed for the Concord River in 1835, but was subsequently reinstituted for the Merrimack River in 1866 and extended to its tributaries (including the Concord River) in 1876 (MA Senate and House of Representatives, 1835, 1866, and 1876). These and other acts requiring and repealing fish passage obligations throughout history have since been superseded by Massachusetts General Law Chapter 130, which established *MarineFisheries* and the authorization to require dam owners to provide fish passage at dams (Section 19). Regardless of legal mandates, the demand for water often kept the Billerica fishway closed (e.g., as recounted in MA House of Representatives, 1860, page 169, "…there was a fish-way in the Dam of 1798. It was not kept open. All the water was wanted for the Dam.").

2.3 Infrastructure

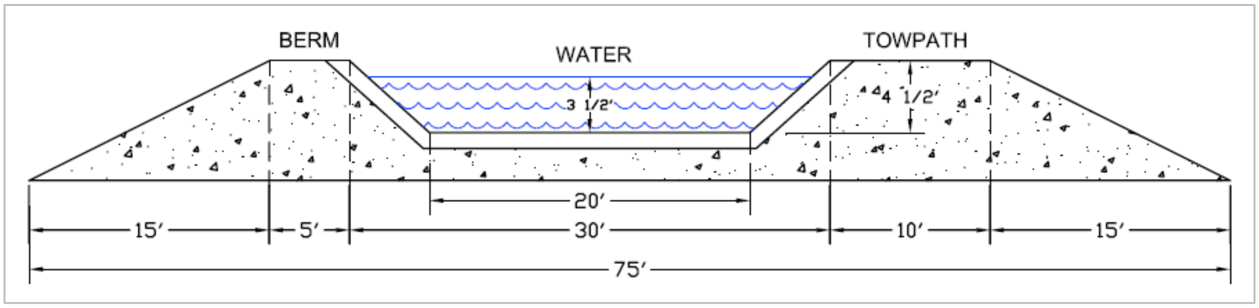
One potential restoration alternative considered by this study is alteration or removal of the Talbot Mills Dam. Whenever a dam is considered for removal, legitimate concerns are raised about the potential impacts to infrastructure upstream or downstream of the dam due to lower water levels, higher water velocities, and/or scouring of sediments. This section describes the various instream infrastructure in the vicinity of the Talbot Mills Dam that were considered in the feasibility analysis.

2.3.1 Middlesex Canal

The historic Middlesex Canal, which is listed in the National Register of Historic Places, was a 27.25-mile-long waterway connecting the Merrimack River at Middlesex Village in Chelmsford, Massachusetts (now part of the City of Lowell) with the Charles River in Charlestown, Massachusetts (which is connected to the Boston Harbor). The canal route crossed the Concord River in North Billerica just upstream of the Talbot Mills Dam. After a 1794 survey determined that the Concord River was the highest point on the proposed route, the water surface elevation in the canal was set to one foot higher than the cap sill of the dam in order to prevent an increase in upstream flooding (Ingraham, 1995). Consequently, the dam impoundment was used as the principal water source for the canal. The canal water surface elevation was also reportedly level with the top of an iron bolt set in 1825 near the dam as a benchmark with an elevation of 108.81 feet NAVD 88[38] (Breen, 2015).

Construction of the canal began in 1794 in North Billerica and was completed in 1803. The typical canal prism was 30 feet wide at the top and 20 feet wide at the bottom with an average water depth of 3 ½ feet, as shown in the figure below (Waterfield Design Group, 2008a). Assuming a canal water surface elevation of approximately 108.81 feet NAVD 88, the canal bottom elevation can be estimated to be approximately 105.31 feet NAVD 88 (108.81-foot water surface minus 3.5-foot water depth) (Breen, 2015).

[38] The bolt still exists today (see photo in **Appendix B**) and in 2013 its top elevation was re-measured as 108.81 feet NAVD 88 from a temporary benchmark set in 2000 from the 1965 US monument MY0308 (Breen, 2013).



Typical Middlesex Canal prism and buffer cross-section (Waterfield Design Group, 2008a).

Use of the canal slowly declined after the construction of nearby railroads in the 1830s (Ingraham, 1995). After canal operation ceased in 1851, its infrastructure quickly fell into disrepair. Although portions of the canal are still visible today (as either wetted or dry prisms), much of it was built over by roads and other construction.

Figure 2.3.1-1 depicts the route and current condition of the former canal in the vicinity of the Talbot Mills Dam. As shown on the map, canal Segment 24 crosses the impoundment on a northwest-southeast axis that lies approximately 150 to 1,000 feet from the dam, respectively. A short section of wetted canal can be seen on the south side of the old Talbot cloth warehouse building at the left edge of the dam embankment. Several historic features related to the canal are located within the impoundment, including a peninsula and anchor stone for a former floating towpath, which was a 150-foot-long structure that enabled draft animals to pull canal boats across the impoundment.

Part of the mission of the MCC is to create a Middlesex Canal Heritage Park, of which a key design focal point is the proposed Mill Pond/Canal Park in the vicinity of the Talbot Mills Dam and Mill Pond. As conceptually designed, the park will highlight four remaining major canal structures at the site: reconstruction of portions of the east and west ends of the former floating towpath, repair of the only remaining lock on the canal (between Faulkner Street and the Talbot Mills complex), and reconstruction of the Red Lock (downstream of the Talbot Mills complex). **Figure 2.3.1-2** shows the proposed concept plan for the park.

As part of this study, the potential effects of restoration alternatives on the Middlesex Canal (e.g., lower water surface elevations in Segment 24 of the canal) were investigated.

2.3.2 Billerica Water & Wastewater Treatment Infrastructure

Water Supply Intake

The Billerica Department of Public Works (DPW) Water Division[39] withdraws water from the Concord River to supply drinking water to the town of Billerica[40]. The DPW is currently authorized by Water Management Act (WMA) Permit #9P31403101 to withdraw an average daily volume of 0.93 MGD and by WMA Registration #31403101 to withdraw of 4.41 MGD, for a total average daily withdrawal (registered plus permitted) of 5.34 MGD. Actual average daily use from 1992 to 2014 has averaged 4.53 MGD.

[39] Also known as Billerica Water Works.

[40] Public Water System (PWS) ID No. 3031000-01S.

The water supply intake (pictured at right) is located approximately 6,700 feet (about 1 ¼ miles) upstream of the Talbot Mills Dam (about 1,200 feet downstream of the Route 3A/Boston Road bridge), which is within the dam's impoundment[41]. The intake structure was built in 1955 and consists of a screened wet well and three pumps used to withdraw water from the river (J. McGovern, personal communication, 2014). **Figure 2.3.2-1** provides an excerpt from the 1954 engineering plans for the intake structure showing the following key elevations:[42]

- Maximum flood elevation = 117.2 feet NAVD 88
- Normal high water elevation = 113.2 feet NAVD 88
- Minimum low water elevation = 107.2 feet NAVD 88
- Structure invert elevation = 102.2 feet NAVD 88

As part of this study, the potential effects of restoration alternatives on the Billerica water supply intake (e.g., lower water surface elevations at the intake) were investigated.

Water Main Crossing

A 24-inch-diameter force water main pipe crosses the Concord River within the dam impoundment at a point approximately 900 feet upstream of the water supply intake (about 7,600 feet or 1.4 miles upstream of the Talbot Mills Dam). The main is located immediately downstream of an abandoned abutment from the former Bridge Street bridge, which is about 325 feet downstream from the Route 3A/Boston Road bridge. **Figures 2.3.2-2 and 2.3.2-3** provide excerpts of the plan and profile views from the 1969 engineering plans for the water main. According to the plan, the water main was buried a minimum of 2 feet below the channel bottom, with a top elevation near the channel centerline of approximately 103 feet NAVD 88[43]. The channel bottom was surveyed at the abandoned abutment for the 2014 FIS, and was found to have a minimum channel elevation of 104.8 feet NAVD 88, which corresponds closely to the elevation shown on the 1969 plans. As part of this study, the potential effects of restoration alternatives on the water main crossing (e.g., the potential for scour due to higher water velocities) were investigated.

Sewer Main Crossing

A 16-inch-diameter ductile iron sewer main pipe crosses the Concord River within the dam impoundment immediately upstream of the abandoned former Bridge Street bridge abutment noted above. **Figure 2.3.2-3** provides the 1976 record plan and profile drawings for the sewer main. According to the plan, the sewer main was buried about two feet below the channel bottom, with a top elevation near the channel

---

[41] Note that the water treatment plant was moved from the Boston Road location to a new location off Treble Cove Road upstream. The possibility of moving the intake to the Treble Cove location was investigated (CDM, c. 2001), but ultimately the intake location was maintained at the Boston Road location.

[42] Although not specified, it is assumed that elevations in the plans are given in NGVD 29, as NAVD 88 had not yet been introduced at the time of publication (1954). Elevations in this report have been converted to NAVD 88.

[43] Although not specified, it is assumed that elevations in the plans are given in NGVD 29, as NAVD 88 had not yet been introduced at the time of publication (1969). Elevations in this report have been converted to NAVD 88.

centerline of approximately 101.9 feet NAVD 88[44], and is seated almost entirely within the ledge (with the top of the ledge being approximately equal to the top of the pipe). As noted above, the channel bottom was surveyed at the abandoned abutment for the 2014 FIS, and was found to have a minimum channel elevation of 104.8 feet NAVD 88. As part of this study, the potential effects of restoration alternatives on the sewer main crossing (e.g., the potential for scour due to higher water velocities) were investigated.

2.3.3 Bridges

Three bridges in the vicinity of the Talbot Mills Dam are discussed in this section—the Faulkner Street bridge immediately downstream of the dam, and the Pollard Street and Boston Road/Route 3A bridges within 1 ½ miles upstream of the dam. An additional seven bridges are located further upstream (as well as at least two abandoned bridges that cause constrictions), but were not covered in detail here, as any potential impacts due to restoration alternatives at the Talbot Mills Dam are likely to be negligible upstream of the hydraulic grade controls at Pollard Street and Boston Road. As part of this study, the potential effects of restoration alternatives on the bridges (e.g., the potential for scour due to higher water velocities) were investigated.

Faulkner Street

The Faulkner Street bridge is located immediately downstream of the Talbot Mills Dam. The left bridge abutment is directly connected to the left spillway abutment, while the right bridge abutment is connected to the right spillway abutment by an approximately 100-foot-long stone masonry retaining wall. The curved concrete double arch structure was constructed in 1910 and is approximately 106 feet long, 32 feet wide, and has two individual spans about 42 feet wide at the base separated by a center pier (FEMA, 2014; Geotechnical Consultants, 2015). The center pier and abutments appear to be armored and founded directly on bedrock, and no significant indications of scour have been observed during inspections (Geotechnical Consultants, 2015).

No plans for the Faulkner Street bridge could be found on file with the Town of Billerica or the Massachusetts Department of Transportation (DOT).

[44] Although not specified, it is assumed that elevations in the plans are given in NGVD 29, as NAVD 88 had not yet been introduced at the time of publication (1969). Elevations in this report have been converted to NAVD 88.

Pollard Street

The Pollard Street bridge (State Bridge No. B-12-5) is located approximately 2,935 feet upstream of the Talbot Mills Dam. The 1998 concrete structure has an overall span of about 182 feet, with two 4-foot-wide piers set 62 feet apart on center and a deck width of approximately 48.8 feet. The bridge reportedly passes over the Fordway Bar, a natural bar of hard gravel that is about 700 feet in length, stretching between points approximately 2,700 to 3,400 feet upstream of the dam (see **Section 2.1.2**), and in fact used to be known as the Fordway Bridge. According to an 1861 survey, the elevation of the Fordway Bar is about 107.2 feet NAVD 88. The channel bottom immediately downstream of the Pollard Street bridge was re-surveyed for the 2014 FIS, and was found to have a minimum channel elevation of 106.59 feet NAVD 88. Since the midpoint of the Fordway Bar is reported to be about 100 feet above the bridge, it is likely that the highest point of the bar feature lies somewhere upstream as reported by the 1861 survey; however, this was not confirmed as part of this study. A bridge was present at this site as early as 1659, but after being rebuilt several times and carried away by a flood in 1699, it was not rebuilt for almost 200 years until 1893. The predecessor to the current structure was built in 1912 and represented the best known early example of a continuous multi-span reinforced concrete T-beam bridge in Massachusetts (NPS, 1996). The present bridge was designed with piers that are better aligned with the flow of the river, which may have contributed to lower peak flood elevations observed upstream of the bridge for larger floods (E. Reiner, personal communication, February 4, 2016).

Plan and profile views of the Pollard Street bridge are shown in **Figure 2.3.3-1**. Boring logs are provided in **Figure 2.3.3-2**. According to the boring data, it appears that the bridge abutments and piers are founded on dense to very dense substrates that are likely not particularly susceptible to erosion to due scour.

Boston Road/Massachusetts Route 3A

The Boston Road/Route 3A bridge (State Bridge No. B-12-003) is located approximately 1 ½ miles upstream of the Talbot Mills Dam. The 1920 triple arch concrete structure has an overall length of about 180 feet and a deck width of approximately 39.2 feet. It has a 65-foot-wide center arch flanked by two 50-foot wide arches. The bridge has received various repairs over the years. According to the DOT's list of scheduled projects, it is currently in the preliminary design phase for approximately $4 million worth of rehabilitation work (DOT, 2015).

Plan and profile views of the Boston Road/Route 3A bridge are shown in **Figure 2.3.3-4**. Boring logs are provided in **Figure 2.3.3-5**. According to the boring data, it appears that the bridge abutments and piers are founded on very hard sand and gravel substrates and boulders that are likely not particularly susceptible to erosion to due scour.

2.4 Diadromous Fishery Resources

2.4.1 Target Species

A primary goal of this project is to provide upstream and downstream fish passage for diadromous and resident species. The term "diadromous" refers to fish that migrate between fresh water and marine environments, and includes both anadromous and catadromous types. Anadromous fish hatch from eggs deposited at fresh water habitats, migrate as juveniles to salt water where they remain until maturity, then return to natal rivers to complete their reproductive cycle. Catadromous fish spawn in the ocean and migrate to fresh water to grow to adult size.

Diadromous fish species targeted for restoration in the Concord River include both species of river herring (blueback herring and alewife), American shad, American eel, and sea lamprey. The restoration of diadromous species is important to the greater Merrimack River watershed as they provide forage to many species of fish and wildlife (e.g., striped bass, trout, cod, bluefish, tuna, ospreys, herons, cormorants, otters, seals, whales, etc.) and facilitate the transport of nutrients between marine and freshwater environments. Because of their status as forage species, diadromous fish are important for commercial and recreational fisheries of other species. Their impacts extend far beyond the site of a single restoration project, as the target species are distributed along the entire Atlantic coast from Newfoundland (alewife) to Florida (blueback herring), from Greenland to South America (American eel), and even the European coast (sea lamprey). Diadromous fish also provide cultural benefits to citizens who value fish runs for food, bait, and as a sign of a healthy river.

The Concord River has long been known for its sluggish waters that abound in aquatic or semi-aquatic vegetation, and its banks are fringed with wild grasses and sedges that stretch for miles along both sides of the corridor. The Native Americans called it the *Musketaquid,* or "grass-grown" river, because the grasses and placid waters create a good environment for a variety of fish, including shad, river herring, bass, pickerel, carp, and American eel (PAL, 2016).

The banks of the Concord River were once inhabited by large numbers of Native Americans, who seasonally harvested diadromous fishes from the river, including "salmon, shad, lamprey eels[45], sturgeon, bass, and diverse others" (Hazen, 1883). At first, the English settlers who displaced the native people were still primarily engaged in farming and fishing. However, as colonists began building dams along the Concord River for mill power and industrial use starting as early as the seventeenth century, diadromous fish populations began to decline, in part because the dams prevented mature fish from returning upstream to spawn. By the mid-1800s, the native populations of shad and alewife became extinct (LPCT, n.d.). Despite numerous attempts to provide some means of fish passage throughout its history, the Talbot Mills Dam in North Billerica is one of the many blockages that led to the collapse of the diadromous fishery on the Concord River.

As mentioned previously, the Concord River is an ideal candidate for restoration of these diadromous species, as it is low in the Merrimack River watershed and fish must only navigate past one dam—the Essex Dam in Lawrence—before reaching the mouth of the Concord River. Also, the Concord and Sudbury rivers contain significant amounts of spawning and rearing habitat—over 35 miles or 740 acres of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles

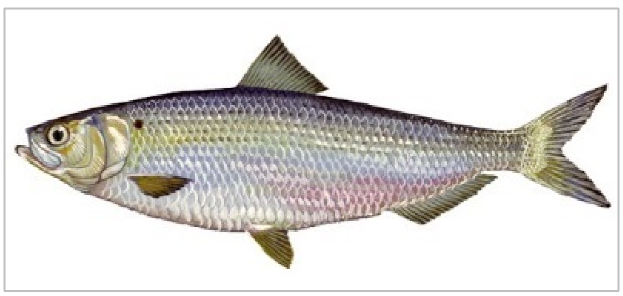
[45] Lamprey eel is a colloquial reference to sea lamprey.

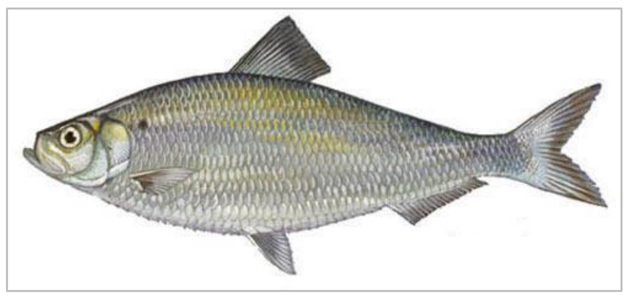
of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams).

Historical diadromous fish returns (since 1983) for the Merrimack River at the Essex Dam in Lawrence are shown in **Table 2.4.1-1** for all target species and in **Figures 2.4.1-1** through **2.4-1-3** for river herring, American shad, and sea lamprey[46].

River Herring

River herring are actually two closely related members of the *Clupeidae* family—the alewife (*Alosa pseudoharengus*) and the blueback herring (*Alosa aestivalis*), both of which are anadromous species that spend most of their life in the ocean but must migrate to freshwater to spawn. Their appearances and life histories are so similar that they are often grouped together and managed as one species. Alewives begin to spawn in late March to mid-May when water temperatures reach about 51°F, but can arrive earlier following mild winters. Bluebacks begin to spawn about 3 to 4 weeks later in the spring (late April through June) when water temperatures reach about 57°F. While both species are capable of spawning in a variety of freshwater environments, bluebacks generally spawn in more riverine areas, whereas alewives tend to spawn in more lacustrine (ponds and lakes) areas. After utilizing the freshwater habitat for a nursery area for most of the summer, juvenile herring begin their migration to the ocean in July. Migration peaks usually occur in late summer and early fall but are variable and can continue into December. After maturing in the marine environment until about 3 to 5 years of age, the fish return to freshwater, many to their natal streams (Nelson et al., 2011).





*Blueback herring (*Alosa aestivalis*)* *Alewife (*Alosa pseudoharengus*)*
Imagery Credit: Duane Raver/USFWS

Adult alewife average 10 to 14 inches in length and weigh less than a pound. Blueback herring are generally smaller than alewife, averaging around 9.5 to 12 inches in length. Adult river herring swim at a cruising speed of about 3 feet per second (ft/s) and a sustained speed up to 5 ft/s, and can reach burst speeds of 7 ft/s (Bell, 1991).

Alewife are found from northeastern Newfoundland to South Carolina, but are most abundant in the Mid-Atlantic and the Northeast. Blueback herring are found from Nova Scotia to northern Florida, but are most numerous in waters from Chesapeake Bay south (ASMFC, 2016).

Historically, river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts and were sold as food or for commercial bait (Belding, 1921). More than 100 coastal

[46] The installation of a new crest gate in 2009 and a new permanent eel ladder in 2013 (and subsequent adjustments of the ladder) at the Essex Dam have led to highly variable and unreliable eel counts. As such, a corresponding chart has not been provided for the eel data.

Massachusetts rivers and streams are home to the two species. River herring are ecologically important because they serve as forage for many marine and freshwater fish predators such as striped bass, cod, and yellow perch, as well as other wildlife. They also provide recreational and cultural benefits to citizens who value them for food and bait (Nelson et al., 2011). Additionally, their migration plays a role in the transfer of nutrients between freshwater and marine systems.

In recent years, however, river herring abundance throughout Massachusetts has declined to historically low levels. In 2005, the declines prompted *MarineFisheries* to establish a three-year moratorium on the sale and harvest of river herring throughout the state, which has since been extended and is still ongoing. In addition, the National Marine Fisheries Service has listed blueback herring and alewife as Species of Special Concern under their Endangered Species Act review process. A 2011 petition to list the species as threatened under the Act was reviewed but resulted in a negative finding for Threatened or Endangered Status.

In the past, limited efforts have been made to stock river herring in the SuAsCo watershed with unknown success. The USFWS facilitated a nine-year river herring restoration program on the Concord River from 2000 through 2008 (USFWS, 2007). Approximately 5,000 to 7,500 alewife were transferred on an annual basis to various release sites on the Concord and Sudbury rivers as part of the restoration effort. However, numerous efforts to document juvenile production from stocking efforts through electrofishing and observation at dams were unsuccessful. It is possible that juveniles migrating downstream during high water may have passed over Talbot Mills and Centennial Falls dams, and not aggregated in one location for a long enough time to be observed. Concerns have also been raised that stocking efforts did not result in juvenile production. If production failure was a problem, potential causes may include turbidity, which can cause the failure of spawning, hatching, and/or juvenile foraging. Additionally, donor stocks may not have remained in the system until spawning, as the stocking locations were not ideal and stocked fish were not able to be retained until spawning (USFWS, 2007).

In the last five years, herring counts at Essex Dam on the Merrimack river have been steadily increasing, from 518 herring in 2010 to 128,692 herring in 2015 (USFWS, 2015). This is likely due to an increase in restoration activities and stocking efforts. Fishery resource agencies have reinitiated intensive stocking efforts for river herring in the Merrimack River in recent years. The approximately 740 acres of riverine habitat on the Concord, Sudbury, and Assabet Rivers between the Talbot Mills Dam and the next upstream dams has the potential to produce up to 173,900 river herring at the rate of 235 fish per acre (Kircheis et. al, 2002).

American Shad

Imagery Credit: Duane Raver/USFWS

The American shad (*Alosa sapidissima*) is also a member of the *Clupeidae*, or herring, family and closely resembles river herring, with the exception of its larger size. New England shad populations overwinter in the mid-Atlantic coastal region and migrate northward in the spring, using their olfactory sense to locate natal rivers. They ascend the larger river systems such as the Merrimack and Connecticut Rivers when spring water temperatures reach approximately 62°F, usually beginning in May (Brady et al., 2005). Shad are river spawners, generally spawning well upstream of the tidal interface at mid-river runs in relatively shallow depths with more apparent selection to moderate to

high water velocity than to a specific substrate type (Greene et al., 2009). Juvenile shad hatch in about one week and feed on zooplankton in the river until the late summer or fall, when they migrate downstream to the ocean (NH FGD, 2015). Males reach sexual maturity at 3 to 5 years whereas females mature at 4 to 6 years (Brady et al., 2005).

There is a significant difference in size between the sexes, with males usually weighing between 1 and 3 pounds, while females can reach over 8 pounds and may grow to 2 feet in length (Brady et al., 2005; NH FGD, 2015). Adult shad averaging 12 to 14 inches in length swim at a cruising speed of about 3 ft/s and a sustained speed of 3 to 7 ft/s, and can reach burst speeds of 8 to 13.5 ft/s (Bell, 1991).

American shad once supported a large and important commercial and recreational fishery. American shad was historically an important fish resource in the Merrimack River, both for Native Americans and later for colonial settlers. In pre-colonial times, the shad run extended from the mouth of the Merrimack River to Lake Winnipesaukee in central New Hampshire. Approximately 830,000 shad were harvested from the Merrimack River in 1789, and as late as 1841, records indicate the landing of 365,000 adult American shad. The construction of dams on the Merrimack River in the 1800s, combined with pollution and overfishing, severely impacted anadromous fish populations in the river and likely extirpated the annual shad run upstream of the Essex Dam in Lawrence (MRTC, 2010). Today, the Merrimack River supports a relatively large run of American shad that is managed by multi-jurisdiction management plan (MRTC, 1997). In 2015, 86,857 American shad were counted returning to the Essex Dam on the Merrimack River (USFWS, 2015). There is no longer a commercial fishery for American shad in Massachusetts, where it is now considered a sport fish and is sought by anglers in rivers where the fish congregate in sufficient numbers (Brady et al., 2005).

The historic range of American shad was from the St. Lawrence River to Florida. Shad are still distributed throughout their historic range but shad are concentrated in east coast rivers between Connecticut and North Carolina. Although they have been observed in the lower Concord River, shad do not currently utilize it or other Merrimack River tributaries for spawning (Brady et al. 2005). However, the Concord River is estimated to have approximately 90 acres of suitable American shad nursery habitat, which has the potential to produce 5,400 to 9,000 shad at rates of 60 to 100 shad per acre, respectively (MRTC, 2010).

The principal threat identified for most shad runs in Massachusetts is barriers to migration. Dams are particularly troublesome because many traditional fish ladders do not pass American shad effectively. Although other factors are important, improving fish passage at dams still offers the greatest potential for restoring American shad populations. (NH FGD, 2015).

American Eel

The American eel (*Anguilla rostrata*) is the only catadromous species in North America, meaning that it spends most of its lifetime in ponds and rivers and migrates to the ocean to spawn. All adult American eels spawn in the Sargasso Sea located in the western Atlantic Ocean. The larvae drift into the Gulf Stream and mature into clear “glass eels” as they approach the coast, and develop into elvers soon after. In the Gulf of Maine, migration of glass eels and elvers toward the coast occurs mainly from April to July, though some will migrate into early

Imagery Credit: Duane Raver/USFWS

fall. It can take several years for eels to migrate up rivers, during which time they may travel hundreds of miles. As elvers grow, they become known as yellow eels. Yellow eels may spend 6 to 30 or more years in freshwater before they metamorphose into mature silver eels. On dark, rainy nights during September to December, most silver eels descend rivers and begin their journey to the Sargasso Sea. Eels spawn only once, so their spawning migration also represents the last stage of their life before dying (Gulf of Maine Council on the Marine Environment, 2007).

Eel swimming performance is dependent upon age and size. As they make their way upstream, juveniles gradually increase in size as they grow from glass eels (2 to 3 inches long) to elvers (2½ to 4 inches long) to yellow eels (generally considered to be greater than 6 inches long). Adult females may attain lengths of nearly 50 inches, while males may only reach about 16 inches. As such, in the lower part of a watershed, eelways should be designed to pass small (2- to 5-inch long) eels with poor swimming ability, while further upstream, eelways must pass larger (more than 12-inch-long), stronger eels (Gulf of Maine Council on the Marine Environment, 2007). At the Talbot Mills Dam, eels are expected to be in the elver or yellow eel stage. Sustained swimming speeds are estimated to be about 0.25 ft/s for 2-inch-long glass eels, 0.5 for 4-inch-long glass eels, and 2 to 7 ft/s for adult eels ranging in length from 2 to 8 feet, respectively (Bell, 1991). Elvers that are 3 to 4 inches long can swim at burst speeds of approximately 2 to 3 ft/s over distances of less than 5 feet. However, at water velocities of 1 ft/s, elvers generally cannot swim further than 10 feet. Older juveniles can swim 5 ft/s but cannot swim far against fast water. Water velocities in excess of swimming speed, long distances, lack of refuges from currents, strong turbulence, and complex flows will all reduce swimming performance and hinder migration. Eels are good climbers and can ascend vertical surfaces if there is a wet, rough substrate for them to climb. However, a large proportion of eels will not attempt to climb and passage structures should be provided (Gulf of Maine Council on the Marine Environment, 2007). Additionally, eels may suffer from increased predation as they aggregate at the base of structures seeking passage routes.

American eels range from Greenland to northeastern South America, occurring in all major streams along the coastline. They represent a single breeding population, meaning that eels from South America, Greenland, and anywhere in between may breed with each other. Thus, there are no distinct watershed or regional "stocks" as there are for anadromous species (Gulf of Maine Council on the Marine Environment, 2007).

Prior to colonial settlement, the American eel was likely the most abundant fish species in the SuAsCo watershed. Of all the diadromous fish species that once migrated from the sea into the Concord River—including river herring, American shad, and sea lamprey—the American eel is the sole species that has been able to persist in the watershed. However, eel populations throughout most of their range have greatly declined, particularly during the past 30 years (Smithwood, 2014).

American eels are prevalent in the SuAsCo system and have been collected in surveys of the mainstem and tributaries of the Sudbury, Assabet, and Concord Rivers (MassDEP, 2005). In 2015, 5,022 American eels were counted returning to the Essex Dam on the Merrimack River (USFWS, 2015). It is believed that the 8-foot-high Centennial Falls dam presents only a moderate impediment to eel passage, while the taller 10-foot-high Talbot Mills Dam likely presents a greater hindrance to upstream passage of American eels (Smithwood, 2013). There has been no study to date of eel passage at the Talbot Mills Dam, but it is known to occur to some extent, as eels are present upstream of the dam. Two possible avenues of upstream eel migration around this structure were thought to be the sluiceway that goes under the Faulkner Mills complex and/or and a former wetted rock area on the river right side of the dam. However, the wetted rock site has been altered by the construction of a park area. It would be advantageous to

determine the current mean by which eels pass this dam and to determine if there are measures that could be taken to improve their passage in the near term until more permanent fish passage alternatives can be implemented (Smithwood, 2012).

Restoration efforts are underway in the Merrimack River watershed to help bring this species back to its former prominence. Around 2009, a modification was made to the Essex Dam in Lawrence, MA led to a large increase in the number of elvers observed passing upstream via the fish lift (Smithwood, 2012). A permanent eel ladder was later added. In 2013 and 2014, eel surveys were conducted on the Sudbury River in the town of Sudbury to qualitatively evaluate the effectiveness of eel passage improvements and other management activities (Smithwood, 2013).

Sea Lamprey

Imagery Credit: Duane Raver/USFWS

The sea lamprey (*Petromyzon marinus*) is an anadromous, eel-like fish native to coastal North Atlantic watersheds. Adult sea lamprey spend one to three years in the ocean, where they parasitize on large fishes and sharks. During spring, they ascend large coastal rivers and streams where they construct pit and mound rock nests, spawn, and then die shortly afterwards. Upon hatching, juveniles or "ammocoetes" drift downstream and burrow into fine sediments, where they remain for 4 to 8 years filter feeding upon planktonic drift. Eventually, they emerge and undergo metamorphosis, developing an eye and oral mouth disk, at which point they are referred to as "transformers," which average between about 4 to 8 inches long. The transformers then migrate to the ocean to begin the parasitic phase (Kircheis, 2004; Weaver, n.d.).

Spawning season varies longitudinally within the range of the lamprey, but in nearby Maine[47], spawning occurs from late May through early summer. Typically in July, larval lamprey then begin a metamorphosis that lasts for four to six months. Transformers then usually migrate to the ocean between September and December. However, because they are not strong swimmers, their migration is highly dependent on water flow, so if flows are low or migration is impeded by barriers such as dams, some transformers may overwinter in freshwater, resuming their downstream movement in the spring during high flows (Kircheis, 2004).

Recently matured lamprey are typically 6 to 8 inches in length, and may eventually reach a length of up to 3 feet (NH FGD, 2015). Sea lamprey swim at a cruising speed of about 1 ft/s and sustained speeds up to 3 ft/s, and can burst up to 7 ft/s (Bell, 1991). Lamprey use their oral discs to attach to substrate, preferring smooth surfaces for attachment sites. Attachment presumably allows lamprey to rest following periods of aerobic activity, and the behavior has been observed at high velocity and high turbulence areas at fishway openings.

Some lamprey can use their attachment behavior to climb steep and even vertical surfaces while navigating barriers, by attaching and incrementally moving forward in "burst swimming" movements. However, most observations of lamprey climbing behavior are for the more thoroughly studied Pacific lamprey (*Lampetra tridentata*) (Keefer et al., 2012).

---

[47] No information was available for Massachusetts, but timing is likely similar or slightly earlier.

Sea lamprey are abundant along the coast of eastern North America in the temperate waters of the Atlantic Ocean, and are also native to the Mediterranean and the western European coast. In 2015, 5,035 sea lamprey were counted returning to the Essex Dam on the Merrimack River (USFWS, 2015). Conversely, they are invasive to the Great Lakes of North America, where millions of dollars are spent annually to control populations and range expansion (Weaver, n.d.). However, it is important to note that anadromous sea lamprey are a natural component of coastal aquatic ecosystems in the Northeast, and they do not typically predate or parasitize fish while in freshwater (Kircheis, 2004).

Historically, sea lamprey were harvested for food, but there is little commercial value or interest for them in North America today. However, current research has begun to identify the importance of sea lamprey as a keystone species that alter stream habitats through their nest building activities during spawning and provide forage and marine-derived nutrients to freshwater systems, benefitting other anadromous and resident species and recreational and commercial fisheries (Weaver, n.d.).

Sea lamprey are not currently listed as threatened or endangered, but are likely in decline, and thus have been acknowledged in conservation management plans in Europe and North America. Some natural resource agencies have only recently begun to keep records of annual returns of sea lamprey and thus it is uncertain how current trends stack up to historical abundances. Sea lamprey are likely negatively affected by migration barriers (i.e., dams), degraded freshwater spawning habitat, and declines in large fishes that serve as their food base in the ocean (Weaver, n.d.).

There are no concerted efforts specifically targeting sea lamprey at this time; however, they benefit directly from management strategies seeking to restore river herring and American shad populations through dam removal and improved fish passage techniques (Weaver, n.d.).

2.4.2 Target Fish Passage Thresholds

In order for diadromous fish to readily pass to and from their spawning habitat, certain physiological and behavioral needs and physical river conditions must be met, including seasonal flow magnitudes, depths, and velocities. These characteristics vary among the target species. Important considerations for restoration activities are described below.

Flow Timing

It is important to understand when diadromous fish are typically moving up and downstream in a river to be able to evaluate whether parameters such as water depth and velocity will be appropriate during those times.

Table 2.4.2-1 summarizes key timeframes for the various life stages and events of the target species, as described in the previous section. In coordination with project partners, an overall range of April 15 through July 15 was selected for the upstream migration period and July 1 through December 31 was selected for the downstream migration period to capture the key timing of events for all target species.

Flow Depth

Water depth in the river channel and through obstacles such as bridges and culverts must be sufficient to accommodate the physical dimensions of fish navigating upstream. In order for fish to swim normally, the minimum depth of flow should be generally be 1.5 to 2 times the body thickness of the largest target

species[48]. Since American shad is the largest of the target species in terms of body thickness, its dimensions serve as a conservative surrogate for all of the target species. Assuming an average body thickness to total body length ratio of 30% and an adult body length of 14 inches, body thickness would be about 4 inches, and the minimum depth required for passage would be about 6 to 8 inches.

The number and length of obstacles fish must negotiate should be considered, and this guideline should be adjusted as necessary. If fish encounter few passage barriers, they can likely negotiate fairly shallow water. However, the same species moving up a stream with many obstacles may arrive at the spawning area in poor condition if passage depths are minimal (Bovee, 1992).

Below sharp elevation changes, the USFWS recommends plunge pools with depths of at least 4 feet or 25% of the fall height, whichever is greater (Towler, 2014).

Flow Velocity

Diadromous and other migratory riverine species often encounter zones of high velocity flow, such as where flow is restricted going through a road crossing or a narrow, rocky section of channel, that impede their migrations. Generally, fish swimming performance is characterized by the following levels of swimming speeds (Bell, 1991):

- **Cruising speed** – A speed that can be maintained for long periods of time; employed for general movement and migration
- **Sustained speed** – A speed that can be maintained for minutes; employed for passage through difficult areas
- **Burst speed** – A single effort that is not sustainable; employed for feeding or escape purposes

Table 2.4.2-2 provides a summary of the various swimming speeds for the target fish species, as discussed in the previous section. The most important swimming speed for fish passage considerations is sustained speed. Where flows exceed maximum sustained swim speed, successful passage may still be possible, provided that fish can accomplish the needed burst speed without additional impedance such as high water temperatures and/or low dissolved oxygen (Bell, 1991).

Eel and lamprey generally have lower sustained swimming speeds than those of the three herring family target species, but they exhibit climbing and/or attachment behaviors that may help them navigate obstructions that are impassable to herring and shad. Of the three alosine target species, alewife appear to be the weakest swimmers, and thus can be used as a conservative threshold for the others. Considering this information in conjunction with the swimming speeds in **Table 2.4.2-2**, it was determined that a maximum water velocity of 5 ft/s to 7 ft/s would be an appropriate target to ensure that most target species should be able to navigate barriers using either sustained or burst speeds.

Flow Turbulence

There are two basic types of stream flow—laminar flow, which is smooth and uniform, and turbulent flow, which is irregular and unpredictable. Turbulence is common in a river when features such as large rocks, holes, or sudden changes in bed elevation or channel width obstruct flow particles and cause them to move in random directions, creating vortices, eddies, and other non-uniform flow patterns. In the process, energy is dissipated, which leads to reduced flow velocities.

[48] The USFWS recommends 2 times body thickness (Towler, 2014).

It is a common misconception that laminar flow is necessary for successful fish passage. In rivers, laminar conditions generally only exist in slow-moving impoundments. Rivers are naturally turbulent environments and fish are accustomed to moderate levels of turbulence (Towler, 2014). Turbulence also helps to reduce velocities and create zones of rest for fish behind obstructions, which may improve passage success.

However, excessive turbulence has been shown to impact both swimming behavior and fish passage performance (Towler, 2014). American shad are notoriously finicky about navigating river flows. The slightest change in flow can prevent a shad from navigating a zone of turbulence or entering a fishway. However, when conditions are favorable, shad will move through obstacles or fish passage facilities by the thousands (NH FGD, 2015).

To quantify turbulence and the related aeration of flow, the USFWS uses the energy dissipation factor (EDF) to measure the volumetric energy dissipation rate in a pool, chute, or stream reach. Generally, the USFWS recommends a maximum EDF of 3.15 ft-lb/s-ft^3 for effective passage of American shad (Towler, 2014). Although a quantitative analysis of turbulence and EDF in the Concord River was beyond the scope of this feasibility study, it was considered in a qualitative assessment.

This page intentionally left blank.

3. Technical Assessment

This section describes the various analyses conducted during the course of this project to provide additional information for the alternatives analysis, including a topographic survey and sediment, hydrologic, hydraulic, and cultural resources analyses.

3.1 Topographic Survey

To support the feasibility analysis, a topographic survey was conducted on October 6, 2014 at the Talbot Mills Dam and Middlesex Falls sites. The survey data was primarily used in developing an existing conditions site plan at Talbot Mills Dam and adding detail to an existing FEMA FIS hydraulic model. A survey grade real-time kinematic (RTK) GPS unit[49] consisting of a base station and rover was used in conjunction with a total station. The following data was collected during the survey:

- Key elevations of the Talbot Mills Dam, abutments, and other pertinent structures
- Catch basin rims along Faulkner Street to tie in to the existing base plan provided in the dam safety inspection report, shown in **Figure 2.2.3-3** (Geotechnical Consultants, 2015)
- Water surface elevations of the Talbot Mills Dam impoundment directly above the dam and at the upstream extent of the sediment survey described in **Section 3.2.1** below (used as reference points for the sediment depth mapping)
- Key elevations of the breached former Middlesex Dam abutment, raceway channel, and other pertinent structures at the Middlesex Falls site

To supplement upland topography for the base mapping and hydraulic model development, Light Detection and Ranging (LiDAR) elevation data available from the MassGIS was used. LiDAR data for the Concord River were collected on December 2-12, 2010 and have an average point spacing less than 3.3 feet and a fundamental vertical accuracy of about 0.58 feet.

3.2 Sediment Analysis

The quantity and quality of sediment impounded upstream of the Talbot Mills Dam are key data in determining the range of viable fish passage alternatives. Since the Concord River upstream of the dam is slow-flowing with a gentle gradient, it carries a relatively low sediment load; however, some sediment has accumulated behind the dam over its 300-year history. Management of impounded sediment under certain fish passage alternatives such as dam removal can include removal, stabilization, or release downstream. Information about the characteristics of the sediment to be managed is critical in dictating the design and cost of these alternatives.

3.2.1 Sediment Depth Mapping & Volume Estimation

To quantify the volume of sediment impounded by the dam, sediment depth mapping was conducted at transects throughout the lower impoundment on October 6, 2014 (concurrent with the topographic survey). The sediment survey was limited to the lower impoundment, as the Fordway Bar and the bedrock outcropping below it would be expected to serve as a new hydraulic control in a potential dam removal scenario, limiting water velocity increases and movement of any sediment upstream of this point.

[49] Accuracy for the RTK GPS unit is typically within 0.03-0.1 feet horizontally and 0.05-0.2 feet vertically.

Sediment depth mapping was conducted at eight transects spanning the impoundment between the dam and a point approximately 2,280 feet upstream. Probe stations were generally spaced at least every 10 feet along transects. At each probing station, a steel rod marked in 0.5-foot increments was driven with a hammer into the sediment until refusal. Vertical changes in sediment composition (e.g., silt, sand, muck, gravel, etc.) were roughly characterized based on feel. Water depths were measured relative to the water surface elevation, which was surveyed as 108.5 feet NAVD 88 on the day of the sediment depth mapping survey.

Maps showing the locations of the sediment transects and other pertinent data are shown in **Figures 3.2.1-1** and **3.2.1-2**. Both maps depict the same information, but **Figure 3.2.1-2** is overlain on a different aerial image which shows the extents of the dense aquatic vegetation (the invasive water chestnut) that typically grows in the impoundment every summer. The maps also show the approximate extents of major sediment deposits in the impoundment, which were delineated based on the probing data, field observations, and the limits of the aquatic vegetation growth. For the purposes of quantifying the volume of sediment that would likely mobilize in a dam removal scenario, the existing channel form through the impoundment was also delineated based the probing data and geomorphic assessment.

The resulting data were used to compute elevations for the top and bottom of sediment at each probing station. Cross-sections of each transect are presented in **Figures 3.2.1-3** through **3.2.1-10**. The cross-sectional area of each transect was calculated and then interpolated between transects to estimate the total volume of impounded sediment. The portion the total volume that would be expected to mobilize in a potential dam removal scenario was then estimated by considering only the sediment within the existing channel form through the impoundment as described above.

Based on these results, it is estimated that at least[50] 18,200 CY of sediment is present in the lower impoundment upstream of the dam. A little over half (about 9,500 CY) of this sediment would be expected to mobilize in a dam removal scenario during natural channel re-forming processes, while the remainder would likely stabilize as floodplain wetlands following the lowering of water levels and re-establishment of river channel form. Although some of the mobilized sediment would be retained behind the next downstream dam—Centennial Falls Dam, located approximately 3.6 miles downstream of the Talbot Mills Dam—it could potentially be transported farther downstream during high flow events.

In general, the sediment depth mapping survey found the lower impoundment to have very little sediment within the main flow path that would likely mobilize in a dam removal scenario. Primary sediment deposits were found on the downstream sides of two small bedrock outcroppings (i.e., islands), as well as two larger deposits in backwater areas off the river-left and right sides of the main flow path. The most significant deposit is on the river-right side, approximately 300 feet upstream of the dam in the vicinity of transect T-6 and the historic floating towpath peninsula. Much of the sediment found in the lower impoundment, especially in this large backwater area, consists primarily of organic material and becomes covered with invasive water chestnut during the growing season. Lower water surface elevations and increased water velocities that would occur in a dam removal alternative would likely reduce or eliminate the water chestnut problem in this area of the Concord River.

---

[50] It should be noted that the sediment transects did not cover the farthest extents of the large backwater area on river right (north and south of the floating towpath peninsula), so the total sediment volume is actually higher. However, this area is mapped by the MassDEP as a wetland, not open water, and is not likely to mobilize in a dam breach scenario.

The most upstream transect, T-8 (not shown in the maps) was collected at the rocky section of channel below the Fordway Bar (about 750 feet below the Pollard Street bridge or 2,180 feet upstream of the dam). The channel substrate consisted primarily of solid ledge and virtually no sediment was found. It is highly likely that if the dam were removed, this bedrock feature would serve as the new hydraulic grade control and the channel bottom would not "headcut" (i.e., erode with an abrupt vertical face that migrates upstream over time) above this point. At the time of the survey, the location of the Fordway Bar (i.e., the hard gravel depositional feature upstream of the bedrock grade control) was not known, so it was not surveyed. If the dam removal alternative were to progress to the next phase of feasibility study, it would be beneficial to conduct bathymetric mapping in the lower impoundment to confirm the location and elevation of the bar feature, followed by additional probing to evaluate the likelihood of the bar serving as a grade control or eroding slowly over time in a dam removal scenario.

3.2.2 Sediment Sampling

To characterize the quality of sediment impounded by the dam to inform potential fish passage alternatives, sediment sampling was conducted. Typically, when evaluating the feasibility of dam removal, samples are collected within the dam impoundment and at other locations in the river as follows:

- **Upstream of Dam Impoundment** – At least one sample is usually collected upstream of the area impounded by the dam to characterize sediment that is likely to mobilize during future storm events and be transported downstream of the dam regardless of whether or not the dam is removed.

- **Mobile Sediment within Dam Impoundment** – Several samples are usually collected within the dam impoundment from sediment deposits that are expected to mobilize post-dam removal to characterize contaminant levels potentially present in sediment requiring either active or passive management. The recommended number of samples is generally one per 1,000 CY of mobile sediment.

- **Stable Sediment within Dam Impoundment** – At least one sample is usually collected within the dam impoundment from sediment deposits that are expected to stabilize as new floodplain wetlands post-dam removal to characterize potential risks to human health from newly exposed sediment.

- **Downstream of Dam Impoundment** – At least one sample is usually collected downstream of the dam in depositional areas that would be expected to receive sediment mobilized from the impoundment post-dam removal to characterize potential ecological risks from pollutants that might be bound to or otherwise associated with the mobilized sediment. The finding of similar or higher pollutant levels downstream, for example, might lead to a conclusion of limited ecological risk from sediment with similar or lower contaminant levels moving downstream due to dam removal.

The sediment sampling for Talbot Mills Dam was conducted on November 6, 2014. A total of four samples were collected from the following locations:

- **Mobile Sediment within Dam Impoundment (IMP-1 & IMP-2)** – Two samples within the lower impoundment along the potentially mobile edge of the sediment deposits on the left and right sides of the river, approximately 200 feet and 500 feet upstream of the dam, respectively

- **Downstream of Dam Impoundment** (**DS-1) –** One sample at a powerline crossing below a large island in the Concord River, approximately 3,300 feet downstream of the dam

- **Upstream of Dam Impoundment (US-2)** – One sample on the Concord River just below the confluence of the Sudbury and Assabet Rivers, approximately 11.5 miles upstream of the dam[51]

The sampling locations are shown in **Figure 3.2.2-1**. Close-ups of the impoundment locations were shown in **Figures 3.2.1-1** and **3.2.1-2** with the sediment depth mapping results. A summary of sampling locations is provided in **Table 3.2.2-1**. Samples were collected with a stainless steel hand core system outfitted with a Cellulose Acetate Butyrate (CAB) liner. The push core system was advanced up to five feet or until refusal. Each sediment core was composited. The samples were processed on shore, including completion of chain of custody forms, and were delivered to Con-Test Analytical Laboratory, a Massachusetts-certified laboratory, for testing. Laboratory analysis included the following parameters (reported within detection limits meeting or exceeding those found in 314 CMR 9.07(2)(b)(6)):

- Heavy metals (Arsenic, Cadmium, Chromium III and IV, Copper, Lead, Mercury, Nickel, and Zinc)
- PAHs
- PCBs
- Organochlorine pesticides
- TOC
- Percent water
- Grain size distribution (Sieve Nos. 4, 10, 40, 60, and 200)

Table 3.2.2-2 presents the findings of the sediment testing. Results are compared to screening criteria including the MCP Method 1 Standards (Category GW-1/SW-1) and the TECs and PECs for Freshwater Ecosystems (MacDonald et al., 2000).

In general, sediment chemistry suggests the presence of limited pollutant concentrations. As expected in a developed watershed, PAH compounds were detected in the impoundment at levels above the TECs; however, concentrations were well below the PEC and MCP Method 1 Standards. The impoundment samples contained elevated level of some metals. Total chromium in the impoundment (two samples averaged) exceeded the PEC and MCP benchmark values; however the hexavalent chromium results (Chromium VI) were very low[52]. Other metals such as copper, lead, and mercury were detected in the impoundment samples at concentrations slightly above the PEC benchmark values. The impoundment samples also contained very low levels of total PCBs, well below the PEC and MCP values. All pesticide parameters were below detectable limits.

[51] Although the influence of Talbot Mills Dam appears to extend into the Sudbury and Assabet Rivers under certain high flows, this area represents the farthest upstream section of the impoundment while still remaining on the Concord River.

[52] Chromium (Cr) is a naturally occurring metal found in small quantities associated with other metals, particularly iron. Due to its extensive use in industrial processes, large quantities of chromium compounds are discharged into the environment. Although chromium can exist in all oxidation states from 0 to VI, Cr (III) and Cr (VI) are the most prevalent. Cr (III) is an essential nutrient, but Cr (VI) is a known mutagen and carcinogen and is more soluble and therefore, more mobile than Cr (III) (Applied Speciation, 2009). The MCP presents standards for Total Cr, Cr III, and Cr VI. If Total Cr results are elevated, it is important to test the material for the Cr VI species to fully evaluate the risk of contamination.

If the dam removal alternative progresses to the next phase of the feasibility study, additional samples will likely be needed to inform the sediment management plan. Up to 8 additional samples may be required to be collected within the impoundment to fully characterize the estimated volume of mobile sediment with one sample per 1,000 CY of sediment (for a total of 10 samples within the approximately 9,500-CY volume of mobile sediment). Samples could also be collected within areas of the impoundment expected to stabilize as floodplain wetlands post-dam removal as discussed above, such as in the areas north and south of the floating towpath peninsula. Additionally, samples could be taken in depositional areas downstream of the dam to provide context of contaminant levels in the river system compared to levels in the impoundment. Upstream of the dam's influence, samples could be collected in either or both of the Sudbury and Assabet Rivers.

3.3 Hydrologic Analysis

Flow data was evaluated for use in the hydraulic model developed as part of this study (**Section 3.3.2**) to estimate water surface profiles and other parameters under existing conditions and potential fish passage alternatives.

In the SuAsCo watershed, the USGS maintains active streamflow gages on the Concord River in Lowell (Gage No. 01099500), on the Sudbury River in Saxonville (Gage No. 01098530), on the Assabet River in Maynard (No. 01097000), and on Nashoba Brook (a tributary to the Assabet River) in Acton (Gage No. 01097300), as well as additional discontinued gages. This analysis used the Concord River gage, which is located 0.8 miles upstream from the mouth of the river, downstream of River Meadow Brook and the Rogers Street Bridge, has a reported drainage area of 400 square miles[53], and has operated continuously since October of 1936 (USGS, 2015).

The original FEMA FIS for the Concord River in Billerica was published in 1985. Hydrologic and hydraulic analyses for this study were completed in July 1983 by Schoenfeld Associates, Inc. A revised FIS was recently prepared for Middlesex County (including the Concord River) in 2014 by the Strategic Alliance for Risk Reduction (STARR), a joint venture between Atkins, Greenhorne & O'Mara, Inc.[54], Stantec, and Camp, Dresser, and McKee. The revision included new hydrologic and hydraulic analyses, which were completed in October 2012 (FEMA, 2014).

The FIS reports a drainage area of 370 square miles for the Concord River at the Talbot Mills Dam (FEMA, 2014). Updated basin delineations obtained from the USGS StreamStats program indicates a drainage area of 368 square miles at the dam. Because these values are all relatively close, the FIS published value of 370 square miles was used for this analysis. Discharges reported for the Concord River gage were adjusted to the Talbot Mills Dam location by ratio of drainage areas (370 square miles / 400 square miles = 0.925).

3.3.1 Flow Duration Analysis

A duration analysis was conducted for average daily flows at the Concord River gage using the full period of record (October 1936 through December 2015). Monthly and annual flow statistics are shown in **Table**

[53] Interestingly, the USGS notes that although the physical drainage area at the gage is 400 square miles, the net drainage area is actually 307 square miles, due to a water supply diversion from approximately 93 square miles in the Sudbury River basin and Lake Cochituate for use by the Boston metropolitan district (USGS, 2015b). However, the use of this water supply diversion was discontinued in 1976.

[54] Greenhorne & O'Mara, Inc. was acquired by Stantec in 2012.

3.3.1-1 for the gage and the Talbot Mills Dam locations. The table also includes flow statistics for upstream (April 15 to July 15) and downstream (July 1 to December 31) fish migration periods, considering the range of typical patterns for the various target species as presented in **Table 2.4.2-1**.

Corresponding flow duration curves for the Talbot Mills Dam location are shown in **Figures 3.3.1-1** through **3.3.1-7**. Flow duration curves depict the average percentage of time that specific flowrates are equaled or exceeded at a particular site. These curves are useful for better understanding the nature of the streamflow in a particular river. For example, “flat”-sloped flow duration curves often indicate relatively little variability in flows, as compared to a site with a steep flow duration curve.

3.3.2 Flood Frequency Analysis

Flood events of a magnitude which are expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during a given year.[55]

The FIS includes four locations for which flood frequency estimates were developed along the Concord River: the Concord/Carlisle corporate limits (with a reported drainage area of 352 square miles), the Carlisle/Billerica corporate limits (360 square miles), the Talbot Mills Dam (370 square miles), and the Billerica/Tewksbury corporate limits (373 square miles). For the original (1985) FIS, flood discharges were estimated for the Concord River by determining and routing flows on the Sudbury and Assabet Rivers. Because those rivers are gaged, a log-Pearson Type III statistical analysis of the gage data was conducted using the USGS Bulletin 17B methodology (USGS, 1981). The analysis for the Assabet River was adjusted to reflect the effects of a series of floodwater retention reservoirs in the upper watershed. Hydrographs produced at the headwaters of the Concord River were then routed downstream, adding in additional inflow due to runoff from tributary drainage areas and reducing flow due to storage in the Concord River floodplain. The routed flows were further modified based on data from the Concord River gage in Lowell (FEMA, 2014).

For the first countywide FIS published in 2010, an updated hydrologic analysis was conducted and the USACE Hydrologic Engineering Center’s Hydrologic Modeling System (HEC-HMS) was used to develop runoff hydrographs, but the reported flood discharges for the Concord River matched those published in 1985. For the revised (2014) countywide analysis, flood discharges were estimated using regional regression equations, validated using a schematic HEC-HMS rainfall runoff model of the Sudbury, Assabet, and Concord Rivers, and compared to estimates made using updated stream gage data. The stream gage analysis utilized the station skew coefficient for the Concord River gage as it is affected by urbanization

[55] Although the recurrence interval represents the long term average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than one year are considered. For example, the risk of having a flood which equals or exceeds the 100-year flood (1 percent chance of annual exceedence) in any 50-year period is approximately 40 percent.

and flow regulation. However, reported flood discharges for the effective (2014) still match those published in the original (1985) FIS[56] (FEMA, 2014).

The NOAA Fisheries Service recommends considering climate change when developing flood frequency estimates for river restoration projects by extending the flood record beyond dated FEMA studies and recalculating flood flows (Collins, 2011). Thus, an updated flood frequency analysis was conducted to compare with the FIS estimates. Annual peak flows at the Concord River gage for the period of record (published data available for 77 years from 1938 through 2014) were entered into the USGS's PeakFQ program to estimate storm events for various recurrence intervals using the USGS Bulletin 17B methodology (USGS, 1981), which creates a Log Pearson Type III statistical evaluation of the data. Consistent with the effective FIS, the station skew coefficient was used as the gage is affected by urbanization and flow regulation. Results were adjusted to the four FIS flow change locations on the Concord River by ratio of drainage area.

When the updated flood record includes a substantial period before 1970 (e.g., greater than 20 years), NOAA also recommends computing pre-1970, post-1970, and full record curves and considering choosing the most conservative (largest) estimates for design flows. Due to the fact that the Concord River gage record includes 32 years prior to 1970, pre-1970 and post-1970 estimates were also computed and adjusted accordingly.

All results, including the FIS published flows, are shown in **Table 3.3.2-1** and **Figure 3.3.2-1** for comparison at the Talbot Mills Dam location[57]. For this study, important flood flows include the 2-, 100-, and 500-year flood flows. The 2-year flood, which is often referred to as the channel-forming or bankfull flow, is important for predicting the dimensions of the channel that would form upstream of the Talbot Mills Dam in a dam removal scenario, as well as evaluating erosive forces on infrastructure such as bridge abutments and buried pipes. The 100-year flood, also referred to by FEMA as the base flood, is important as it is the regulatory flood for which FIS inundation maps are developed, as well as the spillway design flood that the Talbot Mills Dam is required to pass without overtopping. The 500-year flood is important for sizing the width of the spillway breach in a dam removal scenario to ensure that backwater due to the remaining dam structures is minimized.

Peak discharges selected for use in the hydraulic model are highlighted in the table and the figure. Because the regulatory FIS 100-year flood flow is within 10% of updated estimates, it was selected for this analysis to maintain consistency with other studies. The FIS 500-year flood flow was also selected, since it is conservatively higher (approximately 15%) than updated estimates. The 2-year flood flow calculated

---

[56] Discrepancies were found between peak discharge values published in the FIS report and those in the HEC-RAS model used to develop the FIS, which was provided by STARR. There are many more flow change locations in the model than in the published report, and the flows at corresponding river stations do not match. Modeled flows were higher in some cases (e.g., for the 10-year flow) and lower in others (e.g., for the 500-year flow, which differs from published values by almost 2,000 cfs—a 20% difference). Discharge values published in the FIS were used for this analysis as they were assumed to be the regulatory flood flows.

[57] Note that the published FIS 500-year flood flow does not appear to follow the trend of the available data for lower flood flows. This may be due in part to differences in calculation methods (i.e., a flow routing analysis for the FIS vs. a statistical analysis of stream gage data for the updated flows. Also note that there is a discrepancy between modeled and published flows for the 2014 FIS, as discussed in the footnote above. The modeled 500-year flood flow is approximately 6,950 cfs at the Talbot Mills Dam, which would put it more in line with the trend of the flows in **Figure 3.3.2-1**. For this study, the published FIS value was used as it is more conservative; however, this discrepancy could be further investigated in future phases of the project.

from the post-1970 period was selected because it is conservatively higher (approximately 8%) than that calculated from the full period of record.

3.3.3 Summary of Flows for Hydraulic Analysis

A summary of all flows selected for use in the hydraulic model and their respective rationales and data sources is presented for the Talbot Mills Dam location in **Table 3.3.3-1**. These flows were also developed for the other three flow change locations in the model using drainage area ratios (with the exception of the FEMA FIS flood flows, for which published peak discharge values were used).

3.4 Hydraulic Analysis

Hydraulic models of river systems are developed to simulate baseline conditions and predict water depths, velocities, and water surface profiles given various flows and alternate conditions. HEC-RAS was used to develop models of the Concord, Sudbury, and Assabet Rivers for use in evaluating various fish passage alternatives on the Concord River. Baseline models that had been prepared for the 2014 FIS were obtained from STARR and modified for the project as detailed below. The hydrologic and hydraulic input data for these models were updated considerably since the 1985 FIS, including additional surveyed transects (particularly at hydraulic grade controls), updated survey of bridges and buildings, incorporation of more detailed Light Detection and Ranging (LiDAR)-based topography for overbank areas, and other changes (STARR, 2012).

FEMA recommends that the following steps be taken when modifying FIS hydraulic models for proposed projects. Aligning the project with FEMA's standard process early in the feasibility phase will minimize effort later if any alternatives advance to the permitting phase in the future.

3.4.1 Duplicate Effective Model

The "duplicate effective model" is a copy of the hydraulic model used to develop the effective FIS, which is referred to as the "effective model." The effective 2014 FIS hydraulic models for the Concord, Sudbury, and Assabet Rivers were obtained, reviewed, and duplicated using HEC-RAS. As part of the effective model development effort by STARR, base topography was obtained from a 10 foot by 10 foot horizontal grid digital elevation model (DEM) with a vertical precision of 0.03 feet derived from LiDAR data. Detailed field survey data was collected for approximately 151 bridges, culverts, and dams and 15 riverine cross sections. At each structure, channel cross sections were surveyed immediately upstream and downstream of the crossing along with a top-of-road profile. For all flows, the normal depth method was used as a downstream boundary condition, using a downstream channel slope of 0.00376 to approximate the slope of the energy grade line. Channel roughness coefficients (Manning's "n" values) ranged from 0.03 to 0.06. Typical values of contraction and expansion coefficients used for structures were 0.3 and 0.5, respectively (STARR, 2012).

3.4.2 Corrected Effective Model

A "corrected effective model" is then developed to correct any errors that are found in the duplicate effective model, add any additional cross sections, or incorporate more detailed topographic information (excluding any manmade physical changes since the date of the effective model).

The primary correction made to the duplicate effective model was to modify the elevations and dimensions of the Talbot Mills Dam to reflect Gomez and Sullivan's survey. As mentioned in **Section 2.2.3**, Gomez and Sullivan found the spillway to have an average crest elevation of 108.2 feet NAVD 88 in a

survey conducted on October 6, 2014[58]. This elevation corresponds exactly with that reported in the text of the 2014 FIS and in both the report text and flood profiles of earlier (2010 and 1985) publications of the FIS. However, in the hydraulic model used to develop the 2014 FIS, the spillway crest elevation is modeled 2.5 feet higher at 110.67 feet NAVD 88. Consequently, the regulatory (100-year) flood elevation at the dam is almost 2 feet higher in the 2014 FIS (115.9 feet NAVD 88 vs. 114.0 feet NAVD 88 in the 2010 and 1985 publications), a difference that propagates upstream and is still over a half of a foot in magnitude at the upstream extent of the Concord River model[59].

Also at the Talbot Mills Dam, the approximately 12-foot-wide sluiceway on river-right that leads to the Faulkner Mills complex was not represented in the effective model and thus was added to the corrected effective model using survey data from Gomez and Sullivan's 2014 survey as well as the 2009 survey for the dam safety inspection report (Geotechnical Consultants, 2015).

Additionally, more detailed topographic information was incorporated into the model for several areas, including:

- **Talbot Mills Dam vicinity** – Selected features from Gomez and Sullivan's October 6, 2014 survey in the vicinity of Talbot Mills Dam
- **Talbot Mills Dam impoundment** – Top of sediment elevations from seven sediment depth probing transects within the impoundment collected on October 6, 2014
- **Fordway Bar** – Channel elevations from the eighth transect collected at the time of the 2014 survey across the rocky channel downstream of the Fordway Bar
- **Middlesex Falls** – Topographic and breached structure data from the NRCS's 2000 survey (shown in **Figures 2.2.1-2** and **2.2.1-3**) as well as Gomez and Sullivan's October 6, 2014 survey (included the far-river right raceway channel)

Lastly, at Middlesex Falls, a "flow split" was added to the model to be able to evaluate the main channel and the river right raceway channel separately.

3.4.3 Existing Conditions Model

The corrected effective model may then be modified to produce the existing conditions model by incorporating any modifications that have occurred within the floodplain since the date of the effective model. Since the effective model is relatively recent (2014), no additional modifications were incorporated into the model geometry at this step. However, the existing conditions model was used to add the additional flows desired for the analysis that were presented in **Table 3.3.3-1**. In addition to serving as a baseline for comparison with proposed alternatives, the existing conditions model was used to perform several checks, as discussed below.

Calibration and Validation Check

The effective model was previously calibrated by STARR based on a March-April 2010 storm event at the USGS stream gage downstream of Rogers Road in Lowell. The observed high water elevation at the gage was calculated as gage elevation plus peak flood stage height (66.61 + 9.74 = 76.35 feet NAVD 88). The

[58] Using an RTK GPS with a vertical accuracy of 0.05 to 0.2 feet.

[59] The STARR team has confirmed that the elevation used in the model was an error, and that their survey found the dam to be approximately 108.1 feet NAVD 88. The FIS is currently undergoing revisions and a preliminary version was been published on April 29, 2015 (which also contains the dam elevation error). Now that the STARR team is aware of the error, it is assumed that the preliminary FIS will be revised.

downstream boundary condition was set to normal depth. The peak flow from the gage was input into the model, resulting in a modeled water surface elevation of 75.90 feet NAVD 88 at the gage. The 0.45-foot difference between observed and modeled high water elevations is within the calibration limit of 0.5 feet set forth by FEMA standards.

The existing conditions model was also compared to the effective model for informational purposes only, as the results were expected to be different due to the significant difference (2.5 feet) in the height of the Talbot Mills Dam between the two models. As predicted, water surface elevations are considerably lower in the existing conditions model upstream of the Talbot Mills Dam, ranging from 1.8 feet at the dam to 0.3 feet at the upstream extent of the river. Water surface elevations are similar in the lower reach of the river, with the exception of at Middlesex Falls, where water surface elevations are higher in the existing conditions model as expected due to the addition of the bedrock grade control, which was not present in the effective model.

Model results were also calibrated to normal (i.e., non-flood) flows using data from the field survey. The flow at the Talbot Mills Dam on the day the field survey was conducted (October 6, 2014) was approximately 120 cfs [60]. During the survey, the water surface elevation was measured to be approximately 108.5 feet NAVD 88 immediately upstream of the dam and 108.8 feet NAVD 88 about 175 feet below the Pollard Street bridge. For the initial existing conditions model run, the sluice gate leading to Faulkner Mill (approximately 12 feet wide by 8.8 feet high) was assumed to be closed. Simulating a flow of 120 cfs in the model with the sluice gate closed yielded computed water surface elevations slightly higher than observed upstream of the dam. The sluice gate was then set to be 6 inches open to account for the observed leakage on the day of the field survey. Re-running the flow of 120 cfs in the model with the sluice gate 6 inches open yielded a computed water surface elevation of 108.5 feet NAVD 88 upstream of the dam at cross-section 25129 (the same as observed) and 108.6 feet NAVD 88 below the Pollard Street bridge at cross-section 27852 (0.2 feet lower than observed). Differences are within acceptable ranges and no further changes were made to the effective model.

Existing Conditions Results

Once the existing conditions model was calibrated, the range of flows given in **Table 3.3.3-1** were run in the model to simulate water surface profiles under existing conditions. A plot of selected existing water surface profiles is shown in **Figure 3.4.3-1**, and a table of selected model output parameters (e.g., channel elevation, water surface elevation, flow depth, velocity, top width, surface area, and volume) for key locations is provided in **Table F-1** in **Appendix F**. The profile confirms the findings of historical surveys (Alvord et al., 1862) reporting that the Talbot Mills Dam spillway crest is higher than any point on the channel bottom along the entire Concord River, and in fact extending approximately 13.3 miles up the Sudbury River (about 3.8 miles below the Saxonville Dam) and 2.6 feet up the Assabet River (just above the Route 2/Elm Street bridge). The next highest known point is at the Fordway Bar just upstream of the Pollard Street bridge, where the minimum channel elevation was surveyed for the 2014 FIS as 106.59 feet NAVD 88[61].

---

[60] Based on an average daily flow of 130 cfs at the Lowell gage adjusted to the Talbot Mills Dam based on drainage area ratio of 370/400 square miles.

[61] As discussed in **Section 2.1.2**, the minimum channel elevation may be higher at the highest point of the Fordway Bar, reported to be 107.2 feet NAVD 88 about 100 feet upstream of the bridge (Alvord et al., 1862); however this elevation was not confirmed as part of this study and thus was not included in the model.

The profiles also show that a number of bridges upstream of the dam appear to be undersized, acting as a hydraulic control and causing a backwater effect and higher water surface elevations upstream (similar to a dam). The first bridge upstream of the dam that shows this effect is the Boston Road/Route 3A bridge. The Pollard Street bridge was replaced more recently (1998) with a design including piers in line with the flow of the river and appears to be appropriately sized. Several bridges also appear to be overtopped by the 500-year flood.

Upstream Extent of Impoundment Check

As a quick check of the upstream extent of the impoundment, the dam was removed from the model by deleting the inline structure without modifying any other cross-sections. Low (September 95% exceedence) and high (500-year flood) flows were simulated to depict the full range of the dam's influence. A profiles comparing water surface elevations in the existing vs. dam out conditions is shown in **Figure 3.4.3-2**. As expected, the modeling results show that influence of the dam is largely confined to the reach below the Fordway Bar and the Pollard Street bridge, especially at low to moderate flows. Under low flow conditions, the modeled water surface elevation with the dam removed converges with that of existing conditions at the bedrock grade control below Fordway Bar (approximately 2,180 feet upstream of the dam). Under high flow (500-year flood) conditions, the difference in water surface elevations is less than 0.5 feet upstream of the Pollard Street bridge and less than 0.2 feet at the upstream extent of the Concord River[62]. This confirms that the dam's influence does in fact extend into the Sudbury and Assabet Rivers, but only under high flows.

The profile shows that the Fordway Bar feature and the bedrock grade control downstream would serve as a new hydraulic control if the dam were removed. The steep drop in water surface elevation visible at the bedrock grade control indicates that a falls would likely develop at this location with the lower water levels. Additionally, even with the dam removed, the model shows that there would still a sharp drop in water surface elevation and likely a falls at the site of the former dam. This is based on the sediment probing effort upstream of the dam (**Section 3.2.1**) that found little sediment and hit "hard" substrate with an approximate minimum elevation of 103.5 feet NAVD 88 (about 5 feet below the spillway crest). Some of this resistance may have been due to fill and/or structures associated with the former 1798 dam that is reportedly buried approximately 8 to 12 feet upstream of the current dam (although the sediment transect was more in the range of 12 to 35 feet upstream from the vertical face of the dam). If found, this structure would also be removed in a dam removal scenario. However, based on the extent of bedrock outcroppings immediately downstream of the dam and historical reports (Ingraham, 1995) that former dams at this site have utilized the ledge as part of their structure, it is likely that a significant grade control exists below the dam or just upstream, and that a falls would develop at the site if it were removed. In fact, 1700 map of Billerica (**Figure 2.2.3-6**) documents the existence of a series of falls in the Concord River between the present day Pollard Street and Faulkner Street bridges, which further supports the model results (Ingraham, 1995).

Spillway Capacity Check

Before considering conceptual plans for fish passage, it was important to determine whether the Talbot Mills Dam meets dam safety regulations. As noted in **Section 2.2.3**, existing significant hazard potential

[62] Note that this quick impoundment extent check does not take into account the anticipated mobilization of sediment and thus lower channel elevations that would be anticipated in a dam removal scenario, which would result in slightly larger differences in water surface elevation. A more thorough analysis accounting for sediment movement was conducted for the discussion of the partial dam removal alternative in **Section 4.3.3**.

dams of intermediate size are required to have the capacity to pass a spillway design flood equivalent to the 100-year flood (DCR, 2005). Simulating a flow of 5,675 cfs in the model (the regulatory 100-year flood flow from the effective FIS) yields a water surface elevation of 114.1 feet NAVD 88 at the Talbot Mills Dam, which is depicted in **Figure 3.4.3-3**[63]. At this elevation, floodwaters would overtop the left and right spillway abutments by about 0.7 and 1.3 feet, respectively. Additionally, parts of Faulkner Street and the paved park area adjacent to the right abutment would be overtopped by a few inches. The dam crest, which lies at elevation 113.8 feet NAVD 88 according to both the dam safety report and 2014 FIS (Geotechnical Consultants, 2015; FEMA, 2014), would also be overtopped. Therefore, the dam does not appear to meet dam safety regulations to pass the spillway design flood[64]. This deficiency would need to be addressed by the dam owner if the dam is maintained or altered for fish passage (e.g., by adding a fish ladder).

Fish Passage Thresholds Check

The model was used to evaluate whether flow conditions are currently appropriate for fish passage throughout the Concord River, other than at the three obstructions of interest for this study. **Table F-2** in **Appendix F** presents water depths, velocities, and wetted top widths for existing conditions throughout the model extents under high and low fish passage design flows. The results show that flow conditions are generally within acceptable ranges, especially for the low fish passage flow, which has a maximum velocity of 4.8 ft/s and an average of 0.7 ft/s. In the lower, steeper section of the river below Centennial Falls Dam, there are several areas of higher velocity under the high fish passage flow, with a maximum of 14.7 ft/s[65]. Most of these locations are at natural rapids and it is likely that fish can still pass upstream using burst speeds as needed. Also, these velocities represent an average across the entire channel. In reality, the velocity distribution will vary across the channel cross-section with areas of lower velocity that the fish should be able to navigate through (unlike in a culvert or other channel constriction where fish have nowhere to circumvent velocity barriers). It is also important to note that these velocities correspond to flows that are exceeded only 5% of the time during the fish migration season. More suitable velocities would be found in these areas under the range of flows experienced during the fish migration season.

3.4.4 Proposed Conditions Model

Once the existing conditions model had been calibrated and used for the various background checks, it was then ready to be modified to reflect proposed conditions. For this study, proposed models were developed for the following alternatives:

---

[63] All gates/outlets were assumed to be closed for this analysis. Although some leakage does occur through the sluice gate and low flow outlets, they would not contribute significantly to the capacity of the dam during a flood and may become clogged with debris, so the conservative assumption was made.

[64] ODS regulations do not explicitly prohibit the overtopping of spillway abutments or embankment sections in analyzing whether the dam can pass the spillway design flood. However, ODS recommends that engineers use their best professional judgement to evaluate whether the abutments and/or embankments are structurally sound enough and designed for overtopping. Due to leakage through both abutments and the fact that the embankment section is a public road, Gomez and Sullivan does not recommend that these structures be overtopped in the spillway design flood, and therefore is of the opinion that the dam does not meet dam safety regulations.

[65] Cross-section 2012 (downstream of Middlesex Falls) has the highest reported velocities and lowest depths due to a transition from supercritical to subcritical flow, which results in a hydraulic jump. Additional survey data would be needed in this area to determine whether a true velocity/depth barrier exists. Therefore, these values were not included in the overall statistics.

- Middlesex Falls
  - Channel modifications
- Talbot Mills Dam
  - Technical fishway
  - Removal of primary spillway
  - Removal of primary spillway and right abutment
  - Removal of primary spillway and both abutments

Additional details and results of these analyses are presented in **Section 4**.

3.5 Cultural Resources Analysis

As a preferred alternative has not yet been selected for this project, federal and state funding and sources and permitting requirements are still unknown. However, it is anticipated that the project will require review under Section 106 of the National Historic Preservation Act (NHPA), as amended, and its implementing regulations (36 CFR 800), and in accordance with Massachusetts General Laws, Chapter 9, sections 26-27C (950 CMR 70/71) and possibly the Massachusetts Environmental Policy Act (301 CMR 11). As such, PAL completed a historic and archaeological reconnaissance survey at the Talbot Mills Dam to inform fish passage alternatives at that site in accordance with 950 CMR 70 as part of this feasibility study. A Project Notification Form (PNF) and application for a State Archaeologist's permit to conduct the survey were submitted to the Massachusetts Historical Commission (MHC) on November 10, 2014 and the permit was received (as revised) November 24, 2014. Correspondence with MHC regarding the cultural analysis is provided in **Appendix G**. The survey focused on the dam structure and lands adjacent to the lower impoundment. Tasks included an existing conditions inventory and assessment of recorded historic and archaeological resources, an archaeological sensitivity assessment, and a recommended (preliminary) Area of Potential Effects (APE). Archival research and visual field survey were conducted to locate and identify any visible historic resources and archaeological sites and archaeologically sensitive areas where potentially significant belowground resources may be present.

A technical report, *Historic and archaeological reconnaissance survey: Concord River diadromous fish restoration project, Talbot Mills Dam, Billerica, Massachusetts*, was prepared and submitted to the MHC on January 19, 2016 (PAL, 2016). A redacted[66] version of the report will be made publically available and can be provided upon request.

A project's APE is defined in the National Historic Preservation Act Section 106 regulations as the "geographic area or areas within which an undertaking may directly or indirectly cause alterations in the character or uses of historic properties" (36 CFR 800.16[d]). Direct effects are those that may result from a physical disturbance, taking, demolition, alteration, or relocation of a historic property. Indirect effects are those that may cause changes in the property's use, result in alterations to features of the property's setting that contribute to its significance, and/or introduce "visual, atmospheric, or audible elements that diminish the integrity of the property's significant historic features" (36 CFR 800.5[2]).

The Talbot Mills Dam (MHC No. BIL.900/BILHA-09) is a historic property listed in the National Register as a contributing resource to the Middlesex Canal Historic and Archaeological District (MHC Nos. BIL.T, BIL.K, BIL.P) and is a potential contributing resource to the Billerica Mills Historic District (MHC Nos. BIL.O, BIL.E). In addition to the dam, the potential direct project APE also contains the historic Middlesex Canal Segment

[66] The redacted version of the report omits sensitive archeological information.

24 (MHC Nos. BIL.P, BIL.T, BIL.929/BIL-HA-08, listed in the National Register), the canal floating towpath peninsula (MHC No. BIL-HA-39), and the canal floating towpath anchor stone (MHC No. BIL-HA-40).

The Talbot Mills Dam is also within the North Billerica Mills Local Historic District (LHD). Because any new construction or alterations to the exterior of buildings and structures within the LHD would not receive a building permit until the proposed work has been issued a certificate of appropriateness from the Billerica Historic Districts Commission (BHDC), PAL recommends consultation with the BHDC regarding the project.

The potential direct project APE was also assigned high sensitivity for both pre-contact Native American and post-contact Euro-American archaeological resources. The dam, abutments, retaining/training walls, and open paved area on the northeast side of the dam are assigned high archaeological sensitivity for the potential to contain buried remains of earlier dam structures and/or early fishway/fish ladder structures, and buried structural remains of a mid-nineteenth-century dye/store house associated with the Faulkner Manufacturing Company. The upstream dam impoundment and shorelines are also assigned high sensitivity for both pre-contact Native American resources and post-contact structural elements associated with the Middlesex Canal (i.e., the canal prism, floating towpath, and towpath anchor stone).

PAL's assessment of potential adverse effects associated with proposed fish passage alternatives at Talbot Mills Dam, as well recommendations for minimizing adverse effects, can be found in **Section 4.3** under each applicable alternative.

4. Restoration Alternatives Analysis

Alternatives to restore diadromous fish passage in the Concord River were developed for each of the three sites of interest: Middlesex Falls, Centennial Falls Dam, and Talbot Mills Dam. Possible scenarios were identified in part through review of planning documents such as the Nyanza Restoration Plan (Stratus Consulting, 2012), discussed with project partners, presented to the public at an informational session, and narrowed to those with the greatest potential to be ecologically effective and feasible to implement. The following alternatives that were determined to be most feasible for each site were analyzed:

- Middlesex Falls
  - No Action
  - Channel Improvements (1A)
- Centennial Falls Dam
  - No Action
  - Fishway Improvements (2A)
  - Volunteer Coordination (2B)
- Talbot Mills Dam
  - No Action
  - Technical Fishway (3A)
  - Partial Dam Removal (3B)

Each alternative includes a discussion of its conceptual design, ability to meet target fish passage thresholds, potential benefits and impacts, recommendations for additional studies, and budgetary opinion of cost where applicable. Other concepts that were considered but not fully developed as alternatives for this analysis are provided at the end of each site's section. A "no action" alternative is discussed at each site for the purpose of providing a baseline against which the proposed alternatives can be compared.

4.1 Middlesex Falls

4.1.1 No Action

Although a "no action" alternative is typically presented primarily for comparison with proposed alternatives, in the case of Middlesex Falls it may be a viable alternative, at least in the short term.

Conceptual Design

The "no action" alternative involves making no fish passage improvements at the Middlesex Falls site.

Ability to Meet Target Fish Passage Thresholds

The concern at Middlesex Falls is for high water velocities and/or turbulence impeding the upstream passage of some fish. **Figure 4.1.1-1** is an aerial image of the Middlesex Falls area showing the HEC-RAS cross-sections through the falls, and **Table 4.1.1-1** presents a summary of existing water depths and velocities at those cross-sections under high and low upstream passage flows. Assuming a target velocity threshold of 5 to 7 ft/s determined in **Section 2.4.2**, it appears that velocities are within acceptable ranges for the low fish passage design flow. For the high fish passage design flow, velocities do exceed 5 ft/s at some sections—up to 7 ft/s—but are still within the range of burst speeds for river herring and American shad, and possibly sea lamprey.

Table 4.1.1-1 also shows that minimum water depths within the channel all exceed 0.5 feet, which is the target threshold for fish passage.

As described in **Section 2.4.2**, turbulence due to the large rock outcroppings and steep elevation change of the falls may impeded fish passage under certain flow conditions, particularly for American shad. However, turbulence also helps to reduce velocities and create zones of rest for fish behind obstructions, which may improve passage success.

It is known that American eel and at least some river herring can migrate through Middlesex Falls, as they have been observed at upstream locations.

Potential Benefits and Impacts

This alternative represents no change from existing conditions, and thus would have no associated benefits or impacts.

Recommendations for Additional Studies

It is difficult for a one-dimensional model like HEC-RAS, which requires the assumption of gradually varied flow, to accurately predict the complex hydraulics of a waterfall site such as this. Even if velocities are shown to be within acceptable ranges, turbulence may still impede passage to some extent. A two-dimensional model such as River2D could provide more detailed results than HEC-RAS, but still may not capture of all the complexities of the site, and its development would likely be cost prohibitive compared to the relatively low cost of implementing the proposed alternative.

Direct field observations of flow patterns and/or measurements of flow velocities under a range of fish passage season flows would be beneficial in understanding the hydraulics of the site, but may not be feasible due to safety concerns of accessing the river channel during spring flows.

The best way to evaluate passage at this site may be to monitor for fish migrating at this point or at the Centennial Falls Dam upstream using volunteer efforts (as part of Alternative 2B discussed in **Section 4.2.3**). This could be done as a short-term study during planning and design phases for fish passage at the Talbot Mills Dam upstream. If a preferred alternative for the Talbot Mills Dam is selected and moves toward implementation, the Middlesex Falls site could be reevaluated at that time to determine whether fish passage observations have been satisfactory or if an alternative should be reinvestigated to improve passage.

Budgetary Cost Opinion

There is no cost associated with this alternative.

4.1.2 Channel Improvements (1A)

Conceptual Design

One proposed alternative to improve fish passage at Middlesex Falls is to create a channel through the falls to reduce turbulence. The best location for this channel has been identified as adjacent to the remaining island-side abutment. This would be achieved by removing sections of ledge in the river channel that result in turbulence. The ledge could be removed using a combination of mechanical equipment, explosives, and manual labor. **Drawings 1** and **2** in **Appendix D** show the existing plan and proposed channel improvements at Middlesex Falls. The total volume of rock to be excavated as shown

in the plans is approximately 45 CY. To model the proposed improvements, the recommended areas of ledge were "removed" from cross-sections through the falls as shown on the plans and the range of fish passage flows were simulated. Water depths and velocities at cross-sections through the falls under existing and proposed conditions are tabulated in **Table 4.1.2-1**. Refer back to **Figure 4.1.1-1** for a plan view identifying the cross-section locations.

Construction Access

Construction access could be possible from either the left bank of the main channel or the right bank via the island. If property access is granted and flows are low enough to cross the channel with heavy equipment during the time of construction, the left bank would likely present the shortest and least expensive access route. However, the island route may be preferred from the standpoint of available staging area adjacent to the side of the channel where the work will occur. It is assumed that a temporary construction access road would need to be built to cross the former raceway channel and minimize ground disturbance. The steep slope on the right bank of the raceway channel may present an issue and a temporary access ramp may need to be built.

Ability to Meet Target Fish Passage Thresholds

Table 4.1.2-1 shows that minimum water depths within the proposed channel would still exceed 0.5 feet, which is the target threshold for fish passage. However, water velocities would remain similar to existing conditions, and in fact would increase slightly, by up to 2.4 ft/s under the low fish passage flow.

Potential Benefits and Impacts

Fisheries

Improving passage success rates at Middlesex Falls would contribute positively to the diadromous fishery in the Concord River. Migration upstream of the falls opens access to another mile of river up to the Centennial Falls Dam, and, if passage is successful at the Centennial Falls Dam fishway, another 3 miles beyond up to the Talbot Mills Dam. However, as discussed above, this alternative has not shown a significant improvement for fish passage, and in fact may increase water velocities through the falls.

Water Quality & Aquatic Habitat

This alternative would not significantly impact or benefit water quality or aquatic habitat. There would be a temporary impact to water quality due to construction activities, but since the substrate is primarily solid ledge, turbidity would be very low, and any potential impacts would be mitigated with appropriate soil and erosion controls.

Wetlands & Riparian Habitat

No change to wetlands or riparian habitat would be expected for this alternative.

Sediment Transport

As mentioned previously, the substrate at the site is primarily solid ledge and very little sediment is present. It is not anticipated that sediment sampling or a management plan would be needed.

Flooding

This alternative would not have significant impacts or benefits for flooding. Water surface elevations would be slightly lower through the falls due to the physical lowering of the channel thalweg, but the difference is negligible above the upstream extent of the falls (cross-section 2423).

Infrastructure

This alternative would not pose any threats to infrastructure. Changes in water depths and velocities are isolated to the falls (as shown in **Figure 4.1.2-1**) and would not affect any infrastructure up- or downstream of the site.

Cultural Resources

A cultural resources analysis was not conducted for the Middlesex Falls site. A PNF would need to be submitted to the MHC to determine the need for further assessment, if any. The area of the proposed channel modifications is not likely to have a high sensitivity for either pre-contact Native American or post-contact Euro-American archaeological resources as it consists primarily of solid ledge. However, the island and/or channel banks may contain sensitive areas that would need to be considered for construction access.

Recreation & Aesthetics

The lower Concord River is used for whitewater boating recreational activities, particularly for whitewater rafting trips coordinated by the LPCT. Coordination could occur with the LPCT and other interested boaters to ensure that the proposed channel modifications will not impact key whitewater features of this rapid. The site could be viewed with the LPCT under the range of flows suitable for whitewater rafting to point out any boating "lines" and discuss the proposed project.

The proposed project should not have a significant impact on the aesthetics of the site. The appearance of the falls may change slightly, but it will maintain the look of a natural falls. In addition, the location of this site is not in an area that is frequented or readily viewable by the public.

Operation and Maintenance

As the proposed channel will be blasted out of solid ledge, little operation or maintenance is anticipated. However, follow-up monitoring could occur to ensure that target fish passage thresholds are met and successful upstream migration is observed. If that is not the case, additional channel modifications may be necessary.

Recommendations for Additional Studies

As discussed above, a whitewater boating study could be conducted to ensure that boater interests in the site are maintained.

Additionally, as mentioned for the "no action" alternative, it would be desirable to conduct field observations and/or water velocity measurements at the site during the range of fish passage design flows to confirm the findings of the hydraulic model before proceeding with design and implementation. However, this may not be feasible due to safety concerns of entering the channel during higher flows.

Regardless, volunteer monitoring for fish migrating at this site or at the Centennial Falls Dam upstream could be coordinated (as part of Alternative 2B discussed in **Section 4.2.3**) both prior to and following implementation of this alternative.

Summary and Cost Opinion

A budgetary cost opinion was not developed for this alternative as it does not appear to be a practical alternative to pursue at this time. The cost would also be largely dependent upon the amount of ledge to be removed, which is uncertain. A cost of $460 per cubic yard of ledge removal was developed as a budgetary guideline[67]. Assuming a volume of approximately 45 CY, the cost for the ledge removal alone would be on the order of $20,700. This does not include additional engineering, bid and construction phase services, permitting, site access, erosion and sedimentation controls, or water control.

In summary, although the proposed channel modifications at Middlesex Falls would have little or no impact to other resources, it is not clear that the alternative would improve diadromous fish passage in the Concord River. Therefore, it may make sense to focus funds and efforts elsewhere in the watershed (e.g., Talbot Mills Dam) first while continuing to monitor the Middlesex Falls site. If a preferred alternative for the Talbot Mills Dam is selected and moves toward implementation, the Middlesex Falls site could be reevaluated at that time to determine whether fish passage observations have been satisfactory or if an alternative should be reinvestigated to improve passage.

4.1.3 Other Concepts Considered

Former Raceway Channel

It has been suggested that the former raceway channel on the right side of the river could be utilized for fish passage as-is or with modifications. At its narrowest point, where it flows through remnant sections of concrete walls and over a concrete sill, it is approximately 15 feet wide. Preliminary modeling results show that, under the high fish passage flow, approximately 10% of the flow is diverted down the raceway channel (with the other 90% going through Middlesex Falls). Given this flow of about 160 cfs, the average channel velocity at the pinch point of the raceway channel would be approximately 6 ft/s, which exceeds the low target threshold of 5 ft/s but is still less than the high target threshold of 7 ft/s. However, the channel bottom drops abruptly below this point, which could present a physical barrier to passage under certain flows. Additionally, at the low end of fish passage flows, the model shows that virtually no water flows down the raceway channel. Therefore, it may not provide enough attraction flow for fish to find the downstream entrance, particularly at low flows. Additional survey would be needed in the channel and above and below the junction points with the mainstem river to confirm its hydraulics. Removal of part or all of the concrete remnants (i.e., sill and walls) may help reduce water velocities and excessive drops.

It should be noted that the LPCT has also identified this channel as a possible whitewater boating route with modifications (such as removing steel I-beams that span between the concrete walls and present a safety hazard). As with other alternatives, a whitewater boating study could be conducted to identify any potential impacts before pursuing this alternative.

[67] The estimated cost for ledge removal assumes a crew of one 1.5-CY hydraulic excavator with a hydraulic hammer attachment, an operator, a dump truck and driver, and two laborers, and a daily productivity rate of 10 CY/day. Costs were obtained from R. S. Means Construction Cost Data.

Fishway

A simple fishway with an entrance channel has also been suggested for this site. However, this would likely involve higher costs and greater design complexities than the proposed alternative. If the proposed channel improvements are not found to be feasible or are implemented but not effective in improving passage success, this alternative can be explored in the future.

Abutment Removal

Concern has been expressed about whether the remaining abutments from the breached dam cause a hydraulic constriction, which increases water velocities at the falls. However, this is more of a concern for higher flood flows, as the hydraulic model shows that the abutments do not appear to have a significant effect on the range of fish of fish passage flows.

4.2 Centennial Falls Dam

4.2.1 No Action

Conceptual Design

The "no action" alternative involves making no fish passage improvements at the Centennial Falls Dam site.

Ability to Meet Target Fish Passage Thresholds

Although the LPCT, whose volunteers have performed fish counts in the past, has reported that fish are utilizing the fishway (Stratus Consulting, 2012), little evidence exists and there are no data for which fish return trends can be analyzed. Therefore, the level of passage success that would occur if no action were taken at Centennial Falls Dam is unknown, but unlikely to be satisfactory.

Potential Benefits and Impacts

This alternative represents no change from existing conditions, and thus would have no associated benefits or impacts.

<u>Operation and Maintenance</u>

In this alternative, the project owner would continue to be required to operate and maintain the fish passage facilities according to the fishway operations plan approved by the FERC on February 23, 2005 (FERC, 2005).

Recommendations for Additional Studies

A more formal monitoring program would need to be developed in order to evaluate whether or not the "no action" alternative would meet target fish passage thresholds.

Budgetary Cost Opinion

The only cost associated with the "no action" alternative would be for ongoing fishway operation and maintenance, which is unknown.

4.2.2 Fishway Improvements (2A)

Conceptual Design

This alternative involves addressing any outstanding issues at the Centennial Falls Dam fish passage facilities including, but not limited to, those identified during the most recent inspection conducted by the USFWS on May 19, 2015 (USFWS, 2015, June 23):

- **Fish ladder entrance drop** – Low tailwater levels cause an excessive drop from the water surface within the entrance channel as well as negative hydraulics (e.g., turbulence, aeration) just downstream of the lowermost baffle. The USFWS recommends that the fishway be operable through a range of flows equivalent to the 95% exceedence flow (low flow) to the 5% exceedence flow (high flow)[68]. The project owner is advised to work with USFWS engineering personnel to implement additional weir boards to appropriately backwater the lowermost baffle. The boards would be cut as v-notch weirs and could be affixed to the concrete via angle iron. Boulders could also be configured downstream of the entrance to provide additional backwatering.

- **Tailwater staff gage –** A tailwater staff gage should be placed on the downstream face of the fish ladder entrance wall or other convenient location that can be easily tied into the fish ladder elevations in order to collect tailwater data. Tailwater elevations should be recorded at flows within the full range of fish passage flows and sent to USFWS affiliates. This information would be utilized to develop a tailwater rating curve and assist in the design of entrance channel weirs.

- **Trash rack –** A trash rack with 8-inch clear spacing should be implemented at the fishway exit to prevent coarse debris from entering the fish ladder. Additionally, the fish ladder should be inspected for debris on a daily basis during the upstream migratory season.

Ability to Meet Target Fish Passage Thresholds

The proposed improvements are expected to bring the fishway at Centennial Falls Dam back into compliance and meet target fish passage thresholds as designed. Modeling to evaluate the hydraulics of the fishway was beyond the scope of this project, but implementing a more formal monitoring program (as part of Alternative 2B discussed in **Section 4.2.3**) would be anticipated to be just as accurate, if not more so, in evaluating the effectiveness of the fishway.

Potential Benefits and Impacts

This alternative would not be expected to have any impacts or benefits to resources such as water quality and aquatic habitat, wetlands and riparian habitat, sediment transport, flooding, infrastructure, cultural resources, or recreation and aesthetics. Relevant considerations are discussed below.

<u>Fisheries</u>

Improving passage success rates at Centennial Falls Dam would contribute positively to the diadromous fishery in the Concord River. Successful migration above the dam would open access to another 3 miles upstream to the Talbot Mills Dam. Although the FERC exemption does not include a requirement for

---

[68] Approximately 106 cfs (95% exceedence) and 1641 (5% exceedence) for the upstream migration period (April 15 to July 15) for the period of record at the Lowell gage (October 1936 through December 2015) adjusted by drainage area ratio (373 square miles / 400 square miles = 0.9325).

providing American eel passage, it appears that eel are able to pass above the leaky, relatively low Centennial Falls Dam, but passage efficiency is unknown.

Operation and Maintenance

In this alternative, the project owner would continue to operate and maintain the fish passage facilities according to the fishway operations plan approved by the FERC on February 23, 2005 (FERC, 2005), which includes the following measures:

- By March 20 of each year, an inspection of all fish passage facilities and flow monitoring devices will be conducted (including the barrier dam, non-overflow section, and tailrace screen) to assess their condition and need for repairs.
- By March 30 of each year, a schedule of repairs will be developed for the facilities, which will accommodate normal[69] maintenance and repair of the facilities prior to May 1 of each year.
- By March 30 of each year, the operator of the Lawrence Hydroelectric Project (FERC No. 2800) at the Essex Dam will be contacted in order to coordinate the commencement of the project's fish ladder.
- For each year of the project's operation, the commencement of operation of the fish ladder will be initiated by the removal of all stop logs and installation and alignment of baffles in a state of good repair. The tailrace screen will be installed and maintained in operable condition for the duration of each upstream fish passage season.
- At the start of upstream operation, stoplogs will be placed in the entrance and lower end of the fish ladder sufficient to create a 4- to 6-inch head difference between the tailwater and water surface inside the entrance, as measured at the upstream and downstream faces of the stoplogs.
- Upstream fish passage operations will be terminated on August 1 each year and any adjustments to stoplogs, baffles, and other facilities will be made.
- The downstream fish passage facilities will be operated 14 days after commencement of the fish ladder operation and continue through November 15 each year.
- Flow in the downstream bypass facility shall be controlled with stoplogs at the lower control weir set to elevation 96.5 feet with no stoplogs in the upper weir.

Follow-up monitoring should occur to ensure that target fish passage thresholds are met and successful upstream migration is observed. If that is not the case, additional fishway modifications may be necessary.

[69] The project owner defines normal repairs as those that can be accomplished without dewatering any area other than temporary closure of the Denil fish ladder. Repairs requiring dewatering or other extraordinary actions will have a separate schedule and proposal for action with notification given to state and federal agencies.

Recommendations for Additional Studies

Volunteer monitoring to establish fish count data in the river could be coordinated (as part of Alternative 2B discussed in **Section 4.2.3**).

Summary and Cost Opinion

A budgetary opinion of cost was not developed for this alternative as part of this study, as costs are expected to be relatively minor and will be the responsibility of the hydro project owner. In summary, the proposed fishway improvements at Centennial Falls Dam are a viable alternative that would likely improve diadromous fish passage in the Concord River with little or no impacts to other resources.

4.2.3 Volunteer Coordination (2B)

Conceptual Design

This alternative is not one that would need to be implemented instead of the proposed fishway improvements at Centennial Falls Dam (Alternative 2A), but rather can be implemented in conjunction with that alternative or any others throughout the watershed to inform and promote fish passage restoration efforts.

The proposed project would include supporting assessments, based on volunteer-based observational data, of the current passage capability of the existing fishway. The project would improve volunteer capacity and capability to monitor upstream fish passage. Funding would be provided for a part-time volunteer coordinator to organize volunteers, develop training materials, and perform training. Training and observation would be targeted for the times of the year when fish are expected to pass through the structure (approximately April 15 through July 15). As this site is a focal point for public stewardship and awareness of the watershed-wide diadromous fish restoration effort, the volunteer coordinator will also conduct community outreach and education as part of recruiting volunteers and publicizing fish passage results. A summary report will be prepared to describe observations recorded during the study period and an interpretive sign will be developed and installed at the fishway or along the Concord River greenway adjacent to the fishway (Stratus Consulting, 2012).

Additionally, as the fishway is not directly accessible for public viewing, a video monitoring system is proposed to be installed at the fishway to facilitate volunteer-based observations. Volunteers would be recruited to review video and tally fish passing through the fishway.

Ability to Meet Target Fish Passage Thresholds

This alternative is not intended to directly influence the ability of the site to meet target fish passage thresholds, but instead will collect necessary data to evaluate the ability of other alternatives to meet these thresholds and improve fish passage in the Concord River.

Potential Benefits and Impacts

This alternative would not be expected to have any impacts or benefits to resources such as water quality and aquatic habitat, wetlands and riparian habitat, sediment transport, flooding, infrastructure, cultural resources, or recreation and aesthetics. Relevant considerations are discussed below.

Fisheries

This alternative is anticipated to indirectly benefit the diadromous fishery in the Concord River by providing important data to evaluate passage success at this and other sites, as well as promoting the overall restoration effort to the public.

Operation and Maintenance

In this alternative, the project owner would continue to operate and maintain the fish passage facilities according to the fishway operations plan approved by the FERC on February 23, 2005 (FERC, 2005) described in **Section 4.2.2** above.

Recommendations for Additional Studies

No additional studies are recommend for this alternative.

Summary and Cost Opinion

A budgetary opinion of cost was not developed for this alternative as part of this study. The cost for support of volunteer monitoring efforts, outreach, and reporting for the Centennial Falls Dam was estimated at $25,000 in the Nyanza Restoration Plan (Stratus Consulting, 2012). This includes $15,000 for the volunteer coordinator, $5,000 for reporting, and $5,000 for interpretive signage. It does not include the cost of the video monitoring system.

In summary, this alternative is considered viable, as the opportunity for continued stewardship and public education at that site and throughout the watershed would help ensure the lasting effectiveness of fish passage improvements at this site and others.

4.2.4 Other Concepts Considered

Fishway Replacement

If the Denil ladder cannot be retrofitted to meet target fish passage thresholds, it could be rebuilt to meet agency specifications, or possibly replaced with a nature-like fishway such as a bypass channel or rock ramp. However, the proposed improvements are relatively minor and a full fishway replacement is not anticipated.

Dam Breach/Removal

Dam breach or removal would be another way to achieve fish passage, including for non-alosine target species such as American eel and sea lamprey, but is not feasible as long as this site is an active hydropower project.

4.3 Talbot Mills Dam

4.3.1 No Action

Conceptual Design

The “no action” alternative assumes that none of the proposed or other fish passage restoration alternatives would be implemented at the Talbot Mills Dam, and the dam would remain in place.

Ability to Meet Target Fish Passage Thresholds

No action at the Talbot Mills Dam would not meet target fish passage thresholds. The dam is an upstream barrier to diadromous and resident riverine fishes, so passage efficiency would be essentially zero (with the exception of American eel, which may be able to pass wetted rock surfaces at the dam in small numbers).

Potential Benefits and Impacts

Fisheries

Failure to provide some form of upstream passage at the Talbot Mills Dam will continue to block diadromous species from accessing historic spawning, foraging, and nursery areas within the Concord River drainage. Resident freshwater fish that move up and down a river to find suitable spawning, rearing, and foraging habitat are also affected. Maintaining the existing condition will prevent restoration efforts from extending the current range of diadromous species as well as continue the current fragmentation of habitat and freshwater fish populations.

Water Quality & Aquatic Habitat

Dams transform rivers into slower-moving and deeper lake-like habitats with relatively larger surface areas. This conversion can have impacts for water quality such as increased water temperatures and reduced dissolved oxygen, which lead to eutrophication[70] and warming. Such alterations can shift the aquatic community composition toward a warm water fishery. If existing conditions are maintained at the Talbot Mills Dam, the Concord River would be expected to continue its status as a Category 5 impaired water in the Massachusetts Integrated List of Waters (MassDEP, 2014).

With the dam in place, the existing invasive water chestnut present in the lower dam impoundment will continue to grow each summer and will likely spread over time as the impoundment becomes more and more eutrophic. Water chestnut further degrades water quality and productivity in rivers and ponds due to the large amount of water surface covered by the plants and the resulting decaying biomass. In addition, recreational access can be extremely restricted when the water chestnuts are in full growth because the tangled mass of water chestnut stems in the water makes it difficult or impossible to paddle a boat, fish, or swim through it.

Wetlands & Riparian Habitat

The Talbot Mills Dam impoundment is classified by MassDEP as an open water wetland. However, it does not represent natural (pre-dam) conditions. Maintaining the dam would continue the unnatural lacustrine conditions caused by its impoundment of the river.

Sediment Transport

The slow-moving waters in dam impoundments can become sinks for sediment that would normally stay suspended in faster moving waters and be transported downstream in a functioning river system. These sediment traps can also sequester important nutrients upstream of dams, changing the availability of nutrients and the composition of plant and microbial communities downstream. Sediment impounded by dams will also accumulate and store toxic materials that are adsorbed physically on sediment particles or absorbed actively by the biota attached to the sediments. Additionally, gravels and cobbles are retained behind dams, which limits their recruitment downstream and leads to habitat changes in streams

[70] The process by which bodies of water receive excess nutrients that stimulate excessive plant growth.

and estuaries. If the dam were to unexpectedly fail (as discussed under **Operation and Maintenance** below), the unplanned downstream release of sediments and potential contaminants could have significant water quality impacts.

It should be noted that although it has been in place for at least 300 years in some form, the existing mill pond is not a permanent feature, but rather in a state of transition. Due to the process of sediment accumulation described above, the lower impoundment will continue to fill in and become more eutrophic over time if the dam remains in place. Eventually, the river will cut a new channel through the accumulated sediment, leading to a situation known as a "perched" channel. Therefore, even under the "no action" alternative, the impoundment would likely eventually transition to a state that would be similar to a dam removal scenario in upstream appearance.

Flooding

The Talbot Mills Dam is operated as a "run-of-river" dam where inflow equals outflow on a nearly continuous basis and therefore does not provide flood control as discussed in **Section 2.2.3**. In fact, the dam increases upstream water surface elevations—by at least 3.5 feet upstream of the dam and 0.8 feet at the upstream extent of the Concord River for the 100- and 500-year floods[71]. Under the "no action" alternative, it would continue to artificially raise the river's water surface elevation, contributing to upstream flooding.

Infrastructure

No impacts to public infrastructure are anticipated with this alternative, unless the dam were to unexpectedly fail (as discussed under **Operation and Maintenance** below).

Cultural Resources

Implementation of required maintenance and repair measures (as discussed under "Operation and Maintenance" below) would likely result in some impacts to cultural resources. Repairing or replacing the left spillway abutment, low level outlets, and sluiceway and stilling basin gates would all negatively impact the historic dam and appurtenant structures. Additionally, if the dam were to fail unexpectedly due to its compromised condition, dam structures and potential historic and/or archeological artifacts buried in its vicinity could suffer greater impacts than if it were removed in a controlled fashion. However, it should be noted that these impacts would not be considered part of the "no action" alternative for this project under the Section 106 or state level review process.

Recreation & Aesthetics

Potential impacts or benefits to recreation and aesthetics due to the dam are somewhat subjective and based on individual preferences. While some people may value the existing aesthetics of water falling smoothly over the spillway of a historic structure and the flatwater boating opportunities provided by the slow-moving backwater created by that structure, others may prefer the aesthetics and recreational opportunities associated with alternatives discussed below. Under existing conditions, boaters paddling in the vicinity of the dam must portage around the hazard of the structure, which does not have any

---

[71] These hydraulic modeling results are based on the conceptual removal of the primary spillway and abutments and associated mobilization of impounded sediment that would be expected to occur (discussed in **Section 4.3.3**). Due to the lack of detailed drawings showing the bedrock profile underneath the dam, elevations under the spillway were assumed from sediment probing data conducted just upstream (**Section 3.2.1**). Flooding impacts of the dam could be more significant if the bedrock profile under the dam is lower than the sediment probing data suggest.

warning signs or safety systems to prevent the possibility of going over the spillway, and where access to the river is limited.

<u>Operation and Maintenance</u>

If the dam remains in place, the dam owner (currently CRT Development Realty) will continue to be responsible for ongoing operation and maintenance costs as well as liability. Although the dam was reported to be in "fair" condition in the most recent dam safety inspection report, several deficiencies were noted (discussed in **Section 2.2.3**), and the structure will only continue to degrade over time. The following remedial measures recommended in the inspection report would need to be implemented if the dam were to remain in place:

- Prepare and implement routine inspection and maintenance plans
- Inspect the interior of the of the Talbot Mills complex, particularly the downstream end of the former intake structures
- Repair/replace the sluiceway and stilling basin gates so that the gates are operational and can provide emergency bypass control
- Repair/replace the left spillway abutment to provide an operational low level outlet and emergency bypass control
- Remove trees located just downstream of the primary spillway and on the upstream face of the left embankment near the former intake gates to the Talbot Mills complex

Additionally, this study found that the dam does not meet the dam safety requirement of being able to pass the spillway design flood—in this case the 100-year flood—without overtopping[72]. If the dam were to remain in place, an engineering assessment would need to be conducted to confirm this finding and investigate options to increase spillway capacity. The amount of water that can pass over a spillway is a product of length of the spillway, the depth of water atop the spillway (head), and a weir coefficient (which is related to the spillway shape and head). The capacity of an existing spillway can be increased by lengthening the spillway crest and/or increasing the operating head or weir coefficient. Some increase in the weir coefficient may be possible by improving the spillway crest shape (e.g., from broad-crested to an ogee crest), but this approach is generally costly for the limited results attained. To increase head, the spillway crest elevation would need to be lowered. Due to the physical constraints at the site, increasing spillway length is not feasible without replacing the spillway with an alternate design such as a labyrinth weir, which uses a zig-zag layout to fit more spillway length within a given overall structure width. Any of these potential spillway retrofit/replacement projects would involve destruction or significant modification of the historic structure and many of the associated impacts of dam removal with none of the ecological or other benefits, likely at a substantially higher cost.

Lastly, it is worth noting that if not properly maintained and repaired as needed, including addressing the costly spillway capacity issue, the aging (over 185-year-old) structure will eventually fail, which could occur unexpectedly. Dams have a finite life expectancy, often stated to be on the order of 50 years (FEMA 1999, ASDSO 2001; as cited in Johnson and Graber, 2002). The end result would be equivalent to dam removal, but without all of the meticulous planning and mitigation measures associated with a dam removal project, which could lead to significant impacts for natural and cultural resources as well as infrastructure.

[72] This finding contradicts that in the most recent dam safety inspection report (Geotechnical Consultants, 2015) but is based on an updated analysis and more detailed hydraulic modeling, as discussed in **Section 3.4.3**.

For example, if the dam were to fail suddenly in a flood, the following resources could potentially be impacted more significantly than in a planned dam removal scenario:

- The opportunity for thorough monitoring for and documentation of potential historic and/or archeological artifacts buried in the vicinity of the dam (such as the 1798 dam reportedly submerged upstream) would be lost if the dam fails unexpectedly. Conversely, if the dam was removed in a controlled fashion, these artifacts could be carefully managed.

- The possibility of retaining certain historic features of the dam (such one or both abutments) to honor the history of the site may be compromised if the dam fails during a catastrophic event, which could potentially damage these structures beyond repair.

- The resulting flood wave associated with a sudden dam break (as opposed to a controlled release over time with a planned dam removal) could damage downstream infrastructure, including the historic Faulkner Street bridge and the Talbot and Faulkner Mill complexes, and potentially cause loss of life.

- If sediment impounded upstream of the dam is determined to require active management (i.e., dredging and/or in-place stabilization), unexpected failure could result in the unintentional release of contaminated sediments and associated risks to ecological health.

Recommendations for Additional Studies

If the dam were to remain in place, an engineering assessment to evaluate options for increasing spillway capacity would be recommended.

Summary and Cost Opinion

A formal cost opinion was not developed for the “no action” alternative as there are many unknowns beyond the scope of this study regarding the costs of necessary operation, maintenance, and repairs associated with leaving the dam in place. The dam safety inspection report provided conceptual opinions of probable construction costs for several recommended remedial measures, including tree removal ($5,000), repair/replacement of the sluiceway and stilling basin gates ($60,000) and repair replacement of the left spillway abutment ($40,000), for a total estimated repair cost of approximately $105,000 (Geotechnical Consultants, 2015). However, these estimates are lower than expected and may not include all costs associated with implementing these measures, such as engineering, permitting, water control, cultural resource mitigation, etc. Particularly if the left abutment or any of the gates must be replaced rather than just repaired, estimated costs would likely be more on the order of several hundred thousand dollars. Addressing the spillway capacity issue per dam safety requirements would add substantially to the cost. Costs to repair or rebuild a deteriorating small dam are typically high—from hundreds of thousands to even millions of dollars in some cases (Born et al., 1998; AR/FE/TU, 1999; TU, 2001; as cited in Johnson and Graber, 2002).

In summary, the “no action” alternative would continue to negatively impact fisheries, water quality and aquatic habitat, wetlands and riparian habitat, upstream flooding, and, for some people, recreation and aesthetics. An aging structure that does not have a formal maintenance plan and does not meet dam safety criteria would remain in place, to potentially fail in a sudden and catastrophic manner, causing substantial impacts to these and other resources. Restoration of diadromous fish passage in the Concord River would not be possible with no action at Talbot Mills Dam.

4.3.2 Technical Fishway (3A)

Background

A fishway refers to the structures and measures that provide for safe, timely, and effective upstream and downstream fish passage. Fishways can be broadly categorized as ether technical or nature-like. Nature-like fishways are designed to approximate (functionally and/or aesthetically) natural river reaches, and include options such as bypass channels or rock ramps (see **Section 4.3.4** for a discussion of these alternatives at Talbot Mills Dam). Technical fishways are engineered structures that can be further categorized as upstream or downstream passes, and—for upstream passage—either volitional[73] (i.e., fish ladders) or non-volitional (e.g., lifts, locks, and trap-and-transport methods).

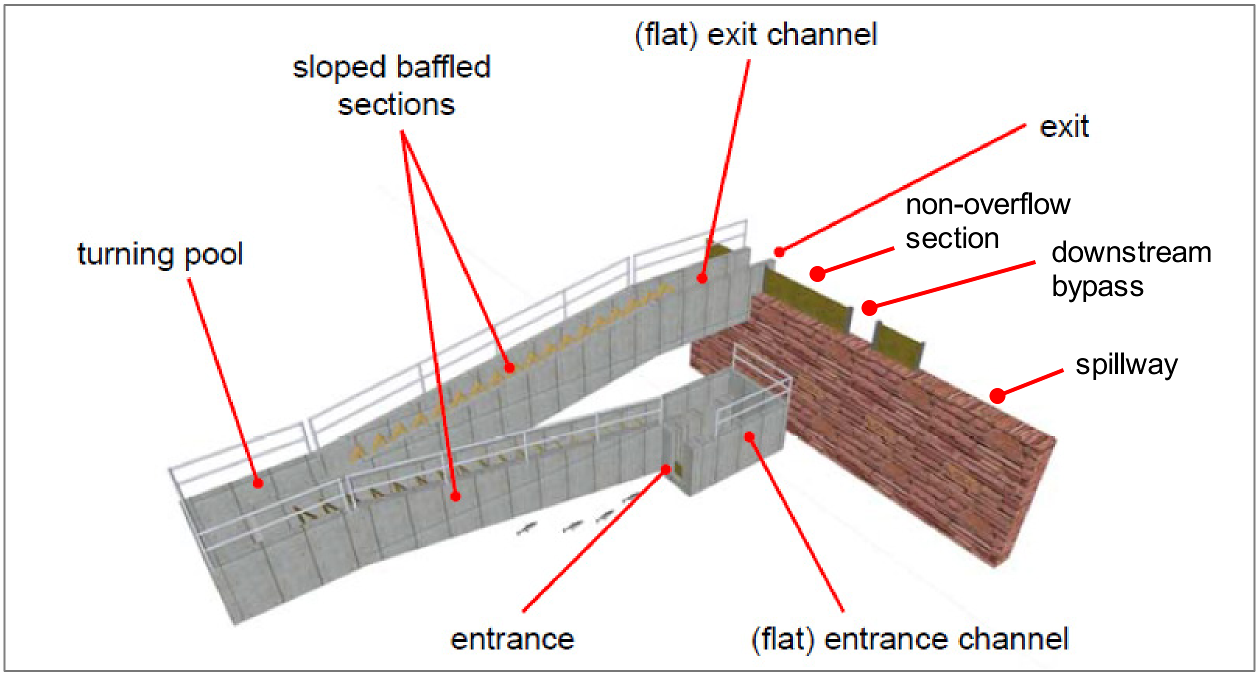
Fish ladders are structures that pass water over a fish passage barrier (e.g., a dam) using a cascading effect that slows the water velocity to accommodate the swimming speed of target fish species. Fish ladders are generally categorized as pool-type or baffled chutes. Variations of the pool-and-weir type are the most common type of fishway currently in place on coastal Massachusetts streams. This style has the advantage of adequate function under low flow regimes and is the favored design when public viewing is desired. However, pool-type fishways can require frequent manual adjustments and have lower maximum allowable slopes than baffled chute designs, which leads to longer overall fishway lengths for a given design head.

Of the baffled chute designs, the steeppass and the Denil are the two primary variations in general use. Steeppasses have multi-plane baffles that result in high energy dissipation rates, allowing somewhat steeper angles, slower water velocities, and/or shorter ladders than other designs. They are typically prefabricated from aluminum, which can make installation relatively easy and inexpensive. However, they are best suited for passing primarily river herring in small, coastal watersheds (20-30 square miles)[74].

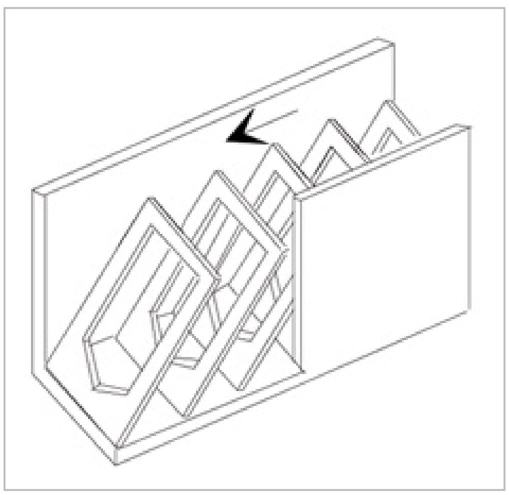
Passage of other target species such as American shad is more effective with the larger design of a Denil ladder. In appropriate locations, Denil fishways are generally reliable for passage of river herring and adult salmonids and in some cases American shad, other alosines, and other migratory and resident species. The successful use of Denil fishways with a wide variety of anadromous and riverine fish is in large part due to the "U" shape of the baffles, which allows fish to swim through the channel at their preferred depth and velocity. Because standard Denil fishways, with their single-plane baffles, are less effective at energy dissipation than steeppasses, Denil fishways are typically longer for a similar ease of passage. They are relatively low cost in comparison with the larger pool-type technical fishways (Brownell et al., n.d.).

Since Denil fishways have smaller dimensions and higher velocities than most conventional fishways, debris blockage has been a reoccurring issue. Aside from hindering fish from exiting the fish ladder, a piece of debris can drastically change the hydraulics in the fishway, resulting in a hydraulic barrier that fish cannot traverse. Trash racks at the fishway exit, with sufficient clear space through which the fish can exit, as well as screens along the top of the structure can help prevent debris blockage, as long as they are properly maintained.

[73] The term "volitional" implies that fish move through the fishway willingly and without human assistance.
[74] Ideally, fishway capacities are designed for the size of the fish run, not the size of the watershed; however, the run size is often unknown, so drainage area and spawning potential of the watershed can be used as surrogates.



Typical components of a standard Denil fishway (Towler, 2014).



Standard Denil fishway schematic (left) and example (right) at Potter Hill Dam, Pawcatuck River, Westerly, RI.

Fish ladders can be fabricated from many different materials including concrete, metal, and wood. Concrete in particular lends itself to custom modification to blend with surrounding structures, such as historic stone masonry. Below are several examples of fishways installed at historic dams where aesthetics were a primary concern for stakeholders, including a detail of concrete stamped and stained to match existing stone masonry as a requirement of a Section 106 historical consultation process.

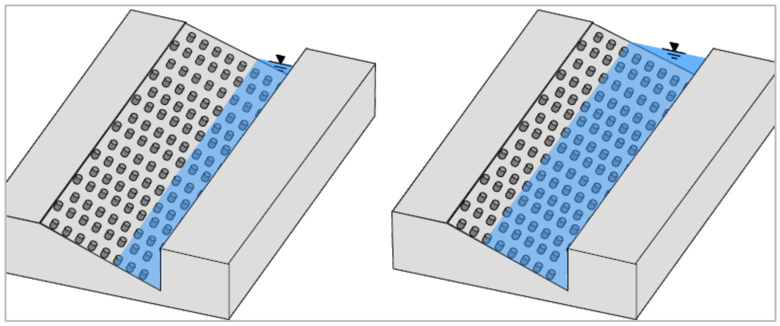
Examples of fish ladders installed at historic dams: A Denil ladder with integrated eelway at Horseshoe Falls Dam on the Pawcatuck River in Shannock Village, Rhode Island (left) and a steeppass (with eel ramp later added) at East 182nd Street Dam on the Bronx River in Bronx, NY (right).

Example of a concrete Denil fish ladder stamped and hand-stained to match existing stone masonry of a historic dam spillway as a requirement of the Section 106 consultation process for the Horseshoe Falls Dam on the Pawcatuck River in Shannock Village, Rhode Island.

American Eel

Most traditional fishways such as fish ladders were designed for migratory fish with excellent jumping or swimming ability. Although larger eels may use conventional technical fishways to some degree, most small elvers have difficulty using traditional fishways because water velocities and turbulence limit upstream progress. Although climbing behaviors are largely responsible for the presence of eels upstream of barriers with no fish or eel passage structures (such as the Talbot Mills Dam), the efficiency of eels in passing barriers by these methods is probably low (Brownell et al., n.d.).

Selection of an appropriate design for an eel pass structure is dependent on habitat, size, and life history stage of the eels to be passed. Occasionally a simple structural modification is implemented by roughening or attaching substrate to the downstream face of the dam or other barrier to enhance the eels' ability to climb directly over the barrier, but these solutions are generally only practical for low-head dams (less than about 6 feet) to minimize the climbing distance and exposure to predators. More often, a separate eel pass is used. The most common design is a ramp furnished with a climbing medium, such as artificial mesh or brushes, which gives eels something to climb through or over. The size of the substrate must be carefully matched to the size range of eels to be passed at the site; sometimes a mix of substrates is used to target a broader range. Typically, small amount of flow is directed down the ramp to create a constantly wetted climbing surface, and attraction flow is supplied at the entrance. Water depth over the ramp is carefully balanced to accommodate ascending eels while preventing the flushing of small eels down the ramp by excessive flow. A lateral slope can be incorporated into the design (as shown in the figure at right) to provide a constant wetted margin along the climbing substrate under a range of conditions from low (left in figure) to high (right in figure) headpond levels. The ramp is typically covered to protect eels from birds and other predators (Gulf of Maine Council on the Marine Environment, 2007; Brownell et al., n.d.).

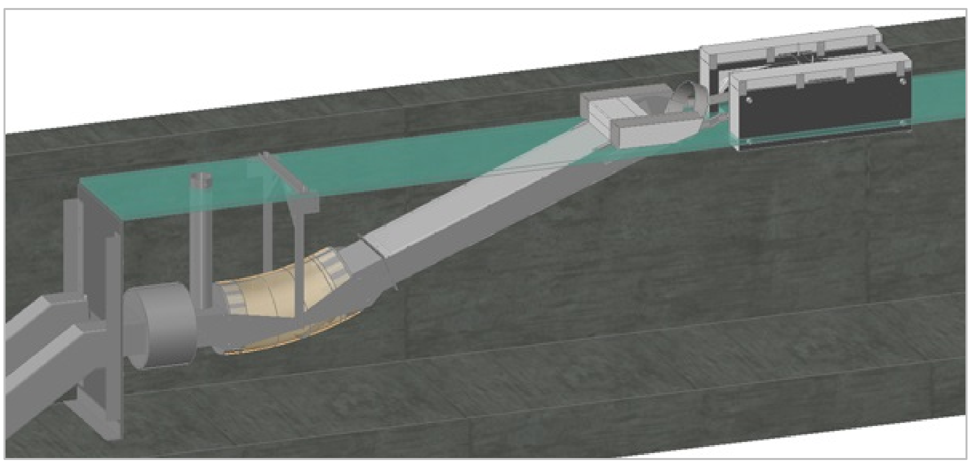


Example of a simple full-height eel ramp exiting to the headpond (left) and close-up of dual substrate types (right).

An eelway can also be incorporated into the design of a traditional fish ladder, such as a Denil, as shown in the images below and in the Horseshoe Falls Dam fish ladder example shown above.

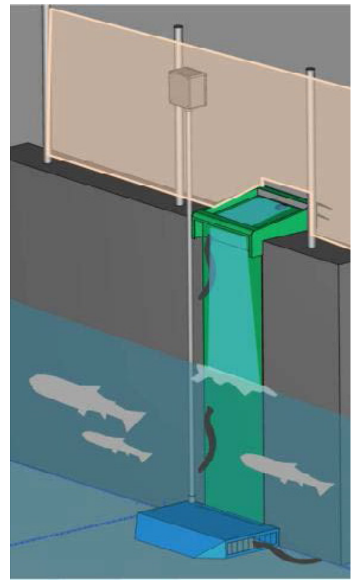
Example of an eel ramp incorporated into a concrete Denil fishway at Upper Mystic Lake Dam in Massachusetts.

A solar-powered pump can be used to provide the constant flow rate needed for an eel ladder, but presents additional operation and maintenance concerns. Recently, an innovative alternate water control assembly that employs a self-regulating floating baffle at the ramp exit was fabricated, piloted, lab tested, and integrated into a fish ladder at a historic dam to address aesthetic, maintenance, and layout constraints, as shown below.



Innovative eel ramp water control assembly that employs a self-regulating floating baffle at the exit installed at the historic Horseshoe Falls Dam on the Pawcatuck River in Shannock Village, Rhode Island in 2012.

Sea Lamprey



Sea lamprey are another target species whose passage is sometimes given special consideration. Lamprey-specific passage facilities have been more recently developed and include structures such as the lamprey passage system, the lamprey flume system, or a wetted wall (shown at right), as well as other fixes including concrete rounding, vertical step removal, open access to low velocity routes, and velocity reducing bumps on traditional fishway floors. However, most of these solutions have been designed and tested for the Pacific lamprey, which is morphologically and behaviorally similar to the sea lamprey, but has stronger swimming capabilities. Instead, fish ladders primarily designed for other target species such as river herring and American shad are a viable option. Although there are few directed studies of traditional fishway passage or efficiency for sea lamprey, experience and regional observations have shown that traditional technical fishways will pass sea lamprey to a limited degree (Brownell et al., n.d.). Additionally, successful passage of Pacific lamprey has been demonstrated in Denil fishways of acceptable length[75] and slope (Slatick & Basham, 1985).

Downstream Passage

Downstream passage can be necessary for both adult and juvenile fish. Adults of some anadromous species may spawn multiple times if they survive the outmigration from their spawning areas, and adult American eels must successfully pass downstream to get to their spawning grounds in the Sargasso Sea. Juveniles of all anadromous fish have to get to the ocean to mature and return to their natal stream for spawning. Of the target species and life stages, adult sea lamprey are the one exception for downstream passage considerations as they die after spawning; thus downstream passage protection for post-spawning adult sea lamprey is not necessary. Dams and other barriers do not necessarily hinder downstream migration, especially low-head dams and other small structures where water flows over the dam or passes through open gates instead of through hydropower turbines. However, simple downstream passage facilities—such as a small notch in the spillway and a plunge pool of sufficient depth below—can help ensure safe, timely, and effective downstream passage for all life stages of target species (Brownell et al., n.d.).

Conceptual Design

Due to its relative effectiveness at passing target species including American shad, a Denil fishway was selected for the concept design at the Talbot Mills Dam. A simple eel ramp is proposed to accommodate upstream migrating elvers. Since experience has shown that sea lamprey can effectively utilize a Denil ladder, a separate lamprey-specific structure was not included in the concept design. A downstream passage notch in the spillway is also proposed.

Concept plans for the fishway alternative are shown in **Drawing 4** of **Appendix D**. A conceptual photographic rendering of the proposed fishway is shown in **Figure E-2** of **Appendix E**. The plan consists of a concrete Denil fish ladder attached to the river right (northeasterly) concrete abutment of the dam. This location was chosen for several reasons: 1) it represents the largest area between the dam and the

[75] The data show that Denil ladders greater than 66 feet may be unacceptable to American shad, but Pacific lamprey successfully passed through all ladders up to 89 feet in length.

Faulkner Street bridge in which to place a fishway, 2) it is the site of the historic fishway that was previously operated at the dam, and 3) the right abutment has been disturbed more recently than the rest of the historic dam when it was repaired with concrete sometime in the past (possibly when the former fishway was decommissioned). A notch would be cut in the abutment to allow for attachment of the fish ladder, which would also be anchored to the stone retaining wall downstream. Existing rock substrate may need to be removed from the area under the proposed fish ladder to create a relatively flat surface atop which forms can be built for pouring concrete.

Ideally, the fishway entrance would be located on the deepest side of the river, or thalweg, to maximize fish passage efficiency. Although there appear to be deeper pools on the left side of the river immediately below the spillway, survey data collected along the upstream face of the Faulkner Street bridge for the FIS (FEMA, 2014) indicate that the right side of the river is about 2.5 feet deeper, as shown in **Figure 4.3.2-1**. Removal of ledge substrate between the bridge and the fishway entrance may be needed to further define the thalweg channel.

The fish ladder was designed to primarily target river herring and American shad migration during upstream migration, with consideration also given to sea lamprey. The upstream migration periods for river herring and American shad are April 15 to June 15 and May 15 to July 15, respectively, so an overall range of April 15 to July 15 was used to develop design flows. A flow duration curve developed for the site during this period (**Figure 3.3.1-6**) was used to determine the 95% exceedence and the 5% percent exceedence flows (105 cfs and 1628 cfs, respectively), which were used as low and high design flows per USFWS recommendations (Towler, 2014). The hydraulic model was used to estimate headwater and tailwater elevations corresponding to these flows.

The estimated headwater elevation for the high design flow is expected to overtop the right abutment, which would create conditions outside of a reasonable operating range. Instead, the top of the abutment was used for the highest headwater elevation. The high and low design flow conditions were compared to determine the largest head differential between headwater and tailwater, and the low design flow was found to control the design with a headwater at elevation 108.7 feet NAVD 88 and a tailwater at elevation 98.3 feet NAVD 88, for a total head of approximately 10.4 feet.

For the target species, the USFWS recommends the following design criteria for a standard Denil fishway (Towler, 2014):

- **Entrance** – The entrance invert should be set so that the depth of water at the low operating tailwater elevation is 2 feet or 2 body depths (whichever is greater), which should be maintained by submerged stoplogs. Additionally, the entrance should be narrower (typically 62.5%) than the channel width to create a strong attraction flow jet.

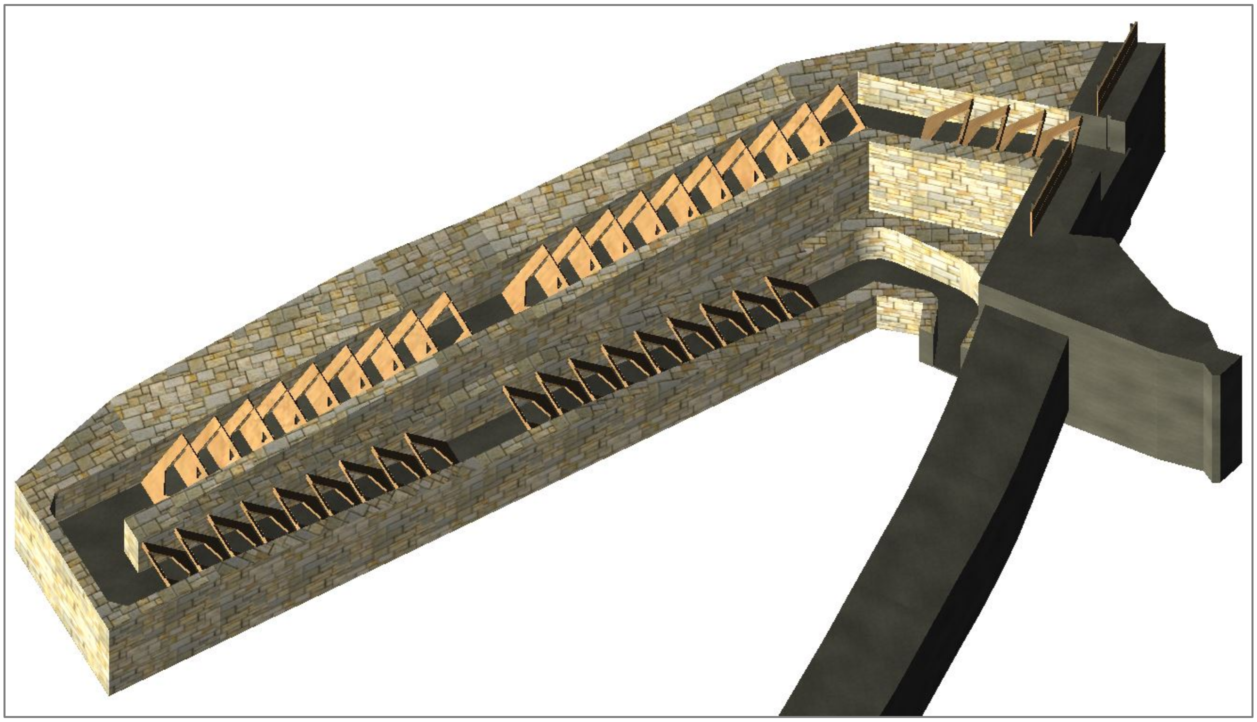
- **Slope** – The slope of a Denil fishway designed to pass American shad should not exceed 12.5% (1 horizontal to 8 vertical, or 1H:8V).

- **Channel Width** – The width of a Denil fishway designed to pass American shad should be 4 feet.

- **Turning and Resting Pools** – Resting pools should be incorporated at least every 6 to 9 feet of vertical rise, either between two chute sections or as turning pools at switchbacks.

- **Baffles** – Baffles, typically built from dimensional lumber, are set at a 45 degree angle to the sloped floor of the fishway channel with a height 1 foot greater than the high design flow water surface elevation.

Considering these design guidelines, a slope of 1H:9V was used with a resting pool for every 22.5 feet of horizontal distance (corresponding to 2.5 feet of vertical distance along the slope). One switchback turning pool was needed to allow the ladder to fit within the site constraints (i.e., upstream of the bridge) and also to place the fishway entrance adjacent to the spillway where it will receive the most attraction flow. The fishway could optionally be fitted with metal screens along the top and a trash rack at the exit to prevent debris from entering, but if public viewing is desired, the metal screens could be omitted and the fishway could be checked more frequently for debris. Alternately, a smaller upstream exit section could remain uncovered to facilitate viewing.



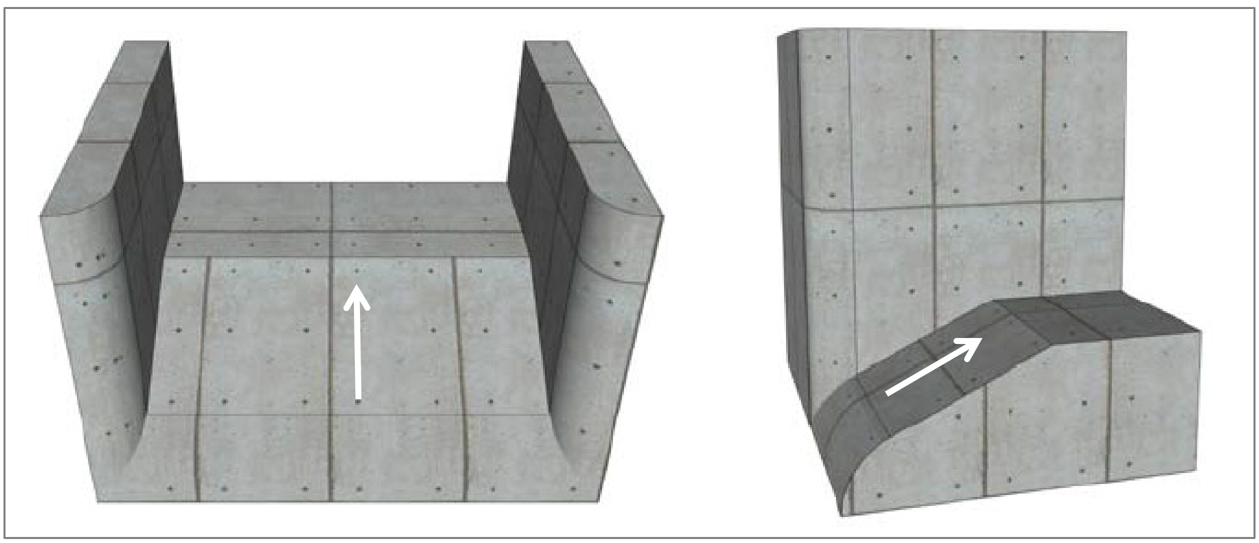
Conceptual rendering of a Denil fish ladder installed at the right abutment of the Talbot Mills Dam

To enhance upstream passage of American eel, an eel ramp is proposed to be anchored to the spillway side of the right spillway abutment. Recommended eel ramp design criteria include 8- to 18-inch widths, 4- to 6-inch channel depths, and flow depths ranging from 1/16 to 1/8 inch over climbing substrates. The ramp slope should be less than 45 degrees and individual sections should not exceed 10 feet in vertical height. Resting “pools” between these sections are flat stretches of ramp that should have a width and length equal to the ramp width with at least 1 inch of water depth. The ramp should be fully covered with an opaque cover for its entire width and length, except above the high water level at the entrance. The need for attraction flow is dependent on the size of the ramp and the presence of competing flows, but is typically 80 to 300 gallons per minute (0.2 to 0.7 cfs) if required (Towler, 2014).

Based on these criteria and the site layout, a three-section, 18-inch-wide ramp is proposed to be anchored to the fish ladder at its entrance and directly to the spillway adjacent to the right abutment at its exit

(crossing above the fish ladder entrance). Assuming a total head of approximately 10.4 feet as above, a total ramp length of about 13.1 feet due to the site constraints, and a resting section length equal to the ramp width (18 inches), the slope would be approximately 1V:1.1H, slightly less than the 45-degree maximum limit. A mix of climbing substrates should be used to accommodate various sizes of elvers and yellow eels. Ideally, the ramp would be designed to be wetted with appropriate water depths over a range of headpond levels by gravity flow to avoid the operation and maintenance associated with pumps. This could be accomplished in part by incorporating a lateral slope as described previously.

A notch is proposed to be cut into the dam spillway create a "downstream bypass" that will direct fish passing over the spillway to a deeper plunge pool. The dimensions of the notch would be approximately 3 feet wide by 2 feet deep. The bypass location was selected as the river left (southwesterly) end of the spillway adjacent to the abutment to avoid interference with the Denil entrance and take advantage of what appears to be a deeper existing plunge pool in that area. The exact channel elevations below the proposed bypass are unknown, but existing pool depths about 10 feet downstream at a surveyed cross-section along the upstream face of the Faulkner Street bridge (shown in **Figure 4.3.2-1**) appear to be 1.2 to 5.5 feet under the low and high design flows, respectively. Therefore, some removal of channel bed substrate (i.e., bedrock) may be needed to meet the USFWS 4-foot depth recommendation. Ideally, the bypass would have a sloping upstream face—a design known as a "uniform acceleration weir," as shown in the figure below—to minimize regions of high acceleration.



Schematic of a uniform acceleration weir downstream bypass from the upstream (left) and side (right) views (Towler, 2014).

Stoplog structures would be installed in the fishway entrance (for maintenance of the fishway) and exit as well as in the downstream passage notch (to control the flow through the fishway under varying head conditions and to shut off flow to the fishway and/or notch, when desired).

The hydraulic model shows that at the high design flow, water is expected to overtop the right concrete abutment to which the upstream exit of the Denil would be attached by about 3 inches. A set of low (approximately 6 inches high) flashboards could be installed along the top of the abutment to avoid overtopping during the normal fish passage season, but be designed to fail at higher flood flows to avoid further impacting spillway capacity.

Per USFWS guidelines, a fishway entrance located adjacent to a spillway should be protected by a non-overflow section to reduce spill into the fishway and interference with the entrance jet hydraulics (Towler, 2014). This can be achieved using flashboards along a short length (approximately 8 feet) of the spillway adjacent to the fishway entrance.

<u>Construction</u>

Temporary construction access and staging would likely be concentrated in the small paved open area above the stone retaining wall between the river right abutment and Faulkner Street. Providing access for heavy equipment into the channel downstream of the dam would prove difficult due to the high vertical retaining walls. Ideally, the need for heavy equipment in the channel could be avoided and the work could be accomplished from atop the wall. Concrete could be poured from above and concrete forms, rebar, etc. could be lowered using a hoist or similar. It may also be possible to lift a small excavator into the channel using a crane if needed. Access to the left abutment for the downstream passage notch could be provided from Faulkner Street. Water control could be accomplished with sand bags around the work area in the channel combined with a cofferdam designed to contain water to the left portion of the spillway (except during the downstream bypass construction).

Ability to Meet Target Fish Passage Thresholds

The effectiveness of the proposed fish passage structures has been discussed previously. Denil fishways have been shown to be effective for the target species of river herring, American shad, and sea lamprey, while the eel ramp is expected to provide efficient passage for American eel.

Potential Benefits and Impacts

<u>Fisheries</u>

Passage of other aquatic species and overall connectivity of the river will be limited but will improve over existing conditions. Denil fishways have been demonstrated to pass most freshwater fish species (adult stages) present in coastal drainages in Massachusetts. Successful passage at this site would open access to over 35 miles of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams). Diadromous fish populations could potentially become self-sustaining in the Concord River system with the implementation of this alternative.

<u>Water Quality & Aquatic Habitat</u>

Any temporary minor impacts to water quality and/or aquatic habitat due to construction activities would be mitigated with appropriate erosion and sedimentation control measures to be approved by the regulatory agencies. As stated previously, the channel substrate in the work area consists primarily of solid ledge, which does not pose a major threat to water quality and aquatic habitat.

<u>Wetlands & Riparian Habitat</u>

Installation of a fish ladder in the channel below the dam would result in a small loss of wetland area (about 1,000 square feet) currently classified as open water wetlands. However, this resource conversion to further the broader goal of diadromous fish restoration in the Concord River watershed would likely be considered acceptable to regulatory agencies. Any temporary minor impacts to wetlands and/or riparian habitat due to construction activities would be mitigated with appropriate erosion, sedimentation, and pollutant control measures to be approved by the regulatory agencies.

Sediment Transport

Minimal impact to the sediment accumulated in the Talbot Mills Dam impoundment would occur with the installation of a fishway. Over time, a channel through the pond may naturally form as continuous flows transport sediment downstream. However, this would be a gradual process that would not create a significant water quality impact.

Upstream Water Levels & Flooding

The proposed fishway facilities would have mixed effects on upstream water levels. The fish ladder and eel ramp would reduce spillway capacity under high flows, raising the 100-year flood water surface elevation by approximately 0.04 to 0.1 feet, while the downstream bypass notch would lower the crest of the spillway for normal flows, lowering the upstream water surface elevation by about 0.02 to 0.07 feet. These minor changes in water surface elevations are not expected to have a significant effect on other resources.

However, even a slight increase in the 100-year flood elevation requires a project to file a Conditional Letter of Map Revision (CLOMR) with FEMA prior to constructing the project to officially revise the current Flood Insurance Rate Map (FIRM) to reflect the proposed changes to floodplains, floodways, and flood elevations (44 CFR Ch. 1, Parts 60, 65, and 72). A CLOMR officially revises the FIRM, and sometimes the FIS report. Obtaining a CLOMR is a relatively expensive and rigorous process, and involves developing a hydraulic model to FEMA's standards (as described in **Section 3.4**).

Infrastructure

As shown in **Section 3.4.3**, the Talbot Mills Dam currently does not meet dam safety regulations to be able to pass the spillway design flood (in this case the 100-year flood) without overtopping the top of dam elevation (reported as 113.8 feet NAVD 88). The spillway capacity estimate for the dam includes the assumption that the abutments provide auxiliary capacity during high flows. The attachment of a fishway to the right abutment, along with related structures on the abutment and spillway (e.g., flashboards, eel ramp, downstream passage notch) would further reduce the capacity of the dam to pass flood flows. To simulate this in the hydraulic model, all flow to the right of the proposed attachment point for the eel ramp (at the right edge of the spillway adjacent to the right abutment) was classified as "ineffective" flow, meaning it no longer contributes to the spillway capacity calculation. Additionally, the downstream passage notch was "cut" into the spillway in the model. The sluiceway gate was conservatively assumed to be closed as for the existing conditions spillway capacity check. With these proposed fishway conditions, simulating the 100-year flood flow (5,675 cfs) yields a water surface elevation of 114.2 feet NAVD 88, compared to 114.1 feet NAVD 88 for existing conditions, which represents a relatively small reduction in capacity that would not have significant upstream impacts.

However, it is important to note that in order to make modifications to an existing dam, such as to add a fishway, the ODS will require the dam owner to bring the dam into compliance with dam safety regulations as part of the design, which would involve addressing all of the deficiencies discussed in **Section 4.3.1** (under "Operation and Maintenance"), including the addition of spillway capacity. The dam owner would also continue to be responsible for ongoing maintenance and repairs for the dam.

Sometimes there is the potential for erosion due to scour in the area at the base of a fishway due to the concentration of higher velocity flows, especially if a structure is present downstream, such as the Faulkner Street bridge below the Talbot Mills Dam. However, as stated previously, the channel immediately downstream of the dam and continuing through the Faulkner Street bridge appears to

consist almost exclusively of solid ledge and large boulders, and the bridge pier and abutments appear to be armored and founded directly on bedrock, so the potential for scour at this bridge is very low.

There is a pipe that exits the stone retaining wall downstream of the right dam abutment in the area of the proposed fishway. An assessment will need to be conducted to determine if the pipe is still in use, and if so, whether it can be rerouted (possibly extended underneath the fishway).

No impacts to any other structures, including upstream bridges and the former Middlesex Canal, are expected.

Cultural Resources

PAL's historic and archaeological reconnaissance survey (**Section 3.5**) confirmed that the Talbot Mills Dam included a fishway during the historic period of operation. If reinstitution of a fishway is selected for further study/design, it is recommended that the design of the new structure conform to the *Secretary of the Interior's Standards for the Treatment of Historic Properties* (SOI Standards; 36 CFR Part 68) to minimize potential adverse effects to the historic districts. Further research about the location and appearance of the historic period fishway would be recommended so that any new design is sympathetic to the surrounding historic context of the districts, requires minimal alterations to the dam, and is thus compliant with the standards.

Additionally, archaeological monitoring is recommended in the high-sensitivity areas during construction of the fish ladder and any optional structures. The archaeological monitoring would be designed to identify and record any buried surviving components of the documented early through late eighteenth-century dams and/or fishways. Any such structural remains that may be exposed during construction activities have the potential to contribute to an understanding of the historic waterpower infrastructure of the Talbot Mills Dam as a contributing resource to the Middlesex Canal Historic and Archaeological District and a potential contributing resource to the Billerica Mills Historic District.

Access and staging for installation of the fish ladder would likely be concentrated in the small paved open area above the stone retaining wall between the river right abutment and Faulkner Street. If any construction activities would directly impact soils below the paved ground surface or the existing retaining/training wall (which is not anticipated for the current concept design), intensive archaeological survey would be recommended prior to construction and/or archaeological monitoring during construction in the high-sensitivity area to identify and record any potentially significant buried structural remains associated with the mid-nineteenth-century dye/store house and earlier dam retaining walls.

If the fishway alternative is selected for further analysis and design, the lead federal agency for this project (NOAA) would consult with interested parties on ways to avoid, minimize, or mitigate any adverse effects to historic properties that may result from the project.

Recreation & Aesthetics

Implementation of a fishway at the Talbot Mills Dam would be expected to improve recreational resources. The proposed fishway location is at the base of a small park, from which the public could view fish ascending the ladder. Additionally, the restoration of diadromous fish in the Concord River would represent a recreational benefit, as some target species are valued as sport fish (e.g., American shad), or were in the past before their declines led to moratoriums on their harvest (e.g., river herring). Recreational benefits would also extend to the recreational and commercial fisheries of other species

(e.g., striped bass, trout, cod, bluefish, tuna, etc.) that forage upon diadromous fish along the Atlantic coast.

The aesthetics of the fish ladder itself are more subjective. As noted above, the concrete medium of the fishway would allow for custom modification to blend with surrounding structures, such as the historic stone masonry retaining wall behind the proposed location. Additionally, the ability to view fish returning to the river would provide recreational and cultural benefits to citizens who value fish runs for food, bait, and as a sign of a healthy river.

Operation and Maintenance

MarineFisheries requires operation & maintenance (O&M) plans for all fishways in Massachusetts to be prepared in coordination with property owners to ensure efficient passage is compatible with existing uses. Operation and maintenance of a fishway is an intensive process during the fish passage season. The O&M plan would include guidance for regular (at least weekly, sometimes daily) inspection before and during the fish passage season to remove debris and check for damage or other issues. Stoplog management would involve removal and replacement of stoplogs in the fishway and downstream passage notch as needed at the change of fish passage seasons or to regulate higher flows. An automated water level sensor at the dam that can be monitored remotely would assist with stoplog management.

Again, it is important to note that in order to make modifications to an existing dam, such as to add a fishway, the ODS will require the dam owner to bring the dam into compliance with dam safety regulations as part of the design, which would involve addressing all of the deficiencies discussed in **Section 4.3.1** (under "Operation and Maintenance"), including the need to add spillway capacity to be able to pass the spillway design flood. The dam owner would also continue to be responsible for ongoing maintenance and repairs for the dam.

Recommendations for Additional Studies

If the fishway alternative were to progress to the next level of feasibility study, additional recommended studies include, but are not limited to, the following:

- **Topographic survey** – Detailed topographic survey should be collected of the Talbot Mills Dam and vicinity, including all potential construction access and staging areas and the channel downstream of the dam. Specific attention should be paid to mapping the bedrock surface in the area of the proposed fishway as well as below the proposed downstream passage notch, to identify the volume of material that may need to be removed in these locations.

- **Wetlands, wildlife, & botanical resources survey** – A formal wetland delineation would be needed to quantify the size, type, function, and value of the wetlands within and adjacent to the proposed work area. Additionally, state and federal agencies should be consulted to identify any potential rare, threatened, or endangered species in the project vicinity.

- **Hydraulic modeling** – The existing hydraulic model should be updated to incorporate the more detailed topographic survey and confirm fishway design parameters.

- **Cultural resources mitigation planning** – While not technically a study, it will be essential to initiate planning efforts to mitigate potential impacts to historic and/or archeological impacts as early as possible in the process.

Summary and Cost Opinion

A budgetary cost opinion for this alternative is shown in **Table 4.3.2-1**. The estimated cost for additional studies, engineering, permitting, and construction of a technical fishway at the Talbot Mills Dam is approximately $590,000. This includes estimated costs associated with required dam repairs, as discussed in **Section 4.3.1**.

In summary, installation of a fishway—including a Denil ladder, eel ramp, and downstream bypass notch—at the Talbot Mills Dam would provide effective passage for target species, furthering the goal of diadromous fish restoration in the Concord River. Passage of other aquatic species and overall connectivity of the river would be limited but would represent an improvement over existing conditions. With the exception of cultural resources and aesthetics, little to no impacts to other resources are anticipated. The obligation to bring the dam into compliance with dam safety regulations as well as the continued responsibility for ongoing operation, maintenance, and liability associated with the dam would impact the cost effectiveness of this alternative. Still, a fishway at Talbot Mills Dam is a viable alternative for restoring diadromous fish in the Concord River that could advance to the next phase of this project for further study.

4.3.3 Partial Dam Removal (3B)

Complete or partial removal of dams has been shown to be a simple, viable option for fish passage at some dam barriers. When implemented correctly, dam removal has the advantage of restoring connectivity of rivers in both upstream and downstream directions for a wide variety of fish and other aquatic species.

Conceptual Design

Full removal of the entire Talbot Mills Dam and all appurtenances (including the former intake gates to the Faulkner Mills complex, the sluiceway channel, and any embankment sections that may or may not have been constructed as part of the original dam) is not feasible due to the integral nature of some structures with Faulkner Street and other adjacent structures. Therefore, the dam removal alternative considered for this study is a partial dam removal that would consist of removing the entire primary spillway structure down to bedrock or below. If found, the 1798 dam structure that is reportedly buried upstream would also be removed. One or both spillway abutments may optionally be preserved in an effort to honor the historic significance of the site at a slight cost to hydraulic capacity, as discussed below.

Concept plans for the dam removal alternative are shown in **Drawing 5** of **Appendix D**. A conceptual photographic rendering of the proposed dam removal is shown in **Figure E-3** of **Appendix E**.

<u>Construction</u>

Temporary construction access and staging would likely be concentrated in the small paved open area above the stone retaining wall between the river right abutment and Faulkner Street. Providing access for heavy equipment into the channel downstream of the dam would prove difficult due to the high vertical retaining walls. Options include lifting a small excavator into the channel via crane, or building a temporary ramp of stone fill from the top of the wall to the channel bottom. The crane approach would likely be preferred, as the ramp could compromise the integrity of the historic stone retaining wall and any potential historic and/or archeological artifacts contained within.

Due to the potential for the presence of a 1798 legacy dam submerged in the impoundment upstream of the dam, water will need to be carefully diverted around the work area to allow for any possible mitigation

measures that may be required. At this conceptual stage of the design, a cofferdam is assumed to be needed across the entire channel width. Once the cofferdam is established and the area upstream of the spillway is dewatered by pumps, it is possible that the sluiceway could be used for passive water diversion (by angling the cofferdam to direct water toward the sluiceway and opening the sluiceway gate) without the need for full-time pumping. To access the dewatered area along the upstream side of the spillway, temporary wood platforms known as "swamp mats" could be laid in sections along the length of its upstream face to allow an excavator to traverse the soft sediment.

<u>Sediment Management</u>

Dam removal requires management of the sediment impounded by the dam. A sediment management plan is developed base on the quantity and quality of sediment present in the impoundment and in upstream and downstream reaches as well as the results of a due diligence analysis to assess the potential for contaminants in the watershed upstream of the dam. Management alternatives generally fall under one of two approaches—active or passive management. Active management includes more traditional methods to remove or otherwise control the sediment, such as mechanical dredging and channel reconstruction or in-place stabilization. Conversely, passive management, also known as "in-stream management," involves the natural erosion and downstream repositioning of impounded sediments over time. The approach is based on the premise that most (if not all) of the accumulated sediments in impoundments resulted from the presence of the dam, and that the accumulated material would have been transported downstream in the absence of the barrier. In fact, substrate in reaches downstream of dams are often lacking in finer sediments and would benefit from a gradual release of sediments from behind the breached dam.

Recent dam removal projects in Massachusetts and elsewhere in New England have demonstrated that in-stream management of the appropriate types of sediments can be an acceptable sediment management strategy. While minor short-term impacts to downstream receiving areas may occur (e.g., deposition of sediment in pools), the potential for numerous medium- and long-term ecological benefits exists, including benthic habitat improvements and an influx of organic matter. Natural channel formation (versus a constructed channel) is also preferred as it is more likely to result in a dynamically stable stream form, involves far less cost, and avoids related impacts from the use of heavy equipment in recently dewatered soft wetland areas that typically have high archeological sensitivity due to their former status as Native American encampments prior to dam construction.

While additional sediment sampling and analysis would be needed to fully develop a sediment management plan for the potential removal of the Talbot Mills Dam, preliminary assessment indicates that at least partial in-stream sediment management may be feasible. Partial in-stream sediment management at this dam would involve removing material directly behind the primary spillway (including any of the reported fill between the existing and buried 1798 dams, if found) and allowing upstream material to erode naturally over time. Notching the dam to draw down the impoundment and allow dewatered sediment to stabilize prior to construction would facilitate a more gradual erosion process once the dam is removed. Sediment in the large backwater areas to the left and especially to the right (i.e., in the area of the floating towpath peninsula) of the lower impoundment would likely stabilize in place as restored wetland floodplains. Justification for partial instream management at this site may include, but not be limited to, the following factors:

- The volume of potentially mobile sediments within the active channel form of the impoundment is relatively small (approximately 9,500 CY) and would likely provide beneficial habitat-forming material for downstream reaches.

- Preliminary sediment sampling indicates the presence of limited pollutant concentrations.
- Active removal and/or channel construction through the former impoundment presents the potential for significantly greater damage to adjacent resources (e.g., wetlands and historical/archeological resources) associated heavy equipment use.

Hydraulic Analysis

To simulate the dam removal, the primary spillway was replaced in the model with estimated channel elevations representing natural conditions directly beneath the dam. Since historic drawings depicting detailed cross-sections of the dam and underlying hydraulic control (e.g., bedrock) were not available for this study, elevations under the spillway were assumed from sediment probing data conducted just upstream (**Section 3.2.1**)[76]. For the preliminary approach, the spillway abutments were left in place (discussed below). **Figure 4.3.3-1** depicts a cross-section of the proposed breach.

To simulate dam removal through the impoundment, the results of the sediment depth mapping (**Section 3.2.1**) were used to “remove” potentially mobile sediment within the expected future channel through the lower impoundment (at sediment transects T-1 through T-7). Roughness coefficients were modified from 0.05 to 0.035 within the channel to represent the transition to a more typical riverine reach, and from 0.05 to 0.07 within the former backwater area off the main channel to represent the transition to a more vegetated wetland/floodplain.

Figures 4.3.3-2 and **4.3.3-3** provide modeled water surface profiles for the proposed dam removal alternative under a range of high (500-year flood) and low flows for the full extent of the dam impoundment in the Concord River and zoomed into the lower impoundment, respectively. **Table F-3** in **Appendix F** provides selected model output parameters (e.g., channel elevation, water surface elevation, flow depth, velocity, top width, surface area, and volume) at key locations for the proposed dam removal alternative. This table may be compared to **Table F-1** (also in **Appendix F**) to determine the anticipated change from existing conditions.

500-year Flood Backwater Check

According to streamlined permitting regulations for dam removal, a dam breach large enough to ensure floodplain connectivity under the 500-year flood is desired, which will result in minimal backwater at the former dam location due to the 500-year flood. Modeled water surface profiles for existing and proposed dam removal conditions under the 500-year flood were shown in **Figure 4.3.3-2** and **4.3.3-3**. The proposed profile depicts minimal backwater at the former dam location due to the 500-year flood. The profile also shows that the various grade controls throughout the impoundment would constrict the 500-year flood and cause a backwater effect; thus the proposed dam removal would have little effect on water surface elevations above the Fordway Bar.

Breach Width Sensitivity Analysis

Removal of one (river right only) or both spillway abutments was also modeled as a sensitivity test to evaluate whether there would be any additional reduction in backwater due to the 500-year flood over the preferred approach of preserving the spillway abutments. **Figure 4.3.3-4** presents a comparison of water surface elevations under the 500-year flood at the dam for the three potential scenarios: 1) removal

[76] Note that the actual bedrock elevation under the dam may be lower than this conservative assumption.

of the primary spillway only, 2) removal of the primary spillway and right abutment, or 3) removal of the primary spillway and both abutments[77]. The figure shows that, compared to removal of the spillway only, 500-year flood elevations would be reduced by about 0.6 and 0.8 feet with the removal of the right or both abutments, respectively. However, the differences would be negligible (less than 0.2 feet) upstream of the Pollard Street bridge. Water velocity during the upstream fish migration season was also checked at the dam cross-section, but the differences among the scenarios would be small, on the order of 0.2 ft/s less for removal of one or both abutments. Because the differences are relatively small and do not propagate very far upstream, preserving one or both abutments may be a viable option to minimize any potential impacts to cultural resources as a result of the dam removal alternative.

Ability to Meet Target Fish Passage Thresholds

Table F-4 in **Appendix F** provides the average channel velocity and maximum channel depth for the proposed dam removal conditions under the fish passage design flows for all model cross-sections upstream of the dam in existing and dam removal conditions. Differences from existing conditions are negligible above the Pollard Street bridge and Fordway Bar. All proposed velocities and depths meet target fish passage thresholds, with the exception of the high flow immediately upstream of the dam, which has an estimated velocity of 7.5 ft/s. However, this is the high end of the fish passage flow range and barely exceeds the maximum velocity threshold, so it is not a significant concern. Minor alterations to the channel or the removal of one or both spillway abutments could alleviate this small exceedance if it is found to be an issue. Overall, the proposed dam removal alternative is expected to meet target fish passage thresholds.

As mentioned, it is likely that natural falls will develop at the site of the former dam, upstream at the bedrock grade control below the Fordway Bar, and potentially at other location(s) between the two in a post-dam removal scenario. It is possible that these natural features will create flow conditions that do not meet the target fish passage thresholds and may impede fish passage at some flows. If the dam removal alternative progresses to the next level of feasibility study, ground-penetrating radar (GPR) is recommended for the dam. GPR could be conducted above the primary spillway to attempt to map the upper surface of bedrock beneath the dam. This information could then be added to the hydraulic model to more accurately predict whether the falls will impede fish passage under a range of fish passage design flows. (Additionally, GPR could be collected just upstream to attempt to locate and characterize the reportedly buried 1798 dam structure, to help inform cultural resource mitigation approaches and for cost estimating purposes. Additional sediment probing immediately upstream of the dam is also recommended for the same reasons.)

Potential Benefits and Impacts

Fisheries

Dam removal would meet the ultimate goal of full fish passage restoration at the Talbot Mills Dam. Compared to a fishway, complete elimination of the barrier would be effective for all target species as well as resident freshwater fish that demonstrate in-stream migration behaviors. Successful passage at this site would open access to over 35 miles of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional

---

[77] Removal of the primary spillway and left abutment only was not modeled, as the right abutment is larger and presumed to be less historically significant due to its more recent concrete repairs. Therefore, if only one abutment is removed, it is assumed that the left abutment would be the one to remain.

upstream dams). Diadromous fish populations could potentially become self-sustaining in the Concord River system with the implementation of this alternative.

Water Quality & Aquatic Habitat

This alternative is anticipated to improve water quality and aquatic habitat in the Concord River by restoring natural river processes such as flow and sediment regimes. The establishment of new bordering vegetated wetlands along the riparian corridor (described below) will also help to filter runoff and improve water quality. Temperature and dissolved oxygen levels are expected to improve throughout the former impoundment with the transition to a more riverine reach and the associated decreased water depths and increased velocities. These improvements will support the restoration of the diadromous fishery.

Any potential impacts to water quality and aquatic habitat as a result of downstream transport of sediments (e.g., due to aggradation of aquatic habitat and/or release of sediment-bound contaminants) would be minimized with an appropriate sediment management plan for the site.

Wetlands & Riparian Habitat

The Talbot Mills Dam impoundment is classified as an open water wetland. However, it does not represent natural (pre-dam) conditions. Dam removal would restore free-flowing riverine conditions and continuity in the former impoundment, replacing the unnatural lacustrine conditions caused by the dam. Impacts to upstream wetland resources are anticipated to be only short-term in nature, as similar conditions are likely to re-establish at lower elevations along the restored river channel and new bordering vegetated wetlands are created in formerly impounded areas. This transition would be an overall gain for the native plant and animal community.

If dam removal is the preferred alternative, a formal wetland delineation would be required. Specifically, the size, type, function, and value of the wetlands would be quantified. In addition, consultation with state and federal agencies to identify any potential rare, threatened, or endangered species in the project vicinity would be necessary. Short-term impacts to wetlands during construction—including turbidity, altered flows, and disturbances from heavy equipment—should be minimized and timed appropriately to lessen impacts.

The new riparian area created within the current impoundment should be monitored for erosion and for the establishment of invasive species. Native shrubs and trees could be planted along the banks of the new channel in the lower impoundment to provide additional bank stabilization and reduce the potential for the establishment of invasive species. A more passive approach could allow for natural revegetation from the existing seed bank. A vegetation inventory should be performed to determine existing fauna and likelihood of invasive encroachment.

It is possible that artificially raised water levels due to the dam's presence may contribute to upstream bordering vegetated wetlands, such as the Great Meadows NWR along the Concord and Sudbury Rivers. However, the hydraulic modeling results indicate that the predicted drop in water surface elevation for the proposed partial dam removal is small—ranging from less than 0.1 feet under low flows to less than 1 foot for high (flood) flows at the downstream extent of the Great Meadows NWR Concord Unit. The greatest change would be for flood flow flows, when most wetlands and floodplains are already underwater. Further, the adjacent wetlands are already subjected to a broad range of seasonal fluctuation in Concord River water levels—nearly 7 feet from low flows to 2-year flood flows at the downstream extent of the Great Meadows NWR Concord Unit, and even higher (over 12 feet) when larger floods are considered. Also, although much has changed in the hydrology and operation of the watershed

since then, an 1861 study found that lowering the dam produced only a negligible drop of the water level in the upstream wetlands (Alvord et al., 1862). Therefore, it is assumed that the relatively small upstream water level reductions predicted for the proposed partial dam removal would not likely cause significant changes in wetland boundaries, vegetative composition, or value upstream of the Fordway Bar.

<u>Sediment Transport</u>

Dam removal generally redistributes sediments trapped behind a dam, restoring the river and its riverine habitats to pre-dam conditions. Following dam removal, sediment transport controls the process of channel evolution, including upstream erosion in the former impoundment (i.e., "head cutting"), deposition of transported sediment in downstream reaches, narrowing of the channel, and creation of new floodplains. These processes also have important benefits for nutrient cycling and habitat availability. Previously embedded gravel and cobble substrate in the former impoundment may become re-exposed, as the fine sediments that covered them are washed downstream, restoring aquatic habitat for fish and other organisms.

One concern of the dam removal process is the short-term increase in turbidity and water quality impacts that may occur if sediment accumulation is not addressed properly. However, appropriate sediment management can significantly reduce sediment-related impacts. Dams can first be breached with a narrow notch to allow the reservoir to drain before removing the remainder of the dam, or the impoundment can be drawn down in advance (using a low level outlet or gate), allowing fine-grained sediments to consolidate and strengthen and thereby minimizing the likelihood for erosion.

<u>Upstream Water Levels & Flooding</u>

The proposed partial removal of the dam would result in a reduction in water levels upstream. For low and normal flows, the drop in water surface elevation is predicted range from approximately 1.8 feet and 3.1 feet, respectively, immediately upstream of the dam to 0.1 and 0.6 feet, respectively, at the upstream extent of the Concord River.

The Talbot Mills Dam is operated as "run-of-river" dam where inflow equals outflow on a nearly continuous basis and therefore does not provide flood control but rather artificially raises the river's water surface elevation and contributes to upstream flooding as discussed in **Section 2.2.3**. Removal of the dam would reduce this increased level of flooding. For the preliminary approach involving removal of the primary spillway only, water surface elevations would be expected to drop by approximately 2.7 feet to 0.7 feet for the 100-year-flood, from a point just above the dam to the upstream extent of the Concord River, respectively[78]. This would alleviate flooding upstream of the dam.

<u>Infrastructure</u>

Infrastructure that could potentially be impacted by dam removal was discussed in **Section 2.3** and includes the Middlesex Canal (a historic structure), the Billerica water and wastewater treatment facilities, and both downstream and upstream bridges.

If the dam were removed, water levels would drop most significantly in the lower impoundment (mill pond), which would have the greatest effect on the historic Middlesex Canal compared to other infrastructure. Canal Segment 24, which is currently wetted, would likely become dewatered and

[78] Removal of both spillway abutments in addition to the primary spillway would be expected to increase the drop in water surface to 3.5 feet just upstream of the dam and 0.8 feet at the upstream extent of the Concord River.

transition to a dry prism. The water level in the area of the canal entrance near the floating towpath peninsula (cross-section 25698) would drop by about 1.6 feet under low flows and 2.2 feet under the 2-year flood flow.

At the Billerica water supply intake, which is upstream of the Fordway bar grade control, the effect of dam removal on water surface elevations would be somewhat diminished. Water surface elevation under normal and low flows would drop by approximately 0.7 and 0.1 feet to elevations of 109.4 and 107.4 feet NAVD 88, respectively, at cross-section 31902 just upstream of the intake. The invert elevation for the intakes is assumed to be 102.2 feet NAVD 88 according to the drawing in **Figure 2.3.2-1**, which is over 5 feet below the predicted water surface elevation for the low flow (95% exceedence for September). Therefore, the proposed partial removal of the Talbot Mills Dam would not be anticipated to have an impact on the Billerica water supply intake.

As discussed in **Section 2.3.2**, a water main and a sewer main cross the impoundment just upstream of the intake near an abandoned abutment from the former Bridge Street bridge (near cross-section 32728). In the partial dam removal simulation, channel velocities at this location are predicted to increase only slightly under a range of flood flows—specifically from 2.6 to 3.0 ft/s for the 2-year flood and from 4.1 to 4.6 ft/s for the 100-year flood. The 2-year flood is informative for this analysis because it is often considered the channel-forming flow during which many of a river's erosive forces are at work. Based on these negligible velocity increases, dam removal is not anticipated to impact buried water or wastewater infrastructure that crosses the impoundment.

The potential impact to bridges was also assessed. As discussed in **Section 2.3.3**, the Faulkner Street bridge is located immediately downstream of the Talbot Mills Dam. Because the dam is a "run-of-river" dam, as explained in **Section 2.2.3**, inflow generally equals outflow and thus flow characteristics (e.g., depth, velocity) should not change downstream of the dam if it were removed. This is confirmed by the hydraulic model, which reports the same water surface elevations and velocities at the bridge (cross-section 25081) before and after dam removal for the range of flows. Furthermore, the channel immediately downstream of the dam and continuing through the Faulkner Street bridge appears to consist almost exclusively of solid ledge and large boulders, and the bridge pier and abutments appear to be armored and founded directly on bedrock, so the potential for scour at this bridge is very low.

Upstream of the dam, nine bridges cross the impoundment, including the Pollard Street and Boston Road/Route 3A bridges within 1 ½ miles upstream. The hydraulic modeling results show that if the dam were removed, the water surface elevation is predicted to drop about 1.2 to 1.6 feet at the Pollard Street bridge under the 2- and 100-year floods, respectively, with velocities increasing approximately 25% (to 3.0 and 4.4 ft/s, respectively). This could present a moderate risk for scour at the Pollard Street bridge. If dam removal progresses to the next level of feasibility analysis, a sediment transport study could be conducted in which the grain size of the sediment under the bridge would be characterized and the potential for predicted water velocities to transport or "scour out" the sediment in the area of the bridge piers/abutments would be evaluated. Additionally, visual inspection and probing could be conducted around the bridge piers/abutments to confirm whether the dense substrates indicated by the boring logs (**Figures 2.3.3-2** and **2.3.3-3**) are present and would reduce the risk for scour.

There appears to be little impact to structures upstream of the Pollard Street bridge due to dam removal. Water surface elevations at the remaining eight structures would be predicted to drop about 0.8 to 1.1 feet and velocities would likely increase at most by 1.3 ft/s for the 2- and 100-year floods, which is not expected to present an increased risk for scour. As expected, the Fordway Bar feature in the vicinity of

the Pollard Street bridge would act as a new hydraulic grade control following dam removal which would effectively minimize upstream changes to water surface elevation and velocity.

Cultural Resources

PAL's historic and archaeological reconnaissance survey (**Section 3.5**) found that the removal of the Talbot Mills Dam would constitute an adverse effect on the Middlesex Canal Historic and Archaeological District and the Billerica Mills Historic District by destroying an important contributing resource and altering the functional relationship of the impoundment, lock, Canal Segment 24, floating towpath peninsula, and the floating towpath anchor stone of the Middlesex Canal.

If removal of the Talbot Mills Dam is selected as the preferred alternative, archaeological monitoring would be recommended in the high-sensitivity area at the dam during removal activities to record any potentially intact portions of earlier dam and/or fishway structures. As discussed in **Section 2.2.3**, a 1798 dam is reported to lie immediately upstream of the current Talbot Mills Dam. If the 1798 dam remains and possesses integrity, it would have strong associations with the development of the Middlesex Canal and would be a potential contributing resource to the Middlesex Canal Historic and Archaeological District and the Billerica Mills Historic District. If removal of the Talbot Mills Dam also necessitates the removal of the 1798 dam, this activity may also constitute an adverse effect. Archaeological monitoring and recording would be required to confirm the presence of this resource and its status as a historic property within the historic districts.

Dam removal would also create a permanent drawdown of the dam impoundment (Mill Pond) and expose and potentially impact archaeologically sensitive upland shoreline and underwater ground surfaces. Archaeological walkover with close ground surface inspection would be needed for the high-sensitivity pond shoreline and exposed impoundment drawdown areas to locate and identify any potentially significant pre-contact Native American archaeological resource areas and any buried remains of the documented Middlesex Canal elements, including the canal prism, the floating towpath, and the towpath anchor stone.

Access and staging would likely be concentrated in the small paved open area above the stone retaining wall between the river right abutment and Faulkner Street. If any construction activities would directly impact soils below the paved ground surface or the existing retaining/training wall (which is not anticipated for the current concept design), intensive archaeological survey would be recommended prior to construction and/or archaeological monitoring during construction in the high-sensitivity area to identify and record any potentially significant buried structural remains associated with the mid-nineteenth-century dye/store house and earlier dam retaining walls.

If the dam removal alternative is selected for further analysis and design, the lead federal agency for this project (NOAA) would consult with interested parties on ways to avoid, minimize, or mitigate any adverse effects to historic properties that may result from the project.

Recreation & Aesthetics

Potential impacts or benefits to recreation and aesthetics due to the dam are somewhat subjective and based on individual preferences. Some people may value the existing aesthetics of water falling smoothly over the spillway of a historic structure and the flatwater boating opportunities provided by the slow-moving backwater created by that structure. Others may value the aesthetics of water cascading over natural falls, as would likely develop at the site if the dam were removed, and the recreational opportunities provided by a free-flowing river. Removing the barrier of the dam could allow for more

continuous boating trips on the river at higher flow levels without having to portage around the dam[79], as well as the potential for whitewater boating opportunities in the natural falls that would likely develop at the former dam site and upstream[80].

The restoration of diadromous fish in the Concord River would represent a recreational benefit, as some target species are valued as sport fish (e.g., American shad), or were in the past before their declines led to moratoriums on their harvest (e.g., river herring). Recreational benefits would also extend to the recreational and commercial fisheries of other species (e.g., striped bass, trout, cod, bluefish, tuna, etc.) that forage upon diadromous fish along the Atlantic coast. The restored riverine conditions upstream of the dam may result in changes in the resident fish assemblages and/or increased habitat use by fish, potentially providing greater inland angling opportunities as well. The sight of returning diadromous fishes migrating upstream may be valued for aesthetic, recreational, and cultural purposes and as a sign of a healthy river.

There is also the potential for enhancement of upland recreational and aesthetic resources. Following dam removal, much of the lower impoundment (mill pond) would be expected to dewater and stabilize in place, opening up additional land that could be transformed into parks, utilized for river access, or other recreational improvements. As an option, coordination could occur with the MCA and other interested parties on the proposed Mill Pond/Canal Park design (**Figure 2.3.1-2**) to conceptualize a park in which mill dam era history could be coupled with pre-contact history (i.e., Native American use of the free-flowing river and its diadromous fishery) to tell a more complete story at the site.

<u>Operation and Maintenance</u>

Dam removal would eliminate ongoing operation and maintenance costs as well as liability. The potential for the dam to fail unexpectedly and cause unintentional impacts to natural and cultural resources and infrastructure (as discussed in **Section 4.3.1**) would no longer be a concern.

Recommendations for Additional Studies

If the dam removal alternative were to progress to the next level of feasibility study, additional recommended studies include, but are not limited to, the following:

- **Topographic survey** – Detailed topographic survey should be collected of the Talbot Mills Dam and vicinity, including all potential construction access and staging areas and the channel downstream of the dam.

- **Wetlands, wildlife, & botanical resources survey** – A formal wetland delineation would be needed to quantify the size, type, function, and value of the wetlands within and adjacent to the lower impoundment (up to the Pollard Street bridge). A vegetation inventory could be performed to determine existing fauna and likelihood of invasive encroachment. Additionally, state and federal agencies should be consulted to identify any potential rare, threatened, or endangered species in the project vicinity.

---

[79] Portage may still be necessary around the natural falls that would likely develop at the site of the former dam, although the navigability of these falls under varying flows is unknown.

[80] A 1700 map of Billerica (**Figure 2.2.3-6**) documents the existence of a series of falls in the Concord River between the present day Pollard Street and Faulkner Street bridges prior to the damming of the river in North Billerica (Ingraham, 1995).

- **Bathymetric survey** – Bathymetric survey of the lower impoundment and extending up to the Boston Road/Route 3A bridge could be collected to capture the highest point of the Fordway Bar (above the Fordway Bar would be sufficient, but the Boston Road/Route 3A bridge would be conservative to ensure that the highest point of the bar is captured).

- **Sediment probing** – Additional sediment probing immediately upstream (about 8-12 feet) of the dam could be conducted to attempt to locate the 1798 dam structure and in the area of the highest point of the Fordway Bar (as determined by the bathymetric survey) to evaluate the potential for the bar to head cut following dam removal.

- **Ground-penetrating radar** – GPR could be conducted above the primary spillway to attempt to map the upper surface of bedrock beneath the dam for the purposes of the hydraulic model and for evaluating upstream impacts and the ability to meet target fish passage thresholds following dam removal. Additionally, GPR could be collected just upstream to attempt to locate and characterize the reportedly buried 1798 dam structure, to help inform cultural resource mitigation approaches and for cost estimating purposes.

- **Hydraulic modeling** – Additional hydraulic modeling could be conducted to incorporate the results of the bathymetry survey, additional probing, and GPR.

- **Sediment sampling** – Additional samples will likely be needed to inform the sediment management plan. Up to 8 additional samples may be required to be collected within the impoundment to fully characterize the estimated volume of mobile sediment with one sample per 1,000 CY of sediment (for a total of 10 samples within the approximately 9,500-CY volume of mobile sediment). Samples could also be collected within areas of the impoundment expected to stabilize as floodplain wetlands post-dam removal as discussed above, such as in the areas north and south of the floating towpath peninsula. Additionally, samples could be taken in depositional areas downstream of the dam to provide context of contaminant levels in the river system compared to levels in the impoundment. Upstream of the dam's influence, samples could be collected in either or both of the Sudbury and Assabet Rivers.

- **Pollard Street Bridge assessment** – Sediment samples would be collected at the bridge site to characterize the grain size distribution for use in the sediment transport analysis (below). Additionally, visual inspection and probing could be conducted around the bridge piers/abutments to confirm whether the dense substrates indicated by the boring logs are present and would reduce the risk for scour.

- **Sediment transport analysis** – If sediment quality and quantity are determined to be appropriate for stabilization or release, a sediment transport and redistribution analysis could optionally be performed.

- **Recreation/aesthetic study** – Optionally, a survey of recreation and aesthetic interests could be conducted to inform future uses of the site.

- **Cultural resources mitigation planning** – While not technically a study, it will be essential to initiate planning efforts to mitigate potential impacts to historic and/or archeological impacts as early as possible in the process.

Summary and Cost Opinion

A budgetary cost opinion for this alternative is shown in **Table 4.3.3-1**. The estimated cost for additional studies, engineering, permitting, and construction of partial removal of the Talbot Mills Dam is approximately $470,000. This estimate assumes that no significant impounded sediment contamination is found in future sampling efforts and that an instream sediment management approach (e.g., downstream release and natural transport of impounded sediments) is approved by regulatory agencies.

In summary, the proposed partial removal of the Talbot Mills Dam would provide effective passage for target species as well as significant benefits for other resources. Water quality, aquatic habitat connectivity, and natural riverine sediment and flow regimes would be restored. Increased upstream flooding resulting from the dam would be reduced. Aging and unsafe infrastructure would be decommissioned, eliminating ongoing operation, maintenance, and liability costs and concerns. Recreation and aesthetic resources may improve as well, although these benefits are subject to individual preferences of the members of the public using the site. With the exception of cultural resources, few impacts to other resources are anticipated. As such, partial removal of the Talbot Mills Dam is a feasible alternative for restoring diadromous fish in the Concord River that could be further evaluated in future phases of this project.

4.3.4 Other Concepts Considered

Nature-Like Fishway

The concept of nature-like fishways is to restore a passage barrier such as a dam to a more natural, riverine configuration by incorporating natural elements like rocks, boulders, and cobbles to dissipate flow energy, maintain velocities within a passable range for most fish, and provide resting pools. Nature-like fishways are perceived as having advantages over technical fishway designs (e.g., fish ladders) in that they create habitat as well as pathways around structures for many organisms in addition to target fish species.

Three common layouts for a nature-like fishway include a bypass, a rock ramp, or a partial rock ramp (see **Figure 4.3.4-1** for a schematic of each). A bypass is not feasible at the Talbot Mills Dam since there is no space adjacent to the dam that would not be affected by Faulkner Street or the nearby parking lot.

Per USFWS guidelines, rock ramps and partial rock ramps should have maximum recommended slopes of about 3%. For the design head difference of 10.4 feet at the Talbot Mills Dam, this would require a ramp length of about 350 feet. For a full-width rock ramp, which would span the entire length of the primary spillway face, this length would require the ramp passing under the Faulkner Street bridge and continuing approximately an additional 200 feet beyond the bridge. This would require raising the channel downstream of the dam and would significantly reduce the area available for flow to pass under the bridge, which would not be acceptable from a dam or bridge safety perspective.

The length required for a partial-width rock ramp would be problematic as well. To fit the length of the ramp in the river channel, the ramp would need to pass under the bridge. However, the clearance under the bridge is likely not large enough and this layout would also reduce the area under the bridge that flow could pass through. Alternately, the ramp could be turned multiple times between the bridge and the dam face (similar to a fish ladder layout as shown in the schematic). However, several turns would be necessary to fit the required length of ramp, causing the ramp to occupy the space in front of the spillway and further reducing spillway capacity to an unsafe level.

Due to these physical constraints, the conceptual design of a nature-like fishway at the Talbot Mills Dam was not pursued for this feasibility analysis.

Bypass through Sluiceway Channel under Faulkner Mills Complex

Another fish passage alternative that has been discussed for the Talbot Mills Dam is to make use of the existing sluiceway channel that passes under the Faulkner Mills complex. This alternative was not fully developed for this feasibility analysis in part because drawings or dimensions of the channel under the building could not be obtained. An internal survey would require permission from and coordination with the mill owner. Although the exact channel under the building is unknown, it appears to be approximately 350 feet long with a total elevation gain of about 10.2 feet, resulting in a slope of about 3%, which is acceptable for a bypass fishway per USFWS criteria as discussed above. The sluiceway gate structure at the upstream end would need to be removed or modified for fish passage. The water velocity at this gate (assuming it is fully open) is estimated to be approximately 7 ft/s during the fish migration season high flow, which is at the high end of target fish passage thresholds. However, fish would have to pass through another, smaller sluice gate located at the outlet of the stilling basin north of Faulkner Street, which leads into the building. The dimensions of this gate were not measured, but based on field observations, it appears to be about 2 feet wide by 3 feet high. With these dimensions, water velocity under the high fish migration flow would be on the order of 80 ft/s, much too high for fish passage. This gate would need to be replaced with a significantly larger gate (with a flow area of at least 65 square feet to get velocities down to 7 ft/s under the high fish migration flow) in order to accommodate swimming speeds of target species, which would require enlarging the opening to the building. This assumes that the channel on the other side of the gate is wide enough to allow for fish passage, and not a similarly narrow channel or pipe that would be under pressure at this flow. Additionally, any modifications made to send additional flow down this channel would need to be evaluated for potential impacts to infrastructure, such as the sewer line that passes through the downstream entrance.

This page intentionally left blank.

5. Summary and Next Steps

This study has demonstrated that diadromous fish passage restoration in the Concord River is feasible. Alternatives at the two most downstream sites—Middlesex Falls and Centennial Falls Dam—are relatively straightforward and inexpensive and therefore could be implemented fairly quickly if pursued by the project team and interested stakeholders. Channel improvements at Middlesex Falls (Alternative 1A) may help reduce flow turbulence to more acceptable ranges for upstream passage, or this project could be deferred to a later phase after additional monitoring to confirm whether or not fish can successfully navigate the falls at a satisfactory rate. Minor fishway and operational modifications can be made at Centennial Falls Dam (Alternative 2A) to improve fish passage, and the opportunity for continued stewardship and public education at that site and throughout the watershed (Alternative 2B) would help ensure the lasting effectiveness of these enhancements and others.

At the Talbot Mills Dam, alternatives include a technical fishway or partial dam removal. Although more complex than options at the other sites, each of these alternatives has been demonstrated to be technically feasible for implementation at the dam.

Installation of a fishway (Alternative 3A)—including a Denil ladder, eel ramp, and downstream bypass notch—at the Talbot Mills Dam would provide effective passage for target species, furthering the goal of diadromous fish restoration in the Concord River. Passage of other aquatic species and overall connectivity of the river would be limited but would represent an improvement over existing conditions. With the exception of cultural resources and aesthetics, little to no impacts to other resources are anticipated. The obligation to bring the dam into compliance with dam safety regulations as well as the continued responsibility for ongoing operation, maintenance, and liability associated with the dam would impact the cost effectiveness of this alternative. Still, a fishway at Talbot Mills Dam is a viable alternative for restoring diadromous fish in the Concord River that could advance to the next phase of this project for further study.

The proposed partial removal of the Talbot Mills Dam (Alternative 3B) would provide effective passage for target species as well as significant benefits for other resources. Water quality, aquatic habitat connectivity, and natural riverine sediment and flow regimes would be restored. Increased upstream flooding resulting from the dam would be reduced. Aging and unsafe infrastructure would be decommissioned, eliminating ongoing operation, maintenance, and liability costs and concerns. Recreation and aesthetic resources may improve as well, although these benefits are subject to individual preferences of the members of the public using the site. With the exception of cultural resources, few impacts to other resources are anticipated. As such, partial removal of the Talbot Mills Dam is a feasible alternative for restoring diadromous fish in the Concord River that could be further evaluated in future phases of this project.

A summary of potentially required regulatory submittals, reviews, and permits associated with the Talbot Mills Dam alternatives is presented in **Table 5.0-1**. Many assumptions were made, and additional feasibility work will need to be conducted to provide necessary information for the consultation and permitting process. Note that the review process has already been initiated with the MHC with the submittal of the PNF and the permit application to conduct the historic and archaeological reconnaissance survey.

A decision matrix for Talbot Mills Dam alternatives is presented in **Table 5.0-2**. This table compares the relative benefit or impact of each alternative on various resources and considers other factors such as

cost, permitting, operation and maintenance, etc. In future phases of this project, a weighted value could be assigned to each parameter as a means to rank the alternatives with consideration for the goals of project partners and other stakeholders.

Providing fish passage at the Talbot Mills Dam and addressing any potential obstacles at Middlesex Falls and Centennial Falls Dam would restore over 35 miles of diadromous fish habitat on the mainstem Concord, Assabet, and Sudbury Rivers, plus more than 100 miles of habitat on tributaries to these rivers and at least 260 acres of lacustrine habitat (not including areas that could be accessed with fish passage at additional upstream dams). The possibility of combining two or more alternatives together, implemented simultaneously or in several phases, provides the flexibility to develop a watershed-wide restoration plan that has both immediate and long-lasting success.

This feasibility study is not intended to identify a preferred alternative, but rather provides a critical foundation for ongoing and future restoration activities as well as a framework for continued communication between project partners and the public to determine how best to reconcile project goals with other interests. If preferred alternative(s) can be agreed upon, the project will advance to future phases of securing funding, additional feasibility work, consultation with interested parties, design, and construction to ultimately restore diadromous fish passage to the Concord, Sudbury, and Assabet Rivers.

6. References and Suggested Readings

Alvord, D., Storrow, C., and Shedd, J. (1862). *Report of experiments and observations on the Concord and Sudbury Rivers in the year 1861*. Boston: William White. Retrieved from https://archive.org/details/1861EngineersReport

Ambient Engineering and SuAsCo Watershed Community Council. (2005a). Sudbury-Assabet-Concord River watershed action plan. Prepared for the Massachusetts Executive Office of Environmental Affairs. Retrieved from http://www.mass.gov/eea/docs/eea/water/wap-suasco-2006.pdf

Ambient Engineering and SuAsCo Watershed Community Council. (2005b). Sudbury-Assabet-Concord River watershed assessment report. Prepared for the Massachusetts Executive Office of Environmental Affairs. Retrieved from http://www.mass.gov/eea/docs/eea/water/assess-rpt-suasco-2006.pdf

Applied Speciation. (2009). Chromium speciation analysis. Retrieved from http://www.appliedspeciation.com/ChromiumSpeciation.htm

ASMFC. (2010). *Upstream Fish Passage Technologies for Managed Species*. Atlantic States Marine Fisheries Commission Fish Passage Working Group. Retrieved from http://www.asmfc.org/uploads/file/FishPassTechnologyForASMFCspecies_Oct2010.pdf

Barlow, L., Hutchins, L., and DeSimone, L. (2009). *Water withdrawals, use, and wastewater return flows in the Concord River Basin, eastern Massachusetts, 1996-2000* (Scientific Investigations Report 2008-5158). Reston, VA: US Geological Survey. Retrieved from http://pubs.usgs.gov/sir/2008/5158/includes/sir2008-5158.pdf

Belding, D. (1921). *A report upon the alewife fisheries of Massachusetts*. Boston: Commonwealth of MA, Dept. of Conservation, Div. of Fisheries and Game.

Bell, M. (1991). Fisheries handbook of engineering requirements and biological criteria. Portland, OR: US Army Corps of Engineers, North Pacific Division. Retrieved from http://www.stream.fs.fed.us/fishxing/fplibrary/Bell_1991_Fisheries_handbook_of_engineering_requirements_and.pdf

Boston Survey Consultants. (1979a). *Identification and location of high watermarks: Concord River*. Prepared for US Army Corps of Engineers. Boston: Boston Survey Consultants.

Boston Survey Consultants. (1979b). *Identification and location of high watermarks: Sudbury River*. Prepared for US Army Corps of Engineers. Boston: Boston Survey Consultants.

Bovee, K. (1992). *Using the computer based physical habitat simulation system* (IFG 210). Fort Collins, CO: US Fish and Wildlife Service, Aquatic Systems Branch.

Brady, P., Reback, K., McLauglin, K., and Milliken, C. (2005). *A survey of anadromous fish passage in coastal Massachusetts: Part 4. Boston Harbor, North Shore, and Merrimack River* (Technical Report TR-18). Pocasset, MA: MA Div. of Marine Fisheries, Southshore Field Station. Retrieved from http://www.mass.gov/eea/docs/dfg/dmf/publications/tr18-anad-p4-merrimack.pdf

Breault, R., Sorenson, J., and Weiskel, P. (2013). *Estimated sediment thickness, quality, and toxicity to benthic organisms in selected impoundments in Massachusetts* (Scientific Investigations Report 2012-5191). Reston, VA: US Geological Survey. Retrieved from https://pubs.er.usgs.gov/publication/sir20125191

Breen, J. (2013). The 1825 iron bolt and the great Billerica Dam controversy. *Towpath Topics, 52*(1), 8-10. Retrieved from http://middlesexcanal.org/towpath/TowpathTopics-Sept2013color.pdf

Breen, J. (2014). President's message. *Towpath Topics, 53*(1), 2-4. Retrieved from http://middlesexcanal.org/towpath/TowpathTopics-Sept2014color.pdf

Breen, J. (2015). President's message: Deep cut at Bedford & Billerica Railroad (Figure). *Towpath Topics, 53*(3), 5. Retrieved from http://middlesexcanal.org/towpath/TowpathTopics-Mar2015color.pdf

Brownell, P. et al. (n.d.). *Diadromous fish passage: A primer on technology, planning and design for the Atlantic and Gulf Coasts*. NOAA National Marine Fisheries Service in cooperation with the USGS Conte Anadromous Fish Research Center. Retrieved from www.nero.noaa.gov/hcd/docs/FishPassagePrimer.pdf

Castro-Santos, T. (2006). Modeling the effect of varying swim speeds on fish passage through velocity barriers. *Transactions of the American Fisheries Society*, 135: 1230-1237. Retrieved from www.fws.gov/southeast/fisheries/SEFishPassage/TedCastroSantosTAFS2006.pdf

CDM. (c. 2001). *Attachment 7: Billerica Water Treatment Plant intake relocation assessment*. Prepared for the Town of Billerica. Boston: Camp Dresser & McKee Inc.

CDM. (2006). Merrimack River watershed assessment study: Final Phase 1 report. Prepared for US Army Corps of Engineers, New England District. Retrieved from http://www.nae.usace.army.mil/Portals/74/docs/Topics/MerrimackLower/PhaseIFinal.pdf

Chase, B. (2010). *Quality Assurance Program Plan (QAPP) for water quality measurements conducted for diadromous fish habitat monitoring: Version 1.0, 2008-2012* (Tech. Rep. No. TR-42). MA Div. of Marine Fisheries. Retrieved from www.mass.gov/dfwele/dmf/publications/tr_42.pdf

Collins, M. (2011). *Flood frequency estimates for New England river restoration projects: Considering climate change in project design* (FS-2011-01). National Oceanic and Atmospheric Administration, Fisheries Service.

DCR. (2005). *302 CMR 10.00: Dam safety*. West Boylston, MA: Massachusetts Department of Conservation and Recreation, Office of Dam Safety. Retrieved from http://www.mass.gov/eea/docs/dcr/pe/dam-safety/dcr-dam-safety-regulations.pdf

Donahue, B. (1989). Dammed at both ends and cursed in the middle: The flowage of the Concord River meadows, 1798–1862. *Environmental Review, 13*(3/4), 46-67.

DOT. (2015). *Project information database*. Boston, MA: Massachusetts Dept. of Transportation. Retrieved from http://www.massdot.state.ma.us/highway/ProjectInfo.aspx

ENPRO. (2007). *IRA completion and Phase 1 initial site investigation report with tier classification*. Prepared for Veterans of Foreign Wars Solomon Post No. 8819, Inc. Newburyport, MA: ENPRO Services, Inc. Retrieved from http://public.dep.state.ma.us/fileviewer/DefaultScanned.aspx?documentid=15768 via http://public.dep.state.ma.us/SearchableSites2/Site_Info.aspx?textfield_RTN=3-0026097

EPA. (2000). *Ambient water quality criteria recommendations: Rivers and streams in nutrient ecoregion XIV* (Document EPA 822-B-00-022). Washington, DC: US Environmental Protection Agency, Office of Water. Retrieved from www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_14.pdf

FEMA. (1985). *Flood insurance study: Town of Billerica, Massachusetts, Middlesex County* (Community No. 250183). Washington, DC: Federal Emergency Management Agency. Retrieved from https://msc.fema.gov/portal

FEMA. (2010). *Flood insurance study: Middlesex County, Massachusetts* (FIS No. 25017CV001A). Washington, DC: Federal Emergency Management Agency. Retrieved from https://msc.fema.gov/portal

FEMA. (2013). *Flood risk report: Concord River watershed* (Report No. 001). Washington, DC: Federal Emergency Management Agency. Retrieved from http://www.concordma.gov/pages/ConcordMA_Planning/Concord_Flood_Risk_Report.pdf

FEMA. (2014). *Flood insurance study: Middlesex County, Massachusetts* (FIS No. 25017CV001B). Washington, DC: Federal Emergency Management Agency. Retrieved from https://msc.fema.gov/portal

FERC. (2005, February 23). *Order modifying and approving fishway operations plan and schedule of repairs*. Washington, D.C.: The Federal Energy Regulatory Commission. Retrieved from the FERC eLibrary.

French, H. (1861). *Argument of Hon. Henry F. French, of Boston, on the 1st day of March, 1861: before the Joint Committee of the Legislature of Massachusetts, on the petition for the repeal of "an act in relation to the flowage of the meadows on Concord and Sudbury rivers," approved April 4, 1860*. Retrieved from http://catalog.hathitrust.org/Record/100226282

Geotechnical Consultants. (2015). *Talbot Mills Dam Phase I inspection/evaluation report*. Marlborough, MA: Geotechnical Consultants, Inc. Retrieved from the Massachusetts Department of Conservation and Recreation, Office of Dam Safety.

Greene, K., Zimmerman, J., Laney, R., and Thomas-Blate, J. (2009). *Atlantic coast diadromous fish habitat: a review of utilization, threats, recommendations for conservation, and research needs* (Habitat Management Series No. 9). Washington, D.C.: Atlantic States Marine Fisheries Commission. Retrieved from http://www.asmfc.org/files/Habitat/HMS9_Diadromous_Habitat_2009.pdf

Gulf of Maine Council on the Marine Environment. (2007). *American eels: Restoring a vanishing resource in the Gulf of Maine*. Retrieved from http://www.gulfofmaine.org/council/publications/american_eel_high-res.pdf

Hazen, H. (1883). *History of Billerica, Massachusetts*. Boston, MA: A. Williams and Company. Retrieved from https://archive.org/details/historyofbilleri00hazen

Hutchins, N. and Sheldon, H. *This was Billerica*. Historical photographic slides in Billerica Public Library special collection.

Ingraham, A. (1995). *A short history of the milldam at North Billerica, 1653-1995*. Billerica, MA: The Billerica Historical Society. Retrieved from https://archive.org/details/TheMilldamAtNorthBillerica

Johnson, S. and Graber, B. (2002). Enlisting the social sciences in decisions about dam removal. *Bioscience*, 52(8): 731-38. Retrieved from http://www.fws.gov/habitatconservation/Dams.pdf

Keefer, M. et al. (2012). *Adult pacific lamprey passage: data synthesis and fishway improvement prioritization tools.* Prepared for the US Army Corps of Engineers. Moscow, ID: University of Idaho. Retrieved from http://www.uidaho.edu/~/media/Files/orgs/CNR/FERL/Technical%20Reports/2012/2012-8%20Report%20Keefer%20et%20al%20UI%20Lamprey%20data%20synthesis%20FINAL.ashx

Kircheis, F. (2004). *Sea lamprey*. Unpublished thesis. Retrieved from http://www.fws.gov/gomcp/pdfs/lampreyreport.pdf

Kircheis, F., Trial, J., Boucher, D., Mower, B., Squiers, T., Gray, N., O'Donnell, M., and Stahlnecker, J. (2002). *Analysis of impacts related to the introduction of anadromous alewife into a small freshwater lake in central Maine, USA*. Augusta, ME: Maine Dept. of Inland Fisheries & Wildlife, Maine Dept. of Marine Resources, and Maine Dept. of Environmental Protection. Retrieved from http://ijc.org/files/publications/analysis%20of%20impacts%20to%20the%20introduction%20of%20anadromous%20Alewives.pdf

LPCT. (n.d.). *Concord River history* (Brochure). Lowell, MA: Lowell Parks and Conservation Trust. Retrieved from http://www.lowelllandtrust.org/sites/default/files/PDF-files/crg_history_brochure.pdf

MA House of Representatives. (1860). *Report of the Joint Special Committee upon the subject of the flowage of meadows on Concord and Sudbury Rivers.* Boston: William White. Retrieved from https://archive.org/details/reportjointspec01courgoog

MA Senate and House of Representatives. (1814). *1814 Chap. 0137: An act to regulate the shad and alewive fishery within the Town of Billerica*. Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/109436

MA Senate and House of Representatives. (1820). *1820 Chap. 0070: An act to regulate the passageway for fish through The Canal Mill Dam, in Billerica, and for other purposes*. Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/110308

MA Senate and House of Representatives. (1835). *1835 Chap. 0089: An act concerning the proprietors of mills on Concord River*. Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/106861

MA Senate and House of Representatives. (1860). *1860 Chap. 0211: An act in relation to the flowage of the meadows on Concord and Sudbury Rivers.* Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/98612

MA Senate and House of Representatives. (1861). *1861 Chap. 0154: An act to suspend "An act in relation to the flowage of the meadows on Concord and Sudbury Rivers."* Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/98777

MA Senate and House of Representatives. (1866). *1866 Chap. 0238: An act concerning the obstructions to the passage of fish in the Connecticut and Merrimack Rivers.* Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/100160

MA Senate and House of Representatives. (1869). *1869 Chap. 0422: An act in addition to an act concerning the obstructions to the passage of fish in Connecticut and Merrimack Rivers.* Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/101359

MA Senate and House of Representatives. (1876). *1876 Chap. 0050: An act concerning the obstructions to the passage of fish in the tributaries of the Connecticut and Merrimack Rivers.* Boston: Secretary of the Commonwealth. Retrieved from http://archives.lib.state.ma.us/handle/2452/89673

MA Senate. (1918). *Report of the Commission on Waterways and Public Lands on the water resources of the Commonwealth of Massachusetts* (pp. 204-215). Boston: Wright & Potter Printing Co. Retrieved from Google Books.

MassDEP. (2004). *Assabet River total maximum daily load for total phosphorus* (Report No. MA82B-01-2004-01; Control No. CN 201.0). Worcester, MA: MA Dept. of Environmental Protection, Div. of Watershed Mgmt., Watershed Planning Prog. Retrieved from http://www.mass.gov/eea/docs/dep/water/resources/a-thru-m/anuttmdl.pdf

MassDEP. (2005). *SuAsCo Watershed 2001 water quality assessment report* (Report No. 82-AC-1; Control No. CN 92.0). Worcester, MA: MA Dept. of Environmental Protection, Div. of Watershed Mgmt., Watershed Planning Prog. Retrieved from http://www.mass.gov/eea/agencies/massdep/water/watersheds/water-quality-assessments.html

MassDEP. (2013). *Massachusetts surface water quality standards* (Revision of 314 CMR 4.00). Westborough, MA: Dept. of Environmental Protection, Div. of Water Pollution Control, Technical Services Branch. Retrieved from http://www.mass.gov/eea/docs/dep/service/regulations/314cmr04.pdf

MassDEP. (2014). *Massachusetts year 2014 integrated list of waters* (CN 450.0). Worcester, MA: Div. of Watershed Mgmt., Watershed Planning Prog. Retrieved from http://www.mass.gov/eea/docs/dep/water/resources/07v5/14iwlistp.pdf

MassDEP. (2015). *SuAsCo watershed.* Boston, MA: Massachusetts Dept. of Environmental Protection. Retrieved from http://www.mass.gov/eea/waste-mgnt-recycling/water-resources/preserving-water-resources/mass-watersheds/suasco-watershed.html

MassDEP. (2016). *Cleanup sites & locations*. Boston, MA: Massachusetts Dept. of Environmental Protection. Retrieved from http://www.mass.gov/eea/agencies/massdep/cleanup/sites/

MacDonald et al. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Archives of Environmental Contamination and Toxicology, 39*, 20-31.

McKeon, J. (2002, April 1). *Middlesex Dam breach stabilization* (Memorandum). Nashua, NH: US Fish and Wildlife Service, Central New England Fisheries Resource Complex.

MRTC. (1997). *Strategic plan and status review: Anadromous fish restoration program, Merrimack River*. Nashua, NH: US Fish and Wildlife Service, Merrimack River Technical Committee. Retrieved from http://www.fws.gov/northeast/cnefro/pdf/merplan.pdf

MRTC. (2010). *A plan for the restoration of American shad in the Merrimack River Watershed*. Nashua, NH: US Fish and Wildlife Service, Merrimack River Technical Committee. Retrieved from http://www3.epa.gov/region1/npdes/merrimackstation/pdfs/ar/AR-96.pdf

Nelson, G., Brady, P., Sheppard, J., and Armstrong, M. (2011). *An assessment of river herring stocks in Massachusetts* (Tech. Rep. No. TR-46). Gloucester, MA: MA Div. of Marine Fisheries. Retrieved from http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-46.pdf

NH FGD. (2015). *Fish fact sheets*. Concord, NH: New Hampshire Fish and Game Department. Retrieved from http://www.wildlife.state.nh.us/fishing/species.html

NPS. (1995). *Sudbury, Assabet, and Concord Wild and Scenic River study: River conservation plan.* Prepared by SuAsCo Wild and Scenic Committee and the Div. of Rivers and Special Studies. Boston: National Park Service, North Atlantic Regional Office. Retrieved from http://www.rivers.gov/documents/studies/suasco-river-conservation-plan.pdf

NPS. (1996). *Historic American Engineering Record: Fordway Bridge (Pollard Street Bridge)* (HAER No. MA-137). Philadelphia: National Park Service. Retrieved from: https://www.loc.gov/item/ma1585/

NRCS. (2015). *SuAsCo watershed dams*. Amherst, MA: US Department of Agriculture, Natural Resources Conservation Service, Massachusetts. Retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/ma/home/?cid=nrcs144p2_015977

OARS. (2015). *Water quality monitoring program final report: 2014 field season*. Concord, MA: OARS for the Assabet, Sudbury, and Concord Rivers. Retrieved from http://www.oars3rivers.org/sites/default/files/OARS-WQ-2014-Report-web.pdf

OED. (2011). *Centennial Island hydroelectric facility: Feasibility study to add a second turbine/generator package to the existing hydroelectric facility*. Lowell, MA: Olson Electric Development Co., Inc.

PAL. (2016). *Historic and archaeological reconnaissance survey: Concord River diadromous fish restoration project, Talbot Mills Dam, Billerica, Massachusetts* (PAL Report No. 2929). Pawtucket, RI: The Public Archeological Laboratory, Inc. On file at the Massachusetts Historical Commission, Boston, MA (redacted version available).

Poff, N. and Hart, D. (2002). How dams vary and why it matters for the emerging science of dam removal. *Bioscience*, 52(8): 659-68. Retrieved from http://www.fws.gov/habitatconservation/Dams.pdf

Reinhardt, U., Binder, T., and McDonald, D. (2009). Ability of adult sea lamprey to climb inclined surfaces. *American Fisheries Society Symposium, 72*, 125-138.

Slatick, E. and Basham, L. (1985). The effect of Denil fishway length on passage of some nonsalmonid fishes. *Marine Fisheries Review, 47*(1), 83-85. Retrieved from http://spo.nmfs.noaa.gov/mfr471/mfr47113.pdf

Smithwood, D. (2012, January 3). Letter to Nyanza Trustee Council Members RE Draft Restoration Plan/Environment Assessment (RP/EA). In *Restoration plan and environmental assessment for the Nyanza Chemical Waste Dump Superfund Site* (Appendix D). Boulder, CO: Stratus Consulting.

Smithwood, D. (2013). *Pot survey of yellow phase American eel on the Sudbury River, Massachusetts between Fairhaven Bay and Heard Pond, August 12-15, 2013*. Nashua, NH: US Fish and Wildlife Service, Central New England Fishery Resources Office.

Smithwood. (2014, September 27). *The Amazing American eel: Its unique life history and local restoration efforts*. (Presentation abstract). Sudbury, MA: Sudbury Patch. Retrieved from http://patch.com/massachusetts/sudbury/amazing-american-eel-its-unique-life-history-and-local-restoration-efforts-0

STARR. (2012). *Hydraulics report: Concord River watershed*. Prepared for Federal Emergency Management Agency, National Flood Insurance Program. Raleigh, NC: Strategic Alliance for Risk Reduction.

State Board of Health. (1896). Improvement of the Concord and Sudbury Rivers (House Doc. No. 891). In *Twenty-seventh annual report of the State Board of Health of Massachusetts* (Public Doc. No. 34) (pp. xxxvii-xlv). Boston: Wright & Potter Printing Co. Retrieved from Google Books.

Stratus Consulting. (2012). *Restoration plan and environmental assessment for the Nyanza Chemical Waste Dump Superfund Site*. Prepared for Nyanza NRD Trustee Council. Boulder, CO: Stratus Consulting. Retrieved from http://www.mass.gov/eea/docs/dep/cleanup/sites/nyrp.pdf

Sudbury, Assabet and Concord Wild & Scenic River Stewardship Council. (n.d.). *The Concord River boater's trail*. Boston, MA: Sudbury, Assabet and Concord Wild & Scenic River Stewardship Council. Retrieved from http://www.sudbury-assabet-concord.org/concord-river-boaters-trail/downloads.php

Thoreau, H. (1894). *A week on the Concord and Merrimack Rivers*. Boston: Houghton Mifflin and Co.

Thorncraft, G. and Harris, J. (2000). *Fish passage and fishways in New South Wales: A status report*. Sydney: Office of Conservation, NSW Fisheries. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.522.9318&rep=rep1&type=pdf

Towler, B., ed. (2014). *Fish Passage Workshop: Training Manual* (Fish Passage Technical Report TR-2014-1). Amherst, MA: University of Massachusetts. Retrieved from UMass Amherst Libraries, http://scholarworks.umass.edu/fishpassage_technical_reports/2/

USACE. (2010). *Assabet River, Massachusetts: Sediment and dam removal feasibility study*. Concord, MA: US Army Corps of Engineers, New England District. Retrieved from http://www.nae.usace.army.mil/Portals/74/docs/Topics/Assabet/FeasibilityStudy.pdf

USEPA. (2010). *Proposed plan: Iron Horse Park, North Billerica, MA*. Boston: US Environmental Protection Agency, New England. Retrieved from https://semspub.epa.gov/work/01/469099.pdf via http://www.epa.gov/superfund/ironhorse

USFWS. (2004, September 27). *Letter to the Federal Energy Regulatory Commission requesting action to correct outstanding problems with the operation and maintenance of fish passage facilities at the Centennial Island Project*. Concord, NH: US Fish and Wildlife Service, New England Field Office. Retrieved from the FERC eLibrary.

USFWS. (2005). *Great Meadows National Wildlife Refuge: Final comprehensive conservation plan.* US Fish and Wildlife Service. Retrieved from http://www.fws.gov/uploadedFiles/Region_5/NWRS/North_Zone/Eastern_Massachusetts_Complex/Great_Meadows/Final_GRM_CCP.pdf

USFWS. (2007). *Concord River watershed river herring restoration proposal – Year 2007*. Nashua, NH: US Fish and Wildlife Service, Central New England Fishery Resources Office.

USFWS. (2009). *Great Meadows National Wildlife Refuge Concord Impoundments Proposal to Maintain Ditches and Create Freshwater Refugia*. US Fish and Wildlife Service. Retrieved from http://www.fws.gov/uploadedFiles/Region_5/NWRS/North_Zone/Eastern_Massachusetts_Complex/Great_Meadows/Concord_NOI_ProjectDescription29June2009_FINAL.pdf

USFWS. (2011). *Great Meadows National Wildlife Refuge* [Brochure]. Sudbury, MA: US Fish and Wildlife Service, Eastern Massachusetts National Wildlife Refuge Complex. Retrieved from http://www.fws.gov/uploadedFiles/Region_5/NWRS/North_Zone/Eastern_Massachusetts_Complex/Great_Meadows/refugebrochure.pdf

USFWS. (2015). *Anadromous fish returns – Merrimack River*. Nashua, NH: US Fish and Wildlife Service, Central New England Fishery Resources Office. Retrieved from http://www.fws.gov/northeast/cnefro/returns.html

USFWS. (2015, June 23). *Letter to Centennial Island Hydro Co. regarding a May 17, 2015 site visit*. Concord, NH: US Fish and Wildlife Service, New England Field Office. Retrieved from the FERC eLibrary.

USGS. (1981). *Guidelines for determining flood flow frequency* (Bulletin 17B of the Hydrology Subcommittee). Reston, VA: US Geological Survey. Retrieved from http://water.usgs.gov/osw/bulletin17b/dl_flow.pdf

USGS. (2015a). *StreamStats Version 3 for Massachusetts*. Reston, VA: US Geological Survey. Retrieved from http://water.usgs.gov/osw/streamstats/massachusetts.html

USGS. (2015b). *USGS 01099500 Concord R below R Meadow Brook, at Lowell, MA* (National Water Information System: Web Interface). Reston, VA: US Geological Survey. US Geological Survey. Retrieved from http://waterdata.usgs.gov/nwis/uv?site_no=01099500

Waterfield Design Group. (2008a). *Middlesex Canal National Register Historic District assessor's plan map book*. Prepared for the Middlesex Canal Commission in association with the Northern Middlesex Council of Governments and the Massachusetts Historic Commission. Winchester, MA: The Waterfield Design Group, Inc. Retrieved from http://middlesexcanal.org/commission/MCmapbook.pdf

Waterfield Design Group. (2008b). *The Middlesex Canal restoration: Program study*. Prepared for the Middlesex Canal Commission. Winchester, MA: The Waterfield Design Group, Inc. Retrieved from: http://middlesexcanal.org/commission/MCprogramstudy.pdf

Weaver, D. (n.d.). *Sea Lamprey (*Petromyzon marinus*)*. Atlantic Salmon and Sea-run Fish Restoration in Maine. Retrieved from http://northatlanticlcc.org/atlantic-salmon-recovery-project/resources/fact-sheets/sea-lamprey-petromyzon-marinus

Wildman, L. (2013). Dam removal: A history of decision points. In J. De Graff and J. Evans (Eds.), *Reviews in engineering geology v. XXI: The challenges of dam removal and river restoration* (pp. 1-10). Boulder, CO: The Geological Society of America.

Yerrinton and Bacheler. (1862). *Argument of Hon. Josiah G. Abbott, in behalf of the petitioners before Joint Special Committee of the Legislature of Massachusetts, on the petition of C. P. Talbot and others, praying for the repeal of the Act of 1860 for the removal of the dam across Concord River, at Billerica*. Boston: Wright & Potter. Retrieved from https://archive.org/details/argumentofhonjos00abbo

Zarriello, P. and Bent, G. (2011). *Elevation of the March – April 2010 flood high water in selected river reaches in central and eastern Massachusetts* (Open-File Report 2010-1315). Reston, VA: US Geological Survey. Retrieved from http://pubs.usgs.gov/of/2010/1315/

Zarriello, P., Parker, G., Armstrong, D., and Carlson, C. (2010). *Effects of water use and land use on streamflow and aquatic habitat in the Sudbury and Assabet River Basins, Massachusetts (Scientific Investigations Report 2010–5042)*. Reston, VA: US Geological Survey. Retrieved from http://pubs.usgs.gov/sir/2010/5042/

Zimmerman, M. and Sorenson, J. (2005). *Sediment studies in the Assabet River, central Massachusetts, 2003* (Scientific Investigations Report 2005-5131). Reston, VA: US Geological Survey. Retrieved from http://pubs.usgs.gov/sir/2005/5131/pdf/sir2005_5131.pdf