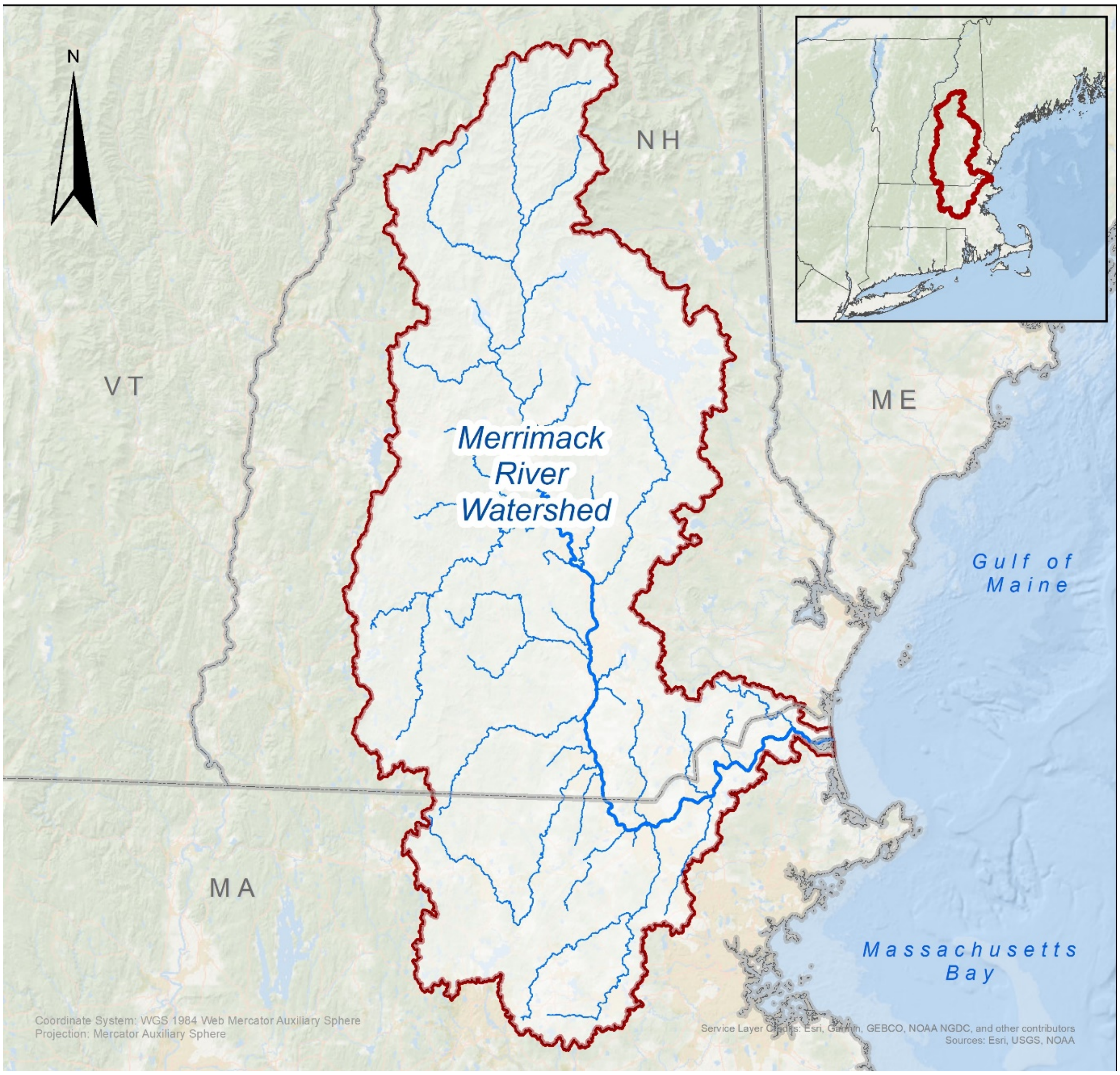
MERRIMACK RIVER WATERSHED COMPREHENSIVE PLAN FOR DIADROMOUS FISHES



The Technical Committee for Anadromous Fishery Management of the Merrimack River Basin

2021

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LIST OF ACRONYMS AND INITIALISMS

°C	Degrees Celsius
°F	Degrees Fahrenheit
aka	Also Known As
ASMFC	Atlantic States Marine Fisheries Commission
BMP	Best Management Practice
cfs or ft^3/s	Cubic Feet per Second
CP	Comprehensive Plan
CRASC	Connecticut River Atlantic Salmon Commission
CRP	Central Rivers Power, LLC
CSO	Combined Sewer Overflow
ECRE	Eagle Creek Renewable Energy, LLC
EOEA	Executive Office of Environmental Affairs (Gubernatorial, MA)
FERC	Federal Energy Regulatory Commission
FMP	Fisheries Management Plan
FPA	Federal Power Act (1935)
FWPA	Federal Water Power Act (1920)
GDB	Geodatabase
GIS	Geographic Information System
HUC	Hydrologic Unit Code
LLC	Limited Liability Company
MADMF	Massachusetts Division of Marine Fisheries
MassGIS	Bureau of Geographic Information (MA)
MassWildlife	Massachusetts Division of Fisheries and Wildlife
MDIFW	Maine Department of Inland Fisheries and Wildlife
MDMR	Maine Division of Marine Resources
MRTC	Merrimack River Technical Committee
MW	Megawatt, one million watts
MWRA	Massachusetts Water Resources Authority
NAACC	The North Atlantic Aquatic Connectivity Collaborative
NAD 83	North American Datum of 1983
NEACAP	Northeast Aquatic Connectivity Assessment Project
NGO	Non-Governmental Organization
NH GRANIT	New Hampshire Geographically Referenced Analysis and Information Transfer System
NHD	National Hydrography Dataset
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NLCD	National Land Cover Database
NMFS	National Marine Fisheries Service aka NOAA Fisheries
NOAA	National Oceanic and Atmospheric Administration
NPS	Non-point Source
OARS	Organization for the Assabet River
PFAS	Per- and Polyfluoroalkyl Substances
PPCP	Pharmaceuticals and Personal Care Products

RFA	Restoration Focus Area
RM	River Mile (Reported as distance from river mouth)
SES	Social-Ecological System
SuAsCo	Sudbury, Assabet, and Concord River Watershed
TBSA	Turbine Blade Strike Analysis
USACE	United States Army Corps of Engineers
USFS	United States Forest Service
USFWS	United States Fish & Wildlife Service
UTM	Universal Transverse Mercator
WGS	World Geodetic System

MERRIMACK RIVER WATERSHED
COMPREHENSIVE PLAN FOR DIADROMOUS FISHES

EXECUTIVE SUMMARY

ES 1.0 Background

Prior to pervasive dam construction in the late 18th and early 19th century, diadromous fish were abundant in the Merrimack River watershed including American shad, river herring (alewife and blueback herring), sturgeon (Atlantic and shortnose), American eel, striped bass, Atlantic salmon, and sea lamprey. These fish migrated inland in great abundance; some as far as several hundred miles, providing sustenance fisheries for Native Americans. Later, the diadromous fishery supported the first Colonial settlers in the region. River herring, shad, and salmon preserved with salt provided nutrients when other food was scarce during the harsh New England winters. People were so reliant upon the seasonal abundance of river herring, shad, and salmon that preserved fish became a form of currency. For many years, seasonal fish migrations were so abundant that one observation at Amoskeag Falls from the end of the 18th century recounted shad "so thick as to crowd each other in the passage up the falls… [and] you could not put in your hand without touching some of them."[1]

Dam construction began throughout the watershed shortly after the arrival of European settlers. The industrial revolution and the construction of dams to harness the power of the river reduced habitat connectivity and the abundance of diadromous fish. Widespread industry in the watershed, including many paper and textile mills, resulted in degraded water quality, further exacerbating the effects of decreased habitat connectivity and lack of access to natal waters.[2] These factors resulted in a severe reduction in anadromous fish abundance, effectively extirpating anadromous fish from the habitats upstream of Essex Dam, the first dam on the Merrimack River.

The present day abundance of diadromous species remains a small percentage of historical levels. Restoration efforts during the past 40 years have improved the habitat and connectivity conditions resulting in a modest increase in diadromous fish abundance. Regulated water quality standards, installation of fish passage facilities, stocking of adult fish above barriers, and dam removals on the tributaries contribute to these successes. The passing of the

[1] Marston, P.M., and Gordon, M. 1938. Notes on fish and early fishing in the Merrimack River system. Biological survey of the Merrimack watershed. New Hampshire Fish and Game Commission, Concord: 186-198.
[2] Kuzmeskus, D. M., et al. (1982). Anadromous Fish: Water and Land Resources of the Merrimack River Basin. Special Report. Laconia, NH.

Clean Water Act led to improved water quality conditions in the Merrimack River such that aquatic connectivity remains the largest obstacle to a restored diadromous fishery.

To develop and enhance the shad population in the Merrimack River, state fishery agencies in MA and NH obtained eggs from adult shad in the Connecticut River that were released from near Sewall's Falls downstream to the Essex Dam impoundment from 1969 to 1978.[3] Annual stocking of river herring collected at the Essex and Amoskeag dams by the state continues today. Although the Atlantic salmon program has ended, the U.S. Fish and Wildlife Service continues to harvest eggs from returning adult shad. The eggs are hatched and the fry released back into the Merrimack River. These management efforts have partially restored the diadromous fishery; however, work remains to restore habitat access for each species to support an economically and ecologically significant abundance.

ES 2.0 Purpose Statement

The purpose of the *Merrimack River Watershed Comprehensive Plan for Diadromous Fishes* (CP) is to create a framework to balance diadromous fish restoration efforts with other water resource uses and ecosystem services in the Merrimack River watershed. We designed the goals, objectives, and recommendations of the CP to protect, conserve, and restore the Merrimack River habitat and natural resources. This CP supports the mission of the Merrimack River Anadromous Fish Restoration Program, as well as the fisheries management efforts of the National Marine Fisheries Service (NOAA Fisheries), the United States Fish and Wildlife Service (USFWS), the Massachusetts Division of Fish and Wildlife (MassWildlife), the Massachusetts Division of Marine Fisheries (MADMF), and the New Hampshire Fish and Game Department (NHFGD).

ES 3.0 CP Goals and Objectives

Goals, objectives, and recommendations for the Merrimack River watershed fall into several categories and vary in scope. Sections 12.0 and 13.0 of the CP describe the comprehensive list of watershed-level and sub-watershed-level goals, objectives, recommendations and priority actions. The following are a selection of high-level goals and objectives for the Merrimack River watershed.

Watershed-Level Goals and Objectives

Goal: The overarching goal of this CP is to coordinate the restoration, protection, and enhancement of diadromous fish stocks and their habitats throughout the Merrimack River watershed.

[3] Both species of river herring were obtained from a variety of sources, inside and outside the Merrimack watershed

Objective 001. Improve habitat accessibility for diadromous fish in a manner consistent with appropriate management actions for resident fisheries. This is facilitated by dam removal, or installation or improvement of safe, timely, and effective fish passage facilities at obstacles that prevent fish from habitats.[4]

Objective 002. Improve habitat quality to support growth and reproduction for native diadromous species in a manner compatible with the management goals for resident freshwater species.

Objective 003. Ensure that water withdrawal impingement or entrainment effects do not cause declines or inhibit recovery of diadromous stocks.

Objective 004. Improve water quality in areas where water quality degradation has negatively affected diadromous fish stocks or is otherwise impaired.

Objective 005. Maintain natural water temperatures and seasonal fluctuations.

Objective 006. Ensure that decisions regarding river flow allocation consider flow needs for diadromous fish migration, spawning, and nursery habitat.

Objective 007. Initiate or continue programs to stock diadromous fish where necessary and practical, as a management measure to develop self-sustaining populations that do not rely on stocking.

Objective 008. Recommend and support research programs that produce data needed for 1) the development of management recommendations relating to sustainable and acceptable yields, 2) the preservation or recovery of stock levels, and 3) optimal utilization of those stocks.

Objective 009. Recommend and support research that advances restoration efforts in the Merrimack River watershed.

Objective 010. Develop and maintain a list of Merrimack River watershed-specific research needs that support restoration efforts.

Objective 011. Build collaborative partnerships among local, state, and federal agencies to align management approaches and reduce duplication of effort or resource allocation.

Objective 012. Engage the recreational fishing community through directed surveys to identify their interests and build support for restoration activities.

Objective 013. Initiate and support programs to provide information and education to the public on the importance of the diadromous fishery of the Merrimack to increase visibility and advocacy.

[4] Dam removal is the preferred option in nearly all cases where restoring fish passage is the goal. We recognize this is not always a feasible option. We recommend alternative strategies (e.g. installing or retrofitting fish passage structures, or rebuilding them based on current data and designs) where dam removal is infeasible.

Species-Specific Goals

Goal: Restore a self-sustaining American shad population in the Merrimack River watershed, with unrestricted access to spawning and juvenile rearing habitat throughout the main stem and major tributaries.

Goal: Restore a self-sustaining blueback herring population in the Merrimack River watershed, with unrestricted access to spawning and juvenile rearing habitat throughout the main stem and major tributaries.

Goal: To restore a self-sustaining population of alewife to the Merrimack River watershed.

Goal: Conserve and enhance the population of American eel in the Merrimack River watershed by reducing anthropogenic mortality and improving access to habitat.

Goal: To restore and maintain runs of Sea Lamprey in the Merrimack River watershed for human and ecological benefits.

ES 4.0 Biological and Geographic Scope of the CP

Biological Scope

The biological scope of the CP focuses on five target diadromous fish species that were historically present in the Merrimack River, have current presence in the watershed, and will benefit from the goals and recommendations outlined in this plan. The five species are American shad, alewife, blueback herring, American eel and sea lamprey. These species were selected based on available distribution data, resource agency goals, as well as recommendations from previous management documents.

We considered several other diadromous species that were historically present in the watershed including Atlantic and shortnose sturgeons, Atlantic salmon, striped bass, rainbow smelt and Atlantic tomcod. These species were designated non-targets in the plan based on their present day distribution, the location of remaining suitable habitat, and whether or not they were likely to benefit from the management recommendations in this CP. Section 2.2 describes the species-specific reasons for non-target designation.

Geographic Scope

The Merrimack River and tributary streams comprise the fourth largest watershed in New England. Draining an area greater than 5,000 square miles, the mainstem of the Merrimack River flows 116 miles from the confluence of the Pemigewasset and Winnipesaukee Rivers in Franklin, NH to the Atlantic Ocean in the Gulf of Maine near Newburyport, MA. The tidal portion of Merrimack River extends to approximately river mile (RM) 22 near Haverhill, MA. Many tributary rivers flow into the Merrimack River, the largest of these are the Pemigewasset

(1,023 mi²), Contoocook (765 mi²), Nashua (533 mi²), Winnipesaukee (473 mi²), Concord (400 mi²), Suncook (255 mi²), Souhegan (221 mi²), and Piscataquog (218 mi²).

Much of the freshwater habitat found in the Merrimack watershed is inaccessible to diadromous fish. Over 3,000 dams are present in the watershed; including 49 Federal Energy Regulatory Commission (Commission) licensed hydroelectric projects on the mainstem and tributaries. The five dams on the mainstem of the Merrimack River each support hydroelectric projects. These dams are: Essex Dam (RM 30, Lawrence, MA), Pawtucket Dam (RM 43, Lowell, MA), Amoskeag Dam (RM 74, Manchester NH), Hooksett Dam (RM 82, Hooksett, NH), and Garvin's Falls Dam (RM 87, Concord, NH). Of the mainstem dams, upstream fish passage is provided at the Essex, Pawtucket, and Amoskeag Dams.

ES 5.0 Methodology and Limitations

The restoration potential for target species was assessed using several analyses including: target species life history, current and historical diadromous fish distributions, watershed barrier inventory,[5] lotic and lentic habitat estimation (surface acreage) by watershed, and production estimation by species based on spawning habitat. Results of the analyses identified key areas to focus restoration efforts and inform restoration recommendations.

Available information was the limiting factor in these analyses. While geospatial information sources such as the National Hydrography Dataset and state dam inventories provided suitable resolution for the analysis, obtaining biological data proved challenging. Much of the historical distribution data is anecdotal; however, it provides the best available information of habitat utilization prior to the construction of dams. Abundance data is similarly lacking from early records. Modern target species abundance estimates used passage data at Essex Dam because few quantitative fisheries surveys exist for diadromous fish in the watershed. Finally, field-based habitat mapping for diadromous species is lacking.

ES 6.0 Key Findings and Discussion

Fish passage facilities at Essex, Pawtucket, and Amoskeag Dams on the mainstem, Centennial Island Dam on the Concord River, and Jackson Mills and Mine Falls Dam on the Nashua River have partially restored access to approximately 4,200 surface acres of spawning and rearing habitat (Figure ES- 1).[6] This represents less than 30 percent of the estimated 14,500 surface acres of historically accessible habitat upstream of Essex Dam (Figure ES- 1).[7] For alewife that prefer to spawn in lakes and ponds, accessibility is poorer. Access to lakes and

[5] Including hydropower dams, non-hydropower dams, and road/stream crossings.
[6] Upstream passage structures are installed at these projects; however, many design and efficiency issues result in poor passage. Improving the efficacy of these structures is necessary to realize production potential.
[7] These estimates underrepresent production because the analysis did not include reaches with average width less than 50 feet.

ponds is severely limited due to ubiquitous small dams in the watershed. Currently, alewife have access to less than two percent of the total historic lentic spawning and rearing habitat on an area basis.

Our analysis identified seven dams currently blocking 3,500 surface acres of habitat on the Mainstem, Concord, Nashua, Souhegan and Piscataquog Rivers (Table ES-1; Figure ES-1). Fish passage at these seven dams will nearly double the accessible diadromous fish spawning and rearing habitat. The process for implementing passage at each dam will differ based on watershed context, licensing status, and input from owners. Garvin's Falls and Hooksett Dams have a settlement agreement[8] that requires fish passage measures. A settlement agreement[9] at Pepperell Dam requires upstream passage within three years following two consecutive years of 5,000 river herring passing Mine Falls Dam, but not prior to 2026. Kelley's Falls will be considering fish passage as a condition of a new license in 2024. The other three dams are privately owned, non-hydropower barriers, with near-term potential for restoration.

Potential production for alosines was estimated based on available spawning habitat under different accessibility scenarios. American shad production potential in accessible habitat in the Merrimack basin is 421,900 returning adult fish (Table ES-2). Under the Interim Scenario, the production increases to 780,200 as a result of the increased access to habitat. The Ideal Scenario estimates a potential production of 1,446,200 adult shad. Estimated production potential for blueback herring in the accessible habitat of the Merrimack River basin is 2,531,400 returning adult fish (Table ES- 2). Under the Interim Scenario, the production increases to 4,681,200 as a result of the increased access to habitat. The Ideal Scenario estimates a potential production of 8,677,200 adult blueback herring. The Interim Scenario estimates a large increase in both available habitat and potential production of target species with successful engagement at the seven dams listed in Table ES-1. American eel and sea lamprey will benefit from fish passage improvements at any dam structure in the watershed.

Our approach for estimating alewife productivity was based on the preferred spawning and rearing habitat, which is different than shad and blueback herring.[10] The production potential in the Current Scenario is negligible without stocking efforts due to the lack of connectivity between mainstem and lentic habitats. Alewife have access to less than two percent[11] of the historical spawning and rearing habitat in the Merrimack River watershed, much less than

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[8] FERC Accession # 20070206-5016

[9] FERC Accession # 20140411-5151

[10] Pardue, G.B. 1983. Habitat Suitability Index Models: Alewife and Blueback Herring. U.S. Department of the Interior Fish and Wildlife Service.; Greene, K.E., Zimmerman, J.L., Laney, R.W., and Thomas-Blate, J.C. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, ASMFC, Washington, D. C.

[11] This percentage considers lentic habitats only; adding impoundments and sluggish river reaches increases the number closer to six percent.

blueback herring or shad. With successful restoration to habitats listed in CP Section 8.1, production estimates for alewife in the Merrimack basin range from 1,279,198[12] to 4,061,740[13] returning adults.

Table ES-1 List of dams where implementation of fish passage is recommended by 2030

FERC Project - #	Dam Name	State	Waterway	License Expiration Date	Acres of Mainstem Habitat Blocked
1893	Garvin Falls	NH	Merrimack River	4/30/2047	1,506
1893	Hooksett	NH	Merrimack River	4/30/2047	555
3025	Kelley's Falls	NH	Piscataquog River	3/31/2024	203
12721	Pepperell	MA	Nashua River	8/31/2055	435
Non-Hydro	Talbot Mills	MA	Concord River	N/A	809
Non-Hydro	McLane	NH	Souhegan	N/A	75
Non-Hydro	Goldman	NH	Souhegan	N/A	<5
3342	Penacook Lower Falls	NH	Contoocook	11/30/2024	8
6689	Penacook Upper Falls	NH	Contoocook	11/30/2028	11
3240	Rolfe Canal	NH	Contoocook	11/30/2024	500

Table ES-2 Potential production of American shad and blueback herring under different habitat scenarios

Habitat Scenario[14]	Acres of habitat	Potential # of Returning Adult American Shad	Potential # of Returning Adult Blueback Herring
Current Scenario	4,219	421,900	2,531,400
Interim Scenario	*3,583*	*358,300*	*2,149,800*
Total (Current + Interim)	7,802	780,200	4,681,200
Ideal Scenario	14,462	1,446,200	8,677,200

Several hydroelectric project licenses that expire by 2030 are a focus of the MRTC. These include projects on the mainstem Merrimack and Nashua Rivers where improving efficiency and effectiveness of existing facilities is the focus, as well as projects on the

[12] For the alewife Interim Scenario. Lentic waters and a few select impoundments that are likely to be accessible either volitionally or with assistance within the next ten to twelve years were considered.
[13] The alewife Ideal Scenario considers habitat reaches that are (1) potential stocking locations identified by MRTC (2019), (2) capable of supporting a sustainable run, or (3) locations previously stocked.
[14] Each scenario listed here only considers habitat upstream of Essex Dam

Contoocook and Piscataquog Rivers where new passage facilities are needed (Table ES-3). Successful implementation and improvement of fish passage at these dams will increase access to habitat.

Table ES-3 Hydroelectric facilities with expiring licenses before 2030 that MRTC agencies will actively participate in the licensing process.

FERC Project - #	Facility Name	Facility Owner	Waterway	License Expiration Date
2790	Lowell	Central Rivers Power	Merrimack River	4/30/2023
3442	Mine Falls	City of Nashua	Nashua River	7/31/2023
3025	Kelley's Falls	Green Mountain Power	Piscataquog River	3/31/2024
3342	Penacook Lower	Briar Hydro Associates	Contoocook River	11/30/2024
3240	Rolfe Canal	Briar Hydro Associates	Contoocook River	11/30/2024
6689	Penacook Upper	Briar Hydro Associates	Contoocook River	11/30/2024
2800	Lawrence	Central Rivers Power	Merrimack River	11/30/2028

In addition to fish passage improvements, we identified other recommendations to achieve the goals of this CP, including:

- Strategic stocking of target diadromous fish species to facilitate habitat colonization or supplement the population
- Research and field surveys to monitor and assess progress toward goals
    - Identify gaps in available data
    - Propose and conduct surveys to update information and fill in data gaps
    - Provide up-to-date data to inform decision making and adaptive management
- Water quality and quantity management
    - Mitigate effects of pollutants and excess nutrients, combined sewer overflows, municipal waste discharge, stormwater runoff, potential for thermal and oxygen stress
    - Collaborate with industry, utilities, municipalities and other stakeholders on flow allocation decisions and water withdrawal regimes
- Outreach programs and public education efforts to increase advocacy for diadromous fish and other watershed resources
- Build partnerships with watershed stakeholders
- Collaborate among local, state, and federal agencies to align management approach and avoid duplication of effort

At a high level, these needs demonstrate the broad scope of potential management strategies the MRTC will consider to meet diadromous fish restoration goals. The recommendations in this CP not related to fish passage are synergistic with improved habitat access and beneficial to the watershed overall.

ES 7.0 Conclusion

Fish passage provisions and water quality improvements over the past several decades have improved conditions for diadromous fish in the Merrimack River. Much work remains to achieve management goals for diadromous fish and their habitat. Ongoing and upcoming licensing at several hydropower projects, as well as license compliance actions, provide an opportunity to increase the amount of accessible habitat and improve habitat quality for diadromous fish. This CP is designed to inform the activities of the MRTC and other stakeholders in support of the restoration of diadromous fishes in the Merrimack River watershed over the next ten to twelve years. Recommended management and restoration actions will facilitate this process and are designed to serve the goals of the CP.

MRTC representatives and their respective agencies are limited to implementing actions in this CP to the extent permitted by law and subject to the availability of staff and resources, in accordance with their respective missions, policies, and regulations. While the CP does not commit staffing or funding resources of the state and federal agencies, where appropriate and as resources allow, the MRTC will support implementing recommended actions. The implementation team will likely be a broader collaborative effort comprising local, state, and federal resource agencies, hydropower developers, and non-government organizations. Through a collaborative process, these stakeholders will guide the implementation of the proposed restoration activities. The collaborative process and the management framework that this CP establishes by this CP will be progress toward the restoration, protection, and enhancement of diadromous fish stocks and their habitats in the Merrimack River watershed.

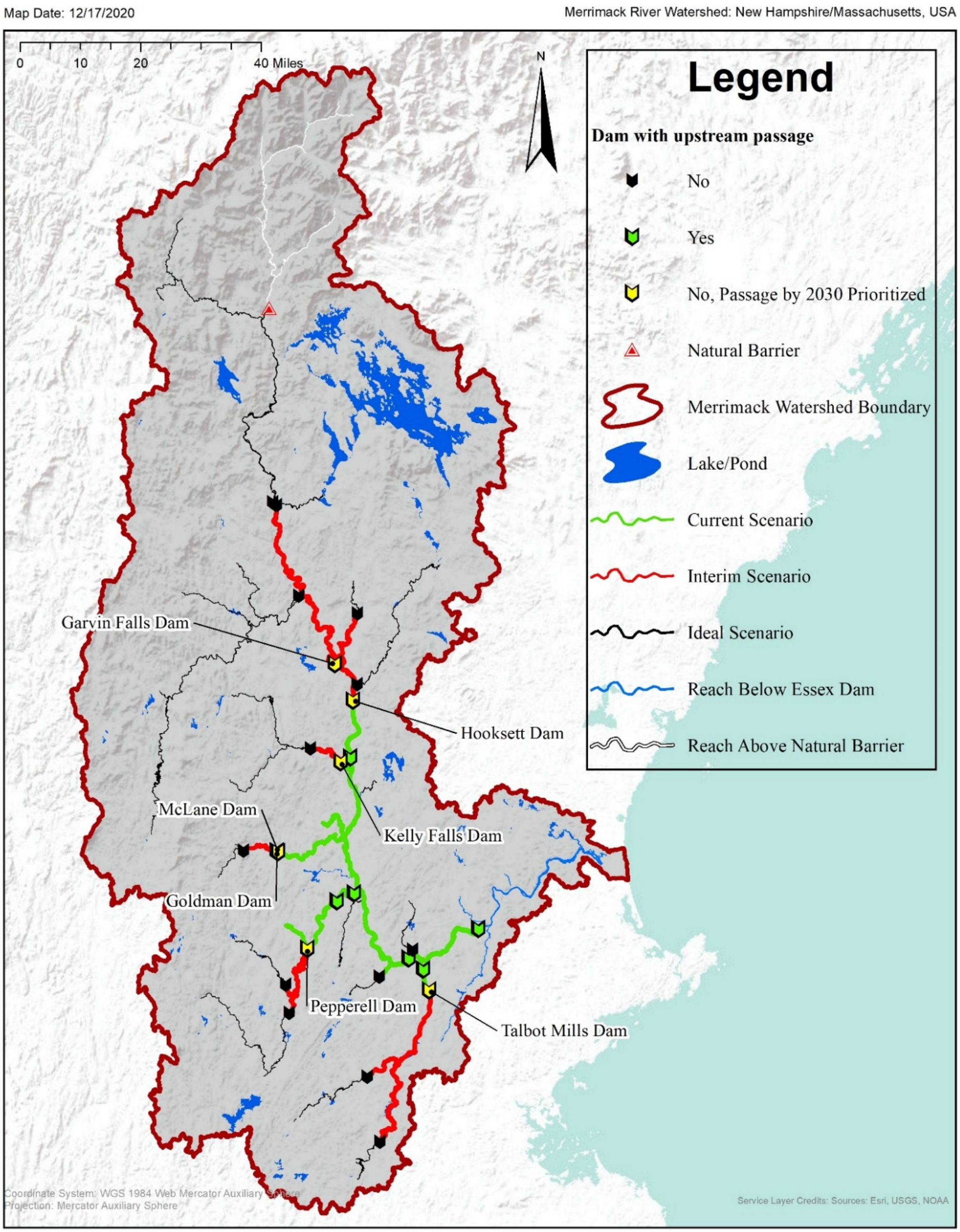

Figure ES-1 Current and Potential Diadromous Fish Access, Merrimack River Watershed

MERRIMACK RIVER WATERSHED
COMPREHENSIVE PLAN FOR DIADROMOUS FISHES

1.0 NEED FOR A PLAN

The Merrimack River Anadromous Fish Restoration Program (Program) manages diadromous fish resources in the watershed. Over the past five decades, this Program has active participation from State and Federal agencies, including the U.S. Fish & Wildlife Service (USFWS), Massachusetts Division of Fish and Wildlife (MassWildlife), Massachusetts Division of Marine Fisheries (MADMF), the New Hampshire Fish and Game Department (NHFGD), the United States Forest Service (USFS), and the National Marine Fisheries Service (NOAA Fisheries). Program partners are currently engaged in several hydropower licensing and compliance activities in the Merrimack River Watershed, as well as proactive restoration actions (e.g., dam removal feasibility studies, fish passage alternative analyses). The broad purpose of our engagement is to support the restoration of diadromous fish and their habitat.

The restoration goals for the Merrimack River Watershed are to provide access to historical spawning, rearing, and migration habitats necessary for diadromous species to complete their life cycles and enhance their populations. The restoration focus includes habitat on the mainstem, major tributaries, minor tributaries, and associated lentic waters (see Section 4.0). Restoration goals are facilitated by structural and operational modifications to barriers and hydroelectric facilities that ensure safe, timely, and effective passage of migrating adult and juvenile fish, including passage necessary for dispersal and seasonal movement. The Program also considers non-hydropower barriers in the focus area to determine potential benefits of modification or removal where feasible.

Achieving specific goals on the Merrimack River will have broader benefits, which include productive and sustainable fisheries, improved riverine connectivity and ecosystem functioning, recovery and conservation of protected resources, and healthy ecosystems that support their natural functions. The resilience of our freshwater, estuarine, and marine ecosystems and surrounding communities depend on healthy aquatic systems, which often depend upon diadromous species. The Merrimack River Anadromous Program, through its member agencies, seeks to exercise its regulatory responsibilities and non-regulatory opportunities while engaging with partners and stakeholders to conserve and restore public trust resources, recover protected species, and increase economic and recreational opportunities.

Several factors highlight the need for a Comprehensive Plan (CP) that prioritize and focus diadromous fish conservation efforts in the Merrimack watershed. These factors include:

1. Urbanization and industrialization have degraded water quality and created a lack of aquatic connectivity in the Merrimack watershed. This has resulted in a reduction of both

the volitional range of diadromous species and the quality of the remaining habitat. State and Federal agencies, along with energy companies and other non-governmental organizations (NGOs) have made progress towards addressing these issues. However, continued focused effort is necessary to re-establish connectivity and improve existing habitat in the watershed.

2. In the Merrimack watershed, many Federal Energy Regulatory Commission licensed hydroelectric projects will require licensing before 2030. Licensing several projects in a watershed provides an opportunity to prioritize restoration activities based on agency goals and emerging opportunities. A comprehensive plan prioritizes action items and serves as a reference during licensing proceedings. Additionally, it provides support for settlement agreements or license amendments.

3. Several existing management documents concerning the Merrimack watershed currently exist that vary in scope, administering agency, timeline, and focus species/area. A comprehensive plan can organize and consolidate common goals from existing management documents and plans, facilitating coordination of effort among agencies, municipalities and other NGOs.

2.0 INTRODUCTION

The headwaters of the Merrimack River flow south from the White Mountains in northern New Hampshire. Near the town of Franklin, New Hampshire, two major tributaries (the Pemigewasset and Winnipesaukee) join to form the Merrimack River. From here, the river continues on a southerly course through central and southern New Hampshire until it crosses the border into Massachusetts near the town of Tyngsborough. Here the river flows to the east. From the city of Lowell, the river - with a roughly three-mile buffer to the north - defines the northern border of Massachusetts. The Merrimack meets the Atlantic Ocean near Plum Island in the town of Newburyport, approximately 12 miles north of Cape Ann (Figure 1).

The Merrimack River supported a variety of Atlantic diadromous fish species including sea lamprey (*Petromyzon marinus*), American eel (*Anguilla rostrata*) Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*), shortnose sturgeon (*A. brevirostrum*), American shad (*Alosa sapidissima*), blueback herring (*A. aestivalis*), alewife (*A. pseudoharengus*), rainbow smelt (*Osmerus mordax*), Atlantic salmon (*Salmo salar*), Atlantic tomcod (*Microgadus tomcod*), and striped bass (*Morone saxatilis*) (Kuzmeskus et al. 1982; Stewart and Auster 1987; Kieffer and Kynard 1996).

2.1 Purpose of a Comprehensive Plan

The intent of this document is to create a framework to help balance diadromous fish restoration efforts with other watershed resource uses and ecosystem services. We designed the goals defined in this document to protect, conserve, and restore the Merrimack River habitat and natural resources. This CP supports the mission of the Merrimack River Anadromous Fish Restoration Program, as well as the independent fisheries management efforts of NOAA Fisheries, the USFWS, MassWildlife, MADMF, NHFGD, and the USFS.

Organized in 1969, the restoration cooperative or Anadromous Fish Restoration Program consists of two committees. The Policy Committee for Anadromous Fishery Management of the Merrimack River (Policy Committee) provides overall program direction and resolves policy issues. This committee is composed of Regional Directors of NOAA Fisheries (Northeast Region), USFWS (Region 5) and Directors of the MADMF, MassWildlife, NHFGD, and (formerly) USFS (White Mountain National Forest Supervisor). The Technical Committee for Anadromous Fishery Management of the Merrimack River[15] or Merrimack River Technical Committee (MRTC) provides oversight of program implementation and advises the Policy Committee on technical issues. The MRTC is composed of staff members (assigned by the Policy Committee) from each of the six agencies. The MRTC remains active producing

[15] The 1969 Statement of Intent for a Cooperative Fishery Restoration Program for the Merrimack River Basin established the Technical Committee for Fisheries Management of the Merrimack River Basin. The term "anadromous" was later added to the Committee's name

documents, recommendations, and holding multiple meetings per year. The USFS has been inactive on the committee since the termination of the Atlantic salmon restoration program.

A series of management plans exist for the Merrimack River. The majority of these documents focus on a single species or include the Merrimack watershed as part of a broader geographic area. Actions and goals described in this CP build off management recommendations in these existing plans to provide synergistic restoration benefits. Section 10.1 contains a list of plans we integrated into the preparation of this CP. We coordinated with State and Federal agencies and partners to identify the most effective resource management strategies to ensure we achieve our collective restoration goals in this CP.

2.2 Scope of Comprehensive Plan

This CP assesses five target diadromous fish species in the Merrimack River watershed that were historically abundant, have current presence, and will benefit from the goals and recommendations outlined in this plan. These species are:

- American shad
- Alewife
- Blueback Herring
- American Eel
- Sea Lamprey

We selected these species based on currently available distribution data, Program agency goals, as well as recommendations from previous management documents. We considered several other diadromous species that were/are present in the watershed including Atlantic and shortnose sturgeons, Atlantic salmon, striped bass, rainbow smelt and Atlantic tomcod. These species were designated non-targets in the scope of this plan for the following reasons:

- Atlantic and shortnose sturgeons were historically present throughout much of the Merrimack River. Prior to dam construction on the lower river in the 19th century, Amoskeag Falls was likely the natural upstream extent based on anecdotal records from the 17th century. Today, these fish are occasionally encountered in the lower river below Essex Dam, and shortnose sturgeon have been documented spawning below the head of tide in Haverhill, MA (Kieffer and Kynard 1996). In New England, NOAA Fisheries has designated critical habitat in several sturgeon-occupied reaches of the Penobscot, Kennebec, Androscoggin, Piscataqua, Cocheco, Salmon Falls, and Merrimack Rivers. In the Merrimack, the lower river from the mouth to base of Essex Dam in Lawrence, MA is designated as critical habitat for Atlantic sturgeon. These fish have not passed the lift at Essex Dam (Kieffer 1991), and as such, the goals for their restoration do not include habitat above the Essex Dam.

- Atlantic salmon were historically an important natural resource in the Merrimack watershed. After years of restoration effort, in 2014 the USFWS ended its collaborative effort to restore the population of sea-run salmon in the Merrimack. Several reasons were cited for terminating the restoration effort including: in-river habitat alteration and degradation leading to severely reduced abundance, poor survival of salmon at sea, dams causing migration impediments, and man-made barriers inhibiting the ability of fish to reach spawning habitat and exit the river efficiently.[16] For these same reasons, we do not consider Atlantic salmon a target species for this CP.[17]

- Striped bass are present in the watershed; however, the Merrimack River does not have a known, extant breeding population. It does provide habitat, perhaps year-round, to striped bass from other spawning areas. Current data indicate the coastal stock recruitment is largely driven by the Chesapeake Bay population and recruitment there is highly driven by environmental variables (B. Gahagan, MADMF, personal communication, April 1, 2020). The historical extent of striped bass in the Merrimack is not well documented, though it is likely Amoskeag Falls, and perhaps to Lake Winnipesaukee. Today, the habitat below Essex Dam is the most important and accessible for striped bass. A focus on increasing the number of striped bass in the river before the alosine stocks have rebounded is counterproductive due to heavy predation pressure concentrated by passage structures. As habitat connectivity improves, and forage fish stocks (shad, herring, and eel) increase because of management activities, striped bass in the system will benefit.

- Early accounts suggest rainbow smelt runs were significant throughout New England. In Massachusetts, rainbow smelt supported sustenance fisheries that evolved into small-scale commercial and recreational fisheries. Although there is little contemporary documentation on smelt fisheries in Massachusetts, the current abundance of these fish is presumed to be far below historic levels (Enterline et al. 2012). Rainbow smelt are primarily an estuarine and coastal species, spawning in small, steep-gradient freshwater streams that are contiguous with estuaries (Collette and Klien-MacPhee 2002). Chase (2006) described hydrologic conditions in the Merrimack River, and hypothesized that spawning habitat may occur in the mainstem and tributaries between the I-95 and I-495 bridges and possibly up to the Essex Dam in low flow years.

- Atlantic tomcod are a year-round resident of estuaries on the Atlantic coast from Virginia to Labrador. They are seldom found at depths greater than 20 feet, and they spawn in freshwater streams near the estuary (Collette and Klien-MacPhee 2002). Although current available data on tomcod in the Merrimack is minimal, the vast majority of their

[16] Climate change is likely a contributing factor to several of these situations
[17] No portion of the Merrimack River watershed has received a critical habitat designation for Atlantic salmon; future restoration of this species may be considered once alosine populations have been restored and Atlantic salmon are delisted under the Endangered Species Act.

present day habitat likely lies below the Essex Dam. The smelt fyke net survey completed by the MADMF is the only monitoring series in Massachusetts that routinely catches tomcod. Tomcod have been caught at all stations; however, only the Fore River station in Braintree (outside of the Merrimack watershed) has enough catches to potentially contribute indices on size or abundance. MADMF considers them to occur in the Merrimack River based on historical information and best professional judgement (Brad Chase, MADMF, personal communication, July 28, 2020).

Habitat and restoration recommendations prescribed by this plan are likely to produce benefit to non-target species as the habitat connectivity and ecological integrity of the system improves.

2.3 Background on Diadromous Fish in the Merrimack River Watershed

Prior to widespread dam construction in the Merrimack watershed in the late 18th and early 19th century, several species of diadromous fish were abundant in the river including American shad, river herring (alewife and blueback herring), sturgeon (Atlantic and shortnose), American eel, striped bass, Atlantic salmon, and sea lamprey. For many years, seasonal fish migrations were so abundant that one observation at Amoskeag Falls from the end of the 18th century recounted shad "so thick as to crowd each other in the passage up the falls… [and] you could not put in your hand without touching some of them."(Marston and Gordon 1938).

Waterfalls and natural sluices found at Pawtucket Falls (river mile (RM) 43), Amoskeag Falls (RM 74), and the outlet of Lake Winnipesaukee, were important fishing grounds among Native Americans, and later among European settlers. These natural obstacles were a challenge for all diadromous fish, and likely impassible for some. They served to concentrate the fish attempting to swim upstream, increasing their vulnerability to capture and harvest. Still, prior to the advent of mainstem dams, remarkable numbers of fish migrated to their natal tributaries, lakes, and ponds. Some accounts indicate American shad reliably reaching the outlet of Lake Winnipesaukee where they were harvested in great numbers (Meader 1869). While historical evidence suggests alosines favored the eastern route up the Winnipesaukee River, once they reached the fork, Atlantic salmon tended to continue north, spawning in the cool, high-gradient waters of the Pemigewasset River (Meader 1869). Anecdotal historical accounts suggest sturgeon were observed with some regularity at the base of Amoskeag Falls which was likely the upstream limit of their natural distribution.

Dam construction began throughout the watershed shortly after the arrival of European settlers. The dams created to harness waterpower during the industrial revolution significantly reduced habitat connectivity, and the abundance of diadromous fish. Pawtucket Dam (RM 43, ca.1847) and the Essex Dam[18] (RM 30, ca. 1848) were the first two major barriers constructed

[18] Also known as the Great Stone Dam

on the Merrimack mainstem that led to the decline of diadromous fish populations (Kuzmeskus et al. 1982). Widespread industry in the watershed, including many paper and textile mills, resulted in severely degraded water quality, exacerbating the effects of decreased habitat connectivity (Kuzmeskus et al. 1982). MRTC (1997) contains a thorough review of the history of diadromous fish in the watershed as well as previous management action.

The present day abundance of diadromous species is a small percentage of historical abundance. Restoration efforts during the past 40 years have improved habitat and connectivity conditions. Regulated water quality standards, installation of fish passage facilities, stocking of fish above barriers, and dam removals have led to these restoration successes. The passing of the Clean Water Act has resulted in sufficiently improved water quality conditions in the Merrimack River such that aquatic connectivity remains the largest obstacle to a restored diadromous fishery (Kuzmeskus et al. 1982). Following installation of fish passage facilities in the 1980s, the state of New Hampshire began actively stocking alewife and blueback herring into spawning habitat throughout the watershed. Collected from Essex and Amoskeag Dams; annual stocking of river herring by the state continues today. Stocking is an interim measure to support restoration efforts until volitional passage and permanent connectivity is implemented. These initial efforts to restore the diadromous fishery have realized some progress; however, work remains to restore each species to historical habitat and an ecologically significant abundance.

3.0 DESCRIPTION OF THE MERRIMACK RIVER WATERSHED

The Merrimack River drains the fourth largest watershed in New England. Encompassing 5,008 square miles and containing over 9,500 river miles, the majority (approximately 75 percent) of the drainage is located in New Hampshire; the remainder is in Massachusetts (Figure 1; Table 1). The Merrimack River flows 116 miles from the confluence of the Pemigewasset and Winnipesaukee Rivers in Franklin, NH to where the river meets the Atlantic Ocean near Plum Island in the city of Newburyport, MA. Many of the river's upper tributaries are high gradient with some originating above 4,000 feet in the White Mountains of New Hampshire. The mainstem of the Merrimack is a mild gradient falling 250 feet from its origin to tidewater. The tidal influence extends many river miles inland with the head of tide generally falling between RM 21 and 22 near Haverhill, MA (Hartwell 1970). There are nearly 3,000 documented dams in the watershed, a clear reminder of the industrial impacts and human influence on the river. In addition to dams, there are numerous other barriers or potential barriers to diadromy, in the form of crossings, culverts, and natural features. Nearly 2.6 million people live in communities in or partially in the watershed, with over 500,000 residents utilizing the river as a primary source for drinking water.

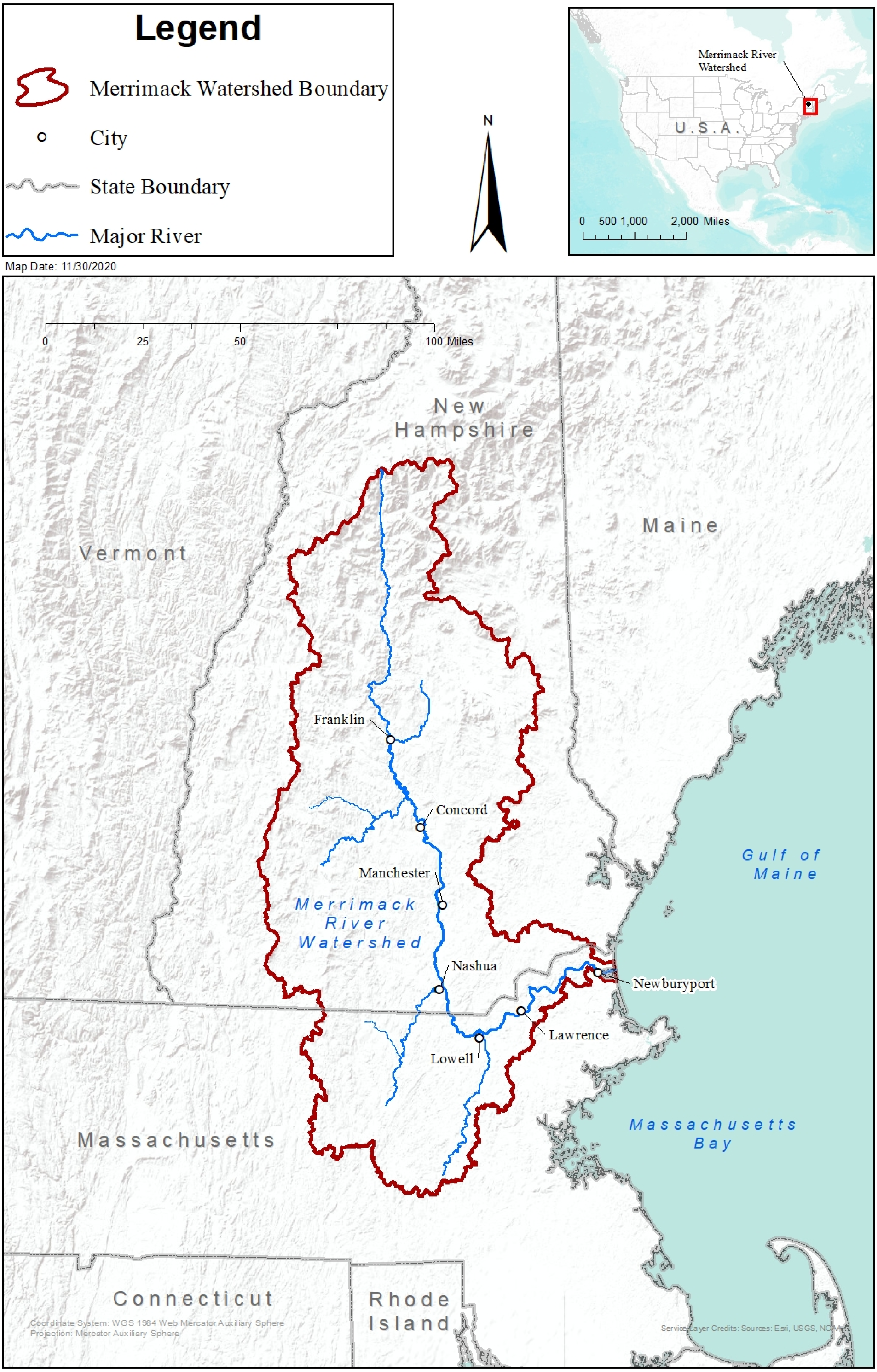

Figure 1. Merrimack River Watershed Overview

3.1 Description of tributary watersheds in the Merrimack basin

The geographic scope of this comprehensive plan comprises the Merrimack River mainstem and 20 tributary watersheds (Figure 2). We defined tributary watersheds using the Hydrological Unit Code (HUC) system described by Seaber et al. (1987). We used the 144 twelve-digit hydrologic units (HUC12) in the watershed to make discrete basins. Any HUC12 that the mainstem Merrimack River (n=11) intersects, we assigned to the "Mainstem" subwatershed. HUC12 watersheds that do not contain any part of the mainstem were assigned to the appropriate basin, in some instances comprising a single HUC12 watershed.

We used the United States Geological Survey's National Hydrography Dataset (NHD) to analyze and enumerate lotic (Hydronetwork) and lentic (medium resolution NHD to eliminate numerous unnamed, minor or analytically insignificant waterbodies) watershed features. Based on these criteria, the Merrimack watershed contains 1,206 lakes and ponds with a total surface area of approximately 200 square miles (Table 1).

There are few natural barriers on the mainstem for most diadromous fish. However, the Pemigewasset and a few tributaries do have areas that are likely natural barriers for most diadromous fish (Figure 3). In the minor tributaries, other natural barriers may exist, which require confirmation from site-specific surveys. The following sections describe the watershed parameters for each basin based on best available data.

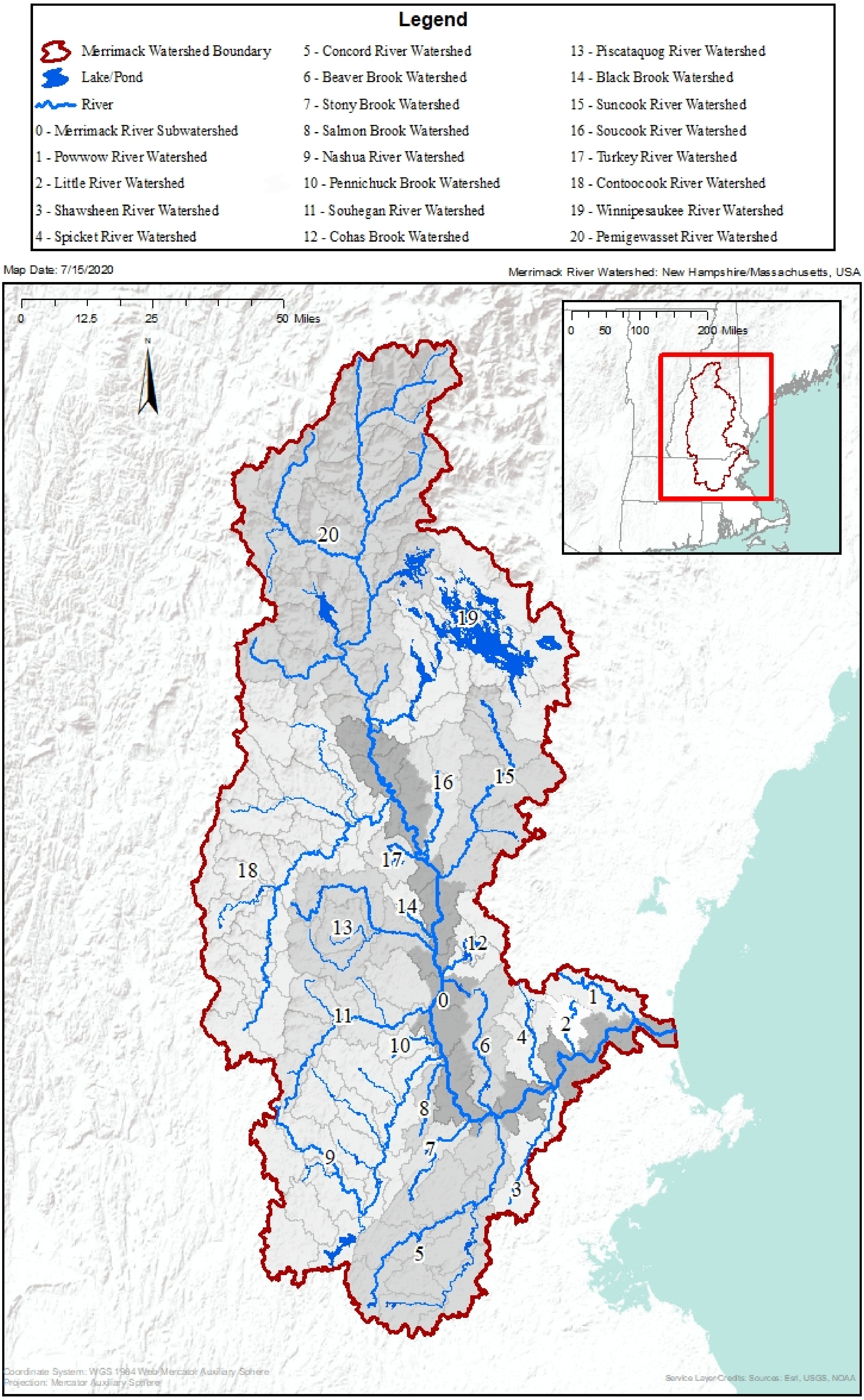

Figure 2. Merrimack River Tributary Watershed Overview

Table 1. Merrimack River Watershed Metrics

	Subwatershed	State with >50% of watershed	State of Confluence with Merrimack	River Mile of Confluence with Merrimack	Drainage Area (square miles)	Total river miles	Count of Lakes & Ponds	Surface Area of Lentic Waters (square miles)
	Merrimack River (Watershed)	NH	-	-	5008.1	9621	1206	200.63
0	Merrimack River (Mainstem Subwatershed)	NH	-	-	829.0	980.3	88	6.12
1	Powwow River	NH	MA	7.3	59.3	147.4	21	2.84
2	Little River	NH	MA	19.5	29.1	65.8	2	0.04
3	Shawsheen River	MA	MA	27.9	78.2	145.6	18	0.69
4	Spicket River	NH	MA	28.4	77.4	169.6	30	2.99
5	Concord River (SuAsCo)	MA	MA	39.3	400.3	924.4	182	11.62
6	Beaver Brook	NH	MA	40.6	94.4	183.2	24	1.98
7	Stony Brook	MA	MA	43.3	45.3	98.4	24	1.28
8	Salmon Brook	MA	NH	53.3	31.1	53.6	21	0.94
9	Nashua River	MA	NH	54.5	532.8	1005.5	178	16.81
10	Pennichuck Brook	NH	NH	57.3	26.9	44.7	11	0.56
11	Souhegan River	NH	NH	62.0	220.5	408.3	42	1.73
12	Cohas Brook	NH	NH	67.4	70.0	157.6	14	4.76
13	Piscataquog River	NH	NH	71.0	217.6	425.5	52	3.16
14	Black Brook	NH	NH	73.5	22.3	53.1	6	0.24
15	Suncook River	NH	NH	82.8	255.9	541.2	64	7.91
16	Soucook River	NH	NH	85.8	91.4	167.9	21	1.15
17	Turkey River	NH	NH	87.5	37.5	72.2	6	0.68
18	Contoocook River	NH	NH	100.3	764.5	1443.8	192	18.61
19	Winnipesaukee River	NH	NH	116.1	472.5	648.4	64	92.12
20	Pemigewasset River	NH	NH	116.1	1023.1	1888.6	146	24.42

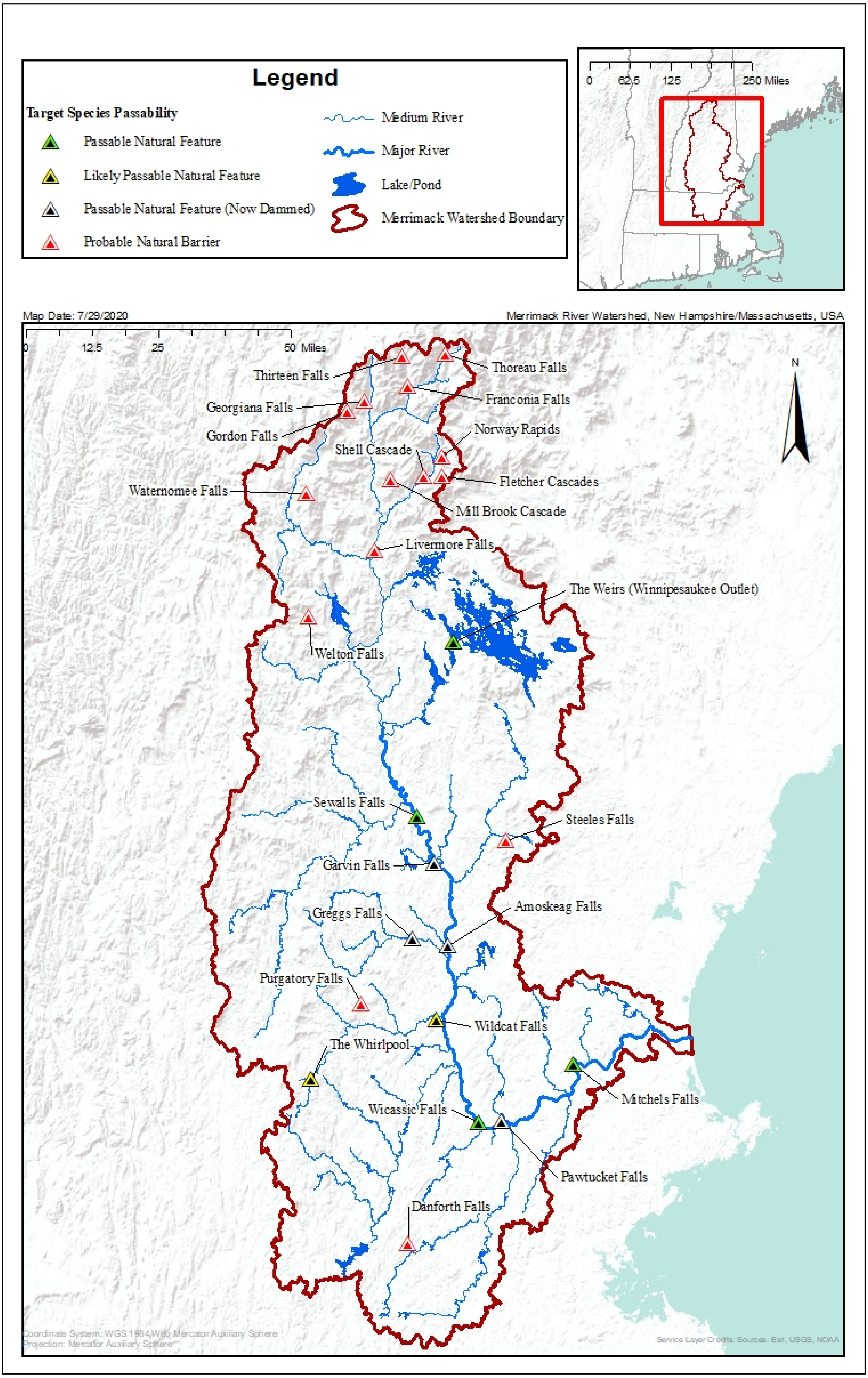

Figure 3. Natural Features and Barriers to Upstream Migration of Diadromous Fish

3.1.0 Merrimack River (Mainstem subwatershed)

The 116-mile Merrimack River originates at the confluence of the Pemigewasset and Winnipesaukee Rivers. The Merrimack River flows 66 miles south through New Hampshire, turns east after crossing the border into Massachusetts, and flows another 50 miles to the Atlantic Ocean. From the headwaters to the ocean, the river increases in size from 150 to 300 feet wide with a mean annual discharge of about 3,100 cubic feet per second (cfs) at the confluence of the Pemigewasset and Winnipesaukee to over 1,000 feet wide with an annual average discharge of 8,000 cfs near the river mouth (MRTC 1997). The Merrimack River fluctuates from the mean flow during precipitation/drought events and seasonally. The maximum recorded flow at Lowell, MA was 179,000 cfs in March 1936 and the minimum flow at the same location was 199 cfs in September of 1923 (Kuzmeskus et al. 1982). The head of tide is located near Haverhill, MA at RM 22. The mainstem subwatershed contains eleven HUC12 watersheds comprising many minor tributaries, oxbows, side channels and man-made canals. There are 88 lakes and ponds (not including named swamps and marshes) in the subwatershed with a total surface area of 6.12 square miles (3,919 acres). Eight ponds, lakes and impoundments, totaling 3.75 square miles, are potential stocking locations for alewife (Greens Pond, Heads Pond, Horseshoe Pond 1 and 2, Naticook Lake, Ottarnic Pond, Penacook Lake, and Sondogardy Pond, see Figure 9). Nesenkeag Brook, Musquash Brook, and several other unnamed minor tributaries provide migratory fish spawning and rearing habitat. The mainstem has five major dams that are part of licensed hydropower projects. Sections 3.1.1-3.1.20 describe the 20 tributary watersheds that intersect the mainstem subwatershed on its course to the ocean.

3.1.1 Powwow River

Moving upstream from the Merrimack estuary near Newburyport, MA, the Powwow River is the first major tributary to the mainstem entering the Merrimack from the north at RM 7.3. The Powwow River flows approximately 26 miles from its origin above Long Pond in the town of Danville, NH to a short tidal reach near the city of Amesbury, MA. Several dams in the watershed have fragmented the river to a series of ponds connected by short river corridors. The Powwow and the 120 miles of tributaries drain an area of 59 square miles. There are 21 lakes and ponds in the watershed with a combined surface area of 2.84 square miles (1,818 acres). In the first two miles of the river there are four barriers - Mill St. Dam, Millyard 2 Dam (Amesbury Falls), Millyard Dam, and Lake Gardner Dam. These four impassable barriers along with a natural falls near the confluence limit the cost-effectiveness of diadromous fish restoration in the Powwow River.

3.1.2 Little River

The Little River flows south into the Merrimack River in the city of Haverhill, MA at RM 19.5. The Little River watershed is one of the smallest in the Merrimack watershed. Originating from a small, unnamed pond in Kingston, NH, the 13-mile Little River and an additional 52 miles of tributaries drain the 29 square miles watershed. This small watershed contains only two ponds, which have a surface area of 0.04 square miles (23 acres). The impassable Little River Dam in Haverhill is just 0.5 miles from the confluence with the Merrimack, with most of this reach travelling beneath the heavily developed Haverhill waterfront. Another dam blocks the river approximately 3.5 miles further upstream. The Little River lacks connectivity, has a heavily urbanized watershed, and questionable habitat integrity limiting the feasibility of restoration.

3.1.3 Shawsheen River

Eight miles upstream from the Little River, and above the head of tide, the Shawsheen River meets the Merrimack from the south at RM 27.9 on the Lawrence/North Andover, MA line. Originating from a low-lying area at Hanscom Field in Bedford, MA, the Shawsheen River flows north for 26.6 miles. An additional 119 miles of tributaries combine with the Shawsheen River to drain an area of 78 square miles. There are 18 lakes and ponds in the Shawsheen watershed with a total surface area of 0.69 square miles (442 acres).

Based on anecdotal evidence, the Shawsheen was an important watershed for diadromous fish, occasionally supporting significant runs of river herring, particularly during years with high flow. Because there are no fish passage barriers between the confluence of the Shawsheen and the ocean, the upstream habitat is a high priority for restoration. Until recently, there were several dams blocking migratory fish on the Shawsheen. In 2017, both the Marland Place Dam (ca. 1700s) and the Balmoral Dam (ca. 1920s) were removed, restoring access to miles of habitat inaccessible for centuries. The Ballardvale Dam remains the last barrier on the Shawsheen. Because this dam is in the lower half of the watershed, removing or modifying it would provide access to a substantial amount of historical habitat. The Shawsheen is an important river system with significant diadromous fish (particularly river herring) restoration potential.

3.1.4 Spicket River

The last river to enter the Merrimack below the first major dam (Essex Dam), the Spicket River is only a half-mile upstream of the Shawsheen confluence. The Spicket meets the Merrimack from the north – combining with the outflow of the Essex Dam North Canal – before flowing into the Merrimack at RM 28.4 in the city of Lawrence, MA. Originating near Big Island Pond in Hampstead, NH, the 14.2-mile Spicket River with its 155 miles of tributaries drain a 77 square mile watershed. This watershed contains 30 lakes and ponds with a combined surface area of 2.99 square miles (1,914 acres). There is an impassable dam only a few hundred feet from the confluence, with at least four more barriers in the first few miles of the Spicket River. This number of impassable barriers and poor habitat quality near the confluence severely diminishes the cost effectiveness of anadromous fish restoration in the Spicket River.

3.1.5 Concord River

The Concord River and its two major tributaries, the Assabet and Sudbury Rivers (collectively referred to as "SuAsCo") comprise the fifth largest tributary watershed in the Merrimack basin. The mainstem of the Concord flows 16 miles north from the confluence of the Assabet and Sudbury Rivers at Egg Rock in Concord, MA, to the Merrimack River at RM 39.3 in Lowell. MA. Over 900 miles of tributary streams feed the Concord, draining the 400 square-mile watershed. There are 182 lakes and ponds in the watershed with a total surface area of 11.62 square miles (7,434 acres), including Walden Pond, known from the literary works of Henry David Thoreau. There are also recreationally important wetlands in the river corridor including Bridge Brook Swamp, Sudbury River Swamp, and Great Meadows National Wildlife Refuge.

The Concord River has three obstacles to fish passage. Near the mouth of the Concord (0.4 miles from the confluence with the Merrimack River), is the breached Middlesex Dam. This structure is passable under normal flow conditions, though likely causing delays in migration. Another mile upstream is the Centennial Island Hydroelectric Project. Volitional passage is provided in the bypass reach via a fish ladder at the north end of the dam. Continuing approximately 3 miles upstream is the Talbot Mills Dam, the final barrier on the Concord River mainstem. Talbot Mills Dam is a complete barrier to fish passage, except for American eel.[19] Removal of this dam will provide access to 35 miles (740 acres) of historical mainstem river habitat for diadromous fish in the upper Concord, and lower Assabet and Sudbury Rivers. The NOAA Fisheries Restoration Center, MADMF, and other partners are actively engaged with the owner of Talbot Mills Dam to improve fish passage (both modification and removal are being evaluated; removal appears to be the most likely solution).

3.1.5.1 Assabet River

The Assabet River flows 34.3 miles from its swampy origin in Westborough, MA to the Concord River. There are nine dams on the Assabet creating a series of impoundments. About four miles upstream of the confluence lies the first obstacle on the Assabet; Damondale Dam, which is breached and passable for fish. A little less than two miles further upstream is the Assabet River Dam at High Street; a complete barrier to fish passage. All seven dams above the Assabet River Dam lack upstream fish passage, affecting the cost effectiveness of restoration. If fish passage is implemented at Talbot Mills on the Concord, the lower Assabet has a few miles of mainstem habitat and several small tributaries that will become accessible.

3.1.5.2 Sudbury River

Starting at Cedar Swamp in Westborough, MA, the slow and meandering Sudbury River flows 32.9 miles through wetlands and wet meadows to the Concord. The Sudbury supports a

[19] American eel have been documented above this dam, indicating that at least some individuals of this species are capable of scaling the dam under certain conditions. It is still a significant impediment for this species.

significant amount of recreation including bird watchers and paddlers. The ecologically important wetlands in the river corridor host over 220 species of birds providing habitat for nesting, feeding, and resting during migration. Although there are seven dams on the upper river, the lower Sudbury is free flowing for more than 15 miles before reaching Central Street Dam in Saxonville, MA. This dam and all six dams further upriver have no upstream fish passage structures. Upstream fish passage at Talbot Mills on the Concord River would open up a significant amount of mainstem habitat and tributary access on the Sudbury River.

3.1.6 Beaver Brook

Beaver Brook flows into the Merrimack at RM 40.6 below the Pawtucket Dam in Lowell, MA. Flowing south for 28 miles from a bog near Hood Pond and Horns Pond in Derry, NH, Beaver Brook has over 150 miles of tributary streams. Twenty-four lakes and ponds are scattered throughout the 94 square mile watershed with a total surface area of 1.98 square miles (1,267 acres). The first major dam prevents fish passage half a mile upstream from the confluence, with two more barriers within three miles. Passage is needed at these three dams to allow diadromous fish to use the habitat in Beaver Brook; over 15 miles of mainstem Beaver Brook and numerous small tributaries would become accessible under this scenario.

3.1.7 Stony Brook

The last watershed to flow into the Merrimack in Massachusetts; Stony Brook flows northeast for 22 miles from Wolf Swamp in Boxborough, MA to a little more than two miles upstream of the Pawtucket Dam at RM 43.3 in the village of North Chelmsford, MA. Stony Brook and its 76 miles of tributary streams drain the 45 square mile watershed. There are 24 lake and ponds in the watershed, including several impoundments, that total 1.28 square miles (818 acres). The first of several large dams is located less than two miles upstream of the confluence. This and the series of barriers throughout the watershed limit the cost effectiveness of restoration in Stony Brook.

3.1.8 Salmon Brook

The Salmon Brook flows into the Merrimack in Nashua, NH at RM 53.3, roughly 3.5 miles north of the Massachusetts and New Hampshire border. Impounded in multiple locations, the 12.6-mile brook is joined by an additional 41 miles of smaller tributaries to drain a total area of 31 square miles. There are 21 lakes and ponds in the watershed with a total surface area of 0.94 square miles (602 acres). The first of several significant barriers to fish passage is only 500 feet upstream from the confluence with the Merrimack River. The upper portion of the Salmon Brook in Massachusetts is well protected, flowing through a series of conservation lands and parks; however, the lower river has little accessible habitat and is heavily urbanized.

3.1.9 Nashua River

The Nashua River watershed is the third largest in the Merrimack basin consisting of three distinct reaches. The North Nashua River flows 19.3 miles southeast from the confluence of Whitman River and Philips Brook in Fitchburg, MA where it meets the Nashua River in Lancaster, MA. The South Nashua River flows 5.2 miles north from the Wachusett Reservoir Dam outlet where it joins the North Nashua River. From here the Nashua River flows 37.6 miles northeast into New Hampshire, where it flows into the Merrimack at RM 54.5. There are over 1,000 miles of rivers and streams in the 533 square-mile watershed, including several impounded reaches. Because of flow diversion at the Wachusett Reservoir, the Nashua River watershed differs from its historical drainage. There are 178 lakes, ponds, and impoundments in the watershed with a total surface area of 16.8 square miles (10,756 acres). Two contiguous ponds in the watershed are identified by NHFGD as suitable alewife stocking habitat; Flints Pond (50 acres) and Potanipo Pond (136 acres). Major tributaries in the watershed include the Quinapoxet, Stillwater, Squannacook, and Nissitissit Rivers.

The Nashua River was used heavily for industry including many paper mills, particularly in the Fitchburg area. Over 275 dams, in various condition, remain in the watershed as a reminder of its industrial past. There are four major dams on the mainstem Nashua with licenses or exemptions. At RM 1 and RM 4, the Jackson Mills Dam and Mine Falls Dam are the first dams on the Nashua River, respectively. Both hydroelectric facilities have upstream fish passage structures. Another nine miles upstream of Mine Falls Dam is the Pepperell Paper Co. Dam, which does not have fish passage structures. The fourth dam on the mainstem is the Ice House Dam near Devens, MA which also does not have fish passage structures either.

A significant man-made feature of the Nashua River watershed is the Wachusett Reservoir. The Wachusett Reservoir was constructed at the headwaters of the Nashua River in 1905 and filled in 1908. At the time, this was the largest public water supply reservoir in the world. Fed by the Stillwater and Quinapoxet Rivers, the seven square-mile reservoir covers the valley through which the Nashua River historically flowed. The Wachusett Dam is very large (205 feet tall) blocking both up- and downstream fish passage. The Reservoir system supports several hydropower projects, descriptions of these projects are found in section 6.1.3.

3.1.10 Pennichuck Brook

North of Nashua, Pennichuck Brook flows into the Merrimack from the west at RM 57.3. The brook is heavily modified, comprising a series of impoundments connected by short stretches of river. Including the 10.9-mile primary channel of the Pennichuck, a total of 44.7 miles of streams drain the 26.94 square mile watershed. The 11 lakes and ponds in the watershed have a combined surface area of 0.56 square miles (358 acres). With four major dams in the first three miles and the first barrier only 0.75 miles upstream from the Merrimack confluence, the cost effectiveness of diadromous fish restoration is limited.

3.1.11 Souhegan River

At RM 62.0 in the town of Merrimack, NH, the Souhegan River enters the Merrimack River from the west. The Souhegan flows 33.8 miles from its source at the confluence of the south and west branches near New Ipswich, NH. The Souhegan River and tributaries total 408 river miles, draining the 220 square mile watershed. There are 42 lakes and ponds with a total surface area of 1.73 square miles (1,105 acres). Although a few dams have been removed from the lower river, a number of barriers remain, including four hydroelectric projects in the middle and upper reaches. Wildcat Falls is a natural feature approximately 1.25 miles upstream from the Souhegan mouth. During lower flow conditions, these falls are not considered a barrier for most diadromous fish. The first man-made barrier is McLane Dam in Milford, NH, approximately 14 miles upstream of the confluence. The Goldman Dam is another barrier 0.25 miles upstream of the McLane Dam. These dams are both obsolete and no longer serve their original purpose.

Baboosic Lake lies at the headwaters of the Baboosic Brook, which flows into the Souhegan 0.2 miles upstream of the Merrimack confluence. The lake is identified by the River Herring Management Plan (MRTC 2019) as a suitable stocking location for alewives collected at the Essex and Amoskeag Dams. The fish cannot reach the lake without human intervention due to Stowell Pond Dam on Baboosic Brook. Upstream fish passage structure(s) or the removal of Stowell Pond Dam will allow alewife volitional access to the lake. The Souhegan River has cool water with swift currents that are better habitat for Atlantic salmon than alosines.

3.1.12 Cohas Brook

Five miles upstream of the Souhegan confluence, Cohas Brook flows into the Merrimack from the east at RM 67.4. The Cohas has a short run of 17 miles from its source near Calef Pond in Auburn, NH, to the confluence with the Merrimack downstream from Pine Island Pond, near the Manchester airport. Cohas Brook receives 140 river miles of tributaries including the outflow from Massabesic Lake. Massabesic Lake (approximately 2,500 acres) is the main water supply for Manchester, NH. There are 14 lakes and ponds in the watershed with a total surface area of 4.76 square miles (3,044 acres). The Cohas Brook watershed drains an area of 70 square miles.

Both Massabesic Lake and Pine Island Pond (approximately 50 acres) have been identified as suitable alewife spawning and rearing habitat. Although both of these waterbodies are above dams without passage, Pine Island Pond has been a focus for stocking since the late 1990s, receiving thousands of adult fish for the past 20 years. Installing upstream fish passage at Pine Island Pond is feasible and cost effective due to the small size of the dam and proximity to the mainstem. Massabesic Lake was historically productive for alewife with plenty of habitat. The dam outlet of Massabesic Lake regulates flows under a water level management plan for drinking water supply. Without commitment from the water district to modify operations, low outlet flow conditions may affect successful downstream migration of adult and juvenile alewife.

3.1.13 Piscataquog River

The Piscataquog River flows east for 37 miles from Deering Reservoir in Deering, NH to the Merrimack downstream from the Amoskeag Dam in Manchester, NH at RM 71. Numerous tributaries flow into the Piscataquog, with a combined length of over 388 miles, and a drainage area of 217 square miles. There are 52 lakes and ponds (including four major impoundments) totaling 3.16 square miles (2,025 acres).

The first major barrier is Kelley's Falls Dam, which creates the Pinardville impoundment approximately two miles upstream of the confluence. Several more large dams create a series of impoundments along the river's course including Gregg's Falls Dam (Glen Lake), Hadley Falls Dam, Everett Dam (Everett Lake), Weare Reservoir Dam (Weare Reservoir aka Horace Lake), and Deering Reservoir Dam (Deering Reservoir). With many dams blocking fish passage, the restoration potential for the Piscataquog watershed is challenging, but the watershed has high production potential for river herring with many suitable locations for stocking.

3.1.14 Black Brook

Flowing southeast from Kimball Pond in Dunbarton, NH, Black Brook is the smallest watershed in the Merrimack drainage. Black Brook flows into the Merrimack at RM 73.5, upstream of the Amoskeag Dam in Manchester, NH. Black Brook has a drainage area of 22 square miles with 10 miles of mainstem and an additional 43 miles of tributaries. The six lakes and ponds in the watershed combine for a total surface area of 0.24 square miles (155 acres). The Maxwell Pond Dam near the mouth of Black Brook was removed in 2011. The only remaining barriers to fish passage are the Pierce Brook Dam (ruins; near Black Brook RM 6.2) and the dam at Kimball Pond (Black Brook RM 9.9). Kimball Pond is one of the lentic waters identified by the River Herring Management Plan (MRTC 2019) as a potential stocking location. With two small remaining barriers on the Black Brook, restoring volitional passage to this pond should be achievable and cost effective.

3.1.15 Suncook River

The Suncook River enters the Merrimack at RM 82.8, two miles upstream of the Hooksett Dam – the first Merrimack mainstem dam without upstream fish passage. Originating from Manning Lake in Gilmanton, NH, the Suncook River flows 38.2 miles south to the confluence with the Merrimack River. The Suncook River watershed has 500 miles of tributary streams draining a total area of over 250 square miles. The 64 lakes and ponds in the watershed, including a chain of lakes/impoundments on the Suncook mainstem, have a combined surface area of 7.91 square miles (5,062 acres). The MRTC has identified several lakes in the watershed as potential stocking locations for returning adult alewives. These lakes include Brindle Pond, Northwood Lake, Upper and Lower Suncook Lakes, Pleasant Lake, Jenness Pond, Locke Lake, Harvey Lake, Crystal Lake, Halfmoon Lake, and Long Pond with many of the lakes and ponds impounded by dams. Three large, impassable dams (China Mill, Webster Mill, and Pembroke Dams) are located in the first mile of this river.

3.1.16 Soucook River

The Soucook River flows 24.6 miles south from the confluence of Bumfagen Brook and Gues Meadow Brook in Loudon, NH to the Merrimack at RM 85.8 downstream from the Garvin's Falls Dam. In addition to the Soucook mainstem, over 143 miles of tributaries drain the 91 square-mile watershed. There are 21 lakes and ponds in the watershed with a total surface area of 1.15 square miles (734 acres). The Soucook River is relatively free flowing compared to other rivers in the Merrimack basin, with only a few small dams in the upper watershed. Some reaches of the mainstem are suitable for blueback herring and American shad, but, with the exception of Fox Pond and Rocky Pond in the upper watershed, few contiguous lakes or impoundments offer suitable spawning habitat for alewife. Fish passage improvements made at the upper mainstem Merrimack dams (e.g., Hooksett Dam) will provide access to the Soucook watershed.

3.1.17 Turkey River

A mile upstream of the Garvin's Falls Dam, the Turkey River flows 6.3 miles southeast from the outlet dam of the Turkey Pond complex (Turkey Pond and Little Turkey Pond) to the Merrimack at RM 87.5. The Turkey River has 66 miles of tributary streams draining the 37 square-mile watershed. There are six lakes and ponds in watershed with a total surface area of 0.68 square miles (435 acres). The Turkey Pond complex (337 acres) has potential to be an alewife stocking location. There are two dams on the Turkey River that lack upstream fish passage. Three more dams near the mouth of the river are classified as "in ruins" by the state. A survey of these dams is needed to determine if they are an obstacle to upstream passage. In addition to these barriers on the Turkey River, upstream passage is required at Garvin's Falls and Hooksett on the Merrimack for diadromous fish to reach the mouth of the Turkey River.

3.1.18 Contoocook River

Originating from the combined outlet of Mountain Brook Reservoir, Pool Pond, and Contoocook Lake in Jaffrey, NH, the Contoocook River flows 74 miles northeast to the Merrimack at RM 100.3 in Penacook, NH. In addition to the mainstem of the Contoocook, 1,370 miles of tributary streams drain the 764.5 square mile watershed; the second largest in the Merrimack drainage. There are 192 lakes and ponds in the watershed with a total surface area of 18.61 square miles (11,908 acres). Three lakes in the lower watershed are potential alewife stocking locations: Lake Winnepocket, Pillsbury Lake, and Walker Pond.

There are over 30 dams on the Contoocook mainstem, including 11 hydropower dams. The first two hydropower facilities (Penacook Upper and Lower Falls Dams) block the mainstem in the first mile upstream of the Merrimack confluence. None of these dams have upstream fish passage structures for anadromous fish (Penacook Upper Falls Dam has an eel trap and lift).

3.1.19 Winnipesaukee River

The Winnipesaukee River flows 20 miles from the outlet of Lake Winnipesaukee near Endicott Rock, to the Pemigewasset River to form the beginning of the Merrimack at RM 116.1 in the town of Franklin, NH. The lower river has several reaches dominated by rapids making it a popular destination for whitewater recreation. The upper river is comprised of a series of impoundments, bays, and lakes including Silver Lake, Lake Winnisquam, Opechee Bay, and Paugus Bay. The Winnipesaukee watershed encompasses much of the New Hampshire lakes region. The watershed contains 64 lakes and ponds with a combined surface area of over 92 square miles (58,958 acres) with Lake Winnipesaukee accounting for more than two-thirds of the total. In addition, over 625 miles of tributary streams flow into the Winnipesaukee River to drain the 472 square-mile watershed.

There are six impassable dams (all are hydropower projects) on the mainstem of the river. The first, Franklin Falls Dam, is 0.5 miles above the river mouth. The next dam, Stevens Mill, is one mile upstream from Franklin Falls. Franklin Falls Dam and Stevens Mill operate as hydropower facilities with federal exemptions from licensing. Restoration of diadromy to Lake Winnipesaukee will be challenging given the high density of dams on this tributary, yet the restoration potential is immense. There are two dams (Clement and Lakeport) scheduled to undergo licensing in the next 10 years, which will provide an opportunity for engagement.

Historically, shad and river herring were capable of reaching Lake Winnipesaukee. Lake Winnisquam and Silver Lake are important stocking locations for adult river herring. At over 4,000 acres at an annual stocking target of 6 fish/acre, Lake Winnisquam is the primary stocking site in the Merrimack watershed to increase the river herring returns in the lower Merrimack River. Downstream passage efficiency and effectiveness is important at the nine dams downstream of Lake Winnisquam on the Winnipesaukee and Merrimack Rivers to increase river herring returns.

With a surface area of 71.6 square miles (about 45,800 acres), Lake Winnipesaukee (spelled Winnipiseogee in early records) is the largest lake in New Hampshire and the third largest in New England. The lake has over 280 miles of shoreline and approximately 260 islands. At 180 feet deep, the lake supports a diverse fish community of warm, cool, and cold water fish. The historical terminus of the American shad migration, Lake Winnipesaukee once contained a significant portion of the shad spawning habitat. Today, diadromous fish can no longer reach the lake due to eight impassable dams on the Winnipesaukee and Merrimack Rivers. Stocking alosines in Lake Winnipesaukee is not currently considered due to the lack of connectivity and concern for potential effects to the cold-water fishery of the lake.

3.1.20 Pemigewasset River

The Pemigewasset is the largest and northernmost watershed, with its tributaries draining the tallest peaks in New Hampshire. The mainstem flows 65.7 miles from Profile Lake at nearly 2,000 feet in elevation near Franconia, NH, to the confluence with the Winnipesaukee River forming the Merrimack River in Franklin, NH. Over 1,800 miles of tributaries contribute to the Pemigewasset to drain the 1,023 square-mile watershed. Much of the middle and upper Pemigewasset is cool, high gradient Atlantic salmon habitat with many falls, riffles, and swift currents. Most other diadromous species preferring the warmer and calmer waters of the Winnipesaukee and other tributaries to the Merrimack. There are 146 lakes and ponds in the watershed with a combine surface area of nearly 25 square miles (15,628 acres).

Livermore Falls, a natural feature 30 miles upstream of where the Pemigewasset meets the Merrimack, is likely the natural upstream extent of diadromous fish except for Atlantic salmon and American eel. There are a number of man-made obstacles on the river with the Eastman Falls hydropower project and the flood control Franklin Falls Dam in the first 2.5 miles. Webster Lake in the lower Pemigewasset watershed is one site with stocking potential for river herring. At almost 600 acres, the lake has ample habitat for alewife reproduction. Volitional passage into Webster Lake, however, is unlikely due to steep gradient and three dams on the 1.5-mile Chance Pond Brook that connects Webster to the Pemigewasset in addition to the Merrimack mainstem dams. Stocking may still be a productive management strategy pending resources and improvement of downstream passage.

3.2 Development and Land Use in the Merrimack Watershed

3.2.1 Historical Land Use

Prior to the arrival of European settlers, Native Americans of the Penacook tribe inhabited the Merrimack River valley. Related to the Abenaki of Maine, the Penacook people (sometimes called Pawtucket or Merrimac) lived near, fished, hunted, and traveled the Merrimack River. Historians estimate a population of 12,000 Penacook living in the Merrimack Valley prior to European colonization (Daly 1997). The Penacook utilized the natural resources of the Merrimack River and valley, cultivating maize, corn, and squash in the fertile floodplains, and harvesting the seasonal abundance of diadromous fish. Important fishing grounds included “The Weirs” at the outlet of Lake Winnipesaukee, Amoskeag Falls in Manchester, NH, and Pawtucket Falls in Lowell, MA. These fishing grounds supported some of the largest annual gatherings including celebrations, feasts, weddings, and trade.

Direct contact with Europeans is not documented until the early 1600s. At that time, the Penacook were a confederacy ruled by Passaconnaway from his seat in the village at the falls called Naumkeag (Amoskeag) in Manchester, NH. By the 1620s, the Pilgrims began exploring inland from Plymouth encountering the Penacook people. These early meetings were peaceful for the most part. However, deadly illness transmitted by the Europeans spread through native populations who had no natural immunity (Daly 1997). In many villages, these outbreaks killed between 75 to 100 percent of the afflicted.

During the remainder of the 17th and early 18th century, the traditional way of life for the Penacook changed drastically due to disease, conflict, and eventual displacement by European colonialists. The Penacook that remained, withdrew north to Maine and Canada in the 1670s with a few attempts to return to their native lands (Daly 1997). A few and scattered Penacook villages persisted until about 1700 when the Penacook moved north for a final time, becoming completely absorbed by the Abenaki by the end of Queen Anne's War in 1713. As the European settlers continued to expand throughout the 18th century, they cleared forests and built numerous mills, farmsteads, and new towns changing the landscape of the Penacook's native lands.

The Merrimack River initially served as an exploration and navigation route for settlers to the interior portions of the watershed. When European colonization expanded in the early-1700s, sizeable stands of old-growth timber dominated much of the landscape. The first sawmills were constructed in the late 1600s. One of the earliest documented artificial impoundments in the watershed was created by a sawmill dam on River Meadow Brook (a minor tributary of the Concord River) in the town of Chelmsford. This mill was in operation by 1694 and over the following decades, several more mills were erected near Pawtucket Falls.

Although there were probably many small dams constructed on tributaries during the early 1600s; dam construction in the watershed began in earnest in the 1700s, with the first mainstem dams built at the beginning of the 1800s. In the 1800s, industrial development on the Merrimack River and tributaries was substantial and widespread, often larger dams were constructed on top of low-head dams. The river provided power for the mills (primarily lumber, grist, textile, and paper) and with the addition of canals, served as shipping corridors. Timber, agricultural products, and other goods were carried from rural Merrimack Valley communities to Boston via the historic Middlesex Canal – the first of its kind in America. For a few decades, this 27-mile waterway (originating near Lowell, MA) increased the amount of product brought to markets in Boston. Use of the canal declined and it fell into disuse by the 1850s with the advent of railroads. Today, although much of the once prominent canal has been lost to development and urban sprawl, some sections are still filled with water while others have been converted to walkable trails. All of this industry caused major impacts on water quality in the 1800s through the 1900s. Some of these antiquated structures built on or near the river still exist today, a constant reminder of the region's industrial history.

3.2.2 Current Land Use

The industrial revolution significantly altered the landscape of the Merrimack Valley with urbanized areas expanding to cover over 16 percent of the land area. The majority of urbanized land area is associated with the largest cities in the river corridor; namely, Lawrence, Lowell, Nashua, Manchester, and Concord. However, the watershed remains predominantly wooded, with approximately 65 percent of the land covered in forested terrain. Table 2 describes current (2016) land use in the Merrimack Watershed.

Table 2. Merrimack River Watershed Land Use

Land Use/ Cover Type	Area (Square Miles)	Percent of Total Watershed Area
Freshwater		
Woody Wetlands	380.6	7.6%
Emergent Herbaceous Wetlands	34.7	0.7%
Open Water	227.4	4.5%
Freshwater Total	*642.7*	***12.8%***
Urbanized/Developed		
Developed, Open Space	302.4	6.0%
Developed, Low Intensity	264.6	5.3%
Developed, Medium Intensity	203.9	4.1%
Developed, High Intensity	56.0	1.1%
Urbanized/Developed Total	*826.9*	***16.5%***
Forested		
Deciduous Forest	996.2	19.9%
Evergreen Forest	752.8	15.0%
Mixed Forest	1428.9	28.5%
Shrub/Scrub	112.3	2.2%
Forested Total	*3,290.2*	***65.7%***
Agricultural/Other		
Hay/Pasture	150.4	3.0%
Cultivated Crops	10.2	0.2%
Herbaceous	60.5	1.2%
Barren Land	25.6	0.5%
Agricultural/Other Total	*246.8*	***4.9%***
Grand Total	**5,006.6**	**100%**
NOTE: We derived all values from The National Land Cover Database (NLCD) 2016 raster dataset. Area calculations were made using ArcMap Geoprocessing tools "Extract by Mask" (Mask Layer = NHD Merrimack HUC8 Watershed) followed by "Zonal Geometry as Table". Map Datum: WGS_1984, Projection: Albers Conical Equal Area		

3.2.3 Flood Control and Management

The Merrimack Valley is susceptible to flooding. Tributaries in the White Mountains of NH that flow into the Merrimack River accumulate a significant amount of snow through the winter. When the snow melts slowly, the freshet produces normal spring river levels. When it melts quickly, accelerated by early or heavy spring rain, the tributaries and rivers in the watershed can swell rapidly causing higher water levels. In addition, a large portion of the Merrimack mainstem may freeze over. The river ice, like the mountain snow, is not the cause of flooding when it slowly melts, but can be problematic when thick ice rapidly breaks up during high flows. Infrastructure in the river corridor (bridges, dams, canals etc.) can create massive ice/debris jams that cause flooding. When coupled with rain events this combination of snowmelt, ice floes, river infrastructure, and rainfall can have disastrous consequences.

In the spring of 1936, across New England, a storm event led to one of the worst floods on record. On March 11, rain started falling throughout the Northeast for 14 days. Falling on snow covered hills and valleys, the rain rapidly melted the snow and ice in the region. Some of the heaviest downpours in recorded history drenched the east coast causing rivers to swell and large tracts of land to become inundated. Pinkham Notch in northern New Hampshire recorded over 22 inches of rain during the storm. The raging rivers and ice jams washed out roads, burst dams, and wiped out homes; leaving 14,000 people homeless and killing nearly 200. This disaster prompted Congress to act, and in June, President Franklin D. Roosevelt signed into law the Flood Control Act of 1936. The Act empowered the United States Army Corps of Engineers (USACE) to build numerous flood control dams, levees, and channel improvements.

Today, there are approximately 47 flood control dams in the Merrimack watershed; the USACE manages 12, with the remainder falling under the jurisdiction of the New Hampshire Department of Environmental Services or the MA Department of Conservation and Recreation. In addition to mitigating the regional impacts of flooding, the USACE projects are often designed to support multiple uses including water supply, irrigation, hydroelectric power, natural resources, and recreation.

3.2.4 Hydropower

In the Merrimack Valley, by the early 1800s, milldams were being constructed near natural features that provided the greatest potential for power production. In Lowell, MA, a dam across the 32-foot Pawtucket Falls, and an associated system of constructed canals, powered a complex of textile mills that became a manufacturing hub in New England. The Lowell mills employed a new kind of waterwheel – the turbine – which generated more efficient power to drive the gears, belts, and shafts powering looms that produced millions of yards of cloth (National Park Service 2017). The Francis style turbine was invented by James B. Francis of Lowell, MA in 1848. Textile production continued for decades, until the 1880s when the nation’s first hydroelectric power plants came online and redefined hydropower by producing electricity instead of driving machines to do mechanical work. This advancement changed the manufacturing process and American life.

Many hydroelectric facilities in the Merrimack Watershed have been retrofitted at dams that originally supported industrial complexes (such as Lowell mills), but no longer serve that purpose. For this reason, much of the ancillary and generation facilities are antiquated, though some project owners have upgraded their facilities over the years. Many of the historic mill buildings in the watershed have been converted to residential or commercial real estate. No developers have constructed new hydroelectric dams since the early 1980s. Section 6.1 summarizes the extent of hydropower in the watershed and includes individual project descriptions.

3.3 Water Quality in the Merrimack Watershed

Water resources in the Merrimack has been a focus of stakeholders in the watershed throughout history starting with Native Americans. The agrarian society before the early 19th century was rapidly transformed by the industrial revolution. Throughout history, the specific concerns have shifted along with changes in the primary use of the river and development in the watershed. One common public sentiment concerning the river is the desire to protect and conserve this important watershed. This desire to conserve freshwater resources is often the antithesis of industrial progress, and economic drivers often sway the balance when conservation is at odds with capitalism. Unfortunately, for natural resources, this was the case for many years in the Merrimack watershed.

3.3.1 Historic Water Quality

The Merrimack Valley has a high concentration of mills starting in the early 19th century. With the mills came associated effects on the river's connectivity and water quality. Dams were built to create millponds providing head pressure for waterpower that drove the machinery in the mills, and the figurative wheels of American progress. A byproduct of industry is waste, and the Merrimack developments were no exception. Mills dumped waste in the form of dyes, rubbish, sawdust, sediment, and numerous other manufacturing byproducts into the river. In addition to industrial waste, human waste was also a significant issue with increased population in close proximity to the river.

Before wastewater treatment was developed, cities would pipe waste directly into the river. By the 1920s, approximately 12 million gallons of Lowell's sewage was discharged into the river daily. This waste carried disease and bacteria making contact with the water hazardous. The decreased connectivity due to large dams, manufacturing byproducts, and human waste entering the river severely degraded the water and habitat quality decimating diadromous fish populations.[20] By the 1960s total discharge of municipal and industrial waste into the Merrimack River exceeded 120 million gallons per day (excluding industrial cooling water) and the river

[20] The native Atlantic salmon, perhaps the Merrimack's most charismatic diadromous fish, was extirpated by the turn of the 20th century.

was listed as one of the ten most polluted waterways in the nation (Pahren et al. 1966; Boshoven 1992). The passing of the Water Quality Act in 1965 and the Clean Water Act in 1972 led to enforceable pollution abatement regulations. Beginning in the early 1990s, focus shifted to the effects of nonpoint source pollution as urbanization in the watershed increased and managers became better at identifying and mitigating point sources of pollution (EOEA 2001). Since the 1970s, there have been dramatic improvements to water quality in the Merrimack River due to water pollution control (Kuzmeskus et al. 1982).

3.3.2 Current Water Quality

Although some of the pollution sources and volume have changed, the Merrimack River still faces many of the same challenges. While water quality has improved dramatically since the 1970s, urban runoff, combined sewer overflows (CSOs), dam impacts, heated discharge from power plants, and historical sediment contaminants continue to affect overall water quality. As of the late 1990s, all 50 miles of the Merrimack River from the Atlantic Ocean to the NH border were classified as non-supporting of Class B waters (Fishable, swimmable, and boatable; see classification defined by NHWSPCC (1978)). The Mainstem from the New Hampshire border up to the origin in Franklin, NH, are considered Class B waters.

Contemporary reports indicate pathogens are the major water quality concern for the river, coming primarily from the combined effects of CSOs and urban runoff. CSOs remain in operation in six communities across the Merrimack watershed; Haverhill, Lawrence, Lowell, and Fitchburg (Nashua River) in Massachusetts, and Nashua, and Manchester in New Hampshire. Some historical pollutants are still a concern today with sediments containing high levels of mercury and other industrial pollutants. Atmospheric deposition of toxics is also a concern, and fish consumption advisories are in effect for much of the lower watershed as a result (Meek and Kennedy 2010). The majority of lotic waters in the historical range of the diadromous species covered in this CP are Class B or C (USACE 2006).

3.4 Public Access and Recreational Opportunity

Many types of recreation occur on the Merrimack mainstem, tributaries, and headwaters. With at least 13 improved boat ramps (four in NH and nine in MA) on the mainstem, there is ample public access to the river. The University of Massachusetts Lowell boathouse is located on the Vandenberg Esplanade upstream of the Pawtucket Dam making this reach popular among rowers. The university and other local rowing groups often host regattas, and in the summer, the boathouse offers canoe and kayak rentals to the public. The turbulent flow often found downstream of hydropower dams attracts whitewater rafters and kayakers. American Whitewater, an organization representing whitewater enthusiasts across the nation, lists several areas below dams on the Merrimack, Concord, Winnipesaukee, and Pemigewasset Rivers as popular locations.

Angling opportunity exists on the Merrimack mainstem. However, runs of diadromous fish are only a fraction of their historical abundance and are only found in fishable abundance downstream of Essex Dam. Popular angling targets upstream of the Essex Dam are primarily introduced species such as largemouth and smallmouth bass, common carp, and northern pike. A stark contrast to the historical fish community of Atlantic salmon, shad, striped bass, and sturgeon that used to swim the Merrimack River and tributaries in great abundance. Popular spots for anglers include the Vandenberg Esplanade, tailraces of dams, bridges, and the many junction pools where the Merrimack's tributaries enter the mainstem. With the current fish consumption advisories in the watershed, most modern angling is for sport only, unlike the historical sustenance fisheries.

4.0 RESTORATION FOCUS AREA

Restoration efforts in the Merrimack Watershed focus on the mainstem and selected tributary watersheds where volitional or assisted diadromous fish passage is a management goal[21]. These areas generally support a direct pathway for action, the ability to engage, and a high potential for near-term benefits. The restoration focus area (RFA) is divided into Type I, Type II, and Type III categories (Table 3). Type IV watersheds are those that currently fall outside of the RFA.

4.1 Description of Restoration Focus Area Criteria

Type I focus areas include reaches 1) with ongoing restoration activities, 2) in areas where diadromous fish can currently access, 3) have projects with regulatory engagement, and 4) where there is a reasonable expectation to improve passage within ten to twelve years. This includes the Merrimack mainstem and parts of the Nashua, Concord, Shawsheen, and Piscataquog River watersheds (Figure 4).

Type II focus areas include watersheds where there is the potential for engagement in the foreseeable future (10 to 12 year) and one or more of the criteria for Type I are not met. Reasons a watershed may not meet the criteria for Type I include a current lack of access for diadromous fish, restoration activities are in the planning (but not implementation) phase, and/or regulatory engagement is undetermined. In some instances, restoration in Type II areas may be facilitated by successful engagement in Type I focus areas; however, there is no requirement for sequential engagement. Type II focus areas include the downstream portions of the Winnipesaukee River, Contoocook River, Souhegan River, and Cohas Brook watersheds as well as the entire Beaver Brook watershed.

Type III focus areas encompass watersheds where there is limited opportunity for federal engagement or opportunities are more than 10-12 years in the future; however, restoration activities may be underway or planned by other stakeholders. We view these activities as beneficial to the broader watershed, and likely to provide cumulative ecosystem benefits. Type III areas include the Black Brook, Soucook River, Suncook River, and Turkey River watersheds.

4.2 Watersheds Outside of Focus Area

The portion of the Merrimack watershed that does not meet the criteria of Type I-III focus areas is designated Type IV. However, we recognize there is restoration potential in these

[21] Generally, this refers to both upstream and downstream passage collectively; however, there are situations where downstream passage may remain an engagement focus, while upstream passage is not considered a feasible short-term objective. An example of this scenario would be dams with stocked habitats or eel presence upstream, where upstream passage potential is limited due to high dam density, poor cost effectiveness, or other management challenges.

areas. Therefore, we will maintain an adaptive management approach to take advantage of new opportunities, when available. Seven tributary watersheds were designated Type IV: Powwow River, Little River, Spicket River, Stony Brook, Salmon Brook, Pennichuck Brook, and Pemigewasset River.

Several characteristics were common among tributary watersheds categorized as Type IV. The most common was the absence of a clear pathway to initiate restoration activities. An absence of regulated projects associated with the barriers in a watershed eliminates the ability to seek fish passage improvements through the licensing process. Poor cost effectiveness of restoration activities was another common characteristic. Many obsolete dams are distributed in dense clusters of three to five dams in a short river reach. This makes restoration cost prohibitive and diminishes return on investment. In some cases, natural barriers are present, or were historically present prior to dam construction. Another characteristic that influenced selection is a lack of potential habitat in the restored reach. Watersheds with projects that result in very small increases in historical or high quality habitat are considered a lower priority. Proximity to unimpeded river reaches was also considered. Major tributaries in the lower watershed have few or no downstream mainstem barriers, these areas are conducive to restoration of diadromy without relying on successful engagement at other projects. Finally, the integrity of remaining habitat was considered. Heavily modified or urbanized watersheds are considered lower priority compared to those with more pristine habitat.

Table 3. Merrimack River Watershed Restoration Focus Areas

Watershed Number	Watershed	Drainage Area (square miles)	CP Restoration Focus Area	Prioritization	Primary characteristic(s) affecting restoration effectiveness/potential
0	Mainstem Subwatershed	-	Yes	Type I	Fish passage efficiency, lack of passage at two mainstem dams
1	Powwow River	59.3	No	Type IV	High dam density near river mouth, cost effectiveness of restoration
2	Little River	29.1	No	Type IV	Urbanization, two dams near river mouth lacking passage
3	Shawsheen River	78.2	Yes	Type I	Ballardvale Dam
4	Spicket River	77.4	No	Type IV	Five dams on lower river, cost effectiveness of restoration
5	Concord River (SuAsCo)	400.3	Yes	Type I	Talbot Mills Dam, numerous upper watershed dams, water quality
6	Beaver Brook	94.4	Yes	Type II	Three obsolete dams in lower river lacking upstream passage
7	Stony Brook	45.3	No	Type IV	Multiple impoundments, cost effectiveness of restoration
8	Salmon Brook	31.1	No	Type IV	Urbanization, several dams on lower river
9	Nashua River	532.8	Yes	Type I	Fish passage efficiency at Jackson Mills and Mine Falls, lack of passage at Pepperell and Ice House projects
10	Pennichuck Brook	26.9	No	Type IV	Many impoundments; four dams near river mouth, water supply withdrawals may conflict with outmigration
11	Souhegan River	220.5	Yes	Type II	No fish passage on remaining dams, high dam density in upper river
12	Cohas Brook	70.0	Yes	Type II	Pine Island Pond Dam, managed flows from Massabesic may conflict with outmigration in dry years
13	Piscataquog River	217.6	Yes	Type I	Lack of fish passage, series of impoundments
14	Black Brook	22.3	Yes	Type III	Pierce Brook and Kimball Pond Dams
15	Suncook River	255.9	Yes	Type III	Need passage at Hooksett to reach mouth, no passage at China Mill and Webster-Pembroke projects, other dams further up
16	Soucook River	91.4	Yes	Type III	Need passage at Hooksett to reach mouth, a few dams in upper river
17	Turkey River	37.5	Yes	Type III	Need passage at Hooksett and Garvin's Falls to reach mouth, two dams on near Turkey Pond lacking passage, several dams in ruins near river mouth - unknown passage
18	Contoocook River	764.5	Yes	Type II	Need passage at Hooksett and Garvin's Falls to reach mouth, passage lacking at Penacook projects and Rolfe Canal, numerous dams throughout watershed
19	Winnipesaukee River	472.5	Yes	Type II	Need passage at Hooksett and Garvin's Falls to reach mouth, all six mainstem dams lack passage, downstream protections for juveniles that result from stocking
20	Pemigewasset River	1023.1	No	Type IV	Need passage at Hooksett and Garvin's Falls to reach mouth, natural barrier mid-watershed

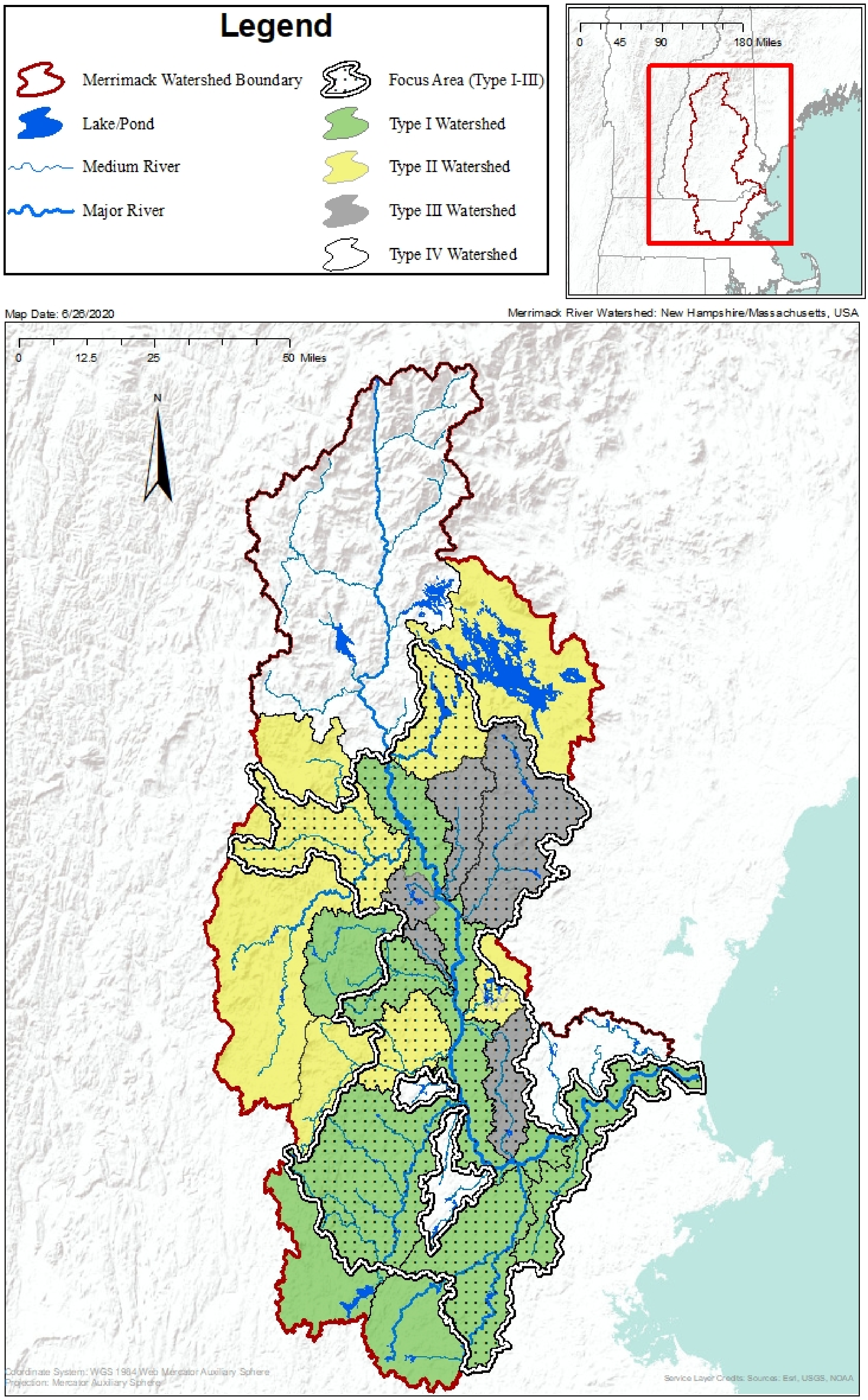

Figure 4. Geographic Scope of Restoration Focus Areas

5.0 RESTORATION POTENTIAL METHODS

We determined the restoration potential for the target diadromous species in the Merrimack River Watershed through an evaluation of each species' biological and population characteristics (distribution, habitat requirements, and current status). We also conducted an examination of geospatial data related to waterway barrier characteristics, current and historical species ranges, and potential habitat availability upon removal or modification of select barriers. These analyses rely on the best available data to inform a potential restoration approach for each of the diadromous species. The restoration potential for each species forms part of this CP framework that will provide local, state and federal agencies, interested partners, and stakeholders with information necessary to prioritize management efforts and proactive restoration opportunities, identify settlement opportunities with stakeholders, and support actions under regulatory authorities.

The biological analysis consisted of a review of available literature specific to each species located in the watershed, as well as more general literature related to species life history. The geospatial analysis consisted of an evaluation of the barriers present in the watershed and the potential available habitat for each diadromous species resulting from removal or modification of these facilities. The RFAs (see Section 4.0) consist of the following HUC12 watersheds (n=60):

- Merrimack River (Type I)
  - Outlet Merrimack River
  - Creek Brook-Merrimack River
  - Fish Brook-Merrimack River
  - Limit Brook-Merrimack River
  - Nesenkeag Brook-Merrimack River
  - Little Cohas Brook-Merrimack River
  - Bowman Brook-Merrimack River
  - Browns Brook-Merrimack River
  - Bow Bog Brook-Merrimack River
  - Tannery Brook-Merrimack River
  - Punch Brook-Merrimack River
- Shawsheen River (Type I)
  - Lower Shawsheen River
  - Middle Shawsheen River
  - Upper Shawsheen River
- Concord River (Type I)
  - River Meadow Brook

  - Mill Brook-Concord River
  - Fort Pond Brook
  - Elizabeth Brook-Assabet River
  - Hop Brook-Sudbury River
  - Lake Cochituate-Sudbury River
- Beaver Brook (Type II)
  - Lower Beaver Brook
  - Golden Brook
  - Upper Beaver Brook
- Nashua River (Type I)
  - Unkety Brook-Nashua River
  - Nissitissit River
  - Witch Brook-Squannacook River
  - Willard Brook
  - Mulpus Brook-Nashua River
  - Still River-Nashua River
  - Monoosnoc Brook-North Nashua River
  - Sand Brook-North Nashua River
- Souhegan River (Type II)
  - Baboosic Brook
  - Souhegan River
- Cohas Brook (Type II)
  - Cohas Brook
  - Massabesic Lake
- Piscataquog River (Type I)
  - Piscataquog River
  - Gorham Brook-Piscataquog River
  - South Branch Piscataquog River
- Black Brook (Type III)
  - Black Brook
- Suncook River (Type III)
  - Suncook River
  - Little Suncook River
  - Perry Brook-Suncook River

  - Big River
  - Upper Suncook Lake-Suncook River
  - Crystal Lake

- Soucook River (Type III)
  - Soucook River
  - Gues Meadow Brook

- Turkey River (Type III)
  - Turkey River

- Contoocook River (Type II)
  - Contoocook River
  - Deer Meadow Brook
  - Hardy Spring Brook-Contoocook River
  - Hopkinton Lake
  - Blackwater River
  - Lower Warner River
  - Lane River
  - Upper Warner River

- Winnipesaukee River (Type II)
  - Winnipesaukee River
  - Tioga River
  - Winnisquam Lake
  - Paugus Bay

5.1 Geospatial Considerations

Geospatial analysis was used to determine the potential available habitat for diadromous species resulting from removal or modification of barriers in the RFAs. For American shad, river herring, sea lamprey, and American eel, we accessed several online geographic information system (GIS) data sources to gather the information necessary to determine available habitat as described in the following sections. Habitat determinations were also informed by individual species plans (Section 10.1).

All data for this CP are maintained in two Esri file geodatabases (GDB) with different functions. The first GDB contained feature classes set up with compatible datum and equal area projections to facilitate accurate area calculations. This GDB was used to generate watershed metrics, tabular geospatial data, and other analytical mapping functions. The second GDB contained feature classes and layers set up with appropriate datum and projections to facilitate visualization. This GDB was used to create CP figures, visualize habitats and restoration potential, and to facilitate web publishing of map products.

5.1.1 Watershed Delineation

Each watershed was defined using the HUC system. We categorized the 144 HUC12 polygons in the watershed based on the river most closely associated. All HUC12s (n=11) that the mainstem Merrimack River intersects were assigned to the Mainstem subwatershed. This corridor contains many minor or unnamed tributaries as well as lentic features such as oxbow lakes. HUC12s that do not intersect the mainstem we assigned to the appropriate tributary watershed. In some instances, the watershed was small enough to contain only a single HUC12. A total of 21 watersheds were defined by this method (See Section 3.1).

5.1.2 River Mile and Lentic Feature Calculations

We used the United States Geological Survey's National Hydrography Dataset (NHD) to analyze and enumerate lotic features using the Geometric river network feature class (Hydronetwork). We used the Utility Network Analyst tool in ArcMap (v10.7) to select reaches and the attribute table to calculate metrics. Lentic features were extracted at the HUC4 level from the medium resolution NHD eliminating numerous unnamed, minor, or analytically insignificant watershed features. Only perennial lake and pond features were included for this analysis. We also created a layer by extraction from the larger list of lentic features in the watershed based on the waterbodies identified by MRTC (2019) as suitable for river herring restoration. Lentic feature metrics were calculated using the North American Datum of 1983 (NAD 83) under the Universal Transverse Mercator Zone 19 North (UTM zone 19N) or the Albers Equal Area Conic projection as appropriate.

5.1.3 River Surface Area Calculation

We used the NHDPlusBurnWaterbody feature class contained in the NHDPlus_H_0107_HU4 geodatabase to calculate the surface area of lotic features. This feature class contains both lentic and lotic features. We created a new feature class by extraction that contained only the polygons associated with lotic features. The resulting series of polygons was further manipulated for analytical purposes. Polygon river reaches were split or merged based on the location of known dams (from Merrimack Dams Layer described in section 5.1.4) in the watershed. This resulted in each polygon representing a river reach either between two dams, spanning from the mouth of the river to the first dam, or from the last dam to the end of available reach. For each watershed, the polygon layer only includes river reaches that have an average width greater than 50 feet; therefore, small tributaries are not included in this analysis. We also expanded the attribute table to include reach name (which we assigned to each newly defined polygon), whether or not the reach is currently accessible for diadromous fish, the number of impassable dams below the reach, and surface acreage. This attribute table can be used to generate theoretical production estimates by reach, tributary watershed, or for the complete watershed; this analysis is contained in section 8.0.

5.1.4 Dam Inventory

We analyzed barrier data assembled into a single layer from two sources. We retrieved the Dam Inventory (Version: 12/31/2019) from the New Hampshire Geographically Referenced Analysis and Information Transfer System (NH GRANIT). We combined these data with the Massachusetts Dams data layer (Version: 2012) maintained by the Bureau of Geographic Information (MassGIS) and derived from a dam safety database of the Massachusetts Office of Dam Safety. By extracting all data points (from both layers) that were in the Merrimack River watershed, we created a new layer (Merrimack Dams) containing all Merrimack watershed dams. Column headings and included data differed between these two databases and it was necessary to create additional columns in the new layer to allow us to sort all data via the attribute table. We characterized each dam using the schema outlined in Table 4 to describe the connectivity status.

Table 4. Categorization of Merrimack Watershed Dams

Source	**MA Dams Data Layer +**	**NH Dam Inventory =**	**NMFS Merrimack Dams**
Attribute Table Field	LOCSTATUS	STATUS	Barrier Type
	Verified	Active or Active/Multiple	Dam Barrier
	-	Ruins or Breached	Potential Barrier
	-	Exempt or Pending	Unknown/Probable Barrier
	Not Verified	-	Unknown
	-	Removed or Not Built	Excluded From Layer

5.1.5 Fish Distributions

Several data sources were used to visualize and map historical and current distributions for target species. Dauwalter et al. (2012) assessed contemporary and historical distribution for diadromous fish in Atlantic coast watershed. We extracted data points for the Merrimack River watershed from this data set to inform fish distributions described in this CP. We also incorporated unpublished field survey data provided by NHFGD into our analysis. Current assumed diadromous fish ranges are based on these data and the currently accessible portion of the watershed; either through direct access via contiguous habitat or the presence of structures that provide upstream passage.

5.2 Biological Considerations

We researched the current and historical distribution of each of the five target species in the watershed area and described the key characteristics of each population including habitat requirements, status of the recreational fishery (if applicable), incidental catch rates and other population specific threats, interactions with the inland fishery species, and any historic and current management actions.

We reviewed the literature containing the information previously described for each species. These documents included species-specific management plans (both in and outside the Merrimack River Watershed), state agency websites, species profiles, peer-reviewed literature, and reference books on Atlantic diadromous species. To the extent practicable, information specific to the species population in the Merrimack River Watershed was the focus for this exercise. Otherwise, the broader Atlantic population of the species was the source for information.

6.0 BARRIER INVENTORY AND DESCRIPTION

We completed a barrier inventory for the Merrimack River Watershed as part of the geospatial analysis. The combined biological and geospatial analyses specific to each diadromous species determine the restoration potential (Section 7.0). This evaluation inventories hydroelectric dams in the watershed and identifies projects that should receive priority for fish passage and protection measures. An overarching goal of the CP is to establish a framework that balances the restoration of the diadromous fishery with other watershed resource uses and public benefits. One of the principal mechanisms for addressing this goal is to work with hydroelectric projects owners that seek licenses under the Commission. In addition, this evaluation inventories non-hydropower and natural barriers.

The barrier inventory in this CP focuses on barriers categorized as described in Section 5.1.4. All dam sites are categorized as a barrier or potential barrier. Section 6.1 presents the hydroelectric dam inventory, and section 6.2 presents the inventory of non-hydropower barriers identified as a priority.

6.1 Federally Regulated Hydroelectric Projects

There are currently 49 active hydroelectric projects comprising 57 developments (generating powerhouses) with a combined capacity of approximately 140 megawatts (MW) in the Merrimack River Watershed (Table 5). Twenty-nine developments are exempt from licensing. Twenty-eight developments are operating with a license, ten of which will expire before 2030. Several of these facilities are not located on navigable waterbodies but are included to be comprehensive. Eighteen of the 57 hydroelectric developments are in a Type I RFA of this CP, with an additional 12 in the Type II RFA, and one development in a Type III RFA (Figure 5). In New Hampshire and Massachusetts, two Licensees operate nearly 30 percent of the licensed hydroelectric projects: Central Rivers Power, LLC (CRP) and Eagle Creek Renewable Energy, LLC (a subsidiary of Ontario Power Generation). Other Licensees operating multiple dams in the watershed include Green Mountain Power Corporation, the City of Nashua, and Essex Hydro Associates, LLC.

Table 5. Merrimack River Watershed Hydroelectric Facilities

FERC Project Number	FERC Hydroelectric Project Name (Development)	State	Waterway	Restoration Focus Area	License Expiration Date	Authorized Capacity (MW)
1893	Merrimack River (Amoskeag)	NH	Merrimack River	Type I	4/30/2047	17.500
1893	Merrimack River (Garvin's Falls)	NH	Merrimack River	Type I	4/30/2047	12.400
1893	Merrimack River (Hooksett)	NH	Merrimack River	Type I	4/30/2047	1.600
2456	Ayers Island	NH	Pemigewasset River	-	3/31/2036	8.400
2457	Eastman Falls	NH	Pemigewasset River	-	12/31/2048	6.060
2790	Lowell (Assets)	MA	Merrimack River	Type I	4/30/2023	0.795
2790	Lowell (Bridge St)	MA	Merrimack River	Type I	4/30/2023	2.440
2790	Lowell (Hamilton)	MA	Merrimack River	Type I	4/30/2023	1.180
2790	Lowell (John St)	MA	Merrimack River	Type I	4/30/2023	2.500
2790	Lowell (Lowell)	MA	Merrimack River	Type I	4/30/2023	17.300
2800	Lawrence	MA	Merrimack River	Type I	11/30/2028	16.800
2966	Clement Dam	NH	Winnipesaukee River	Type II	4/30/2032	2.600
2998	Centennial Island	MA	Concord River	Type I	Exempt	0.640
3025	Kelley's Falls	NH	Piscataquog River	Type I	3/31/2024	0.450
3107	Newfound	NH	Newfound River	-	10/31/2031	1.500
3128	Lochmere Dam	NH	Winnipesaukee River	Type II	Exempt	1.000
3180	Gregg's Falls	NH	Piscataquog River	Type I	Exempt	3.479
3185	Webster Pembroke	NH	Suncook River	Type III	Exempt	2.750
3240	Rolfe Canal	NH	Contoocook River	Type II	11/30/2024	4.283
3265	Steeles Pond	NH	Contoocook River	-	Exempt	0.975
3342	Penacook Lower Falls	NH	Contoocook River	Type II	11/30/2024	4.110
3442	Mine Falls	NH	Nashua River	Type I	7/31/2023	3.000
3760	Stevens Mill Dam	NH	Winnipesaukee River	Type II	Exempt	1.936
4253	River Street	NH	Contoocook River	-	Exempt	0.112
4318	Noone Mills Dam	NH	Contoocook River	-	Exempt	0.150
4337	Hoague-Sprague	NH	Contoocook River	Type II	Exempt	1.268
5274	Squam Lake Dam	NH	Squam River	-	Exempt	0.080
5379	Hadley Falls	NH	Piscataquog River	Type I	Exempt	0.250
5638	Ashland Papermill	NH	Squam River	-	Exempt	0.105
5735	Hopkinton	NH	Contoocook River	Type II	Exempt	0.250
6116	Hosiery Mill	NH	Contoocook River	-	Exempt	1.200
6440	Lakeport	NH	Winnipesaukee River	Type II	8/31/2023	0.705
6597	Monadnock Paper Mills (Monadnock)	NH	Contoocook River	-	7/31/2044	0.423
6597	Monadnock Paper Mills (Paper Mill)	NH	Contoocook River	-	7/31/2044	0.746
6597	Monadnock Paper Mills (Pierce)	NH	Contoocook River	-	7/31/2044	0.720
6689	Penacook Upper Falls	NH	Contoocook River	Type II	11/30/2024	3.020
6752	Avery Dam	NH	Winnipesaukee River	Type II	Exempt	0.192
6950	Franklin Falls	NH	Winnipesaukee River	Type II	Exempt	0.660
7148	Assabet Dam	MA	Concord River	Type I	Exempt	0.178
7236	Forsters' Mill	NH	Lane River	Type II	Exempt	0.096
7248	Giles Pond	NH	Salmon Brook (Pemigewasset)	-	Exempt	0.375
7410	Peterborough	NH	Contoocook River	-	7/31/2034	0.623
7590	Jackson Mills	NH	Nashua River	Type I	Exempt	1.000
7920	Waterloom Falls	NH	Souhegan River	-	Exempt	0.150
7921	Otis Falls	NH	Souhegan River	-	Exempt	0.200
7922	Chamberlain Falls	NH	Souhegan River	-	Exempt	0.130
8093	Methuen Falls	MA	Spicket River	-	2/28/2026	0.357
9282	Pine Valley	NH	Souhegan River	-	9/30/2027	0.525
9509	Cheshire Dam	NH	Contoocook River	-	Exempt	0.100
9968	Aqueduct Transfer	MA	Concord River	-	Exempt	0.750
10688	Cosgrove	MA	Nashua River	-	Exempt	3.400
10689	Oakdale	MA	Nashua River	-	Exempt	3.500
12721	Pepperell	MA	Nashua River	Type I	8/31/2055	2.207
12769	Ice House Power	MA	Nashua River	Type I	Exempt	0.280
13237	Crocker	MA	Whitman River	-	8/31/2052	0.145
14332	Cheshire Mills	NH	Nubanusit Brook	-	Exempt	0.090
14657	Zealand Falls	NH	Whitewall Brook	-	7/31/2045	0.003

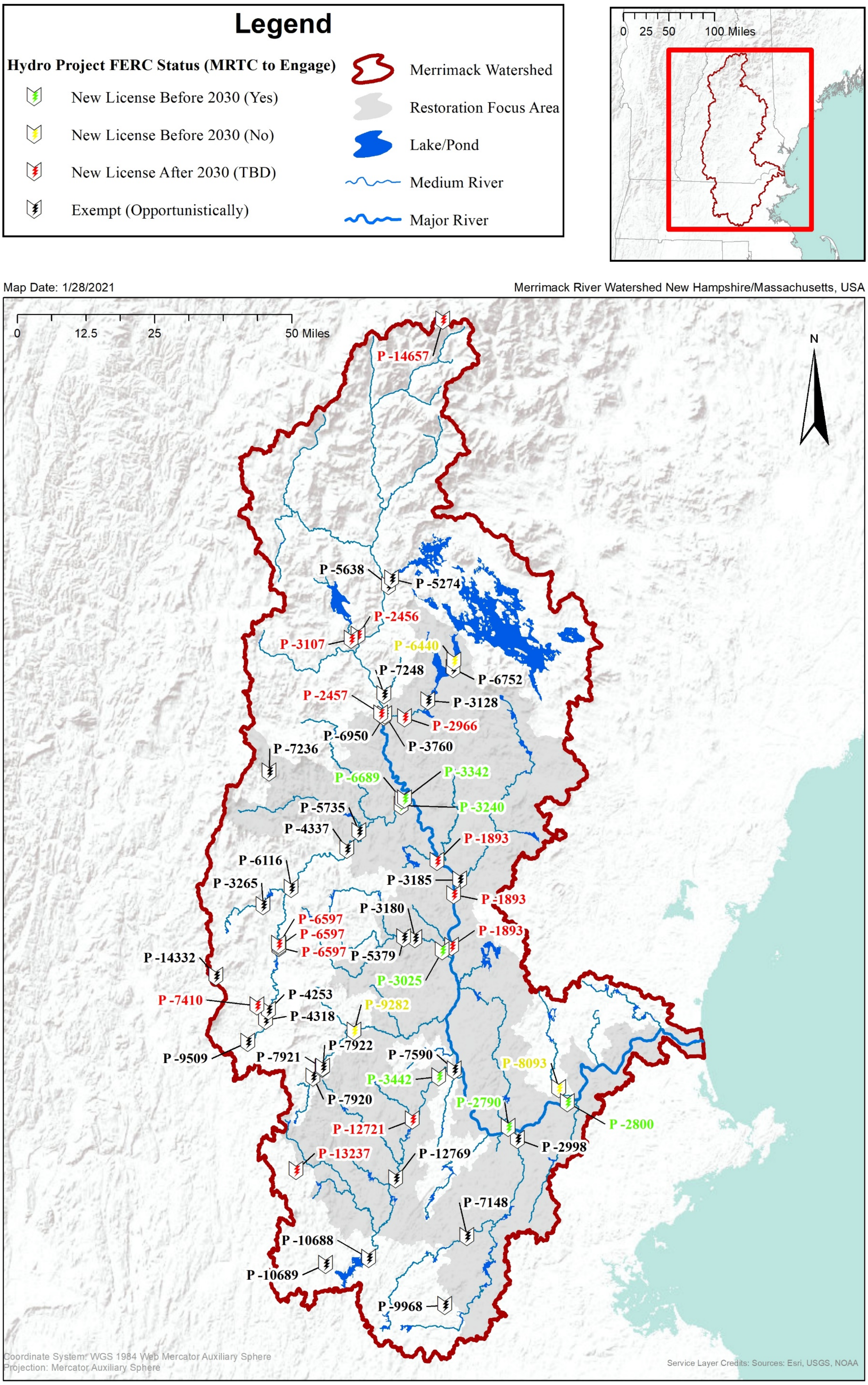

Figure 5. License Status and Distribution of Hydroelectric Projects in the Merrimack River Watershed

The MRTC plans to participate in the licensing process for many of these facilities in the next decade (Table 6) to ensure each project provides safe, timely, and effective fish passage for the restoration of migratory fish populations.

Table 6. Hydroelectric Facilities with License Expiration before 2030.

FERC Project - #	Facility Name	Facility Owner	Waterway	Restoration Focus Area	License Expiration Date
2790	Lowell	Central Rivers Power	Merrimack River	Type I	4/30/2023
3442	Mine Falls	City of Nashua	Nashua River	Type I	7/31/2023
3025	Kelley's Falls	Green Mountain Power	Piscataquog River	Type I	3/31/2024
3342	Penacook Lower Falls	Briar Hydro Associates, LLC	Contoocook River	Type II	11/30/2024
3240	Rolfe Canal	Briar Hydro Associates, LLC	Contoocook River	Type II	11/30/2024
6689	Penacook Upper Falls	Briar Hydro Associates, LLC	Contoocook River	Type II	11/30/2024
2800	Lawrence	Central Rivers Power	Merrimack River	Type I	11/30/2028

6.1.1 Merrimack River

6.1.1.1 Lawrence (Essex Dam) P-2800

The first barrier on the mainstem of the Merrimack River is the Essex Dam, which spans the river at RM 30 approximately eight miles above the head of tide. Originally named the Great Stone Dam, the Essex Company finished construction in 1848. At 900-foot-long and 33-foot-tall, it was the largest dam in the world at that time. The dam was designed to divert water into two power canals for textile manufacturing. The dam is now used for hydroelectric power generation. The dam impounds a 9.8-mile-long, 655-acre reservoir with a storage capacity of roughly 19,900 acre-feet. The original license for the Lawrence Hydroelectric Project was issued by the Commission in 1978 to Lawrence Hydroelectric Associates and Essex Company with an authorized capacity of 16.8 MW. The project was operational by 1981 using two Kaplan turbine units, each rated at 7.4 MW, to generate electricity resulting in an installed capacity of 14.8 MW. The original license included mandatory conditions for the construction and operation of a fish lift and a downstream bypass sluice.

Essex Company is still the licensee, but the project has transferred ownership to Central Rivers Power. Recently the project was upgraded with an automatic crest gate system to better control impoundment levels. In addition, the Commission amended the license to remove the historic canals from the project boundary. The project will begin licensing in 2023, with the original license set to expire in 2028. As the first mainstem barrier, the outcomes of this licensing will determine the future success of diadromous fish restoration in the Merrimack watershed. The MRTC will take an active approach in the licensing process to ensure effective fish passage structures support diadromous fish restoration goals.

6.1.1.2 Lowell (Pawtucket Dam) P-2790

The Pawtucket Dam is the second dam on the Merrimack River constructed on Pawtucket Falls at RM 43 in Lowell, MA. Constructed in 1847, the dam originally provided hydropower through the network of associated canals to run America's first large-scale planned industrial city. At 1,093-foot-long and 15-foot-tall, the stone- masonry gravity dam is one of the largest in the Merrimack watershed. The dam impounds the river 23 miles upstream, with a surface area of 720 acres and a capacity of 3,960 acre-feet of water storage. The dam was recently upgraded with an automatic crest gate system to better control the impoundment water level. The dam currently diverts water to a main hydroelectric development (E.L. Field Powerhouse) with two Kaplan units (17.3 MW) and four other hydropower developments located in the downtown canals with a myriad of antiquated turbine units. The total project authorized capacity is 24.8 MW. Boott Hydropower, LLC obtained the original license in April of 1983. The project is undergoing licensing at the time of this writing with the original license set to expire on April 30, 2023. In the draft license application, the Licensee has proposed decommissioning the developments in the downtown canal system. Boott Hydropower, LLC remains the licensee, but ownership of the project has recently transferred from Enel Green Power to Central Rivers Power.

The Pawtucket dam has several fish passage facilities that began operation in 1986: a fish ladder[22] at the north end of the dam, a fish lift at the power station, a downstream bypass in the power canal, a temporary eel trap at the north end of the dam, and fish counting stations at each upstream passage facility. Many of these fish passage measures are ineffective and challenging infrastructure combined with a lack of downstream entrainment prevention for out-migrating fish causes reduced passage, increased migratory delay, and high project-induced mortality. Fish passage improvements are necessary at Lowell to meet the management goals of this CP.

[22] There was a ladder present at Pawtucket Dam prior to the modern structure; however, it was ineffective, passed very few fish, and often did not function outside of ideal flow conditions.

6.1.1.3 Merrimack River P-1893

The Merrimack River project consists of three developments on the mainstem, Amoskeag, Hooksett, and Garvin's Falls. The three developments have a combined installed capacity of 29.9 MW. The dams are located along a 21-mile stretch of the upper Merrimack in New Hampshire's Hillsborough and Merrimack Counties, near Manchester, Hooksett, and Concord. The original license was issued to the Public Service Company of New Hampshire in 1980, and the project was issued a new license in 2007. Central Rivers Power operates the facilities under the current license set to expire in 2047.

Amoskeag Development (Manchester, NH)

Constructed on the site of the historic Amoskeag Falls, Amoskeag Dam impounds the river at RM 74 in Manchester, NH. Originally constructed in the 1830s to provide hydropower for the mills of the Amoskeag Manufacturing Company; the dam was re-built in the 1920s for hydroelectric power generation. The 29-foot-tall, 710-foot-long dam impounds a seven-mile reach of the mainstem with a surface area of 478 acres. The powerhouse contains three Francis turbine units with a total installed capacity of 16 MW. Fish passage facilities were put into operation in 1989. The fishway facilities include a pool and weir fish ladder, multiple eel traps, and a downstream bypass system at the powerhouse waste gate. A trap and trucking station is part of the ladder allowing adult fish to be collected for stocking. Because the fish ladder was designed for Atlantic salmon, the effectiveness for other diadromous fish has been poor. However, recent modifications to the ladder have shown promise for alosines. With no entrainment prevention at the powerhouse, safe downstream passage at the development remains a concern.

Hooksett Development (Hooksett, NH)

The Hooksett hydroelectric facility is the fourth dam on the Merrimack River, located north of the town of Hooksett at RM 82. The 14-foot-high dam comprises two sections: a 340-foot stone masonry section on the western half of the river connected to a 250-foot concrete section to the east. The dam creates a 5.5-mile, 405-acre reservoir. The powerhouse contains a single vertical propeller turbine with 1.6 MW of installed capacity. Hooksett Dam has no upstream fish passage structures. However, a requirement for upstream passage facilities is included in a settlement agreement for the Merrimack Project. Construction of a nature-like fishway at the western spillway is anticipated the summer of 2022. Gate structures next to the powerhouse are used for downstream passage with minimal success. With no entrainment prevention at the powerhouse, safe downstream passage at the development remains a concern.

Garvin's Falls Development (Concord, NH)

Garvin's Falls is the fifth and final dam on the Merrimack mainstem located five miles upstream of Amoskeag at RM 87. The 18-foot-high, 550-foot-long dam is made of granite and concrete. The 640-acre impoundment created by the dam is eight-miles-long. The two powerhouses each contain two Kaplan/propeller generating units that have a total installed capacity of 12.3 MW. Like Hooksett, there are no anadromous upstream fish passage measures at Garvin's Falls. However, there are seasonal eel traps installed at the development. Provisions for future fishways are contained in the 2007 settlement agreement.[23] A louver-type downstream fish guidance and bypass system is present in the 500-foot-long power canal. Since the cessation of the Atlantic salmon program in the Merrimack River, the louver is no longer installed in the power canal, but the bypass system still operates to pass American eel and stocked alosines. With no entrainment prevention at the powerhouse, safe downstream passage at the development remains a concern.

6.1.2 Sudbury-Assabet-Concord (SuAsCo)

6.1.2.1 Centennial Island P-2998

The first dam on the Concord River is part of the Centennial Island hydroelectric project. The irregularly shaped, 200-foot-long dam supplies water to the powerhouse by routing it through an approximately 1500-foot-long power canal. A non-conduit license exemption was issued for the project in 1981 with an authorized capacity of 0.64 MW. One condition of the license exemption is for the operation and maintenance of fish passage structures. After a considerable consultation among the Exemptee, the Commission, and the USFWS, designs for a Denil-type fish ladder and a downstream bypass were approved, and construction was completed in the early 1990s.

The ladder has persistent issues; recent surveys have found the ladder to be improperly constructed and in poor repair.[24] There are no fish passage performance data to assess the efficacy of the fishway. The project is a focus for agency engagement to improve passage conditions.

6.1.2.2 Assabet Dam P-7148

The Assabet (or Powdermill) Dam impounds the Assabet River about 6.5 miles upstream from the Concord River. The fully-breached Damondale Dam is 1.75 miles downstream of the Assabet Dam, but is no longer a fish passage barrier making Assabet Dam the next upstream barrier from Talbot Mills Dam (see Section 6.2.3). The dam at this project was constructed around 1835 on the site of several previous dams. The site historically supported an industrial complex known as the Massachusetts Powder Works, a large producer of black powder for many years prior to the advent of smokeless powder around the turn of the 20th century.

[23] FERC Accession # 20070206-5016

[24] See 2017 inspection report, FERC Accession # 20171019-5023

The 420-foot-long earthen dam and concrete spillway are used to generate hydroelectric power. The dam is 16 feet tall and creates an impoundment of the Assabet River with a surface area around 20 acres. Because the facility is run-of-river, the turbine often shuts down during low flow periods. Hydroelectricity has been produced on the site since 1923, and the license exemption was issued to Acton Hydroelectric Company in 1983 with an authorized capacity of 0.178 MW. The development does not have fish passage facilities. Ongoing restoration efforts at downstream barriers will likely allow migratory fish to reach the dam in the next decade.

6.1.3 Nashua River

6.1.3.1 Jackson Mills P-7590

The first dam on the Nashua River is the Jackson Mills Dam, which impounds the river 1.25 miles upstream from the confluence with the Merrimack in the city of Nashua, NH. The stone masonry gravity dam was constructed in 1920, with the hydropower facility coming into operation in the mid-1980s. The run-of-river facility consists of a 180-foot-long dam, 33 feet in height including an eight-foot-high automatic crest gate. The dam impounds a 40-acre reservoir with negligible usable storage capacity. The installed capacity of the project is 1.0 MW generated by a single propeller turbine in the powerhouse at the north end of the dam. The Exemptee is planning to replace the existing unit with a Kaplan turbine. The project has a license exemption issued in 1984 to the City of Nashua, NH.

As a condition of the license exemption, the Exemptee was required to install fish passage facilities. Both upstream and downstream passage structures are in place, with a Denil fish ladder for upstream passage, and a stainless steel bypass pipe for fish migrating downstream. Observational evidence and recent site inspections[25] suggest the current fish ladder needs improvements, although no studies have been conducted to confirm. As Jackson Mills is the first dam on the river, effective fish passage is vital for the success of diadromous fish in the Nashua River watershed. More data on the passage efficiency at this project is needed to assess whether the existing fishways will meet management goals. An eel trap has been installed on the site with limited success.

6.1.3.2 Mine Falls P-3442

The second dam on the Nashua River is the Mine Falls hydroelectric project, located four miles upstream of the Jackson Mills project in Nashua, NH. The hydropower facility is situated at the site of a 19th century dam and gatehouse. The dam once served to divert water, via a gatehouse, to a 35-foot-wide hand-dug power canal. The defunct canal flows three miles east, parallel to the Nashua River, to the former site of the Nashua Manufacturing Company textile mill. The dam impounds a 242-acre reservoir with a usable storage capacity of 450 acre-feet. The

[25] FERC Accession # 20180921-5016 and Accession # 20191122-5051

water is routed through a 350-foot power canal to the powerhouse, which contains two Kaplan turbines with an authorized capacity of 3.0 MW. The original license was issued in 1983 to the City of Nashua, and will expire in 2023.

Fish passage was prescribed in the original license to be implemented either by 1985 or upon completion of upstream passage facilities at the Pawtucket Dam. The upstream fish passage measure is a fish lift discharging fish into the power canal. While the presence of upstream passage facilities is beneficial, several improvements are needed to improve fish passage and survival. The current downstream bypass system is generally a safer route of passage though studies indicate a poor entrance efficiency. The existing upstream and downstream facilities will require modifications in the new license.

6.1.3.3 Pepperell P-12721

The Pepperell project is the third dam on the Nashua River nine miles upstream of the Mine Falls project in Pepperell, MA. The 251-foot-long, 23.5-foot-tall Pepperell Paper Company Dam impounds a 3.5-mile-long, 294-acre reservoir and provides water to the powerhouse via a 566-foot-long penstock. The project's three generating units combine for an installed capacity of 2.14 MW. The original 40-year license was issued to the Pepperell Hydro Company, LLC in 2015 and expires in 2055.

Currently there are no upstream fish passage structures, but the license contains numerous conditions (including minimum flow levels) for fish passage resulting from a settlement[26]. The installation of upstream fish passage at Pepperell is required upon passage of 5,000 river herring during two consecutive years at the Mine Falls Project. Downstream protections for alosines and eels, as well as upstream eel passage are required in the license.[27] Full implementation of these fish passage measures is important as upstream fish passage improves at Mine Falls and Jackson Mills.

6.1.3.4 Ice House Power P-12769

Further upriver in the town of Ayer, MA, the Ice House Dam is the fourth on the Nashua River. The original dam was built in the 1790s, and was used as a reference marker when the surrounding towns were laid out. The dam is 12 feet tall and 190 feet in length, impounding a 137-acre reservoir. Water is supplied to the powerhouse via a 50-foot-wide, 109-foot-long power canal with four large gates housed in a headgate structure at the entrance. The restored powerhouse has two turbine generating units with a combined installed capacity of 0.28 MW. The license exemption was issued to Ice House Partners, Inc. in 2008.

[26] FERC Accession # 20140411-5151
[27] The upstream eel ladder was completed and began operation in 2020.
See FERC Accession # 20200803-5141 for further detail.

The project has no fish passage structures in place, but the license exemption contains conditions that such structures will be installed when required by the USFWS and MassWildlife.

6.1.3.5 Cosgrove P-10688

The Cosgrove Intake and Power Plant Project is a water conduit facility located on eastern shore of the Wachusett Reservoir. The project is operated by the Massachusetts Water Resources Authority (MWRA) as part of the Massachusetts public water supply. Water is transferred into the Wachusett Reservoir from the Quabbin Reservoir (this supply makes up over 50 percent of Wachusett's inflow) via the Quabbin Aqueduct. The Cosgrove Aqueduct conveys water to the John J. Carroll Treatment Plant in Marlborough, MA, where the water is treated and distributed to customers. Together, the Quabbin and Wachusett Reservoirs provide most of the water supply for the greater Boston area.

The Cosgrove powerhouse located at the Cosgrove Aqueduct intake has two 1.7-MW turbines. This facility is operated as part of an aqueduct network on a man-made reservoir; there are no fish passage considerations at the project.[28] The Commission issued the license exemption to the MWRA in 1990.

6.1.3.6 Oakdale P-10689

The Oakdale Hydroelectric Project is a water conduit facility located at the outlet of the Quabbin Aqueduct, at the west end of Wachusett Reservoir, near the mouth of the Quinapoxet River. Water enters the Quabbin Aqueduct at Quabbin Aqueduct Intake, Shaft 12, before traveling around 24 miles to its terminus at the Oakdale transfer station in West Boylston, MA. Like the Cosgrove Project, Oakdale is one of a few locations where the MWRA captures energy produced by falling water from higher elevations in the western portion of the system (Quabbin Reservoir) to lower elevations in the distribution region (Greater Boston Area).

Constructed in 1929, the Oakdale facility added hydropower generation to the existing water transmission infrastructure in 1949. The project has a single turbine with an installed capacity near 3.5 MW. Similar to Cosgrove, since the Oakdale facility is operated as part of the drinking water aqueduct network on a man-made reservoir, the lack of fish passage is not considered a project effect. The Commission issued a license exemption for the project to the MWRA in 1990.

[28] Since the MWRA conduit projects are incorporated into drinking water infrastructure and not located on navigable tributaries, fish passage is not a consideration at the project.

6.1.4 Souhegan River

6.1.4.1 Pine Valley P-9282

The first 14 miles of the Souhegan River flow freely since the removal of the Merrimack Village Dam in 2008. The first barriers to fish passage on the mainstem are two, closely situated, non-hydro dams located in Milford, NH. Further upstream, near RM 20, Pine Valley Mills Dam is the third barrier on the Souhegan River. Constructed in 1912, the 200-foot-long, 23-foot-tall stone-masonry dam impounds a seven-acre reservoir. Water is supplied to a turbine in the nearby powerhouse with a capacity of 0.525 MW.

The 40-year license was originally issued to Mr. Winslow H. MacDonald in 1987, and has since been transferred to PVC Commercial Center, LLC. The license will expire in September 2027. The project has a downstream bypass for fish. No upstream passage was required in the original license; however, there is a reservation of authority to require upstream passage at the project if Atlantic salmon were restored to the Souhegan. Upstream fish passage at the two non-hydro dams downstream is needed before migratory fish reach the Pine Valley Project.

6.1.4.2 Chamberlain Falls P-7922

The Chamberlain Falls Project is several miles upstream of the Pine Valley Project, near the town of Greenville, NH. This hydropower project and the next two projects upriver (Otis Falls, and Waterloom Falls) share a single owner, Tridam Energy, LLC. Chamberlain Falls Dam impounds a small (approximately 500 feet) reach of the river below a small non-hydropower dam that sits between Chamberlain and Otis Falls Dam. The total distance between these two projects is less than a quarter of a mile. The Chamberlain Falls project was granted a license exemption in 1985. The authorized capacity of this project is 0.13 MW. There are no fish passage structures currently in place at this development.

6.1.4.3 Otis Falls P-7921

The Otis Falls Project is upstream from the Chamberlain Falls project in Greenville, NH. The stone-masonry gravity dam is 150 feet long and 26 feet tall, with a 94-foot-wide spillway. Originally constructed in 1834, the dam was rebuilt in 1936, and completely reconstructed in 1982 to house the hydropower infrastructure. The dam creates a seven-acre impoundment with a usable storage capacity of 64 acre-feet. The single-turbine Otis Falls project is the largest of the three Tridam Energy, LLC projects on the Souhegan River with an authorized capacity of 0.2 MW. The project received a license exemption in 1985. The project has no fish passage improvements.

6.1.4.4 Waterloom Falls P-7920

Further upriver in New Ipswich, NH, the 205-foot-long, 18-foot-tall concrete Waterloom Falls Dam impounds the Souhegan forming the 75-acre Waterloom Falls Pond. The Waterloom Falls Hydroelectric Project was constructed in the mid-1980s on top of some existing infrastructure. The project has a turbine with a capacity of 0.15 MW. The project received a license exemption in 1985. The exemption has been transferred to Tridam Energy, LLC. Due to the location above numerous barriers at the time of issuance, no requirements for fish passage were included in the license exemption. However, USFWS reserved authority to alter the terms and conditions for the life of the project.

6.1.5 Piscataquog River

6.1.5.1 Kelley's Falls P-3025

The first dam on the Piscataquog River is the Kelley's Falls Project two miles upstream from the Merrimack confluence. The multi-section concrete gravity dam is 503 feet long and 31 feet tall, with the spillway comprising 192 feet of the total length with a height of 21 feet. The dam was constructed in 1916 and impounds a 129-acre reservoir with a storage capacity of 1,350 acre-feet. The powerhouse contains a turbine with a capacity of 0.45 MW. The original license was issued in 1984 with a 40-year term expiring on March 31, 2024. The licensee is Kelley's Falls, LLC (a subsidiary of Green Mountain Power Corporation). MRTC member agencies are actively involved in the licensing process of this project.

Article 26 of the original license included the condition that the "Licensee shall provide upstream and downstream fish passage facilities within one year after completion of fish passage facilities at the downstream Lowell Project (P-2790)". Lowell's fish passage facilities came online in the mid-1980s. In 1987, the license was amended to require the approved upstream and permanent downstream passage in the second year following an annual upstream passage of 15,000 American shad at Amoskeag Dam. There are no upstream fish passage structures in place at the project. The Licensee uses the existing log sluice as a bypass for stocked anadromous species, American eel, and resident species.

6.1.5.2 Gregg's Falls P-3180

Gregg's Falls Dam is owned by the State of New Hampshire located at RM 7 on the Piscataquog. The earthen-fill and concrete gravity dam is 1,360 feet long and 60 feet tall, impounding the 137-acre reservoir known as Glen Lake. Glen Lake has a storage capacity of 3,650 acre-feet. The powerhouse contains two turbines with an installed capacity of 3.48 MW. A license exemption was issued for the project in 1983. Project ownership has changed hands since the original issuance, and the project is now operated by Eagle Creek Renewable Energy, LLC on lease from the State. The project has downstream passage installed for Atlantic salmon.

6.1.5.3 Hadley Falls P-5379

The third dam on the Piscataquog River is the Hadley Falls Project located at the western end of Glen Lake. The dam is 20 feet tall and approximately 300 feet in length including a 176-foot-long spillway that impounds a 24-acre reservoir. The project is owned by the NH Department of Environmental Services and was operated by Algonquin Power & Utilities Corp with an authorized capacity of 0.25 MW under a license exemption that was issued in 1982. The run-of-river project no longer operates and is in a state of disrepair making it a candidate for decommissioning and removal.

6.1.6 Suncook River

There is a series of three dams in close proximity 0.5 miles above the confluence with the Merrimack. The lowermost dam is the China Mill Project, a 1.7 MW facility not federally-regulated. The other two dams comprise the Webster-Pembroke Project (P-3185). At the upstream end of the project, the Webster Dam forms the Suncook River Reservoir. The reservoir has a surface area of 26 acres and a volume of 147 acre-feet. The partially removed, stone-masonry Pembroke Dam, located on the bypass reach about 1,800 feet downstream, receives the minimum flow release and spill from the Webster Dam. The run-of-river project was issued a license exemption in 1983 with an authorized capacity of 2.75 MW. There are no fish passage facilities at the project.

6.1.7 Contoocook River

The first three dams on the Contoocook River support hydropower generation facilities. All three projects (descriptions in sections 6.1.7.1, 6.1.7.2, and 6.1.7.3) are operated by Briar Hydro Associates and owned by Essex Hydro. These run-of-river projects have a license condition to maintain a minimum flow of 338 cfs. The licensing process began in 2019.

6.1.7.1 Penacook Lower Falls P-3342

The first dam on the Contoocook River, Penacook Lower Falls Dam, is located 0.3 miles upstream from the Merrimack. The dam is of recent construction compared to others in the Merrimack watershed, with the hydropower facility starting operation in 1983. The run-of-river facility consists of approximately 700-foot-long dam with spillways at each end and a powerhouse at the downstream end of the north shore. The dam impounds a reservoir with a surface area of 8.4 acres and a 54-acre-foot storage capacity. The authorized capacity of the project is 4.11 MW produced by a Kaplan turbine. At the time of the original license in 1982, upstream fish passage facilities were not required at the project because of numerous downstream dams without fish passage. A modified gate next to the project intake is operated for downstream passage of stocked anadromous fish and American eels.

The original license includes a provision for constructing fish passage structures within three years of the first passage at the next downstream dam – which was Sewall's Falls Dam at the time of licensing – now Garvin's Falls. Each mainstem dam below the Penacook Lower Falls Project will have fish passage facilities within the next decade. The installation of upstream fish passage is an important consideration for the new license issued for this project.

6.1.7.2 Penacook Upper Falls P-6689

The Penacook Upper Falls Project is the second dam on the Contoocook, and is 0.5 mile upstream from Penacook Lower Falls. The dam supports a power generation facility that came online in December 1986. The dam is 187 feet long, 15.5 feet tall impounding an 11-acre reservoir with little storage capacity. A Kaplan turbine operates in the powerhouse at the east end of the dam, with an installed capacity of 2.8 MW. Similar to Penacook Lower Falls, fish passage was not required at the time of construction. However, a condition required fish passage facilities to be installed within one year of the completion of fish passage facilities at all downstream dams. The installation of upstream fish passage is necessary condition for the new license (the current license expires in 2024).

6.1.7.3 Rolfe Canal P-3240

Less than half of a mile upstream from Penacook Upper Falls Dam, the Contoocook bifurcates into a shallow and wide main river corridor to the north and the project tailrace to the south. The two watercourses reconnect about a mile further upstream. The Rolfe Canal Project, which received an original license in 1984, includes structures on both watercourses. Water is diverted into Rolfe Canal by the 300-foot-long, 10-foot high York Dam. A 4,000-foot-long bypass reach extends below the dam with a license-required minimum flow of 100 cfs. The dam creates a reservoir with a surface area of around 50-acres. The Rolfe Canal headgate structure is 700 feet from the bifurcation in the impoundment. Another 3,000 feet downstream from the headgates is a 130-foot-long, 17-foot-high granite block dam that feeds a 900-foot-long penstock leading to the powerhouse with a Kaplan turbine rated at 4.28 MW. The remainder of the Rolfe Canal has a minimum flow of 5 cfs that passes over the Briar Pipe dam and around the Briar Pipe apartments before discharging into the tailrace of the powerhouse.

As with the two Penacook Falls projects, fish passage facilities were not required initially due to lack of passage at downstream dams with the same provisions at the Penacook projects. Because the Rolfe Canal and Penacook projects have the same licensee (Briar-Hydro Associates) and owner (Essex Hydro), the Commission ordered these projects undergo licensing on the same timeline. Installing fish passage on these three projects is an important for meeting management goals in the watershed. The current license is set to expire on November 30, 2024.

6.1.7.4 Hopkinton P-5735

The next dam upstream on the Contoocook River is located west of the New Hampshire Route 103 Bridge in the town of Contoocook. The town of Hopkinton, NH was originally issued a license exemption for the Hopkinton Project by the Commission in 1984. Ownership has been transferred to Green Mountain Power Corporation. The 250-foot-long, 11-foot-tall dam impounds a 110-acre reservoir, and diverts water into a powerhouse at the north end of the dam. The project has an authorized capacity of 0.25 MW. The project has downstream fish passage facilities, but has no upstream fish passage infrastructure. The importance of upstream passage at the project is becoming increasingly evident with the advancement of management goals downstream. With planned improvements on the mainstem and the licensing of the Penacook and Rolfe Canal projects, fish will be able to reach this project in the future.

6.1.7.5 Hoague-Sprague P-4337

The Hoague-Sprague Project is located on a dam of the same name connected to and immediately downstream of the Hopkinton Flood Control Dam operated by the USACE. The dam is 14 feet tall with a spillway that is nearly 300 feet long creating a two-acre impoundment. EHC Hydro Associates received a license exemption for the project in 1982; Green Mountain Power now owns the project. The powerhouse contains two turbine generators with a combined capacity of 1.268 MW. The project has downstream fish passage facilities, but has no upstream fish passage infrastructure. Dams and barriers upstream of this project are outside of the Type II focus area, which terminates at the Hopkinton Flood Control Dam (Figure 4).

6.1.7.6 Hosiery Mill P-6116

The Hosiery Mill Project is located in the town of Hillsborough, NH. The irregularly shaped dam is 15 feet tall and impounds a small, two-acre reservoir. The powerhouse has an authorized capacity of 1.2 MW. The license exemption was issued in 1982. The project is operated by Silver Street Hydro. The project has downstream fish passage facilities, but has no upstream fish passage infrastructure.

6.1.7.7 Steeles Pond P-3265

The Steeles Pond project is located at the outlet of Steeles Pond, an impoundment of the North Branch River approximately 36-acres in size, located in Antrim, NH. The dam’s 75-foot-long spillway has a height of 20 feet. The four turbines in the powerhouse have a total capacity of 0.975 MW. The project operated by New Hampshire Water Resources received a license exemption in 1983. There are no fish passage facilities at this project.

6.1.7.8 Monadnock Paper Mills P-6597

Further upstream on the mainstem of the Contoocook River in Bennington, NH is the Monadnock Project. This project comprises four dams; Paper Mill Dam, Pierce Power Dam, Monadnock Power Dam, and Powder Mill Pond Dam (listed from downstream to upstream). The Powder Mill Pond Dam is a storage development used to regulate flow and has no generation facilities. The other three dams have powerhouses that operate with a total authorized capacity of 1.889 MW. The Commission issued the original license to Monadnock Paper Mills, Inc. in 1984. The project received a new 30-year license in 2014. There are no fish passage facilities at the project.

Nearest to the old mill that gives the project its name, the Paper Mill Development is the furthest downstream dam. The 280-foot-long and 19-foot-tall dam impounds a small reach below the Pierce Dam consisting of a 700-foot-long, 5.5-acre pool with an estimated storage of 26 acre-feet. A single turbine with a capacity of 0.746 MW produces power at this run of river facility. Located approximately 1,400 feet upstream of the Paper Mill Development is the Pierce Power Dam. Spanning 420 feet across the river, the 28-foot-tall dam creates a 7-acre impoundment. The powerhouse situated at the east end of the dam contains two turbines with a combined capacity of 0.72 MW. The third dam at the project – Monadnock Station - is located approximately 900 feet upstream of the Pierce Development. The 515-foot-long, 22-foot-high dam creates a 5-acre impoundment. The powerhouse at the west end of the dam contains two turbines with a combined capacity of 0.423 MW.

6.1.7.9 River Street P-4253

The River Street Project is located on the heavily impounded Nubanusit Brook, which flows into the Contoocook in Peterborough, NH. The Nubanusit Brook has three dams in the first 0.25 miles, with several more further upstream, including a USACE flood control dam. A license exemption for the River Street Project was issued in 1982. The project was operated until around 2006. In 2017, the license was transferred to Contoocook Hydro, LLC who now operates the project. The project, which utilizes the historic, stone-construction Bell Mill Dam (92 foot crest width, 10 feet in height), has an authorized capacity of 0.112 MW. There are no fish passage facilities at the project.

6.1.7.10 Peterborough P-7410

Further up Nubanusit Brook, about a half-mile south of the USACE Edward MacDowell Flood Control Dam, is the Peterborough Project. The project has an authorized capacity of 0.623 MW. The 50-year license was issued in 1984. No fish passage facilities are present at the project.

6.1.7.11 Noone Mills Dam P-4318

On the mainstem Contoocook River roughly one mile southwest of Peterborough, is the Noone Mills Project. Located on the Noone Mills Dam, the project has an authorized capacity of 0.15 MW. The stone-filled, concrete-capped gravity dam is 267 feet long, 20 feet high and impounds the 19-acre Contoocook River Reservoir. River Street Associates received a license exemption for the project in 1981. The project is operated by The Cobbs, LLC. There are no fish passage facilities at this project.

6.1.7.12 Cheshire Dam P-9509

Near the southern extent of the Contoocook watershed in the town of Jaffrey, NH, is the final hydroelectric project on the Contoocook River. The Cheshire Dam, originally constructed in 1871, is comprised of earth, stone, and concrete and has been rebuilt several times. The 300-foot-long, 13-foot-high dam impounds the 38-acre Cheshire Pond. Two crossflow turbines generate electricity with an authorized capacity of 0.1 MW. The Commission issued DD Bean & Sons Co. Inc. a license exemption for the project in 1986. There are no fish passage facilities at the project.

6.1.7.13 Forster's Mill P-7236 (Lane River)

The Forster's Mill Project is located on the Lane River in the town of Sutton, NH. The Lane River is a tributary to the Warner River, which flows into the Contoocook. The dam is approximately 60 feet long and 17 feet high, and impounds a small reservoir of around two acres. The run of river project operates under a license exemption issued in 1984. The project's single crossflow turbine has an authorized capacity of 0.096 MW. There are no fish passage facilities at the project.

6.1.8 Winnipesaukee River

The Winnipesaukee River has six hydroelectric projects over the river's 20-mile course. Two of the projects operate under licenses and the rest have license exemptions. The six projects have a combined authorized capacity of 7.093 MW. Downstream fish passage is particularly important, with Lake Winnisquam – the largest river herring stocking location in the Merrimack watershed – upstream of four of the projects. Lake Winnipesaukee and the river also provide a significant amount of American eel habitat, and fish passage facilities at these projects are crucial to the success of this species in the watershed.

6.1.8.1 Franklin Falls P-6950

The Franklin Falls Dam is the first dam on the Winnipesauke River a half-mile upstream of the Merrimack in the town of Franklin, NH. The small hydropower project, operated by Franklin Falls Hydroelectric Corp., was issued a license exemption in 1983. The project has an authorized capacity of 0.66 MW. There are currently no upstream fish passage facilities at the dam, but the project does have downstream protection in place for out-migrating fish.

6.1.8.2 Stevens Mill Dam P-3760

Stevens Mill Dam is the second dam on the Winnipesaukee 1.4 miles upstream from the confluence. The dam is a concrete gravity structure 80 feet in length and 22 feet high, impounding a one-acre reservoir. Power is produced by two turbines (1.700 and 0.236 MW respectively) in separate powerhouses. The Commission issued a license exemption for the project in 1983 to Franklin Industrial Complex, Inc. The exemption has been transferred to Franklin Power, LLC owned by Eagle Creek Renewable Energy, LLC. There are no upstream fish passage facilities at the dam, but downstream facilities are in operation.

6.1.8.3 Clement Dam P-2966

The Clement Dam is the third and largest (authorized capacity) hydroelectric project on the Winnipesaukee near the towns of Tilton and Northfield, NH. The concrete dam was rebuilt in the 1980s on the site of a historic timber-crib structure that supported a hydropower project in the early 1900s. The dam is 120 feet long and 16.5 feet high, with the spillway section containing 3-foot-high flashboards. The powerhouse contains a single, horizontal Kaplan turbine-generator unit with an installed capacity of 2.4 MW. The original 50-year license was issued in 1982, and has since been transferred to Clement Dam Hydroelectric, LLC. The current owner is Eagle Creek Renewable Energy, LLC. The project has no upstream fish passage facilities, but does have downstream facilities.

6.1.8.4 Lochmere Dam P-3128

The fourth dam on the Winnipesaukee is Lochmere Dam located at the outlet of Lake Winnisquam in the village of Lochmere, NH. The dam is 160 feet long, 11 feet high and diverts water into a power canal on the west end of the dam. At the south end of the canal is a powerhouse containing four turbines with a combined capacity of 1.0 MW. The project was issued a license exemption in 1984. The project is operated by New Hampshire Water Resources and owned by Eagle Creek Renewable Energy, LLC. The project has no upstream fish passage facilities; however, it does have downstream facilities that were recently renovated to contemporary standards.

6.1.8.5 Avery Dam P-6752

The Avery Dam is located in Laconia, NH at the outlet of Opechee Bay upriver of Lake Winnisquam. Daniel Avery constructed a wooden dam on the site around 1791 to provide water for local mills. The dam was rebuilt with concrete in 1949. The Avery Dam is 114 feet long and 20.5 feet high, impounding the 455-acre Opechee Bay. The project has an authorized capacity of 0.192 MW. The Commission issued a license exemption for the project in 1985. Today it is maintained by Avery Hydro, LLC a subsidiary of Dichotomy Capital. There are no fish passage facilities or protections at the dam.

6.1.8.6 Lakeport P-6440

Located in the town of Lakeport, NH, the sixth and final dam on the Winnipesaukee River is the State of New Hampshire's Lakeport Dam. The Lakeport Dam regulates water levels in Lake Winnipesaukee mandated by the state. The 0.705-MW Lakeport Project has three turbines and is located on the 220-foot-long, 10-foot-high Lakeport Dam. The Commission issued Lakeport Hydroelectric Associates (owned by Eagle Creek Renewable Energy, LLC) a 40-year license for the project in 1983. There are no fish passage facilities or protections at the dam.

6.1.9 Pemigewasset River

6.1.9.1 Eastman Falls P-2457

The first dam on the Pemigewasset River, the Eastman Falls Dam, is one mile upstream from the Merrimack River. The concrete gravity dam is 341 feet long and 37 feet high, impounding the 582-acre Eastman Falls Reservoir, which extends upriver to the USACE Franklin Falls Flood Control Dam. The powerhouse at the west end of the dam contains two sections each with a turbine for a combined capacity of 6.06 MW. The Commission issued the original license for the project to the Public Service Company of New Hampshire in 1987. The current license will expire in 2048 and the project has recently transferred ownership to Central Rivers Power.

Upstream eel passage is installed and a downstream passage protection is provided via a bypass facility consisting of a 342-foot-long, 8-foot-deep floating louver array. The louver array extends upstream from the generating facilities to the reservoir shoreline to guide fish away from the generating facility intakes and towards a lowered flashboard on the spillway. At the time of this writing, the project does not have upstream anadromous fish passage facilities; however, USFWS has reserved authority to require such facilities during the term of the license, if necessary.

6.1.9.2 Ayers Island P-2456

Further upriver in Bristol, NH, is the Ayers Island Project. The concrete Ambursen dam is 699 feet long, has a 267-foot-long spillway and a maximum height of 72 feet from the toe of the dam to the crest of the spillway. On top of the spillway section, 7-foot hinged steel flashboards plus 1-foot wooden flashboards increase the dam's height. The dam impounds Ayers Island Reservoir, which extends ten miles upstream with a surface area of 600 acres and gross storage capacity of 10,000 acre-feet. The powerhouse at the east end of the dam contains three, 2.8 MW generating units with a total capacity of 8.4 MW.

The Commission issued the original license to the Public Service Company of New Hampshire in 1967. The project was licensed in 1997 with the current license expiring in 2036. The Ayers Island Project has recently transferred ownership to Central Rivers Power. The project includes a downstream bypass for migratory fish; however, there are currently no upstream passage facilities at the project. The USFWS has reserved authority to prescribe such facilities during the term of the license. There are at least three downstream dams, not including the USACE flood control dam that will require upstream passage facilities before fish can reach Ayers Island. Nonetheless, there is a significant amount of historical diadromous fish habitat in the reach between Eastman Falls and Ayers Island Projects, and above the Ayers Island Project, that could become accessible with upstream fish passage facilities.

6.2 Non-Hydropower and Natural Barriers

Due to early colonization and an industrial history, the Merrimack River watershed has a high concentration of barriers; there are around 3,000 dams in various states of use and disrepair. Stream crossings, such as bridges and culverts, make up an additional 4,450 potential barriers. Keeping a current list of the condition and degree of all this infrastructure is daunting and there is no definitive data source. Because crossings and barriers are numerous throughout the RFA, we focused on the sites that limit passage along the migratory corridor of the target diadromous species. In many cases, these barriers no longer serve the function for which they were built, and remain providing only historical interest. The following sections discuss select barriers based on location in our focus areas, proximity to hydroelectric projects where we are already working towards improved fish passage, and the amount of potential habitat if modified or removed (Figure 6).

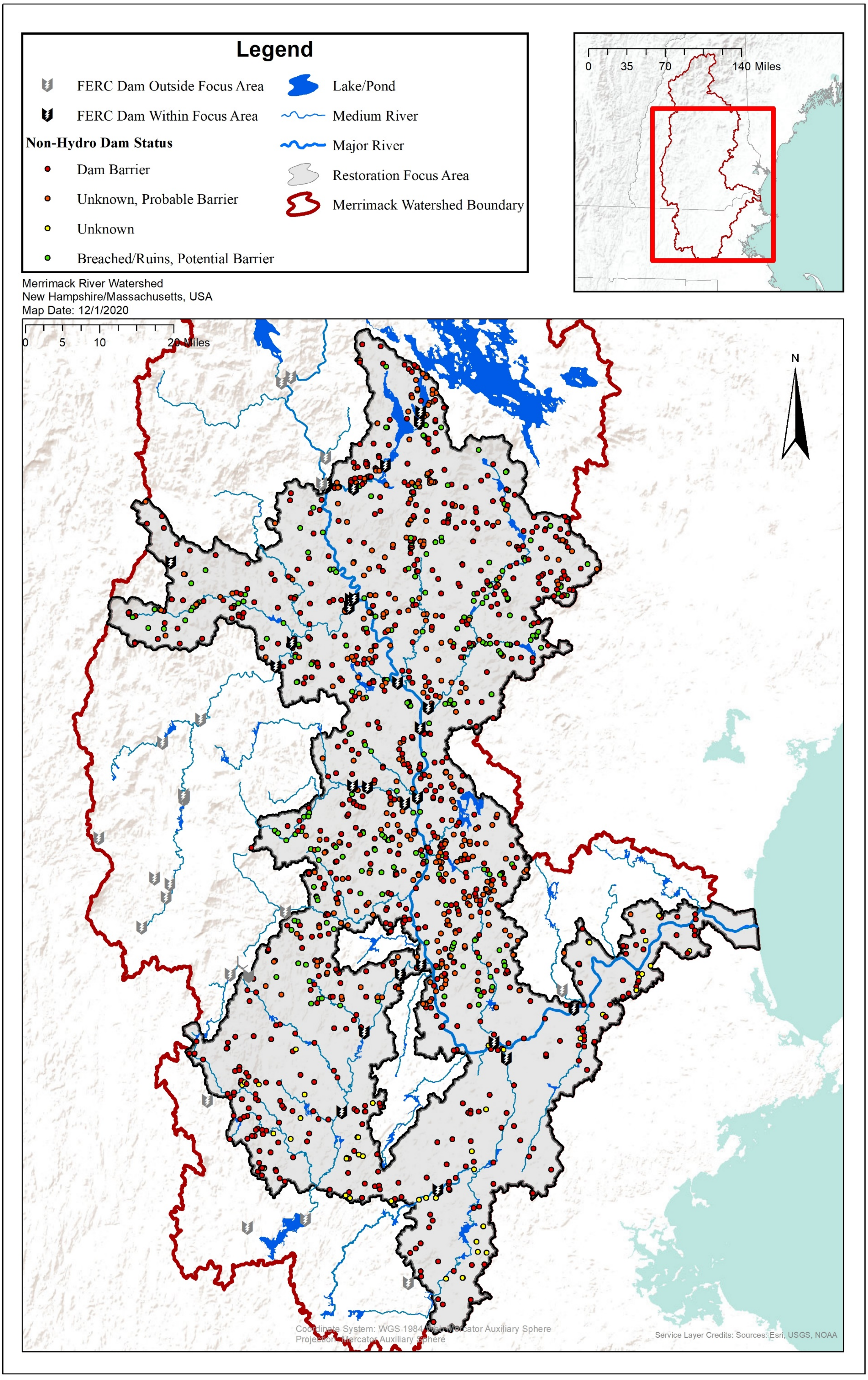

Figure 6. Barriers in the Restoration Focus Area

6.2.1 Merrimack River

The mainstem of the Merrimack no longer has non-hydropower dams. However, small tributaries located in the mainstem subwatershed have obsolete or ruined dams that impede access to a considerable amount of diadromous fish habitat. Many of these features are not well documented, and will require surveys to determine the degree of barrier they create. Below are two of the known restoration opportunities in this subwatershed.

6.2.1.1 Ottarnic Pond Dam

Ottarnic Pond Dam is located at the outlet of Ottarnic Pond, which is the source of First Brook near Hudson, NH. From Ottarnic Pond Dam, First Brook flows 1.5 miles southwest, over two more small dams to the Merrimack River. The pond has around 40 acres of alewife spawning and rearing habitat identified as a stocking location by the MRTC. In May of 2018, Ottarnic Pond was stocked with 1,200 adult river herring collected from the lift at Essex Dam. The success of this stocking is not known at this time. The relative ease for providing fish passage, amount of potential habitat, small size of the three barriers, and Ottarnic Pond's proximity to the Merrimack mainstem make it a good candidate for restoration activities.

6.2.1.2 Nesenkeag Brook Dam (Sawmill Brook Dam)

Five miles north of First Brook, Nesenkeag Brook flows into the Merrimack from the east near Litchfield, NH. This small, relatively free flowing brook has a considerable amount of river herring spawning habitat blocked by the obsolete Sawmill Brook Dam 0.5 miles above the confluence. There are a few catalogued dams in the upper watershed that require a field survey to determine accessibility. The small size of the Sawmill Brook Dam and the potential upstream habitat make this dam a good candidate for removal or installation of fish passage facilities.

6.2.2 Shawsheen River

The Shawsheen River is one of the largest watersheds in the Merrimack basin without hydropower development. Further enhancing the restoration potential is the low number of barriers in the watershed. With the recent removal of the Balmoral and Marland Place Dams in 2016-17, the Ballardvale Dam is the sole remaining barrier on the mainstem of the Shawsheen River that limits free access from the headwaters to the Atlantic Ocean. Following the dam removals, resource agency staff observed river herring at the base of the Ballardvale Dam.

Ballardvale Dam

The Ballardvale Dam impounds the Shawsheen River near the village of Ballardvale, MA. The first dam on the site was constructed in the mid-18th century and rebuilt in the 1830s. The dam provided hydropower for several industries over the past 200 years. The dam is obsolete and creates a complete barrier for anadromous passage, although some eels are able to make it upstream. Access to over 17 miles of the Shawsheen River as well as numerous tributary streams will become available once fish passage is provided.

6.2.3 Concord River

The Talbot Mills Dam is 4.5 miles up the Concord River in the town of Billerica, MA. The dam, rebuilt in 1828, is of stone-masonry construction and has a spillway that is about 127 feet long and 10.2 feet high. Earlier dams existed at this location with the first known dam erected in 1711. The aging dam no longer serves its industrial purpose and is now listed as a flood control structure. However, hydraulic analysis of the site has shown that the dam provides no flood control benefits and may actually aggravate flooding (MADMF 2016).

In addition to being obsolete, the dam is a complete barrier for anadromous fish and a partial barrier for American eel, blocking 35 river miles of mainstem habitat and 100 miles of tributary habitat. There are only two dams between Talbot Mills and the Atlantic Ocean; Essex Dam on the Merrimack, and Centennial Island on the Concord, both have upstream fish passage facilities. NOAA Fisheries Restoration Center and MADMF are working closely with the Talbot Dam owner to improve fish passage at the site with dam removal the preferred alternative pending engineering feasibility. Due to the large amount of habitat upstream, improving fish passage at this dam is a top priority in the Concord River Type I focus area.

6.2.4 Beaver Brook

Three dams located along the first three miles of Beaver Brook block access to over 15 miles of upstream mainstem habitat and numerous tributary streams. The first of these dams, Beaver Brook Dam, is located 0.5 miles from the mouth of Beaver Brook. The second dam is unregistered and was recently identified by the MA Office of Dam Safety as Unnamed Dam (MA03483) located half of a mile upstream of Beaver Brook Dam. The third barrier, Collinsville Dam, is located another 2.5 miles upstream, immediately north of the Lakeview Ave. bridge in Dracut, MA. Removal of all three of these dams is being discussed by the town of Dracut, MA, Division of Ecological Restoration, and the Office of Dam Safety. Due to the amount of potential upstream habitat and only one mainstem dam downstream, restoration projects in the lower Beaver Brook have great potential benefit.

6.2.5 Nashua River

The mainstem Nashua River has only hydropower dams, as described in section 6.1.3. In contrast, the three major tributaries to the Nashua River, the Nissitissit, Squannacook, and North Nashua Rivers, each have a number of potential and known barriers. These tributaries contain a significant amount of lotic and lentic diadromous fish spawning and rearing habitat. Surveys to categorize the barriers that remain on these rivers are necessary to determine the best candidates for removal or construction of fish passage facilities.

6.2.6 Souhegan River

With the removal of the Merrimack Village Dam in 2008, the McLane and Goldman Dams in Milford, NH became the next upstream obstacles for diadromous fish. These closely situated dams no longer serve the purpose for which they were built and a feasibility study to evaluate their removal was completed in 2010. These dams remain a focus for agency engagement. Baboosic Lake – the origin of Baboosic Brook – is another notable feature in the watershed. There is at least one dam (and a few ruins that may represent obstacles for passage) preventing alewife and other migratory fish from reaching approximately 230 acres of spawning habitat in the lake.

6.2.6.1 McLane Dam

About 14 miles upstream of the Merrimack confluence, the McLane Dam impounds the Souhegan River. The 18-foot-tall, 180-foot-long stone masonry spillway was originally built in 1846 and was reconstructed with concrete in 1992. The McLane Dam serves no function and increases the risk of flooding to upstream properties. The dam blocks migration for both resident and diadromous fish.

6.2.6.2 Goldman Dam

Immediately downstream of the Route 13 Bridge (0.25 miles above the McLane Dam), the Souhegan is impounded by the Goldman Dam. This dam was originally constructed in 1810 and rebuilt in the 1960s. The private trust-owned structure has a spillway of approximately 173 feet in length and a low-level outlet at the north end. Like the McLane Dam, Goldman Dam serves no function. Signs of aging, such as undermining of the concrete dam face, are visible. Passage at the McLane and Goldman Dams will open over six miles of historical diadromous fish habitat on the Souhegan River.

6.2.6.3 Stowell Pond Dam

Stowell Pond Dam is located on Baboosic Brook about 11 miles upstream of the Souhegan confluence. Stowell Pond Dam is the only confirmed barrier on Baboosic Brook; however, a few other dams (including the Baboosic Lake Dam) are present on Baboosic Brook that the state classifies as “in ruins”. These ruined dams will require surveys to the severity of the barrier to migratory fish. The Stowell Pond Dam has great potential for restoration through removal or fishway installation.

6.2.7 Cohas Brook

The first barrier on the Cohas Brook is Pine Island Pond Dam. The 70-foot-long dam is located around 1,000 feet upstream of the mouth of the brook. Constructed in the 1890s, the dam creates the 42-acre Pine Island Pond located at the west end of the Manchester, NH airport.

Cohas Brook supported a well-documented run of river herring and the pond is identified by the MRTC as alewife spawning and rearing habitat. Since 2011, Pine Island Pond has received 1,000 to 2,000 adult river herring annually. Although the height of this dam may make fish passage expensive, the proximity to the Merrimack mainstem and the presence of fish passage improvements at downstream dams suggest a potentially high biological return on investment.

6.2.8 Black Brook

Following the removal of Maxwell Pond Dam in 2009, access for diadromous fish was restored to approximately half of the mainstem Black Brook. Two barriers remain: Pierce Brook Dam, which the NH dam inventory classifies as "in ruins", and the Kimball Pond Dam at the outlet of Kimball Pond. Kimball Pond has around 90 acres of potential alewife spawning and rearing habitat that will be accessible if fish passage was provided at these two structures. The Pierce Brook Dam no longer serves any function and has deteriorated to the point that water leaks through the dam. These conditions negatively affect outmigration for diadromous fish reducing the viability of Kimball Pond as a stocking site for alewife. The Kimball Pond Dam maintains the water level of the Kimball Pond.

6.2.9 Suncook River

The China Mill Dam is the first barrier on the Suncook River. The hydropower facility is not federally-regulated. The project does not require a federal license because it began operation prior to the Federal Water Power Act (FWPA, 1920), and is therefore non-jurisdictional under the current FPA.[29] The dam impounds the river and diverts water through a 1,200-foot-long power canal less than half a mile upstream of the river mouth. The dam is roughly 150 feet in length and is a complete barrier to fish passage. The Suncook River watershed is a RFA because of the considerable amount of lentic spawning habitat in the river corridor. The China Mill Dam along with the Webster-Pembroke projects described in section 6.1.6, block anadromous fish access to the river. Although the non-jurisdictional status of the China Mill Project limits engagement, providing fish passage in the lower Suncook remains a priority.

6.2.10 Turkey River

The Turkey Pond complex is situated at the headwaters of the Turkey River. It comprises four ponds, Library Pond, Little Turkey Pond, Turkey Pond, and Turee Pond, containing over 400 acres of potential alewife spawning and rearing habitat. Two dams block access to the ponds (in addition to Garvin's Falls and Hooksett on the Merrimack): the Lower St Paul's School Pond Dam and the Turkey Pond Dam. Additionally, a few ruined dams are present on the lower Turkey River that are unlikely barriers. As passage improvements are made at Hooksett and

[29] In 1935 the FWPA was amended to create the Federal Power Act (FPA)

Garvin's Falls, these two barriers will be considered for improved access to the spawning and rearing habitat.

6.2.11 Pemigewasset River

A little less than three miles above where the Pemigewasset and Winnipesaukee join to form the Merrimack, is the Franklin Falls Dam operated by the USACE for flood control. The Franklin Falls Dam was completed in 1943. The dam is of earth fill construction with stone slope protection. It is 1,740 feet long and 140 feet high with a permanent pool of 440 acres and a flood storage area of 2,800 acres. In order for anadromous fish to reach this dam, fish passage will need to be provided at Hooksett, Garvin's Falls, and Eastman Falls Dams. The connectivity effects of Franklin Falls Dam are not known; however, due to its flow-through design, it is possible that fish may be migrate past the dam during certain river flows without major modifications. As restoration efforts advance at downstream projects, the ability of migratory fish to pass this site will need evaluation.

6.3 Stream Crossings

The Northeast Aquatic Connectivity Assessment Project 2.0 (NEACAP) produced a geospatial dataset that delineated road-stream crossing and other barriers to prioritize aquatic connectivity restoration projects across the 13-state region (Martin and Levine 2017). The NEACAP was carried out as part of the North Atlantic Aquatic Connectivity Collaborative (NAACC). The NAACC was funded from the North Atlantic Landscape Conservation Cooperative to help organizations in the Northeast align efforts that identify and prioritize repairs, upgrades, and replacements of road-stream crossings (https://maps.freshwaternetwork.org/northeast/).

Data obtained from the NEACAP included stream barrier types (crossings, dams, and natural barriers) and "passability scores" for migratory fish. The barriers in the dataset are broken into five classes; severe, significant, moderate, minor, and insignificant according to the NAACC Numeric Scoring System (NAACC 2015). NAACC (2015) noted that the relationship between barrier class (numeric score) and connectivity effects for aquatic organisms is unknown. This uncertainty is due to variations in individual fitness (proportion of a population that can successfully pass), swimming ability and endurance among different species (proportion of species that can successfully pass), and seasonal timing of the connectivity determination (flow regimes/environmental conditions under which a structure is passable). Nonetheless, these scores can be used to compare severity or prioritize barriers for restoration, and along with other data gathered during the NEACAP, comprise the best available information for the region.

We extracted only the road-stream crossings for our analysis. Dams were considered independently according to the methodology outlined in Section 5.1.4. The goal was to determine the degree to which impassable, or likely impassible crossings influence habitat connectivity in the RFA.

The Merrimack watershed has over 4,449 classified crossings, with the majority comprising insignificant or minor barriers (Table 7). Of these, 2,290 are located in the RFA. The vast majority of crossings are located on tertiary tributary streams that provide limited potential spawning habitat. In many cases, these crossings are above one or several impassable dams. For these reasons, we focused only on crossings on river or tributary reaches >50 feet wide, as these are most likely to affect restoration and fish production goals.

Based on these criteria, 51 crossings in the RFA have the potential to limit fish migration. Over 88 percent of these are classified as insignificant barriers, with just six falling into minor or moderate barrier classes. We estimate the impact of these crossings is of little concern at this time. Efforts to improve passage at dams outlined in sections 6.1 and 6.2 will have far greater impact on restoration goals. Nevertheless, opportunistic or targeted efforts to improve connectivity at stream crossings is viewed as beneficial to the watershed as a whole, and is encouraged where practical. We encourage all retrofits, repair, and replacements of existing stream crossings to follow the stream simulation design approach outlined by U.S. Forest Service (USFS 2008).

Table 7. Merrimack River Watershed Stream Crossings

NAACC Passability Description	# Crossings in Merrimack River Watershed	# Crossings in Restoration Focus Area (inclusive)	# Crossings in Restoration Focus Area (located on reaches with a mean width >50 ft.)
Insignificant Barrier	1,251	548	45
Minor Barrier	2,528	1,399	3
Moderate Barrier	630	325	3
Significant Barrier	36	15	-
Severe Barrier	4	3	-
Total	4,449	2,290	51

7.0 DESCRIPTION OF TARGET SPECIES

We evaluated the restoration potential for each of the target diadromous species using a set of factors including:

- the biological and life history characteristics of each species,
- historical and current distribution,
- individual habitat requirements,
- recreational utilization,
- interactions with other diadromous and freshwaters fish species,
- previous and current management strategies, and
- inaccessible potential habitat.

We combined this information with the results of the barrier inventory to inform our approach for species restoration.

The current extent of diadromy in the Merrimack watershed is significantly less than the historical extent (Figure 7). Prior to modern scientific surveys in the early 20th century, information regarding species distribution is anecdotal. Anthropogenic barriers and fragmented migration corridors were already widespread by the time biological surveys were conducted. Our approach to estimating the range prior to industrialization was to identify the natural barriers in the watershed and assume diadromous fish colonized all accessible habitat. Most of the natural barriers in the watershed are located on minor tributary streams and in the Pemigewasset watershed above Livermore Falls[30] (Figure 3). This suggests that the majority of mainstem and major tributary habitats were historically accessible for diadromous species. To validate this approach, we evaluated the data from Dauwalter et al. (2012) summarizing the documented historical range of diadromous fish in several Atlantic coast watersheds including the Merrimack (Figure 7).

[30] Considered the likely natural extent for target species on the Pemigewasset, with the possible exception of American eel

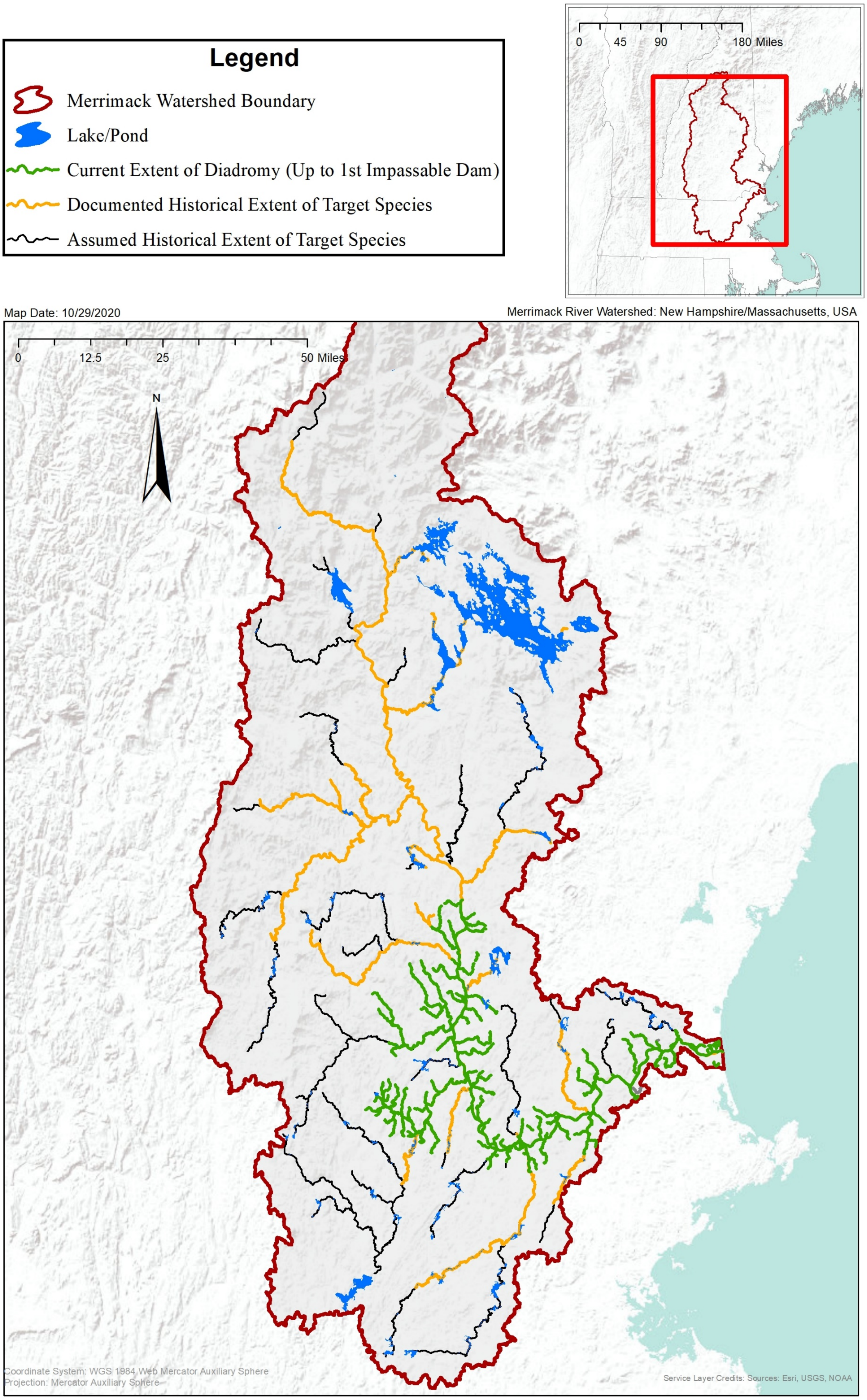

Figure 7. Historical and Current Extent of Diadromy in the Merrimack River Watershed

7.1 American Shad

American shad are an anadromous pelagic species native to the Atlantic coast of North America. Their current distribution is from the St. Lawrence River in Canada to the St. Johns River in Florida (Greene et al. 2009). American shad spend the majority of their lifespan (up to 13 years) in marine waters, before returning as adults to coastal rivers to spawn. Shad migrate long distances homing to natal rivers. Historical records indicate adult shad have migrated over 500 miles up unimpeded rivers during the spawning run (Limburg et al. 2003). On rivers impeded or blocked by barriers, shad are able to migrate using fishways over 200 miles on the Connecticut River (Leonard and McCormick 1999) and over 300 miles on the Columbia River (Harrison 2007). American shad prefer to spawn in upstream and mid-river segments until energy reserves or water temperatures no longer facilitate spawning (Bilkovic et al. 2002). American shad are broadcast spawners with semi-buoyant eggs and females will spawn multiple times during migration. Northern populations of American shad are iteroparous, meaning they have multiple reproductive cycles over the course of their lifetime (e.g., repeat spawners). In northern latitudes, repeat spawners are particularly important due to higher lifetime fecundity rates and reduced annual variability of spawning stock size (Harris and Hightower 2012). For more detailed life history information on American shad see ASMFC (2020)

7.1.1 Habitat Requirements

American shad require various habitats throughout their life cycle, primarily using the mainstem of the rivers for spawning, larval, and juvenile nursery habitat (ASMFC 2010). Favorable spawning substrate includes areas with larger substrate such as gravel; however, American shad will spawn in habitat with widely varied substrate size, from silt to large rocks and boulders (Walburg and Nichols 1967; Bilkovic et al. 2002). The optimum depth range for spawning American shad (and for all life stages) is between 1.5 and 6 meters (5 to 20 feet) (Stier and Crance 1985; Greene et al. 2009). Optimal spawning temperatures are in the range of 14-21 °C (57-70 °F) (Stier and Crance 1985). However, American shad will spawn at a broad range of temperatures from 8-26 °C (47-79 °F) and non-optimal water depths. Shad demonstrate a preference for moving water, Bilkovic (2000) found the optimal water velocity range for shad eggs and larvae is 0.3 to 0.7 meters per second (one to 2.3 feet per second).

American shad eggs and larvae are deposited near spawning areas. Favorable habitat for egg development are areas with extensive woody debris and deep pools away from the shoreline that provide predator avoidance and prey items for larval and juvenile American shad (Chittenden 1969). Survival rates of American shad eggs are higher in these habitats with extensive debris, large substrates (rocks, rubble), and water velocity that prevent finer grained substrates from settling and suffocating the eggs (Walburg and Nichols 1967).

Larvae transform into juveniles 3 to 5 weeks after hatching. Juveniles disperse downstream of the spawning areas, generally staying in the same river for the summer (McCormick et al. 1997). Most juveniles in river systems in the northern Atlantic states will begin their seaward migration when water temperatures are between 18 °C (65 °F) and 26 °C (79 °F) (Watson 1970; Marcy Jr 2004).

Adult shad are pelagic, migrating great distances in marine habitats. They typically live for 5 to 7 years, remaining in the ocean for 2 to 6 years before reaching sexual maturity and returning to freshwater to spawn (Greene et al. 2009). For further reading on shad habitat requirements and preferences at each life stage, refer to Greene et al. (2009).

7.1.2 Recreational Fishery

Angling for American shad is currently permitted in both the New Hampshire and Massachusetts portions of the Merrimack River pursuant to state regulations. New Hampshire does not permit harvest of shad, and the recreational fishery is limited to catch and release. Massachusetts allows anglers to take three shad per day from the Merrimack River without size restrictions and seasonal closures. The number of anglers who actually pursue shad in the watershed is unknown, but likely very few. A larger shad population resulting from successful restoration activities is likely to expand the recreational fishing opportunities and increase angler interest in this species as a result.

7.1.3 Competition, Predation and Interaction with Inland Fishery

American shad have various predators throughout their life cycle. American shad eggs and larvae are prey for any larger fish (Greene et al. 2009). Numerous native and introduced fish species including: black bass (large and smallmouth), chain pickerel, and northern pike, contribute to predation of juvenile shad in freshwater. Larger predators such as striped bass, Atlantic cod, and monkfish are known to consume juvenile American shad (McDermott et al. 2015). One study in the Connecticut River documented a drop in American shad abundance with an increase in striped bass populations (Savoy and Crecco 2004). Once in the ocean, shad are a schooling species consumed by numerous piscivores. American shad also serve as a prey base for riparian fish, birds, and other species entering coastal rivers when other prey are limited and the nesting and breeding season begins for numerous wildlife species (ASMFC 2010). Information on specific competitor species for American shad is limited; however, we expect multiple fish species (resident and migratory) utilize the same habitats and forage on the same prey.

7.1.4 Previous and Current Management/Monitoring Activities

Coast-wide annual landings of American shad have decreased dramatically from 50 million pounds in the early 1900s to 3.8 million pounds in the 1980s (ASMFC 2010). In response to the decline, the Atlantic States Marine Fisheries Commission (ASMFC) completed a Cooperative Interstate Fishery Management Plan (FMP) for American shad in 1985 (ASMFC 1985). This FMP recommended management measures that focused on regulating exploitation and promoting stock restoration efforts at the discretion of individual states with regulatory authority (ASMFC 2010). In 1994, the plan review team and management board determined that the original FMP was insufficient in protecting and restoring the remaining stocks, leading to the adoption of Amendment 1 to the FMP in 1999 (ASMFC 1999). Amendment 1 established benchmarks that created a ceiling for directed fishing mortality. This ceiling was in effect until the adoption of Amendment 3 in 2010. Amendment 3 incorporates the recommendations of the ASMFC stock assessment (ASMFC 2007) that accounted for human-induced instantaneous mortality (e.g., directed fishing, dams, pollution, and bycatch) and natural mortality to establish benchmark values for total instantaneous mortality. Under Amendment 3, states are required to monitor bycatch of American shad in jurisdictional waters and submit sustainable fisheries management plans for areas open to commercial or recreational fisheries.

Prior to the installation of fish passage facilities at the Essex Dam in Lawrence, MA, and the Pawtucket Dam in Lowell, MA, the restoration plan for American shad focused on collecting shad eggs from Connecticut River adults. From 1969 to 1978 over 25 million eggs were transported and seeded into various Merrimack River locations (MRTC 1997). By 1979, the stocking effort transitioned from seeding eggs to transporting adult shad from the Connecticut River. Connecticut River adult shad translocation continued from 1982 until 1996. By the mid-1990s the restoration effort shifted from out of basin transfers to collecting adult shad at the Essex fish lift and releasing them at several upriver locations. Since 2009, a portion of the adult shad captured at Essex are transported to the USFWS Fish Hatchery at Nashua, NH. At the hatchery, adults are spawned and fertilized eggs are cared for until they hatch. The fry, at about 10 days old, are released upstream from the Merrimack mainstem dams near Boscawen, NH. Recently, some fry have also been released in the Nashua River. American shad stocking information is in Appendix A (TABLE A 4). In addition to the stocking effort, annual numbers of returning adult shad are counted at the fish lift located at Essex Dam (TABLE A 1). Shad management is a collaborative effort between state and federal agencies and other partners. The overarching goal established by the MRTC is to restore a self-sustaining annual migration of American shad to the Merrimack River watershed, with unrestricted access to all spawning and juvenile rearing habitat throughout the main stem of river and its major tributaries (MRTC 2010). Section 12.0 details the specific objectives and recommendations that will achieve this goal.

7.1.5 Distribution and Potential Habitat

The historical American shad distribution in the Merrimack River Watershed included the entire mainstem. In addition, major tributaries such as the Concord, Nashua, and Winnipesaukee Rivers supported runs of shad extending as far as Lake Winnipesaukee (Figure

8). Spawning occurred in Lake Winnipesaukee and in suitable areas on the mainstem and major tributary rivers. Livermore Falls, a natural barrier on the Pemigewasset, was likely the northern extent of shad distribution in the watershed. The construction of the Essex Dam in Lawrence, MA effectively eliminated the shad run with only a small remnant population persisting below the dam (MRTC 2010). Early attempts to create fish passage on mainstem dams was ineffective. When Essex and Pawtucket Dams were redeveloped in the 1980s with more contemporary fish passage structures, the population began to rebound after stocking. The present day range ends at Hooksett Dam on the mainstem and at Talbot Mills Dam and Pepperell Dam on the Concord and Nashua Rivers, respectively. Spawning habitat is limited to areas with fish passage on the Merrimack River, MRTC (2010) summarizes current and potential nursery habitats in the mainstem and major tributaries.

According to our analysis (described in section 5.1.3), there are over 19,100 lotic surface acres of American shad habitat in the Merrimack River watershed with 7,200 (38 percent) of these acres currently accessible. In the accessible reaches, passage inefficiencies due to poor facility design or seasonal flow regimes limit restoration goals. Removing all dams is the most effective way to restore connectivity. However, we recognize this is not a feasible solution. Prioritizing specific dams for removal or modification based on the amount or quality of upstream habitat will maximize benefit while minimizing necessary effort and expense. For example, providing fish passage at five select dams (Hooksett, Garvin's Falls, Talbot Mills, Pepperell, and Kelley's Falls) opens over 3,500 acres of shad habitat; nearly double the current amount. Restoring access to these habitats is necessary to realize restoration goals and allow the shad population to reach sustainable levels. Specific watershed-based recommendation are discussed in Section 12.0.

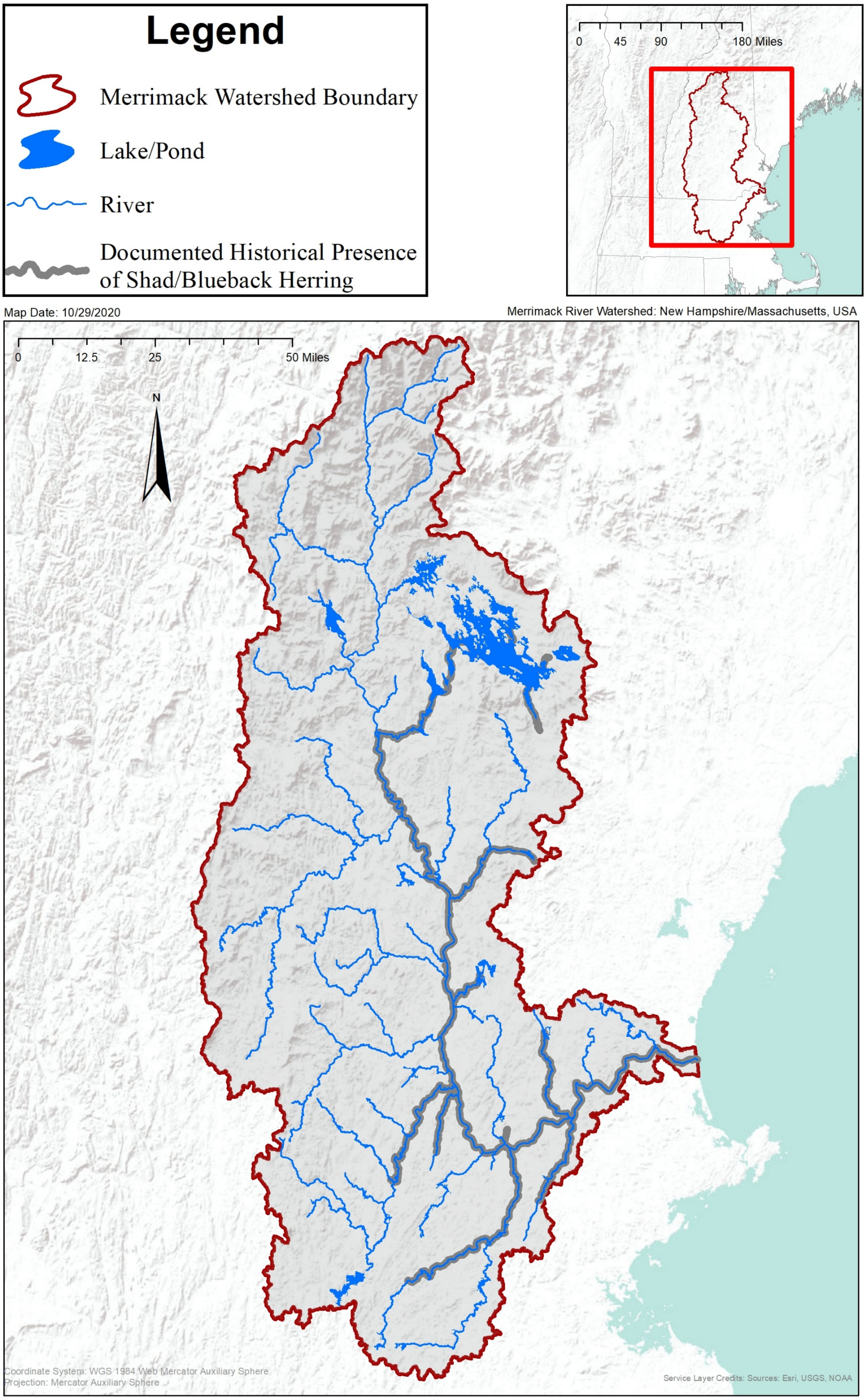

Figure 8. Historical American Shad and Blueback Herring Distribution in the Merrimack River Watershed

7.2 River Herring

Alewife and blueback herring—collectively called river herring—are anadromous fish with a range extending from Cape Breton, Nova Scotia, to the St. Johns River in Florida (Greene et al. 2009). In the northern part of the range (including the Gulf of Maine), alewife are more abundant than blueback herring. In the southern part of the range, this trend reverses and blueback herring are more prevalent (Schmidt et al. 2003). River herring are a schooling fish that spend most of their lifespan in the ocean before returning to freshwater to spawn (Collette and Klien-MacPhee 2002). River herring are iteroparous homing to the same watershed to spawn (Fay et al. 1983). Iteroparity provides repeat opportunities to diversify the genetic pool in a watershed population. River herring can diversify their population genetics by spawning with multiple subpopulations in a single watershed (Palkovacs et al. 2008; Maryland Sea Grant 2009). Adult river herring are fairly strong swimmers, but rarely leap out of the water column to pass obstacles (Castro-Santos 2005). Unlike salmonids, river herring prefer streaming flow and may become disoriented by plunging and turbulent flow. River herring migrate in large schools that often overwhelm upstream fishways.

River herring eggs are demersal in still water or adhesive and pelagic in flowing water during the initial release from the female (Loesch and Lund 1977; Jones et al. 1978; Mullen et al. 1986). After a 24-hour hardening period, the eggs enter the water column (Fay et al. 1983). Time to hatching is temperature dependent, with warmer temperatures resulting in a shorter incubation period (Fay et al. 1983). River herring larvae develop through two stages—a yolk-sac stage and a larval stage. The yolk-sac stage begins upon larvae hatching from the egg until the yolk-sac is fully absorbed, which only lasts a few days for river herring (Jones et al. 1978). The larval stage is the final stage before transformation into juvenile river herring. River herring larvae exhibit habitat selection by preferring salinities of 12 parts per thousand or less and moving downstream from their original spawning grounds (Dovel 1971). River herring larvae can be found in both calm and flowing waters but tend to avoid habitat with fast-flowing waters, such as the center of a river channel (Walsh et al. 2005).

Although river herring are often grouped together, as they are in this CP, there are important distinctions between these two species that influence management strategies.

7.2.1 Alewife

Adult alewife are distinguished from blueback herring by their comparatively larger eyes (diameter is larger than snout length) and the pale color of the peritoneum. Scale imbrication pattern and meristic counts can also be used to separate the species. In addition to morphology, the phenology of alewife is divergent from blueback herring. Alewife exhibit two discrete life-history variants in the form of land-locked (freshwater resident), and anadromous (sea run) populations (Palkovacs et al. 2008). Anadromous alewife use coastal rivers to access lentic habitats with the majority of spawning occurring in lakes and ponds, though alewife are capable of spawning in still water and oxbows in the river corridor (Mullen et al. 1986). Thunberg (1971) examined the olfactory response of alewife when presented with a choice between natal and nearby waters suggesting alewife have a strong homing preference. Others have reported that despite this homing behavior, considerable stock mixing occurs (Mullen et al. 1986). Alewife in the Merrimack River begin the spawning run in late April and early May when water temperatures reach 10.5 °C (51 °F) (Cianci 1969). The spawning run concludes before July and precedes other alosine species by a few weeks. Alewives have exhibited a preferred diel migratory behavior based on light and temperature (Mullen et al. 1986). In general, alewives migrate upstream during the day within a preferred temperature range (i.e. early year spawners will peak during the warmest time of the day and late year spawners will peak during the coolest time of the day). Adult alewives emigrate shortly after spawning. Alewife eggs typically hatch out after 3 days at 22°C (72 ºF) and 6 days at 16 °C (60 ºF) (Kircheis et al. 2004). Juvenile alewives grow in freshwater for one to several months, emigrating from freshwater during August to November (Saunders et al. 2006). Juvenile emigration occurs rapidly as large schools of fish influenced by precipitation events resulting in transient decreases in water temperature and increases in stream flow (Gahagan et al. 2010). Alewife may remain in ponds until sufficient flows flush the waterbody, in some cases the following spring (Dovel 1971).

7.2.2 Blueback herring

Blueback herring can be distinguished from alewife by their smaller eye, which has a diameter less than or equal to snout length. The peritoneum of blueback herring is dark and dusky. Exterior coloration tends to blue to blue-green dorsally compared to the grey-green dorsal coloration common among alewife (Mullen et al. 1986). Blueback herring tend to be smaller than alewife. In the Gulf of Maine, blueback herring typically begin their upstream spawning migration in mid-May (Saunders et al. 2006) depending on when water temperatures exceed 14 °C (57 °F) (Loesch and Lund 1977). Blueback herring spawning migrations typically peak in mid-June, a few weeks after the peak of the alewife spawning runs (Mullen et al. 1986). Post-spawn adults migrate rapidly downstream after spawning usually leaving the spawning area within five days (Loesch and Lund 1977). Juvenile blueback herring migrate to the ocean from August through November in the Gulf of Maine (Saunders et al. 2006).

7.2.3 Hybridization

Alewife and blueback herring maintain reproductive isolation due to spawning temperature and habitat preferences resulting in asynchronous spawning (Hasselman et al. 2014). However, river herring are capable of hybridization despite the species diverging up to one million years ago (Faria et al. 2006). A genetic investigation by Faria et al. (2006) detected a shared mitochondrial DNA haplotype between the species, suggesting introgressive hybridization. Migration delays and barriers caused by dams and inefficient passage structures may increase the occurrence of hybridization. In the Merrimack watershed, there is little evidence that hybridization is currently a management concern. Population monitoring will diagnose any future issues that may arise from hybridization, see Sections 12.2.3 and 12.2.4.

7.2.4 Habitat Requirements

River herring have species-specific spawning habitat needs including varying water flows, substrate types, and water temperatures. In free flowing systems, there is considerable separation both spatially and temporally between the spawning activities of blueback herring and alewife (Fay et al. 1983). Both species migrate far upstream to reach suitable spawning habitat.

Alewife spawning habitat consists of lakes, ponds, and sluggish waters in rivers and small streams (Pardue 1983). Alewife spawning begins with water temperature changes and occurs in littoral zones of lentic ecosystems with a gravel or vegetated substrate (Jones et al. 1978; Greene et al. 2009). Optimal spawning temperature for alewife in central New England ranges from 12 to 16 °C (55-60 ºF) (Kircheis et al. 2004). While more successful in natural streams and ponds, alewife may successfully spawn in eddies, pools and lentic waters created by dams (Greene et al. 2009). Blueback herring prefer to spawn and rear in flowing water over hard substrates along banks and shoals in the mainstem and major tributaries (Loesch and Lund 1977). Their preferred spawning habitats more closely overlap with those of American shad than with alewife. Both alewife and blueback herring cease spawning when water temperatures reach 27 °C (81 °F) (Brady et al. 2005).

Juvenile river herring thrive in freshwater streams for the first few months of their life, but there is little information on the habitat requirements. Juvenile alewife grow in lentic water with the growth rate dependent on the quality of food sources available in the nursery habitats, with more productive habitats resulting in faster growing and larger juvenile alewife (ASMFC 2012a). Vertical diel migration occurs in both species, with fish near the bottom of the water column during the day and near the surface at night (Loesch et al. 1982).

7.2.5 Recreational Fishery

Due to their diet, river herring are seldom caught by traditional rod and reel anglers. Instead of catching river herring for consumption, most anglers target these species to use as bait for larger species. Gill nets, seines, and dip nets are used to harvest these fish. Although conditions in Maine allow regulators to continue to support a recreational fishery for these species, New Hampshire and Massachusetts have many restrictions, with the latter prohibiting take of either species since 2006. In New Hampshire, recreational take is limited to a few rivers and coastal areas, and statewide, all harvest is prohibited on Wednesdays[31] to allow for escapement.

[31] Most rivers where take is allowed have additional special restrictions on timing and method of capture

7.2.6 Competition, Predation and Interaction with Inland Fishery

River herring primarily feed on zooplankton, including copepods, amphipods, and shrimp during each life stage; though migrating adults reduce feeding (Collette and Klien-MacPhee 2002; Greene et al. 2009). Anadromous alewives exhibit size-selective[32] predation on zooplankton that can seasonally affect zooplankton community structure, while landlocked alewives have phenotypic variations that do not produce the same communal zooplankton shifts (Palkovacs and Post 2009). Alewives also feed on other fish larvae including eels, other herring, and fish eggs (Collette and Klien-MacPhee 2002). Larval stage river herring feed on smaller zooplankton species than adults, with the size of their food source increasing with growth. Both alewife and blueback herring show some prey selectivity in the larval stage (Pardue 1983).

River herring may compete with residential freshwater species for food and spawning habitat. Studies evaluating the interspecific competition are limited. Much of the available information regarding interspecies competition has focused on landlocked populations of alewives. Anecdotal information about interspecies competition arose in the 1990's. Some suggested that reintroduced alewife affected the food availability for popular recreational species such as smallmouth bass. In 1995, the State of Maine closed the fishways on the St. Croix River in response to concerned anglers causing an alewife population collapse. One study examined the connection between alewife population growth and the decline of smallmouth bass (*Micropterus dolomieu*) in several lakes in the St. Croix River watershed (Willis et al. 2006). Results of the study indicated the presence of alewife did not slow smallmouth bass growth and diets between the two species do not overlap (Willis et al. 2006).

River herring are a source of prey for many fish and wildlife, including predatory game fish, mammals, and birds of prey (MDMR 2016). Adult freshwater mortality rates are high and vary based on location and spawning year. One study reported 90.7 percent of the alewife spawning population in Love Lake, ME did not survive the migration (Havey 1973). Striped bass are an important predator of river herring and may influence their population size. In the state of Connecticut, the striped bass population size has increased and has been attributed to a decline in river herring numbers (Savoy and Crecco 2004). The seasonal migrations of river herring historically contributed a significant food source to the coastal system (Hall et al. 2012). Restoration of river herring to coastal rivers has the potential to support the sustainability of the ground fishery (McDermott et al. 2015).

7.2.7 Previous and Current Management/Monitoring Activities

Alewife and blueback herring stocks across their range have declined considerably from their historical abundances (ASMFC 2009; NMFS 2013). Both species may serve as important

[32] Showing preference for larger body size zooplankton

prey for federally managed groundfish stocks (Ames 2004). In addition, both species have been designated a Species of Concern by NMFS.[33] On August 5, 2011, NMFS received a petition from the Natural Resource Defense Council to consider listing alewife and blueback herring as threatened species. On August 12, 2013, NMFS published a determination that listing alewife and blueback herring was not warranted at the time, but acknowledged that populations of both species were at historically low abundances and committed to revisiting the status of both species within three to five years (78 FR 48944, August 12, 2013). In March 2017, a D.C. district court vacated the finding that listing blueback herring under the Endangered Species Act was not warranted. On June 19, 2019, NMFS issued a new listing determination that concluded listing alewife and blueback herring was not warranted at the time (84 FR 28630).

River herring were historically abundant in the Merrimack River watershed, and were among the first commercially harvested species in the colonies (MRTC 2019). As early as 1754, the New Hampshire legislature passed laws out of concern for protecting the river herring run. In Cohas Brook, which flows out of Massabesic Lake, a law was enacted requiring (under penalty of fine) mill owners to keep passageways open at their dams between April 5 and the end of May to allow river herring to reach the lake (Noon 2015). Many early conservation efforts for river herring in the Merrimack were ancillary to the restoration of Atlantic salmon. The 19th century fish ladders at Essex, Pawtucket, and Amoskeag Dams were designed to allow adult salmon to reach hatchery facilities near Livermore Falls with some potential benefit to alosines. Early records from the New Hampshire Fish and Game Commission in 1879 and 1882 documented runs of alewife observed at the Essex Dam. Fish passage was not provided consistently at the dams above Amoskeag effectively extirpating the river herring population in the upper Merrimack River. During the 20th century, much of the restoration effort still focused on Atlantic salmon. However, with the establishment of the MRTC in 1969, alosines became a management focus.

Modern attempts to restore river herring, along with other diadromous species, began with new fishway construction at the first three dams on the lower Merrimack River mainstem. In 1984, inter-basin transfers of river herring began with adult fish collected from several New England Rivers[34] and released in Lake Winnisquam and other locations in the watershed (TABLE A 5). The alewife stocked in Lake Winnisquam were originally intended to provide nutrient export and salmonid forage. An unintended consequence of this stocking effort was a remarkable return with passage of over 400,000 fish at Essex Dam five years after the initial stocking. Fishery managers and infrastructure were unprepared for this large influx of fish and most of the river herring were unable to access spawning habitat (MRTC 2019).

The short-lived increase in river herring abundance shrouded the underlying issue of poor habitat connectivity. The run declined soon after the stocking effort ceased (TABLE A 1,

[33] https://www.greateratlantic.fisheries.noaa.gov/protected/pcp/soc/index.html
[34] Primarily the Androscoggin and Royal Rivers in Maine.

TABLE A 4). From 1992 to 1994 no stocking occurred resulting in the return of 51 adult fish in 1996. Intra-basin trap and transport efforts to restore river herring to the Merrimack River began in 1989 as a partnership between the USFWS and NHFGD. Fish were collected at the Essex and Amoskeag Dams and released at various locations[35] throughout the watershed – primarily above impassable dams. In addition to Lake Winnisquam, other locations that have received stocked fish include the Nashua River, Northwood Lake, Pine Island Pond, Potanipo Pond, Eastman Falls impoundment, Suncook Lake, and Silver Lake. Since 2010, the number of river herring trapped and transported has been consistent and increasing each year. The river herring population has responded positively to this effort. However, stocking is a temporary management solution. Passage must be improved and volitional access to spawning habitat restored for the Merrimack River watershed to support a sustainable run of river herring.

The current river herring management framework is a collaborative effort between natural resource agencies, dam owners, and other stakeholders with the overarching goal of restoring a sustainable river herring population to the Merrimack River (MRTC 2019). Section 12.0 details objective and recommendations designed to help managers meet this goal.

7.2.8 Distribution and Potential Habitat

River herring were historically abundant and widespread in the Merrimack River watershed (Figure 8 and Figure 9). River herring were a regionally important resource for the First Nations and the European settlers. As an example, the New Hampshire legislators began implementing laws for protection of river herring in Cohas Brook as early as the 1750s (Noon 2015). Though mill dams were common on smaller tributaries by 1800, the first anthropogenic barriers to affect river herring on the mainstem Merrimack River were the Pawtucket and Essex Dams (ca. 1840s). Essex Dam halted river herring movement upstream restricting migration to the tidal zone and eight miles of the Merrimack mainstem.

Historical data on river herring populations are minimal relying mostly on anecdotal accounts, despite the size and regional importance of the Merrimack watershed. Efforts to restore herring runs on the upper Merrimack began as early as 1830 with the installation of a fish ladder at Amoskeag Dam, and later at Pawtucket and Essex Dams. Early efforts to allow fish passage at dams were ineffective - leading to the functional extirpation of river herring from the upper watershed.

In the 1970s, efforts were made to refurbish the existing fish ladders at Essex and Pawtucket Dams (cleaning out debris, etc.) such that under certain flow conditions, fish used these facilities (MRTC 1997). During the development of the hydroelectric facilities in the 1980s, fish passage facilities at the first three dams on the mainstem were modernized. Adult fish

[35] More than 60 stocking sites have been used since 1984; however, the eight listed (Lake Winnisquam, Nashua River, Northwood Lake, Pine Island Pond, Potanipo Pond, Eastman Falls impoundment, Suncook Lake and Silver Lake) have received >75% of all stocked river herring during that time.

were also released upstream of dams through intra- and inter-basin trap and transport. Trap and transport continues today, but progress is limited by the capacity of collection facilities and fish trap inefficiencies (MRTC 2019). Despite these obstacles, trap and transport is an interim measure that has increased the population. However, past attempts to restore river herring to the Merrimack have proven unsustainable, and a lack of habitat connectivity for returning adults remains the primary concern. Improving access to historic spawning grounds and strengthening the link between marine and freshwater habitats is crucial to the recovery of these fish.

Distributions and abundance are estimated by reviewing footage from the passage facilities at Essex and Pawtucket Dams and through visual observation at other dams in the watershed. Additionally, a presumed range can be established by mapping the currently accessible habitats facilitated by fish passage structures.

7.2.8.1 Alewife

Alewife historically spawned in lakes and ponds connected with the ocean. Significant spawning habitats included Lake Winnisquam (and possibly Lake Winnipesaukee), Massabesic Lake, and a number of lentic waters in the Suncook watershed. Today, there are few volitionally accessible lakes, and successful spawning is heavily reliant on trap and transport efforts. The impoundments created by major dams in the watershed have created river reaches that provide spawning habitat, though likely less productive.

Considering the life history and spawning habitat preferences of alewife; the current state of connectivity is extremely poor. MRTC (2019) identified 6,332 acres of lentic[36] habitat capable of supporting a sustainable run of fish. Of this potential spawning habitat, less than 6 percent (approximately 364 acres) is accessible for alewife. Without aquatic connectivity, stocking continues to be a necessary management action for alewife. Providing access to these lentic waters is essential to allow the stock to become self-sustaining.

7.2.8.2 Blueback Herring

Based on anecdotal accounts, historical blueback herring spawning grounds included the mainstem Merrimack River, major tributaries such as the Concord, Nashua, and Shawsheen, as well as numerous minor tributaries (Figure 8). Like shad, the upstream extent was Livermore Falls on the Pemigewasset.

Blueback herring access less than half of their historical spawning range in the Merrimack watershed. Passage inefficiencies due to poor design and operation and maintenance lead to delays and passage failures in the reaches that are accessible. Prioritizing specific dams for removal or modification based on the amount or quality of habitat blocked can maximize

[36] In addition to lakes and ponds, term lentic in this analysis includes a few impounded or sluggish river reaches that are suitable for alewife spawning (e.g. the Mine Falls impoundment)

benefit while minimizing necessary effort and expense. Similar to American shad, providing fish passage though removal or modification of just five select dams (Hooksett, Garvin's Falls, Talbot Mills, Pepperell, and Kelly Falls Dams) would open up over 3,500 acres[37] of potential habitat; nearly doubling the habitat above the Essex Dam. Restoring access to these habitats is necessary to meet restoration goals and allow the blueback herring population to reach sustainable levels.

[37] In the case of blueback herring, this number is likely even higher because this species is known to spawn in smaller tributaries than shad (in addition to the reaches also suitable for shad), increasing the total amount of potentially usable habitat.

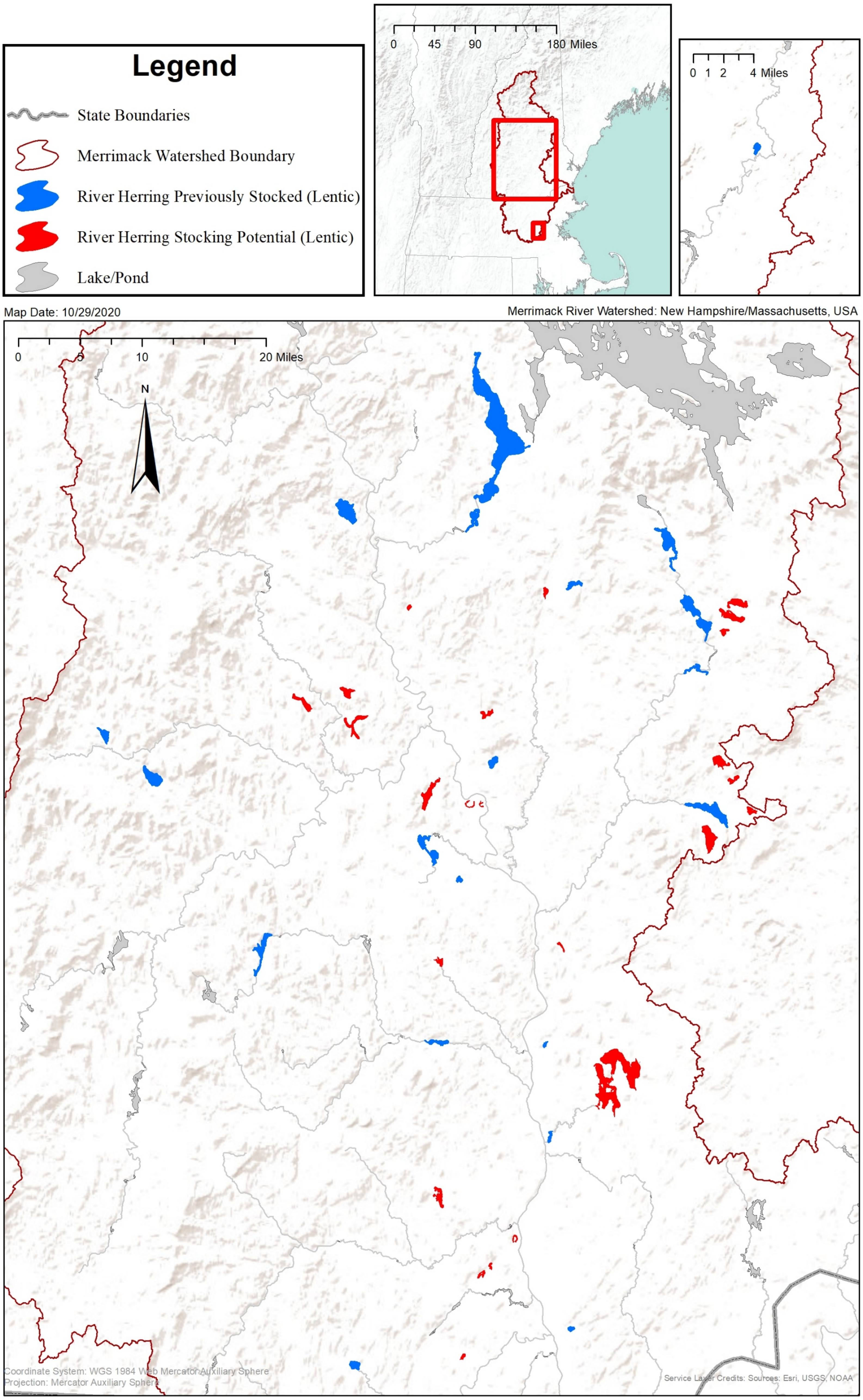

Figure 9. Previous and Potential River Herring Stocking Locations in the Merrimack River Watershed

7.3 American Eel

American eel exist in freshwater, estuarine, and coastal waters from the southern tip of Greenland, along the Atlantic coast of North America, into the Gulf of Mexico and southward to the northern portion of the east coast of South America (Facey and Van Den Avyle 1987). The American eel is the only catadromous species that inhabits the Merrimack basin. American eel spawn and die in the Sargasso Sea. American eel larva, called leptocephali, drift on ocean currents (i.e. no homing behavior) until transforming into glass eels as they approach the continental shelf. Glass eels become elvers by gaining pigment and size when entering freshwater habitats.

Elvers inhabit streams, rivers, lakes and ponds, tidal marshes and estuaries typically seeking muddy substrates and quiescent waters. Elvers can occupy nearly any habitat type, including burrows, tubes, woody debris, inundated man-made structures, and other shelter substrates (Facey and Van Den Avyle 1987). Elvers have the ability to traverse and climb wetted surfaces for long distances providing opportunity to occupy habitat that would otherwise be inaccessible (Collette and Klien-MacPhee 2002; Shepard 2015). Eels are anguilliform swimmers with poor swimming ability for their body size (Solomon and Beach 2004). Adult American eel (called yellow eels) inhabit benthic areas of streams, rivers, lakes and ponds, tidal marshes and estuaries for 10 to 25 years before transforming into silver eels that migrate back to the ocean (Collette and Klien-MacPhee 2002).

Silver American eels leave continental waters in the late summer and fall to undertake a migration to the Sargasso Sea spawning grounds. The spawning migration occurs in August through October in the northern portions of the range, and from October to December in the Mid-Atlantic States and may continue until March in the southern United States. The extensive geographic dispersal and migration distances make American eel difficult to study (Shepard 2015). Additionally, because eel are long-lived, abundance indicators from any life stage other than glass eels usually includes multiple year classes making population estimates challenging (COSEWIC 2006).

7.3.1 Habitat Requirements

Based on distribution and forage preferences, American eel are able to adapt to a diverse array habitats and prey including various insects, crustaceans and fishes (ASMFC 2000). Juvenile eels utilize habitats of varying salinity, including fresh, brackish, and marine waters, to grow into yellow eels. For glass eel, substrate quality and water flow may be important parameters for habitat selection, as they burrow during the day between movements upstream at night (ASMFC 2013). American eel generally inhabit benthic areas in estuaries, rivers, and lakes. Access to soft, undisturbed sediments may be important to migrating elvers for shelter

(Facey and Van Den Avyle 1987). American eel have been documented occupying mud burrows with only their heads exposed (Fahay 1978). Few other fish in freshwater exhibit similar habitat preferences, resulting in little interspecific competition for habitat (Facey and Van Den Avyle 1987). Yellow eels can grow for up to 43 years, reaching reproductive maturity at the silver eel life stage.

Multiple environmental variables influence sexual determination, gender ratios and age at sexual maturity of American eel (ASMFC 2000). Eel tend to mature later and at larger sizes across the northern portion of their range, northern females are generally more fecund and have longer life spans as a result (Helfman et al. 1987). Salinity and density are also potential factors influencing gender determination. Based on the different sizes and distributions among the sexes, Helfman et al. (1987) hypothesized that male and female American eel are subjected to different natural selection pressures resulting in distinct life history traits. They observed that male eel are often found in the more productive habitats, closer to the spawning area, displaying fast growth and maturing at a small size; a life history strategy that is time-constrained. In contrast, female eel distribute among all suitable habitats and are dispersed widely throughout their geographic range. Females also exhibit slower growth, greater size at maturity, longer lifespan and increased fecundity; a life history strategy that is energy constrained (ASMFC 2000).

7.3.2 Recreational Fishery

American eels are subject to fishing pressure from the time they enter coastal waters as glass eels until they leave as silver eels. Fishing mortality is thought to play a role in the decline of the global eel population. There is comparatively little fishing pressure in the Merrimack River (MRTC 2013). Due to the population-wide decline of American eel, ASMFC enacted a Fishery Management Plan (FMP) in 2000 that has been amended multiple times. The glass eel and elver fishery is not legal in New Hampshire and Massachusetts due to reduced recruitment into freshwater nursery habitat (Haro et al. 2000),. Instead, the eel fishing that does occur in the Merrimack is primarily directed at yellow eels (MRTC 2013). Haro et al. (2000) noted that high fishing mortality of yellow and silver eels might have range-wide impacts by reducing the contribution of mature eels to the spawning population.

Recreational fishing for eels is permitted with restrictions for licensed anglers in both New Hampshire and Massachusetts. In accordance with ASMFC (2013) both Massachusetts and New Hampshire allow recreational harvest of up to 25 American eel per day greater than nine inches in length. Massachusetts prohibits the use of eel taken in inland waters for bait or any commercial purpose. New Hampshire closes the eel harvest season from October 2 to June 14. A harvest permit is required to take eel by any method other than angling.

Most recreational harvest of American eel occurs when anglers are targeting other species. Recreational catch of eels has declined since the 1990s. NOAA Fisheries estimated a recreational catch of 57,986 American eel coast-wide in 2007, with 59 percent released alive by anglers. Although recreational take is low, the 2013 FMP addendum recommended recreational fishery management measures to reduce the chance of excessive recreational harvest.[38] Neither New Hampshire nor Massachusetts currently stock American eel in coastal rivers.

7.3.3 Competition, Predation and Interaction with Inland Fishery

American eel are an important ecological resource, serving as prey species for many fish, mammals, and birds. Many larger fish in the Merrimack River watershed including striped bass, black bass, common carp, and northern pike prey on American eel. The effect of predation on eel population is unknown. American eel compete with other fish species of comparable size that utilize similar habitats and forage on the same prey. Larger eels prey on other fish becoming the apex predator in some aquatic habitats.

The swim bladder nematode (*Anguillicola crassus*) parasite is affecting American eel populations (GOM Council 2007). The invasive nematode is native to Southeast Asia and was spread by a Texas aquaculture facility in the mid-1990s, reaching New England watersheds in mid-2000s. The parasite causes a variety of health problems in American eel and can negatively affect migrating silver eels.

7.3.4 Previous and Current Management/Monitoring Activities

American eel populations in U.S. waters are at or near historically low levels due to overfishing, habitat loss, food web alterations, predation, turbine mortality, climate change factors, pollution and disease (ASMFC 2012b). In 2007, the USFWS completed a status review of American eel under the Endangered Species Act. In their final determination, the USFWS concluded that listing the American eel as either threatened or endangered was not warranted at that time (72 FR 4867, February 2, 2007). The USFWS completed a second status review of American eel in 2015 (80 FR 60834, October 8, 2015). Based on the status review, USFWS concluded that, despite low population levels, the species did not warrant listing as threatened or endangered under the Endangered Species Act.

The American eel fishery primarily targets yellow stage eel using eel pots. Silver eels are also caught during their fall migration at weirs and traps. Glass eel harvesting is prohibited along the Atlantic coast except in Maine and South Carolina. In recent years, Maine is the only state reporting significant glass eel and elver harvest. Harvest in Maine has increased recently as market price has risen to over $2,000 per pound at times. Historically a source of food, yellow eels are now primarily sold as bait for recreational fisheries. Markets in Asia import glass eels for seed stock in aquaculture facilities.

[38] This includes the recommendation to set the minimum length at nine inches, and creel limit at 25 per day. Both New Hampshire and Massachusetts have adopted these recommendations in their fishing regulations.

Recommended management actions to meet the coast-wide goal of reducing mortality of American eel include understanding habitat requirements, improving upstream and downstream passage, and increasing habitat restoration (ASMFC 2014). In addition, more rigorous monitoring programs are needed to understand the annual health of the eel stock (ASMFC 2014).

MRTC (2013) outlined goals and recommendation for conserving and enhancing the population of American eel in the Merrimack River basin. The primary actions of the plan are to reduce anthropogenic mortality and improve access to habitat. Section 12.2.5 further details the objectives and recommendations pertaining to American eel in the Merrimack Watershed.

7.3.5 Distribution and Potential Habitat

Historically abundant in watersheds along the Atlantic and Gulf coasts, American eel comprised up to 25 percent of the total fish biomass in some habitats (ASMFC 2012b). Eel abundance sharply declined in the 1970s, with further decline in the 1980s and 1990s. The decline was primarily a result of decreases in habitat accessibility and quality, overfishing, and climate change (Shepard 2015).

American eel were historically abundant throughout the Merrimack River and tributaries (Figure 10) and are still present in the mainstem, all major tributaries, and many inland lentic waters such as Lake Winnipesaukee. Throughout the range, the eel's unique ability to climb wetted surfaces enabled them to reach many areas inaccessible to other migratory fish. However, dams impede or completely block upstream eel passage. The location and configuration of the dam, as well as the size and life stage of the eel, determine passage success. Therefore, the impact a dam has on eel migration is site specific (Shepard 2015). Hydroelectric facilities associated with dams cause high eel mortality during downstream migration. In the Merrimack River watershed, the primary cause of decreased American eel abundance and distribution are dams that limit access to preferred habitat and high mortality during emigration.

American eel are encountered sporadically, in low abundance, during surveys across much of the watershed (NHFGD unpublished data). Upstream eel passage improvements and better downstream protections are necessary to facilitate the restoration of eels to their historical abundance and distribution.

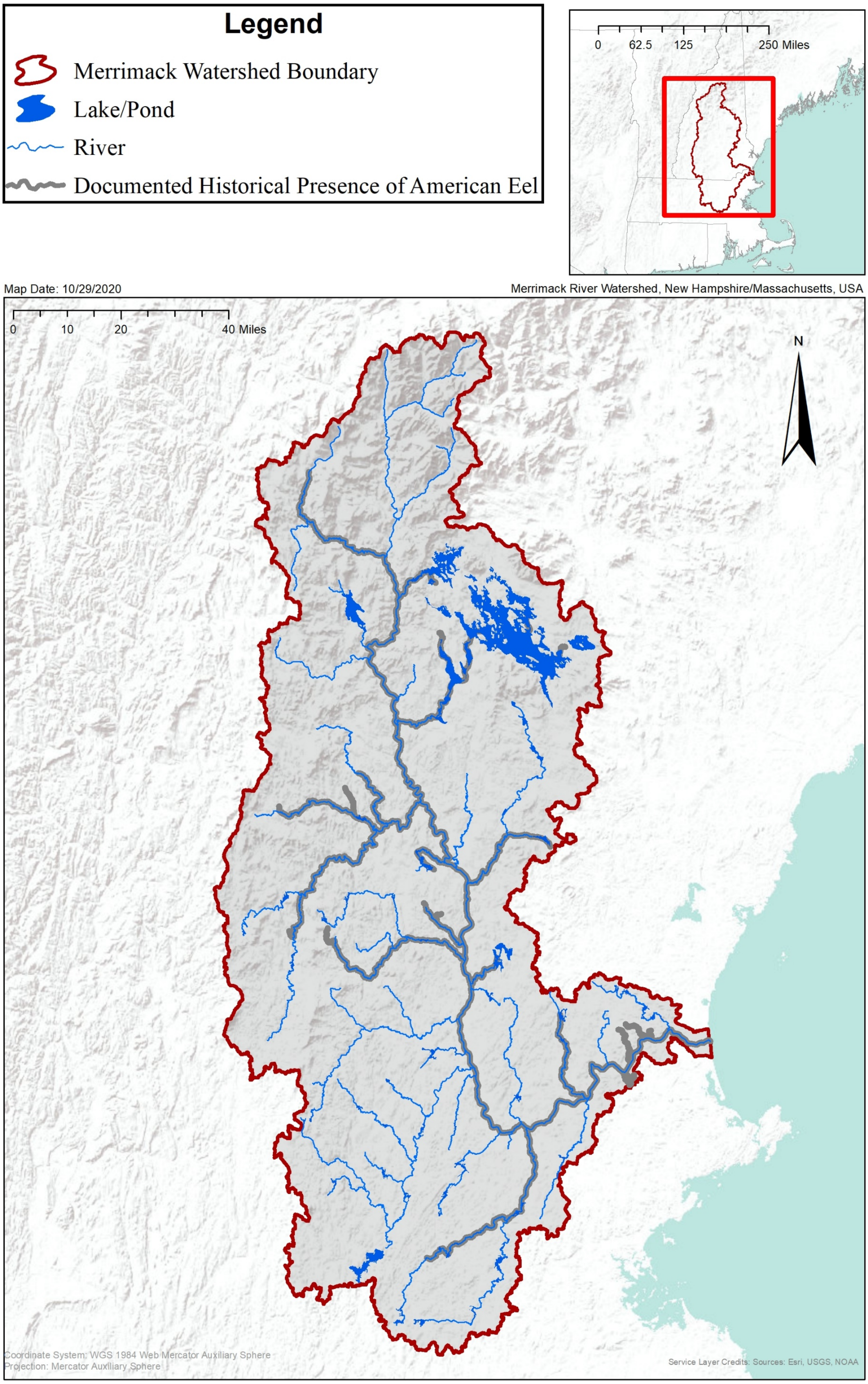

Figure 10. Historical American Eel Distribution in the Merrimack Watershed

7.4 Sea Lamprey

The sea lamprey is an anadromous, semelparous species with an Atlantic Coast range extending from the St. Lawrence River in Canada to the St. Johns River in Florida (Page and Burr 2011). Sea lamprey spend most of their life cycle in freshwater streams, as ammocoetes, living up to five years in streams before developing into juvenile lamprey, or transformers, and migrating to the ocean (Werner 2004). In the ocean, adult lamprey are parasitic feeders by attaching to hosts using their buccal funnel and feeding on tissue and fluids (Kircheis 2004). After feeding at sea for 18 to 22 months, adults return to freshwater streams to spawn and die. Sea lamprey are panmictic meaning they do not home to natal rivers (Kelly and King 2001)

Sea lamprey spawn in riffle sections of rivers with sandy and cobble substrate (Kelly and King 2001; Kircheis 2004). Sea lamprey construct spawning nests (redds) of gravel and small rocks by carrying stones with their mouths and creating a silt free nest that may be as much as 25 cm deep and up to a meter in diameter (Scott and Scott 1988; Kircheis 2004). The lamprey's silt-cleaning activities during nest construction improve the habitat quality for macroinvertebrates and other aquatic organisms (Kircheis 2004; Hogg et al. 2014).

Sea lampreys are important for nutrient cycling (Saunders et al. 2006; Nislow and Kynard 2009; Hogg et al. 2014). The post-spawn carcasses provide marine-derived nutrients to streams and rivers (Saunders et al. 2006; Nislow and Kynard 2009). The nutrients associated with decomposing lamprey enhance primary production, thus improving the trophic structure of the ecosystem.

7.4.1 Habitat Requirements

Sea lamprey require a variety of stream substrates and flow rates for successful recruitment and survival to adulthood. Adult lamprey need a gravelly bottom substrate in rapidly flowing shallow water to construct spawning redds (Collette and Klien-MacPhee 2002). Small amounts of sand are also needed in redds for egg adhesion (Applegate 1950). When gravel is not available for redd construction, lamprey can utilize other materials, including shells, lumps of clay, and rubble (Morman et al. 1980; as cited in Maitland 2003).

Adequate stream flow over redds is required for successful spawning. Currents that are too swift result in disrupted mating and eggs that drift downstream beyond the nest. Ammocoetes require a muddy or sandy bottom in still or running water for burrowing and filter feeding (Maitland 2003). Ammocoetes are commonly found in stream velocities averaging from 0.65 to 1.0 feet per second (Thomas 1962; as cited in Maitland 2003), but can also occur in areas away from the main current in very slow or reverse flowing waters (Maitland 2003). Stream velocities exceeding 2.6 feet per second are too fast to maintain habitats for ammocoetes to burrow (Thomas 1962; as cited in Maitland 2003). Sea lampreys are present in streams of all sizes, with flow ranging from one to 155,000 cfs (Morman et al. 1980; as cited in Maitland 2003).

Migrating adult lamprey can travel up to 200 miles to reach spawning grounds depending on habitat suitability and energy reserves (Collette and Klien-MacPhee 2002). Stream barriers, such as dams and waterfalls, limit the habitat used by lamprey for spawning and rearing. Some low-gradient waterfalls are passed by lamprey using their mouth to cling to immobile substrate to rest between short bursts upstream (Collette and Klien-MacPhee 2002).

Transformer lamprey are not strong swimmers and use stream flow or attach to hosts to migrate downstream. Transformer emigration to the ocean occurs in the fall during rain events. During droughts, transformers may delay or halt migration depending on water temperature and other impediments resuming migration during the spring (Kircheis 2004). Habitat with seasonal streamflow fluctuations is essential for successful adult sea lamprey immigration and transformer emigration.

Sea lamprey require specific water quality parameters for successful spawning, recruitment, and survival, and are not tolerant of heavily polluted habitats. Water temperatures that facilitate successful sea lamprey spawning range from 11-25 °C (52-77 °F) (Maitland 2003). For successful egg hatching, water temperatures in the stream must range between 15-25 °C (59-77 °F) (Maitland 2003). Sea lamprey ammocoetes are most active in water temperatures ranging from 10-14 °C (50-57°F) (Thomas 1962). Ammocoetes can tolerate low levels of dissolved oxygen, even anoxic conditions for a few hours, when burrowed in the substrate (Potter and Hill 1970; Potter et al. 1970). Both transformer and adult sea lampreys cannot tolerate significant levels of pollution (Maitland 2003). Pollution barriers can prevent adults from migrating upstream and be detrimental to transformers migrating downstream. In streams with lower levels of pollution, adults can tolerate downstream low-level pollutants if the upstream waters and spawning area are less polluted (Maitland 2003).

7.4.2 Recreational Fishery

Massachusetts and New Hampshire do not have a recreational fishery for sea lamprey. Due to their feeding strategy and jawless mouths, they are difficult to catch with traditional fishing methods (Collette and Klien-MacPhee 2002).

7.4.3 Competition, Predation and Interaction with Inland Fishery

Ammocoetes burrow in the mud and filter feed on algae and plankton limiting the interaction with the inland fishery. Adults acquire their food source, blood and other body fluids, from a host without killing the fish (Kircheis 2004). Parasitic adult lamprey interact with the host by attaching to the fish with its suction-like mouth, rasping a hole with its circular rows of teeth, and consuming fluids and tissue through its buccal funnel. The resulting wound will scar and heal if the number of lamprey feeding on the host is minimal and the host is in good health (Kircheis 2004). Sea lamprey use a variety of host animals for feeding, including alewife, blueback herring, American eel, American shad, sturgeon (*Acipenser spp.*), Atlantic salmon, as well as other lampreys. Transformer-phase sea lamprey may attach to hosts in freshwater as a means of transport during migration. Transformers have a brief period of attachment to a host fish reducing the chance of host mortality. Adult sea lamprey's digestive tracts stop functioning during the spawning migration and they do not feed in freshwater (Kircheis 2004).

Sea lamprey are a source of forage for both freshwater and marine aquatic species. Lamprey eggs are a prey source for some minnow species (Scott and Crossman 1973), and possibly other fish species including common shiner (*Luxilus cornutus*), fallfish (*Semotilus corporalis*), and American eel (Kircheis 2004). Ammocoetes are a prey item for other fish species and birds (Maitland 2003). Transformers are a source of prey for many aquatic species including striped bass (Kircheis 2004). Both striped bass and other large predators feed on adult sea lamprey. Freshwater fish known to prey on sea lamprey include brown trout (*Salmo trutta*), northern pike (*Esox lucius*), and walleye (*Sander vitreus*). Birds of prey and some mammals, such as raccoons and otters, will also feed on adult lamprey (Kircheis 2004).

Sea lamprey spawning behavior and life history provide beneficial interactions to aquatic species in upstream freshwater habitats. As a semelparous species, sea lamprey play a key role in providing marine-derived nutrients to streams and rivers. The deposition of nutrients from post-spawn adult lamprey nourishes juveniles of other species, such as Atlantic salmon, and acts as a source of primary production in the trophic structure of the aquatic ecosystem (Saunders et al. 2006). Sea lamprey mating behavior involves manipulating the streambed, which can restore and enhance stream substrate and improve water flow through the recently disrupted substrate. Bioturbation by sea lamprey when assembling nests improves stream quality through modification of embeddedness, the presence of microhabitats, find sediment cover, and the benthic macroinvertebrate community (Hogg et al. 2013). Other aquatic species, such as minnows and salmonids, will use lamprey nests after the spawning period is complete (Kircheis 2004).

7.4.4 Previous and Current Management/Monitoring Activities

Commercial harvest of sea lamprey has occurred nearby in Maine for medical and biological research. During the 1970s and 1980s, researchers caught several thousand sea lampreys from the Sheepscot River (Kircheis 2004). Currently, there are three companies that can harvest sea lamprey in the state of Maine, all three of which harvest either ammocoetes or adult lamprey for biological and medical research. When these companies are unable to harvest the volume of adult lamprey they need from Maine waters, they obtain them from fishermen in Nova Scotia or the Great Lakes (Kircheis 2004). New Hampshire and Massachusetts have no commercial fishery of sea lamprey.

Though few data exist in the Merrimack River, sea lamprey have benefited from activities carried out in support of the Anadromous Fish Restoration Program plan (MRTC (1997). Improvements in connectivity and water quality are beneficial, but more species-specific data are needed to quantify and properly manage the Merrimack River population. Federal and state agencies in the northeast United States are developing sea lamprey stocking programs, population assessments, and habitat restoration programs in other rivers. In the Connecticut River watershed, recent efforts by multiple agencies have resulted in the development of a sea lamprey restoration program under the Connecticut River Atlantic Salmon Commission (CRASC 2018). This CP will provide a framework that will support the future restoration of sea lamprey in the Merrimack River watershed, lamprey-specific recommendations and objectives are discussed in Section 12.2.6.

7.4.5 Distribution and Potential Habitat

Information on historical sea lamprey abundance and distribution in the Merrimack River Watershed is limited. Anecdotal records suggest sea lamprey were a colonial food source and were harvested at Amoskeag Falls (Stolte 1981). The historical distribution of sea lamprey, at a minimum, extended to Amoskeag Falls on the Merrimack River mainstem. However, sea lamprey likely spawned and reared upstream of Amoskeag Falls and in most tributaries without significant barriers throughout the watershed.

Sea lamprey have been observed entering the fishways at Essex and Pawtucket Dams, with around 5,279 and 829 passing their respective upstream facilities in 2020. In New Hampshire, electrofishing surveys conducted over the past two decades by the NHFGD have documented lamprey in the lower Souhegan River, Baboosic Brook, Black Brook, and Little Cohas Brook, as well as the mainstem Merrimack River and a few minor tributaries (NHFGD, unpublished data). In Massachusetts, MassWildlife surveys have also recorded sea lamprey in the lower Merrimack Mainstem, Shawsheen River, and Johnson Creek (MassWildlife, unpublished data). Beyond these records, the extent of distribution throughout the rest of the mainstem and other tributaries is unknown. Increased accessibility throughout much of the Merrimack River watershed for sea lamprey will lead to higher population abundances. The mainstem of the Merrimack River up to Livermore Falls on the Pemigewasset River, and many of the tributary watersheds[39] are all potential sea lamprey habitat.

[39] In particular, the Shawsheen, Souhegan, Black Brook, and Little Cohas watersheds, where they have been collected during electrofishing surveys in recent years (NHFGD, MassWildlife; unpublished data).

8.0 PRODUCTION ESTIMATES FOR TARGET SPECIES IN THE MERRIMACK RIVER WATERSHED

8.1 Production Estimate Methods

We estimated the production potential of American shad, blueback herring, and alewife based on spawning habitat in the watershed. This analysis sets goals and determines the level of potential productivity in the Merrimack River watershed under past, current, and future conditions. To better understand the analysis, the following key terms are defined below:

- Potential production: An estimate of adult fish that are produced by an area of spawning habitat. (The reported number is the theoretical return of adult fish to the river mouth per surface acre of spawning habitat. Production estimates are based on population studies conducted on the Connecticut River for American shad (CRASC 2017) and habitats in Maine for river herring (Hall et al. 2012))
- Passage efficiency: The number of fish that successfully pass a fishway divided by the number of fish that attempt passage.
- Escapement: The number of fish that reach spawning habitat. Required escapement refers to the minimum number of adults necessary to maintain a sustainable fishery.
- Return(s): The annual number of adult fish returning to the river mouth.[40]
- Fishway capacity: The quantity of fish that a fishway can safely, timely, and effectively pass over a barrier in a given time period is referred to as the fishway (or biological) capacity (USFWS 2019).
- Shad equivalents: A metric used to quantify fishway capacity; equal to one adult shad or eight adult river herring.
- Habitat reach: A discrete section of aquatic habitat with a defined boundary. In this analysis, reaches are defined by dams or natural features.
- Lentic Water: A lake, pond, marsh, or wetland with still, standing water that may have natural or managed water levels.
- Impoundment: A waterbody created by a dam or other similar construction. Removal of the impounding structure results in a return to lotic habitat.

For shad and blueback herring, we estimated production and escapement under three different scenarios: Current, Interim, and Ideal (Figure 11). The Ideal Scenario is divided into two separate estimates, A and B. Each scenario only considers lotic spawning habitat reaches with an average width greater than 50 feet. Section 5.1.3 describes the specific methodology we

[40] Because the number of adults that return to the river mouth is challenging to measure and often unknown, returns to the first dam are often used as a proxy for this number.

used for surface area calculation and reach definition. With the exception of the Ideal Scenario B, only habitat reaches above the first mainstem dam[41] were considered in the analysis. We defined the criteria for the three scenarios as follows:

1) The Current Scenario considers all river habitat that is accessible by alosines through volitional (direct connection or fish ladder) or assisted access (fish lift).

2) The Interim Scenario includes all habitat in the Current Scenario, and adds habitats that we anticipate will have volitional or assisted access in the Type I and Type II RFAs. This scenario is considered feasible within the next ten to twelve years and includes installing upstream fishways or removal of the following dams: Talbot Mills Dam (Concord), Pepperell Dam (Nashua), McLane & Goldman Dams (Souhegan), Kelley's Falls Dam (Piscataquog) and the Hooksett & Garvin's Falls Dams (Merrimack).

3) The Ideal Scenario is split into two separate estimates:

   a) Ideal Scenario A estimates potential production if all reaches were accessible for spawning above Essex Dam, including tributaries, and

   b) Ideal Scenario B estimates potential production if all reaches were accessible for spawning throughout the entire Merrimack watershed.[42]

Under each scenario, we calculated potential production and required escapement for each reach. Passage efficiency at each fishway was considered in the escapement calculation. The outputs from these calculations are used to estimate the required fishway capacity at each dam, set goals for numbers of returning adult fish, and determine a sustainable population size for the watershed.

[41] Essex Dam in Lawrence, MA

[42] From the upstream side of the US Route 1 bridge in Newburyport, MA, to Livermore Falls in Campton, NH.

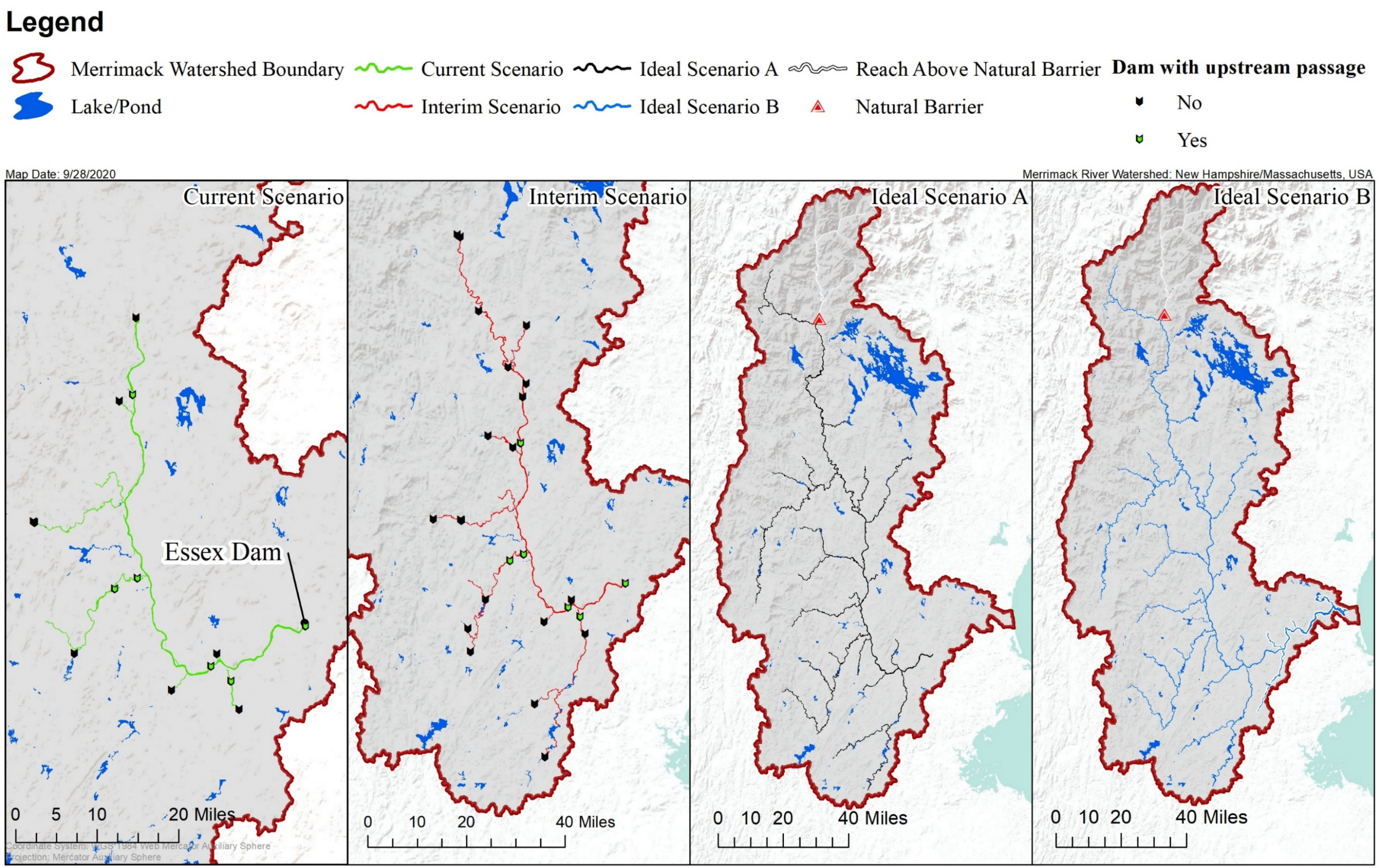

Figure 11. Production Scenarios for American Shad and Blueback Herring

Our approach for estimating alewife productivity is based on spawning habitat, which is different than shad and blueback herring (Pardue 1983; Greene et al. 2009). Alewife have much less accessible spawning habitat in the Merrimack River watershed than blueback herring or shad. Alewife have access to less than 2 percent[43] of their historic spawning habitat compared to roughly 43 percent[44] for blueback herring and shad. Although the alewife production resulting from currently accessible habitat is unknown, we assume production is minimal and suppressed due to poor passage throughout the basin. The population is sustained almost entirely through NHFGD's trap and transport stocking efforts. For this reason, we completed production estimates for only Interim and Ideal Scenarios. The Interim Scenario considers lentic waters and a few select impoundments that are likely to be accessible either volitionally or with assistance within the next 10 to 12 years (Table 8). The Ideal Scenario considers habitat reaches that are (1) identified by MRTC (2019) as having stocking potential, (2) thought to have the capability to support a sustainable run once passage is provided, or (3) have been stocked with river herring in the past (Table 9). The Ideal Scenario is inclusive of all habitat reaches identified in the Interim Scenario. The methodology we used for surface area calculation and reach definition is found in sections 5.1.2 and 5.1.3, respectively. We included impoundment acreage where applicable.

[43] This number considers lentic habitats only; if impoundments and sluggish river reaches are included, the number is closer to 6 percent.
[44] This estimate includes the habitats on the mainstem and tributaries below Essex Dam

Table 8. Interim Scenario Alewife Habitat

Habitat Reach	Watershed	Acres	# of Impassable Dams Below
Essex Impoundment	Merrimack	655	0
Pawtucket Impoundment	Merrimack	720	0
Amoskeag Impoundment	Merrimack	478	0
Mine Falls Impoundment	Nashua	242	0
Potanipo Pond	Nashua	130	0*
Heads Pond	Merrimack	45	1
Naticook Lake	Merrimack	60	1
Hooksett Impoundment	Merrimack	350	1
Garvin Falls Impoundment	Merrimack	640	1
Baboosic Lake	Souhegan	218	1*
Pine Island Pond	Cohas	51	1
Kelley Falls Impoundment	Piscataquog	203	1
Ottarnic Pond	Merrimack	41	2
Kimball Pond	Black Brook	90	2
Turtle Pond	Merrimack	134	3
Rocky Pond	Soucook	74	3
Fox Run Impoundment	Soucook	27	3*
Turkey Pond	Turkey River	337	4
York Impoundment (Includes Blackwater and Warner Rivers to 1st dam)	Contoocook	516	5
Lake Winnepocket	Contoocook	217	6
Pillsbury Lake	Contoocook	67	6
Shellcamp Pond	Soucook	125	6*
Total		5,421	

*Dam ruins present; survey required to verify barrier and confirm number of obstacles in reach

Table 9. Ideal Scenario Alewife Habitat

Habitat Reach	Watershed	Acres
Kimball Pond	Black Brook	90
Massabesic Lake	Cohas Brook	2,513
Pine Island Pond	Cohas Brook	51
Lake Winnepocket	Contoocook	217
Pillsbury Lake	Contoocook	67
Walker Pond	Contoocook	187
York Impoundment (Includes Blackwater and Warner Rivers to 1st dam)	Contoocook	516
Fort Eddy	Merrimack	23
Greens Pond	Merrimack	33
Heads Pond	Merrimack	45
Hoit Marsh	Merrimack	123
Horseshoe Pond (North)	Merrimack	40
Horseshoe Pond (South)	Merrimack	42
Naticook Lake	Merrimack	60
Ottarnic Pond	Merrimack	41
Penacook Lake	Merrimack	362
Sondogardy Pond	Merrimack	38
Turtle Pond	Merrimack	134
Amoskeag Impoundment	Merrimack	478
Essex Impoundment	Merrimack	655
Garvin's Falls Impoundment	Merrimack	640
Hooksett Impoundment	Merrimack	350
Pawtucket impoundment	Merrimack	720
Flints Pond	Nashua	42
Potanipo Pond	Nashua	130
Mine Falls Impoundment	Nashua	242
Webster Lake	Pemigewasset	591
Glen Lake	Piscataquog	128
Kelley Falls Impoundment	Piscataquog	203
Rocky Pond	Soucook	74
Shellcamp Pond	Soucook	125
Fox Run Impoundment	Soucook	27
Baboosic Lake	Souhegan	218
Brindle Pond	Suncook	84
Crystal Lake	Suncook	506
Halfmoon Lake	Suncook	269
Harvey Lake	Suncook	101
Jenness Pond	Suncook	256
Locke Lake	Suncook	327
Long Pond	Suncook	101
Northwood Lake	Suncook	596
Pleasant Lake	Suncook	470
Upper Suncook Lake	Suncook	691
Turkey Pond	Turkey	337
Lake Winnisquam	Winnipesaukee	4,124
Silver Lake	Winnipesaukee	217
Total		**17,284**

8.2 Production Estimate Results and Discussion

8.2.1 American Shad

Shad production estimates per acre of spawning habitat were based on regional examples. USFWS et al. (1987) and MDMR and MDIFW (2008) estimated the American shad productivity for Maine rivers was 111 adult returns per acre of spawning habitat. CRASC (2017) used an estimate of 82 adult returns per acre of Connecticut River mainstem habitat. We chose to use a production of 100 adult shad per acre of spawning habitat that follows MRTC (2010)[45] and MDMR and MDIFW (2016).[46]

Based on American shad management in the region (USFWS et al. 1987; MDMR and MDIFW 2008), we set the required escapement at 50 percent of the adult production potential. Fishway efficiency is poorly studied in the Merrimack watershed with the exception of the Lowell Project (Pawtucket Dam). Normandeau Associates Inc. (1997) determined that upstream shad passage efficiency at the Lowell Project lift was poor, ranging from 0.5 to 2.4 percent. After structural and operational modifications, passage improved in later studies to 42 percent (Boott Hydropower Inc. 2000, 2001). For the production estimate, we calculated required escapement with an internal efficiency of 80 percent for all passage facilities. This efficiency represents realistic fishway performance, while maintaining feasible escapement numbers. The number of shad required to pass each dam increases by orders of magnitude when efficiency is less than 80 percent (Figure 12).

Our estimate of American shad production potential under the Current Scenario is 421,900 returning adult fish (Table 10). Under the Interim Scenario, the estimate increases to 780,200. The minimum escapement required at Essex Dam to reach the potential production under these two scenarios is 273,313 and 635,560 shad, respectively. The current design capacity of the Essex fish lift is 232,620 shad equivalents. Under the Current Scenario the lift is undersized with an internal passage efficiency of 80 percent.[47] Table 11 outlines the production potential and minimum required escapement by reach under the Current and Interim Scenarios. The Ideal Scenarios estimate the returning adult American shad that the Merrimack River watershed supports if all potential spawning habitat is accessible. Ideal Scenario A estimates a potential production of 1,446,200 adult fish for the river reaches upstream of Essex Dam. Ideal Scenario B estimates a potential production of 1,790,800 adult fish in the entire Merrimack River watershed including portions of the Powwow, Little, Spicket and Shawsheen Rivers downstream of Essex Dam.

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[45] 100/acre
[46] 99/acre
[47] The lift is undersized considering only shad – other diadromous fish must also use the lift in order to reach the habitat upstream – when factoring in all fish that require passage the lift capacity is far below what is needed for even the most conservative restoration goals.

Table 10. American Shad Habitat, Production, and Escapement Scenarios

Habitat Scenario	Potential Spawning Habitat (Acres)	Potential Production (# of Adult Shad)	Minimum Required Escapement @ Essex (80% efficiency)
Current Scenario	4,219	421,900	273,313
Interim Scenario	7,802	780,200	635,560
Ideal Scenario A	14,462	1,446,200	-
Ideal Scenario B	17,908	1,790,800	-

We calculated escapement at select dams that meet Interim Scenario production goals for the Merrimack River watershed. We estimated the escapement under several internal upstream passage efficiencies. The minimum number of shad needed to pass the first dam varies based on combined fishway efficiency (Figure 12). With 80 percent fishway efficiency at all projects, a minimum of **635,560** adult American shad will need to pass Essex Dam. Efficiencies at or lower than 50 percent require more returns than the estimated production potential for all habitats in the watershed (Figure 12). The following numbers of adult American shad will need to pass each dam to meet production potential of the upstream habitat (* indicates dam currently lacking upstream passage facilities):

- A minimum of **426,898**[48] at Pawtucket Dam[49]
- A minimum of **177,994** at Amoskeag Dam
- A minimum of **121,875** at Hooksett Dam*
- A minimum of **75,300** at Garvin's Falls Dam*
- A minimum of **45,350** at Centennial Island Dam[50]
- A minimum of **58,734** at Jackson Mills Dam
- A minimum of **43,788** at Mine Falls Dam
- A minimum of **21,750** at Pepperell Dam*
- A minimum of **10,150** at Kelley Falls Dam*

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[48] Assumes 80% fishway efficiency; would be 548,612 at 70% efficiency, or 757,133 at 60% efficiency. Reported numbers for all other dams assume 80% efficiency unless otherwise noted.

[49] Escapement number includes fish necessary for the habitat above McLane and Goldman Dams; would require removal or passage

[50] Includes habitat above Talbot Mills Dam; requires removal or passage

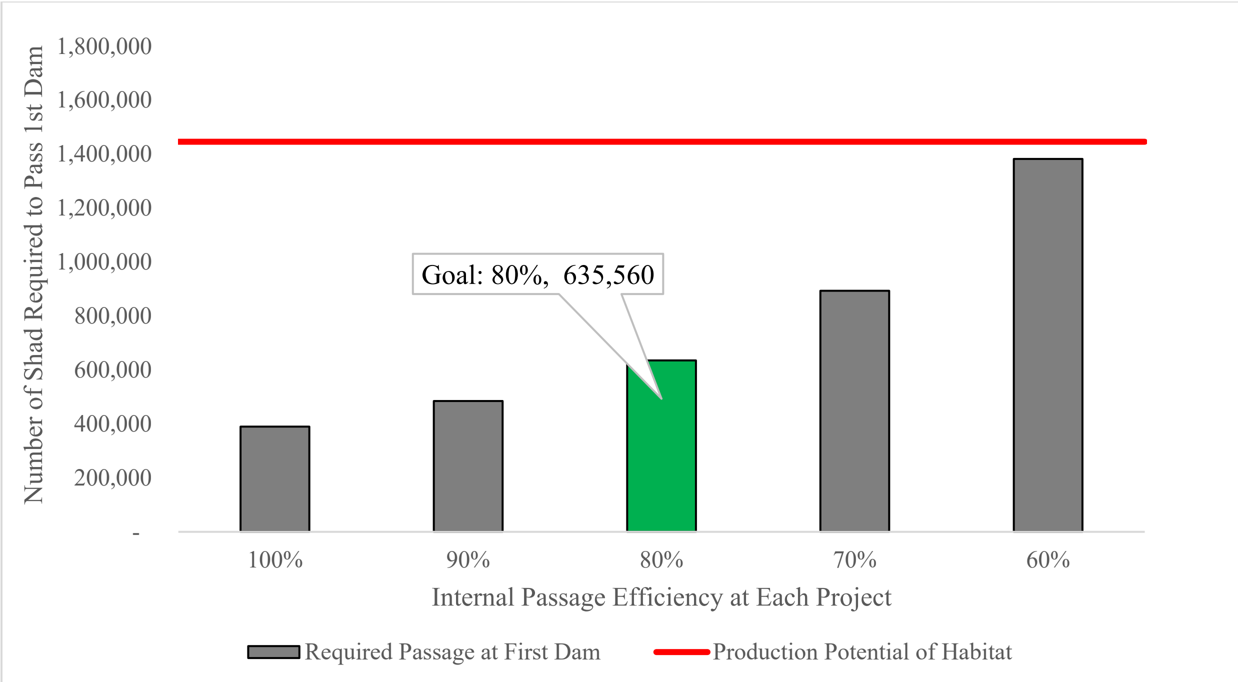

Figure 12. Interim Scenario Required American Shad Passage at the First Dam Using Different Passage Efficiencies[51]

[51] Efficiencies ≤50% require more returns than the estimated production potential for the entire watershed and will not support restoration goals

Table 11. American Shad Production and Escapement Scenarios by Habitat Reach

		Current Scenario			Interim Scenario			Totals	
		Acres of Habitat in Reach	Minimum Required Escapement (# Adult Shad)	Potential Production (# Adult Shad)	Acres of Habitat in Reach	Minimum Required Escapement (# Adult Shad)	Potential Production (# Adult Shad)	Total Production Potential	Total Escapement Required (Current + Interim)
Merrimack River (Type I)	**Essex Dam**		273,313			362,247			**635,560**
	Essex to Pawtucket, includes Concord River and Beaver Brook to 1st dam	905		90,500	-		-	90,500	
	Pawtucket Dam		177,550			249,348			**426,898**
	Pawtucket to Amoskeag, includes Stony Brook, Nashua River, Souhegan River, Piscataquog River, and Baboosic Brook to 1st dam	2,291		229,100	-		-	229,100	
	Amoskeag Dam		25,650			152,344			**177,994**
	Amoskeag to Hooksett, no major tributaries in reach	513		51,300	-		-	51,300	
	Hooksett Dam		-			121,875			**121,875**
	Hooksett to Garvin's Falls, includes Suncook River and Soucook River to 1st dam	-		-	1,506		150,600	150,600	
	Garvin's Falls Dam		-			75,300			**75,300**
	Garvin's Falls to Eastman Falls Dam (Pemigewasset), includes Contoocook River and Winnipesaukee River to 1st dam	-		-	555		55,500	55,500	
Concord River (Type I)	**Centennial Island Dam**		4,900			40,450			**45,350**
	Centennial to Talbot, no major tributaries in reach	98		9,800	-		-	9,800	
	Talbot Mills Dam		-			-			*
	Talbot to 1st dam on the Assabet and Sudbury Rivers	-		-	809		80,900	80,900	
Nashua River (Type I)	**Jackson Mills Dam**		24,750			33,984			**58,734**
	Jackson to Mine Falls, no major tributaries in reach	80		8,000	-		-	8,000	
	Mine Falls Dam		16,600			27,188			**43,788**
	Mine Falls to Pepperell, includes Nissitissit River	332		33,200	-		-	33,200	
	Pepperell Dam		-			21,750			**21,750**
	Pepperell to Ice House Dam, includes Squannacook River to 1st dam	-		-	435		43,500	43,500	
Souhegan River (Type II)	**McLane/Goldman Dam**		-			-			*
	McLane to Pine Valley Dam, includes reach between McLane and Goldman Dam and up to Pine Valley Dam	-		-	75		7,500	7,500	
Piscataquog River (Type I)	**Kelley Falls Dam**		-			10,150			**10,150**
	Kelley Falls to Greggs Falls Dam, no major tributaries in reach	-		-	203		20,300	20,300	
	Total	4,219		421,900	3,583		358,300	**780,200**	

**Recommended removal would result in direct connection; necessary escapement for production in the upstream reach is included in the number for each downstream dam(s).*

8.2.2 Blueback Herring

Blueback herring production estimates per acre of spawning habitat is based on a few regional examples. Available regional estimates range from 35 to 800 adult returns per acre (typically derived by applying a multiplier to the shad production estimate). MDMR and MDIFW (2016) estimated the blueback herring productivity for the Mousam River at 600 adult returns per acre of spawning habitat. We used the same production estimate for the Merrimack River. The 600 per acre value is likely an underestimate because numerous suitable river reaches, tributaries, and small streams less than 50 feet in width are excluded from the analysis.

Fishway efficiency is poorly studied in the Merrimack watershed and is unknown for most of the dams with existing fishways. For this analysis, we estimated required escapement numbers assuming an efficiency of 80 percent for all passage facilities (Figure 13). This efficiency represents realistic fishway performance, while keeping required escapement numbers attainable (Table 13). Fishery managers in Maine set the river herring escapement goal at 15 percent of the adult production potential. The escapement target is accomplished by closing the fishery one day per week (USFWS et al. 1987; MDMR and MDIFW 2016). Recent studies based on commercial harvest data suggest that 15 percent may not be sustainable, so managers have closed the fishery three days per week corresponding to a 45 percent escapement (MDMR and MDIFW 2008). The Merrimack River differs from rivers in Maine because the commercial harvest of river herring is closed. Therefore, factors inhibiting herring escapement to spawning habitat are primarily fishway inefficiencies and predation. For our analysis, we selected the 45 percent escapement goal as appropriate to increase the abundance in the watershed.

We estimate the current production potential for blueback herring is 2,531,400 returning adult fish in the accessible habitat of the Merrimack River basin (Table 12). Under the Interim Scenario, production increases to 4,681,200. With the spawning escapement target of 45 percent, the minimum passage at Essex Dam under these two scenarios would be 1,475,888 and 3,432,022 blueback herring, respectively.

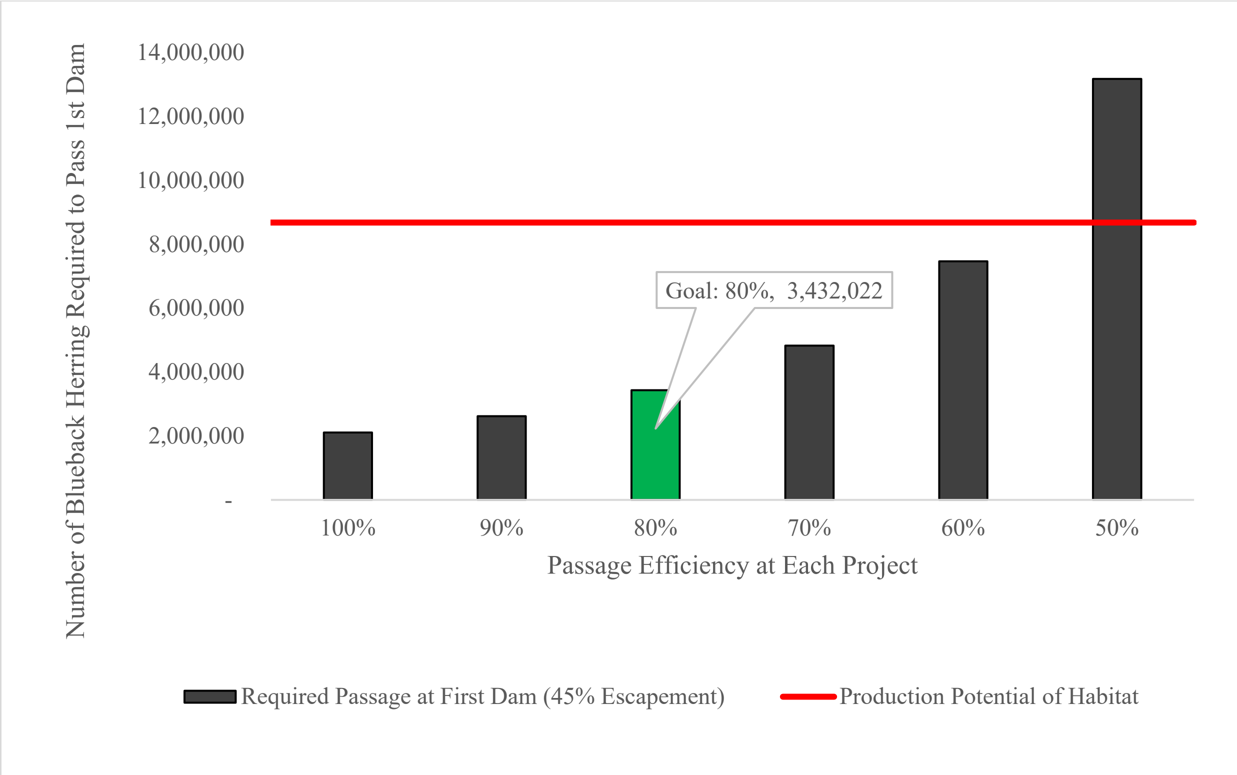

Figure 13. Interim Scenario Required Adult Blueback Herring Passage at the First Dam Using Different Passage Efficiencies.

Table 12. Blueback Herring Habitat, Production, and Escapement Scenarios

Habitat Scenario	Potential Spawning Habitat (Acres)	Potential Production (# of Adult Blueback Herring)	Minimum Required Escapement at Essex (80% efficiency)
Current Scenario	4,219	2,531,400	1,475,888
Interim Scenario	7,802	4,681,200	3,432,022
Ideal Scenario A	14,462	8,677,200	-
Ideal Scenario B	17,908	10,744,800	-

Each blueback herring represents one-eighth of a shad equivalent. The Essex fish lift design capacity of 232,620 shad equivalents is sufficient for the Current Scenario, but not the Interim Scenario, when accounting for only blueback herring. However, even the most conservative objectives for shad exceed the capacity of the lift; leaving no additional capacity for other species. Modifications to increase the upstream passage capacity and efficiency at Essex Dam are necessary to meet production goals for target species. Table 13 outlines the blueback herring production potential and minimum required escapement by individual reach under the Current and Interim Scenarios.

The Ideal Scenarios A and B estimate the blueback herring population that the Merrimack River watershed will support if there were no barriers. Ideal Scenario A estimates a potential production of 8,677,200 adult blueback herring for the river reaches upstream of Essex Dam. Ideal Scenario B estimates 10,744,800 adult blueback herring for the entire Merrimack River watershed including the Powwow, Little, Spicket and Shawsheen Rivers.

We calculated escapement at select dams in order to meet Interim Scenario production goals for blueback herring in the Merrimack River watershed. The minimum passage of blueback herring at the first dam varies based on combined fishway efficiency (Figure 13). With 80 percent fishway efficiency at all projects, a minimum of **3,432,022** adult blueback herring need to pass Essex Dam. Efficiencies at or lower than 50 percent require more returns than the estimated production potential for all habitats in the watershed (Figure 13). The following numbers of adult blueback herring will need to pass each dam to meet production potential of the upstream habitat (* indicates dam currently lacking upstream passage facilities):

- A minimum of **2,305,247**[52] at Pawtucket Dam[53]
- A minimum of **961,166** at Amoskeag Dam
- A minimum of **658,125** at Hooksett Dam*
- A minimum of **406,620** at Garvin's Falls Dam*
- A minimum of **244,890** at Centennial Island Dam[54]
- A minimum of **317,166** at Jackson Mills Dam
- A minimum of **236,453** at Mine Falls Dam
- A minimum of **117,450** at Pepperell Dam*
- A minimum of **54,810** at Kelley Falls Dam*

[52] Assumes 80% fishway efficiency; would require 2,962,505 at 70% efficiency, or 4,088,520 at 60% efficiency. Reported numbers for all other dams assume 80% efficiency unless otherwise noted.
[53] Escapement number includes fish necessary for the habitat above McLane and Goldman Dams; would require removal or passage.
[54] Includes habitat above Talbot Mills Dam; requires removal or passage

Table 13. Blueback Herring Production and Escapement Scenarios by Habitat Reach

			Current Scenario			Interim Scenario			Totals	
		Acres of Habitat in Reach	Minimum Required Escapement (# Blueback Herring)	Potential Production (# Blueback Herring)	Acres of Habitat in Reach	Minimum Required Escapement (# Blueback Herring)	Potential Production (# Blueback Herring)	Total Production Potential	Total Escapement Required: Blueback Herring (Current + Interim)	Total Escapement Required: Shad Equivalents (Current + Interim)
	Essex Dam		1,475,888			1,956,134			**3,432,022**	**429,003**
	Essex to Pawtucket, includes Concord River and Beaver Brook to 1st dam	905		543,000	-		-	543,000		
	Pawtucket Dam		958,770			1,346,477			**2,305,247**	**288,156**
	Pawtucket to Amoskeag, includes Stony Brook, Nashua River, Souhegan River, Piscataquog River, and Baboosic Brook to 1st dam	2,291		1,374,600	-		-	1,374,600		
	Amoskeag Dam		138,510			822,656			**961,166**	**120,146**
Merrimack River (Type I)	Amoskeag to Hooksett, no major tributaries in reach	513		307,800	-		-	307,800		
	Hooksett Dam		-			658,125			**658,125**	**82,266**
	Hooksett to Garvin's Falls, includes Suncook River and Soucook River to 1st dam	-		-	1,506		903,600	903,600		
	Garvin's Falls Dam		-			406,620			**406,620**	**50,828**
	Garvin's Falls to Eastman Falls Dam (Pemigewasset), includes Contoocook River and Winnipesaukee River to 1st dam	-		-	555		333,000	333,000		
	Centennial Island Dam		26,460			218,430			**244,890**	**30,611**
Concord River (Type I)	Centennial to Talbot, no major tributaries in reach	98		58,800	-		-	58,800		
	Talbot Mills Dam		-			-			*	
	Talbot to 1st dam on the Assabet and Sudbury Rivers	-		-	809		485,400	485,400		
	Jackson Mills Dam		133,650			183,516			**317,166**	**39,646**
	Jackson to Mine Falls, no major tributaries in reach	80		48,000	-		-	48,000		
Nashua River (Type I)	**Mine Falls Dam**		89,640			146,813			**236,453**	**29,557**
	Mine Falls to Pepperell, includes Nissitissit River	332		199,200	-		-	199,200		
	Pepperell Dam		-			117,450			**117,450**	**14,681**
	Pepperell to Ice House Dam, includes Squannacook River to 1st dam	-		-	435		261,000	261,000		
	McLane/Goldman Dam		-			-			*	
Souhegan River (Type II)	McLane to Pine Valley Dam, includes reach between McLane and Goldman Dam and up to Pine Valley Dam	-		-	75		45,000	45,000		
	Kelley Falls Dam		-			54,810			**54,810**	**6,851**
Piscataquog River (Type I)	Kelley Falls to Greggs Falls Dam, no major tributaries in reach	-		-	203		121,800	121,800		
	Total	4,219		2,531,400	3,583		2,149,800	**4,681,200**		
	**Recommended removal would result in direct connection; necessary escapement for production in the upstream reach is included in the number for each downstream dam(s).*									

8.2.3 Alewife

We reviewed regional examples to estimate alewife production per acre of spawning habitat. Alewife production estimates are included in several regional management plans (USFWS et al. 1987; MDMR and MDIFW 2008; CTDEP 2009; MDMR and MDIFW 2016). In these plans, production estimates range from 90 to 235 adult returns per acre. We selected production of 235 adult alewife per acre of spawning habitat for our analysis (USFWS et al. 1987; MDMR and MDIFW 2008, 2016). Several minor tributary reaches identified as potential spawning habitat by MRTC (2019) were not included in the surface area calculations due to a lack of data resolution.[55]

Of the 46 alewife spawning lentic habitats identified in the Merrimack watershed, most are small, averaging 375 acres (Figure 14). Lake Winnisquam and Massabesic Lake account for nearly 40 percent of the total acreage. We did not calculate escapement at each dam because of the density of dams and the unique pathways to the many lentic habitats. Therefore, we did not factor escapement into our production estimate for alewife.

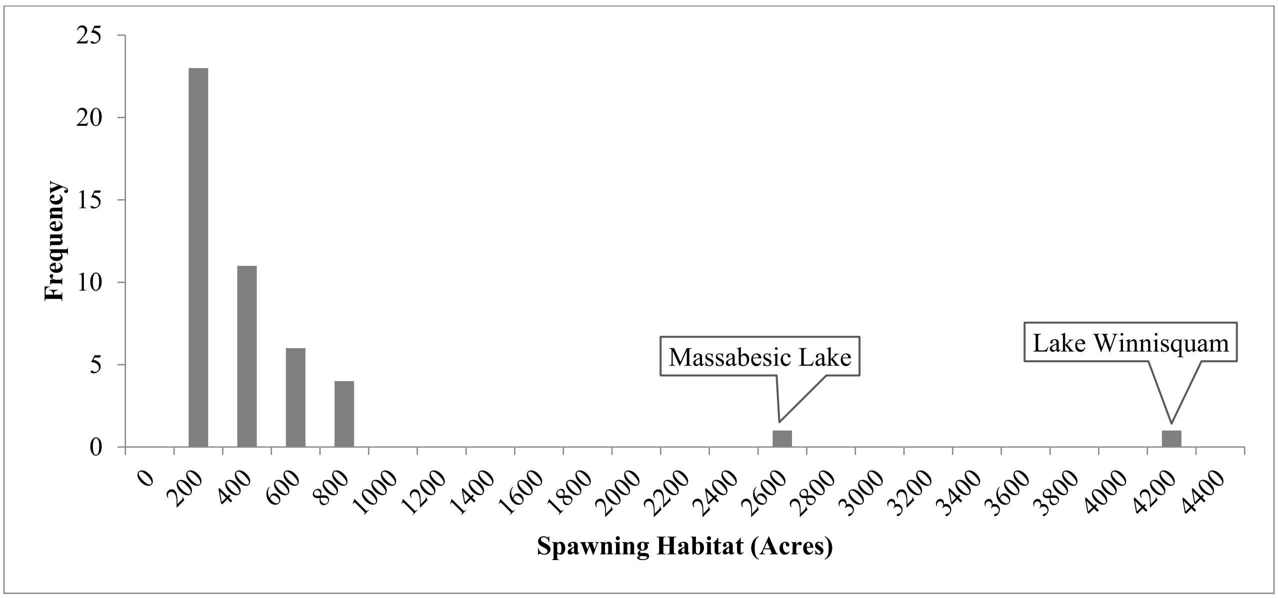

Figure 14. Size-Frequency Distribution of Alewife Spawning Habitat in the Merrimack Watershed

The production potential for alewife is 1,273,935 returning adult fish in the Merrimack basin under the Interim Scenario (Table 14). Under the Ideal Scenario, the production increases to 4,061,740 returning adults. Lake Winnisquam is the largest[56] potential contributor to the alewife population with a production potential of nearly one million alewife. This represents

[55] These reaches had an average width <50 feet, see Section 5.1.3
[56] Lake Winnipesaukee is larger, but is not a current option due to access issues (eight dams lacking passage) and management constraints.

almost 25 percent of the estimated production for the entire watershed. Six dams isolate the lake from the accessible portion of the Merrimack watershed. Lake Winnisquam has been the primary NHFGD river herring stocking location for decades; initially (in the 1980s) receiving fish to supplement the forage for salmonids in the lake, and more recently (since 2012) stocked as a part of the river herring restoration strategy. Over this period, the lake has received nearly half of all river herring stocked in the watershed.

Table 14. Alewife Spawning Habitat and Production Scenarios

	Interim Scenario	**Ideal Scenario**
Acres of Spawning Habitat (Impoundment)	3,831	3,959
Acres of Spawning Habitat (Lentic)	1,590	13,325
Total Acres of Spawning Habitat	5,421	17,284
Estimated Production (235 Adult Returns/Acre)	1,273,935	4,061,740

8.2.4 American Eel

The catadromous, panmictic life history and variable habitat utilization of American eel is not conducive to the same methods of estimating production based on acres of spawning habitat. Therefore, we did not estimate American eel production for the Merrimack watershed.

8.2.5 Sea Lamprey

The life history of sea lamprey is conducive for traditional population metrics because year classes are well defined and both juveniles and adults are susceptible to sampling during migration. Data on this species in the Merrimack River watershed is limited. We lack the data necessary to estimate population size or potential production for the Merrimack watershed. Future data collection to determine run counts, escapement, fecundity, mortality rates, and habitat utilization will facilitate the calculation of population metrics.

9.0 INLAND FISHERY OF THE MERRIMACK WATERSHED

Streams and smaller tributaries in the lower Merrimack River Watershed are generally low-medium gradient, slow moving, typically with sand, silt, and cobble/gravel substrates. Stream characteristics are generally dependent on local topography. Most of these waterways are forested with some areas of heavy development. Farther north in the watershed, rivers and streams become a mix of lower gradient wetland stream reaches interspersed with higher gradient reaches with rocky or cobble substrate. These smaller streams are highly fragmented by small dams, both active and inactive, and numerous under-sized stream crossings - particularly in upper reaches. The mainstem of the Merrimack and its larger tributaries are typical of large New England Rivers, generally low gradient with variation in the substrate which includes rocky areas and bedrock with much of the substrate dominated by sand and silt, with dynamic sediment/siltation patterns. Riparian areas along the mainstem are comprised of forest, farmland, and urban centers.

The Merrimack mainstem and the mid-sized tributary rivers contain typical warmwater fish communities (Table 15), dominated by sunfishes (pumpkinseed, redbreast, bluegill, smallmouth bass; Family *Centrarchidae*), minnows (spottail shiner, fallfish, blacknose dace; Family *Cyprinidae*), catfishes (brown bullhead, yellow bullhead, margined madtom; Family *Ictaluridae*), pickerel (chain and redfin; Family *Esocidae*) and white suckers (Family *Catostomidae*). Presence and abundance of these species is highly dependent on river habitat type (e.g., pool, riffle, run, or impoundment) and varies seasonally.

Coldwater species such as brook trout (*Salvelinus fontinalis*) are present in many cold, groundwater-fed streams. Impoundments and lakes in the watershed are dominated by warmwater lentic fishes such as largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Lepomis macrochirus*), yellow perch (*Perca flavescens*), golden shiner (*Notemigonus crysoleucas*), white sucker, chain pickerel, and sometimes black crappie (*Poxomis nigromaculatus*). Several of these warmwater species were introduced through past stocking events that reflect angler preference more than the historical freshwater community of New England waterways.

White perch (*Morone americana*) are a semi-anadromous temperate bass species found in the watershed. White perch have a range of life cycle characteristics. Some populations live in lakes, impoundments, and large rivers year-round, while others exhibit semi-anadromous behavior where they overwinter in brackish estuarine waters and migrate upriver in spring to spawn. They have been observed consuming river herring in high numbers and would likely benefit from anadromous fish restoration. White perch are an adaptive species and serve as an intermediate example of how predator fish can respond and adapt to changes in habitat and food availability. Though they are typically not as sought after recreationally as smallmouth bass and striped bass, they are likely targeted by some anglers for consumption.

The banks of the Merrimack River mainstem are primarily forested and there are a number of access points for boaters and shore anglers. Largemouth and smallmouth bass are among the most popular freshwater species targeted by anglers. Carp fishing is relatively common in the mainstem Merrimack River south of the Amoskeag Dam. Walleye are uncommon, but are occasionally caught in the lower Merrimack and Contoocook Rivers. Pike are rarely reported upstream of Lowell, but large individuals are often seen in the Lawrence fish lift in early spring. American eels are sometimes captured by anglers throughout the Merrimack River watershed, but they are rarely targeted. Enough shad return to the Merrimack River below the Essex Dam in Lawrence to support a seasonal recreational fishery, but the low number of fish that pass above the Pawtucket Dam in Lowell has limited any interest in a recreational shad fishery in the upper watershed.

An increase in diadromous fish presence may affect inland fish assemblages through changes to predator/prey dynamics, and may affect recreational fisheries. Diadromous fish runs are generally concentrated in higher order rivers and streams, and habitat overlap with inland fishes is typically seasonal. An increase in anadromous fish runs, particularly juvenile alosines, will provide a seasonally reliable and abundant prey source for a number of stream and lake fishes. American eels and sea lamprey also provide forage for lentic and lotic fishes. The potential seasonal influx of prey and nutrients from the marine environment through restored diadromy will be a significant source of increased productivity in freshwater ecosystems throughout a large portion of the Merrimack River watershed. Juvenile alosines alter zooplankton community structure (size and abundance) through grazing, which may alter phytoplankton community structure. Recreationally important fish such as bass, perch, panfish, catfish, and pike will likely benefit from increased anadromous fish runs, supporting enhanced recreational fisheries. Large striped bass follow the river herring migration into the lower Merrimack River each spring. Anglers take advantage of these periods of seasonal abundance and will benefit from future increases in numbers. An increase in the American shad population, especially if it expands the recreational fishery into the Merrimack River watershed upstream of Lowell, will provide tremendous value to anglers and local economies. In addition, a fully restored river herring population may provide opportunities for bait harvest by saltwater anglers and lobster fishermen.

Table 15. Merrimack River Watershed Inland Fish Species

Common Name	Scientific Name	MA	NH	Origin (N=Native, I=Introduced)
Alewife	*Alosa pseudoharangus*	X	X	N
American Eel	*Anguilla rostrata*	X	X	N
Atlantic Salmon	*Salmo salar*	X		N
Banded Sunfish	*Enneacanthus obesus*	X	X	N
Black Crappie	*Pomoxis nigromaculatus*	X	X	I
Blacknose Dace	*Rhinichthys atratulus*	X	X	N
Bluegill	*Lepomis macrochirus*	X	X	I
Brook Trout	*Salvelinus fontinalis*	X	X	N
Brown Bullhead	*Ameiurus nebulosus*	X	X	N
Brown Trout	*Salmo trutta*	X	X	I
Burbot	*Lota*		X	N
Chain Pickerel	*Esox niger*	X	X	N
Common Carp	*Cyprinus carpio*	X	X	I
Common Shiner	*Luxillus cornutus*	X	X	N
Creek Chubsucker	*Erimyzon oblongus*	X	X	N
Fallfish	*Semotilus corporalis*	X	X	N
Fourspine Stickleback	*Apeltes quadracas*	X		N
Golden Shiner	*Notemigonus crysoleucas*	X	X	N
Green Sunfish	*Lepomis cyanellus*	X	X	I
Hybrid Bluegill/Pumpkinseed	*Lepomis macrochirus X Lepomis gibbosus*	X	X	I
Lake Trout	*Salvelinus namaycush*	X	X	I/N
Lake Whitefish	*Coregonus clupeaformis*		X	N
Largemouth Bass	*Micropterus salmoides*	X	X	I
Margined Madtom	*Noturus insignis*	X	X	I
Mummichog	*Fundulus heteroclitus*	X		N
Northern Pike	*Esox lucius*	X		I
Northern Redbelly Dace	*Chrosomus eos*		X	N
Pumpkinseed	*Lepomis gibbosus*	X	X	N
Rainbow Smelt	*Osmerus mordax*	X	X	N
Rainbow Trout	*Oncorhynchus mykiss*	X	X	I
Redbreast Sunfish	*Lepomis auritus*	X	X	N
Redfin Pickerel	*Esox americanus*	X	X	N
Rock Bass	*Ambloplites rupestris*	X	X	I
Round Whitefish	*Prosopium cylindraceum*		X	N
Sea Lamprey	*Petromyzon marinus*	X	X	N
Slimy Sculpin	*Cottus cognatus*		X	N
Smallmouth Bass	*Micropterus dolomieu*	X	X	I
Spottail Shiner	*Notropis hudsonius*	X	X	N
Striped Bass	*Morone saxatilis*	X		N
Swamp Darter	*Etheostoma fusiforme*	X	X	N
Tesselated Darter	*Etheostoma olmstedi*	X	X	N
Walleye	*Sander vitreus*		X	N
White Catfish	*Ameiurus catus*	X		I
White Perch	*Morone americana*	X	X	I/N
White Sucker	*Catostomus commersoni*	X	X	N
Yellow Bullhead	*Ameiurus natalis*	X	X	I
Yellow Perch	*Perca flavescens*	X	X	N

10.0 FISHERIES MANAGEMENT IN THE MERRIMACK RIVER

This section details the current management issues for the CP target species and a list of management plans reviewed while developing the CP.

10.1 Fisheries Management and Watershed Plans

We considered the management and restoration plan concepts, philosophies, and guidelines in the following documents during the development of the CP:

Species-Focused Plans

- MRTC Strategic Plan & Status Review Anadromous Fish Restoration Program Merrimack River (1997)
- MRTC American Shad Restoration Plan (2010)
- MRTC Draft Eel Plan (2013)
- MRTC Draft River Herring Management Plan (2018)
- NMFS Shortnose Sturgeon Recovery Plan (1998)
- ASMFC Amendment 2 to the Fishery Management Plan for Shad and River Herrings: River Herring Management (2009)
- ASMFC River Herring Benchmark Stock Assessment Volume II (2012)
- ASMFC Amendment 3 to the Fishery Management Plan for Shad and River Herrings: American Shad Management (2010)
- ASMFC American Shad Benchmark Stock Assessment and Peer Review Report (2020)
- ASMFC Interstate Fishery Management Plan for the American Eel (2014), as amended

Watershed Plans

- Merrimack River Watershed Conservation Plan (2014)
- Merrimack River Watershed Assessment Study (2006)
- Merrimack River Policy and Technical Committees (1990)

State Plans

- New Hampshire Wildlife Action Plan (2015)
- Massachusetts Wildlife Action Plan (2015)

10.2 Current Management Issues

The following management issues in the Merrimack River watershed affect restoration of the diadromous fishery:

- As the first dam on the river, the restoration success is reliant on fish passage efficacy at the Lawrence Project. The decommissioning of the fish ladder at Lawrence makes the fish lift the only anadromous fish passage to upstream habitats (>15,600 surface acres of river habitat; more than 75 percent of river habitat >50 feet wide). The required manual operation of the lift and cycle time, even under optimal conditions, causes migration delays. Additionally, the lift lacks, by an order of magnitude, the biological capacity to pass the production potential of even the currently accessible upstream habitat.
- The passage efficacy at the Lowell Project is poor. Design flaws and hydrologic conditions influencing attraction flow cause delays or failed passage for many fish. From 1989 to 2015, only 16 percent of the fish that passed Lawrence also passed Lowell.[57]
- The Hooksett and Garvin's Falls Dams on the Merrimack River lack upstream passage facilities. Together these dams block access to the Suncook, Soucook, Contoocook, Winnipesaukee, and Pemigewasset watersheds.
- The Ballardvale Dam on the Shawsheen River is the last barrier between the headwaters of the Shawsheen and the Atlantic Ocean. Fish passage at this site, by a fishway or dam removal, will provide access to 17 miles of the Shawsheen River.
- Poor upstream passage at the Centennial Island Project and the lack of passage at the Talbot Mills Dam a few miles upstream limits access to the Concord, Assabet, and Sudbury Rivers.
- Design and passage efficiency issues at the Jackson Mills and Mine Falls Projects combined with the lack of upstream passage at the Pepperell Project inhibit diadromous fish production in the Nashua River watershed.
- The McLane and Goldman Dams prevent fish access to over six miles of potential habitat in the Souhegan River.
- The Pine Island Pond Dam prevents access to Pine Island Pond, which comprises over 50 acres of suitable spawning habitat for alewife. The small dam also prevents access to several mile of Cohas Brook and tributary streams.
- The Kelley Falls Project on the Piscataquog River lacks upstream passage facilities, preventing access to over five miles of upstream habitat.

[57] This percentage does not represent the fish passage effectiveness of the Lowell project. There are several tributaries with suitable habitat located between the Lawrence and Lowell projects. The percentage of fish ascending the tributaries in this reach is unknown.

- The Upper and Lower Penacook Projects and the Rolfe Canal Project near the confluence of the Contoocook River and Merrimack Rivers prevents access to spawning and rearing habitat in this watershed.
- The density of dams on the Winnipesaukee River prevent migratory fish from reaching upstream habitat. Lake Winnisquam receives the majority of stocked adult river herring in the Merrimack watershed. Safe, timely, and effective downstream passage at each hydroelectric facility is critical to the success of this management effort.
- Few lakes and ponds that alewife historically used for spawning have volitional access. Accessible habitat does not significantly contribute to the returning adult population. This has resulted in a reliance on stocking and trap/transfer activities to sustain the population.
- Many dams lack dedicated upstream passage structures for American eel in the watershed. Fishways designed for anadromous fish are less effective for American eel.
- Effective downstream protection and protection measures for adult and silver-phase American eels at hydropower projects is crucial for increasing abundance coastwide.
- Water quality remains a concern in the Merrimack mainstem and several major tributaries. Point sources of pollution such as CSOs, municipal and industrial discharges, as well as non-point sources (NPS) including urban, agricultural, and septic runoff still contribute to water quality issues.
- Seasonal flows and release schedules may be problematic at many fish passage facilities in the watershed. Low and high flows can negatively affect passage success.

11.0 SOCIAL-ECOLOGICAL BENEFITS OF RESTORED DIADROMY

A healthy, well-functioning riverine system holds intrinsic value measured in economic, social, cultural and ecosystem services (Wilson 2002). Content and performance metrics such as economic value added, community resilience, and cultural opportunity, quantify or define the public[58] benefit derived from discrete features of natural systems. In instances where diadromous fish stocks are depleted, restoration provides the simultaneous opportunity to restore runs of fish and the economic and cultural benefits supported by well-functioning ecosystems.

Several factors inhibit perceived potential benefit, and in some cases, reduce public support for restoration efforts. One phenomenon is shifting baseline syndrome occurring when observers leave the system and younger generations are left unaware of past biological conditions (generational amnesia) or through direct observers forgetting or misremembering biological conditions (personal amnesia) (Papworth et al. 2009). Either case leads to lower expectations of a restored ecosystem as a result of the gradual loss of ecological integrity (Pauly 1995; McClenachan et al. 2015). The low expectations and diminished collective memory of significant runs of fish may reduce the perceived benefit of restoration by the public. Shifting social perceptions are a management challenge, but do not change the benefits that accompany well-functioning ecological systems.

McClenachan et al. (2015) identified five social benefits of restoring the ecosystem connectivity and alewife fisheries in Maine Rivers; (1) unshifted baselines, restored fishing rights, and a second chance at sustainability, (2) diversification and enhancement of local economies and fisheries, (3) community building in postindustrial towns, (4) broadening the community of conservationists, and (5) ecosystem services and recreation. These categories highlight the diverse social benefits derived from the restoration of a single diadromous species, and are applicable to restoration efforts of target species in the Merrimack River watershed.

11.1 Social-Ecological Systems

Social-Ecological System (SES) was introduced by Ratzlaff (1969). Two decades later, Russian microbiologist B.L. Cherkasskii (1988) defined SES as “consisting of two interacting subsystems: the biological (epidemiological ecosystem) and the social (social and economic conditions of life of the society) subsystems where the biological subsystem plays the role of the governed object and the social acts as the internal regulator of these interactions.” Ten years later, although they were unaware of Cherkasskii’s definition at the time, Berkes and Folke (1998) refined the concept into a framework for the study of links between social institutions and ecosystems. A few years later, Anderies et al. (2004) proposed defining SES as “an ecological system intricately linked with and affected by one or more social systems both social and ecological systems contain units that interact interdependently and each may contain interactive

[58] In this section, the terms “social” and “public” benefit(s) are used synonymously.

subsystems as well." The concept of SES continues to evolve. Colding and Barthel (2019) noted that less than half of the publications analyzed defined SES, and suggested that the absence of a unifying definition is a drawback when communicating the concept to a broader multidisciplinary audience. For the purposes of this CP, we use the definition provided by Anderies et al. (2004).

The SES of the Merrimack River watershed comprises numerous social institutions including the general public, private landowners, municipalities, state and federal resource managers, tribal organizations, hydropower operators, utility providers, and NGO's. The ecological component is a diverse, interconnected web of terrestrial, aquatic, and marine habitats and organisms. Keystone species such as river herring are a common thread that connects these diverse systems with the potential to unite or unravel the SES, if not responsibly managed.

11.2 Social Benefits

11.2.1 Economic

The Merrimack River and tributaries supported regionally significant populations of diadromous fish. These large numbers of fish travelling inland, some as far as several hundred miles, provided sustenance fisheries for Native Americans. Later, they supported the first Colonial settlers to the region. Fish (river herring, shad, and salmon) preserved with salt provided nutrients when other food was scarce during the harsh New England winters. People were so reliant upon the seasonal abundance of river herring, shad, and salmon that preserved fish became a form of currency used for trading and settling debts.

By the 1950s river herring were one of the most valuable anadromous fishes harvested commercially in Massachusetts, with a peak harvest (for food and bait) of 33 million pounds in 1958 (Nelson et al. 2011). This harvest level was not sustainable with the concurrent loss of habitat. Fishing effort decreased as foreign purse-seining fleets departed following the establishment of the exclusive economic zone. By the 1980s, harvest was only a small fraction of historical levels (Nelson et al. 2011). The river herring population declined to historic lows by the late 1990s. A moratorium on commercial harvest was implemented in 2005 that remains in effect. As of 2020, the states of Maine, New York and South Carolina have sustainable commercial harvest plans for river herring. New Hampshire allows harvest for personal use as bait; Massachusetts allows recreational harvest.

For many of the reasons described in the recreational benefit section, commercial fisheries will benefit from improved abundance and condition of target species.

11.2.2 Cultural

Runs of salmon, shad, and river herring were a culturally significant phenomenon and helped define the regional identity and sense of place. Through the early 1700s, fish migrations were a much-anticipated annual celebration. Many farmers used hooks and nets instead of hoes and scythes during the migration. With the industrial revolution came a shift from an agrarian- to industrial-based regional economy. Rivers and tributaries were dammed to take advantage of waterpower, causing vital fish habitats throughout the basin to lose their connection to the ocean. The swift loss of connectivity coupled with deteriorating water quality resulting from industrial discharge and runoff, resulted in a precipitous decline of the diadromous fish stocks in the Merrimack River watershed.

Some of New England's most visible and majestic wildlife including bald eagle, osprey, and king fisher, benefit and rely on the seasonal abundance provided by fish such as river herring. The emblem of America, the bald eagle, aggregates in areas with a predictable abundance of prey. These seasonal gatherings of eagles and the forage that supports them are crucial to the long-term stability of eagle populations (DeSorbo et al. 2015). For example, on the Sebasticook River in Maine, recent restoration efforts (a series of dam removals and fish passage installations) have led to the successful recovery[59] of the alewife run. This has created a consistent gathering of bald eagles each year from mid-May through early-July. As many as 64 eagles have been observed in a five-mile stretch of the river, the largest documented aggregation in New England (DeSorbo et al. 2015). Aside from the obvious ecological benefits of such events, the aesthetic opportunity and cultural symbolism of supporting and conserving the once endangered bald eagles is significant, and diadromous fish play a vital role in expanding the occurrence of eagle aggregations. Like the Sebasticook River, the Merrimack has the potential to produce a large abundance of river herring. With successful restoration, scenes such as those observed in Maine may re-emerge on the Merrimack.

In addition to the direct cultural benefits historically provided by diadromous fish, less conspicuous, are numerous indirect benefits, potential modern uses, and future benefits that are yet to be realized. For example, sea lamprey are the subject of medical research aimed at improving our ability to deliver therapeutic drugs to the brain. These fish produce molecules known as variable lymphocyte receptors which may offer a new pathway to treat a variety of serious health conditions including cancer and stroke (Cohut 2019). Emerging uses such as this, and yet undiscovered ones, rely on healthy, sustainable populations that are capable of supporting such inquiry.

From a societal lens, the decline in the region's diadromous fish populations has reduced their relevance to each passing generation. This waning interest also results in a lack of advocacy, diminishing the number of institutions that are motivated to act on behalf of the

[59] A total of 2.75 million alewife ascended the river in 2011, up from only 47,000 individuals in 2006.

species (Waldman 2010). In the Merrimack watershed, widespread damming and the resulting lack of habitat access has caused a reduction in physical space for diadromous fish to exist in the riverine landscape. Perhaps less apparent is the associated loss of space for these fish in the contemporary human psyche as they feature less and less prominently in people's lives (Liebich et al. 2018).

Collectively, the sentiments that a person associates with a place is referred to as a "sense of place" (Williams and Stewart 1998; Stedman 2002; Farnum et al. 2005; Liebich et al. 2018). From a fisheries management perspective, places are areas of biological relevance (e.g. individual lotic and lentic features, watersheds, regional biomes, etc.) and their associated biophysical attributes (Liebich et al. 2018). Notwithstanding, places are more than the sum of the physical parts. Social experiences and personal interpretations are linked to our concept of place. Therefore, a desirable social benefit of restoring diadromous fish in the Merrimack River watershed is restoring the prominence of diadromous fish in the regional sense of place.

11.2.3 Recreational

Diadromous fish provide direct and indirect recreational benefits. The most evident direct benefit is improved angling opportunity. Eels and river herring are excellent baitfish. With a sustainable population, these species could be harvested and used to fish for other desirable game fish (e.g., striped bass). Shad are also a popular gamefish. In rivers with restoration efforts, such as the Kennebec River in Maine, recreational fishing for shad has improved. Permitting the opportunity for harvest of diadromous fish in the Merrimack is a management goal for the recreational fishery. Successful restoration will support this goal.

Indirectly, healthy runs of migratory fish provide a seasonal abundance of marine-derived nutrients that improve growth and condition of resident game species. Predatory inland gamefish including brook trout, rainbow trout, brown trout, lake trout, landlocked salmon, smallmouth bass, largemouth bass, pickerel, northern pike, white perch, and yellow perch all benefit from the seasonal abundance of diadromous fish. In addition to recreational opportunities created in freshwater and estuarine habitats, species such as river herring feed numerous commercially and recreationally important marine predators, including striped bass, bluefish, tuna, cod, haddock, and halibut. These species each benefit from the nutrients provided by diadromous fish forage, improving the quality of fish available to commercial and recreational anglers. One of the ultimate goals of successful restoration is that the diadromous fish of the Merrimack will reach sustainable population levels that support the best possible uses, including recreational and commercial harvest.

11.3 Ecosystem Function Benefits

Limburg and Waldman (2009) summarized four distinct roles of diadromous fish with regard to ecosystem function: provisioning of protein and other products, linking continental and marine ecosystems by transporting embodied productivity upstream, supporting marine food chains through the addition of fish that emigrate from natal rivers, and the important role fish have for both indigenous and nonindigenous peoples. The historical shad, river herring, eel, and lamprey runs of the Merrimack River once supported each of these functions.

Provisioning of Protein

Several life history aspects of diadromous fish make them especially susceptible to (or suitable for) exploitation. The historical abundance of diadromous fish would likely have established interest in these fishes even if they had been difficult quarry; however, their predictable runs and ease of collection as they congregate around their spawning grounds made them extremely attractive to fishermen (Bolster 2008). In addition to table fare, alosines make excellent bait for catching larger, predatory fish or in lobster pots.

Upstream Transport of Marine-derived Nutrients

Semelparous anadromous fish (or incidental/natural mortality from iteroparous stocks) have a significant impact on their associated ecological communities, through direct consumption by wildlife and stream fauna or through nutrient release into the water and riparian zones during decomposition (Limburg and Waldman 2009). Although much of our knowledge regarding nutrient loading by diadromous fish comes from studies focused on pacific salmon *Oncorhynchus* spp. (Schindler et al. 2003; Post and Walters 2009), the nutrient dynamics associated with alosine migrations in Atlantic coast ecosystems are comparable to effects observed in analogous salmon-influenced Pacific coast systems (Durbin et al. 1979). Garman (1992) investigated anadromous alosines in the non-tidal James River in Virginia. He estimated that their annual allochthonous biomass input might have exceeded 155 kg/hectare[60] prior to the incidence of dams. The influx of nutrients are utilized at multiple trophic levels. Carcasses are consumed directly by birds, fish, invertebrates and microorganisms, and nutrient release resulting from decomposition may increase algal and invertebrate abundance (Limburg and Waldman 2009; Walters et al. 2009). Nutrient inputs from iteroparous stocks, through excretion, may also contribute significantly to the nutrient dynamics in smaller tributaries and associated lentic waters such as those frequented by spawning alewives (Post and Walters 2009).

Marine Food Web Support

Similar to the upstream transport of marine-derived nutrients, the marine food web involves diadromous fish as the conveyers of nutrients, but this functions in reverse. At northern latitudes, these nutrient fluxes are primarily composed of juvenile fish migrating from natal rivers to the sea (Limburg and Waldman 2009). Nineteenth century observers documented that the abundant emigration of juvenile anadromous fishes served as important forage for marine species such as Atlantic cod (*Gadus morhua*), closely linking inland production to coastal food

[60] Assumed a carrying capacity 3.6 million adults and a 70% post-spawn mortality rate

webs (Stevenson 1899; Limburg and Waldman 2009). For forage fish such as alewife, seemingly everything in the estuarine and marine environment eats them, including striped bass, bluefish, tuna, cod, haddock, halibut, American eel, brook trout, seabirds, osprey, bald eagle, herons, gulls, terns, cormorants, seals, whales, and turtles (MDMR 2016). Dias et al. (2019) modelled the marine food web impacts of contemporary versus restored biomass of forage fish groups. They conclude that anadromous alosines, especially alewife, demonstrate the largest increase in the keystoneness index[61] among all forage fish groups. Furthermore, their findings highlighted anadromous alosines' importance as a component of the forage fish complex, with the model indicating a potential biomass increase in more than 30 different functional groups in response to restored alosine biomass (Dias et al. 2019). Restoring and enhancing the diadromous fish stocks in the Merrimack River will have a positive impact on numerous ecologically and commercially important species, as well as overall ecosystem function.

Importance for Indigenous and Nonindigenous People

Coastal Native American communities relied upon the annual abundance of diadromous fish for generations before the arrival of European settlers. The seasonal abundance was important for provisioning food for the harsh New England winters. Diadromous fish also contributed to the aesthetic and cultural values by which Natives and the first European settlers knew themselves and the region (Bolster 2008).

[61] The "keystoneness index" refers to a continuous ranking of all functional groups according to the importance of their proximity to a keystone role within the marine ecosystem

12.0 WATERSHED-LEVEL GOALS, OBJECTIVES & RECOMMENDATIONS

Section 12.1 outlines the high-level goals and objectives of this CP that are applicable to the entire Merrimack Watershed. Section 12.2 contains goals and objectives specifically related to restoration of diadromous fish.

12.1 Goal and Objectives for the Merrimack River Watershed

The overarching goal of this CP is to coordinate the restoration, protection, and enhancement of diadromous fish stocks and habitats in the Merrimack River watershed.

12.1.1 Habitat

Objective 001. Improve habitat accessibility for diadromous fish in a manner consistent with appropriate management actions for resident fisheries. This is facilitated by dam removal, or installation or improvement of safe, timely, and effective fish passage facilities at obstacles that prevent fish from reaching habitats.[62]

Action(s)

- Improve habitat access and connectivity wherever possible. While dam removal is the most effective strategy, installing effective upstream and downstream fish passage will mitigate the connectivity problem in the watershed.
- Implement downstream protections for emigrating adults and juveniles at hydroelectric projects with accessible or stocked upstream habitats.
- Optimize passage efficiency at all fish passage facilities. This may include replacement, modification, repair, or operational changes.
- Address road crossings and other potential non-dam barriers that fragment habitat.

Objective 002. Improve habitat quality to support growth and reproduction for diadromous species in a manner compatible with the management goals for resident freshwater species.

Action(s)

- Maintain coordination among resource agencies to ensure management interests are addressed as restoration efforts advance.
- Identify degraded habitats that will benefit from restoration actions.
- Support restoration projects that improve habitat conditions.

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[62] Dam removal is the preferred option in nearly all cases where restoring fish passage is the goal. We recognize this is not always a feasible option. We recommend alternative strategies (e.g. installing or retrofitting fish passage structures, or rebuilding them based on current data and designs) where dam removal is infeasible.

- Promote responsible development and habitat conservation and preservation activities.

Objective 003. Ensure that water withdrawal impingement or entrainment effects do not cause declines or inhibit recovery of diadromous stocks.

Action(s)

- Collaborate with local organizations and permitting agencies to identify and support implementation of best management practices that protect diadromous stocks.

12.1.2 Water Quality

Maintaining water quality is crucial to support the many uses of the water resources of the Merrimack watershed. As a fundamental component of habitat, water quality is essential for diadromous fish restoration. However, water quality has much broader impacts, with use impairments affecting the social-ecological system of the Merrimack watershed. Numerous communities in the watershed use the Merrimack and tributaries for both drinking water and waste assimilation. These two uses compete because removing water from the river reduces its capacity for waste assimilation, resulting in higher concentrations of pollutants. Lower flow can also cause stress or impair movement for aquatic organisms, increase temperature (seasonally), and decrease dissolved oxygen concentration along with other impacts.

Current municipalities with known CSOs include Haverhill, Lawrence, Lowell, and Fitchburg (Nashua River) in MA, and Nashua, and Manchester in NH. A recent (7/13/2020) agreement[63] mandated the city of Manchester, NH to upgrade its sewer infrastructure to mitigate the impacts of CSOs. The city will spend $231 million over the next 20 years, and the planned upgrades are expected reduce the overflow discharges by 74 percent.

Objective 004. Improve water quality in areas where water quality degradation has negatively affected diadromous fish stocks or is otherwise impaired.

Action(s)

- Identify and reduce negative effects of point source pollution such as CSOs and municipal waste discharge.
- Support initiatives that update aging and outdated grey infrastructure to improve function and efficiency.
- Mitigate for NPS pollution through best management practices (BMPs) in areas prone to increased runoff (e.g., impervious surfaces, agriculture).
    - Encourage establishing or increasing forested riparian buffers.

[63] https://www.justice.gov/enrd/consent-decree/file/1293746/download#Lodged%20Consent%20Decree

- o Promote the installation of green infrastructure. This may include rain gardens, pervious pavements, green streets and parking, bioswales, and rainwater harvesting.
- o Reduce road salt usage where practical and safe.
- o Ensure the proper use of fertilizers and landscaping care products to reduce NPS.
- o Remediate pollutants that have accumulated in river sediments or riparian areas.
- o Promote agricultural BMPs to manage nutrient inputs from animal waste and other farming activities.
- o Support research into the identification and treatment of emerging pollutants (e.g., per- and polyfluoroalkyl substances (PFAS), pharmaceuticals & personal care products (PPCPs)).

Objective 005. Maintain natural water temperatures and seasonal fluctuations.

Action(s)

- Monitor water temperatures at the heated discharge of the Bow Power Plant.
- Identify and protect thermal refugia.
- Encourage establishing or increasing forested riparian buffers.

Objective 006. Ensure that decisions regarding river flow allocation consider flow needs for diadromous fish migration, spawning, and nursery habitat.

Action(s)

- Collaborate with consumptive users, flood managers, and permitting agencies to identify and support implementation of flow management practices that protect diadromous stocks.

12.1.3 Stocking

Stocking is an effective method for initiating a restoration program or providing fish passage as an interim measure in challenging habitat reaches. In some cases, stocking may be preferable to certain types of structural passage when the stresses and delay of volitional ascent are substantial (e.g., where alosine must pass multiple projects in a short distance). There are concerns associated with trap and truck operations including migration delay, handling stress, biological capacity, and invasive species. While stocking is often an important component of the restoration process, the overall goal is a self-sustained population of diadromous fish via volitional access to habitats that requires minimal management.

Objective 007. Initiate or continue programs to stock diadromous fish where necessary and practical, as a management measure to develop self-sustaining populations that ultimately do not rely on stocking.

Action(s)

- Conduct intra-basin transfers. Trap and haul fish from the Essex Dam fish lift and the Amoskeag Fish Ladder to suitable habitat in the Merrimack River watershed to promote sustainable spawning runs and facilitate fish passage improvements. Habitats located in the Interim Scenarios are a priority for stocking.
- Inter-basin trap and transfer, if necessary. For example, supplement stocking sites in NH with river herring from out of basin sources in coastal New Hampshire and Maine when available.
- Egg harvest and fry/juvenile stocking. For example, stock larval American Shad from adult fish spawned at the Nashua National Fish Hatchery to assist with shad restoration efforts in the Merrimack River watershed.
- Continue to stock Lake Winnisquam with river herring to maintain large numbers of returning fish that allow evaluation of fish passage in downstream reaches of the Merrimack River watershed.
- Transfer adult American Shad into inaccessible spawning habitat to encourage restoration in the upper Merrimack River.

12.1.4 Research

Federal and state resource agencies strive to apply the best-available scientific information during project selection, implementation, and the regulatory review process. Over the last several years, a number of state, federal, and NGO efforts have identified high priority research needs that support the effective conservation and restoration of diadromous fish and habitats throughout their respective ranges. Regional and coast-wide priorities identified through collaborative management processes that apply to, and would benefit, the Merrimack River watershed include:

- A coast-wide understanding of stock status and trends, including the ecological factors that limit diadromous fish populations in the marine environment.
- An understanding of climate change effects on the quantity, quality, and distribution of spawning and maturation habitats used by diadromous fish.
- An understanding of the effects from the reductions in the size of diadromous fish populations to food webs that include coastal recreational and commercial fisheries.
- Evaluating the importance of genetic diversity in efforts to restore diadromous fish through hatchery-based stock augmentation.
- Evaluating the effects of how water withdrawals affect riverine, estuarine, and coastal habitats, including reductions in water quality and fragmentation of habitat.

- A systematic identification of opportunities to restore access to habitats important to diadromous fish populations through development of upstream and downstream passage technologies.
- A determination of the survival rates needed during upstream and downstream migrations to support restoration.
- An economic analysis of the contributions from recreational and commercial diadromous fisheries to communities.

Objective 008. Recommend and support research programs that will produce data needed for 1) the development of management recommendations relating to sustainable and acceptable yields, 2) the preservation or recovery of stock levels, and 3) optimal utilization of those stocks.

Objective 009. Recommend and support research that advances restoration efforts in the Merrimack River watershed.

Action(s)

- Develop life cycle models for target species in the Merrimack River watershed.
- Refine the aerial production estimates for alosines.
- Develop production estimates for Sea Lamprey.
- Monitor American eel abundance and distribution.
- Develop habitat maps for each of the target species.

Objective 010. Develop and maintain a list of Merrimack River watershed-specific research needs that support restoration efforts.

Action(s)

- Investigate American shad, blueback herring, and American eel life cycle models for the Merrimack River.
- Refine production estimates for alosines based on site surveys and passage/efficiency improvements.
- Map priority migratory fish habitats.
- Develop a sea lamprey production goal.
- Assess diadromous fish populations below Essex Dam.
- Conduct passage efficiency and downstream mortality studies for target species at facilities where such studies have not been completed recently.
- Investigate the interactions between anadromous river herring and rainbow smelt/coldwater fisheries in Lake Winnisquam.

- Assess the feasibility of river herring restoration in reservoirs managed for water supplies or flood control.
- Evaluate the current potential for density dependent growth of juvenile alosine by river reach.
- Evaluate the relationship between spawning success and substrate modification associated with dams (e.g., Pawtucket and Essex dams).

12.1.5 Public Outreach and Stakeholder Engagement

Increased awareness of the benefits of healthy diadromous species populations is important to further conservation. Federal and state resource agencies rely on community and NGO partners for promoting and advancing diadromous fish restoration. This CP is intended to establish a common platform for promoting restoration initiatives with partners to raise general awareness of diadromous fish.

Objective 011. Seek to build collaborative partnerships among local, state, and federal agencies to align management approaches and reduce duplication of effort or resource allocation.

Objective 012. Engage the recreational fishing community through directed surveys to identify their interests and build support for restoration activities.

Objective 013. Initiate and support programs to provide information and education to the public on the importance of the diadromous fishery of the Merrimack to increase visibility and advocacy.

Action(s)

- Promote the use of local resources for school outreach and education. This may include partnerships with hydropower developers with existing outreach and educational facilities.
- Promote World Fish Migration Day events in the Merrimack watershed to raise awareness of open rivers and migratory fish.
- Promote classroom-based projects to support restoration efforts while simultaneously educating children on the importance of migratory fish. These programs will connect the next generation with the environment, fostering a sense of responsibility for the natural resources of the watershed. Examples of such efforts include:
    - Small eel traps or similar traps placed at strategic locations (small dams, road crossings etc.) could be set up for school involvement. Students could check and empty the traps while learning about the species.
    - Similar to trout in the classroom (Trout Unlimited collaboration), other watersheds have had success with eels or smolts (salmon) in the classroom. A similar program could be adapted for use at schools in the Merrimack watershed.

- Offer presentations or road shows as restoration advances. These events can help teach the public and draw attention to ongoing restoration activities.
- Support the recruitment of volunteers to watershed groups.
- Support events that connect the public with migratory fish using public facing web cameras at active passage facilities or restoration projects. This builds a public connection by remotely viewing a live feed of fish migration.
- Provide annual counts to the public to provide spatial and temporal context to diadromous restoration. This action may include coordinating citizen science volunteers to support fish counts, collaboration with hydropower developers, and the maintenance of a public website.

12.2 Goals and Objectives for the Restoration of the Diadromous Fishery

The goal for restoring the diadromous fisheries is centered on achieving self-sustaining runs that meet or exceed the estimated production potential of each target species, and a distribution of fish to suitable habitat throughout the watershed.

12.2.1 Objectives Designed to Benefit All Target Species

Several objectives directly related to diadromous fish are not species specific, and progress towards these objectives will benefit all target species.

Objective 014. Improve passage efficiency at all fish passage facilities in the watershed to achieve safe, timely and effective passage that meets or exceeds the following performance criteria:[64]

Action(s)

- For alosines, achieve and maintain a minimum of 80 percent upstream passage efficiency.
- For alosines and American eel, achieve and maintain a minimum of 95 percent downstream passage survival.
- Ensure diadromous passage facilities do not cause unnecessary delay that exceeds 24 hours at each Project.
- Determine appropriate criteria for the upstream passage of American eel and sea lamprey.

[64] These are based on the best available data and may be modified as new information becomes available

Objective 015. Ensure barriers with stocked or otherwise accessible upstream habitats have appropriate downstream protections to provide safe, timely, and effective downstream passage for all target species.

Action(s)

- Assess downstream passage at each barrier using the appropriate technology and regulatory process.
- Where regulatory processes are not available, determine the appropriate method for assessing the effectiveness of downstream passage at the identified barrier(s).

Objective 016. By 2030, provide upstream passage facilities at Hooksett, Garvin's Falls, Pepperell, Kelley Fall's Dams, Lower Penacook Falls, Rolfe Canal, and Upper Penacook Falls.

Action(s)

- Engage in the licensing and/or compliance activities to ensure upstream and downstream passage is safe, timely, and effective.

Objective 017. By 2030, provide upstream passage or remove the Ballardvale, Talbot Mills, McLane, Goldman and Centennial dams.

Action(s)

- Work with the dam owners and partners to determine the potential for dam removal at each site.
- Identify partners and funding to complete feasibility studies for dam removal and fish passage.
- Work with dam owners and partners to develop a plan and secure funding for completing the selected alternative based on the feasibility study.

12.2.2 American Shad

The goal for American shad is to restore a self-sustaining annual migration to the Merrimack River watershed, with unrestricted access to all spawning and juvenile rearing habitat in the mainstem and major tributaries.

Objective 018. At a minimum, provide adult and juvenile American shad passage to habitat reaches defined in the Interim Scenario (Section 8.0).

Objective 019. Achieve a self-sustaining spawning stock that approaches 1.0 million American shad in the Merrimack River watershed.

Objective 020. With 80 percent fishway efficiency at all projects, pass the target number of adult American shad at each of the mainstem barriers:

Mainstem Barrier	Target # adult shad (80% passage efficiency)
Essex Dam	635,560
Pawtucket Dam	426,898
Amoskeag Dam[65]	177,994
Hooksett Dam[66]	121,875
Garvin's Falls Dam	45,350

Objective 021. With 80 percent fishway efficiency at all projects, pass the target number of adult American shad at the following tributary barriers:

Tributary Barrier	Target # adult shad (80% passage efficiency)
Centennial Island Dam, Concord River	45,350
Jackson Mills Dam, Nashua River	58,734
Mine Falls Dam, Nashua River	43,788
Pepperell Dam, Nashua River	21,759
Kelley Falls Dam, Piscataquog River	10,150

12.2.3 Blueback Herring

The goal for blueback herring it to restore a self-sustaining annual migration to the Merrimack River watershed, with unrestricted access to all spawning and juvenile rearing habitat in the mainstem and major tributaries.

Objective 022. At a minimum, provide adult and juvenile Blueback herring passage to habitat reaches defined in the Interim Scenario (Section 8.0).

Objective 023. Achieve a self-sustaining spawning stock that approaches 5.0 million blueback herring in the Merrimack River watershed.

Objective 024. With 80 percent fishway efficiency at all projects, pass the target number of adult blueback herring at each of the mainstem barriers:

Mainstem Barrier	Target # blueback herring (80% passage efficiency)
Essex Dam	3,432,022
Pawtucket Dam	2,305,247
Amoskeag Dam[67]	961,166
Hooksett Dam[68]	658,125
Garvin Falls Dam	406,620

[65] Pass a minimum of 9,500 adult American shad at Amoskeag Dam per USDOI (2006)
[66] Pass a minimum of 9,800 adult American shad at Hooksett Dam per USDOI (2006)
[67] Pass a minimum of 22,500 adult river herring at Amoskeag Dam per USDOI (2006)
[68] Pass a minimum of 23,200 adult river herring at Hooksett Dam per USDOI (2006)

Objective 025. With 80 percent fishway efficiency at all projects, pass the target number of adult blueback herring at the following tributary barriers:

Tributary Barrier	Target # blueback herring (80% passage efficiency)
Centennial Dam, Concord River	244,890
Jackson Mills Dam	317,166
Mine Falls Dam	236,453
Pepperell Dam	117,450
Kelley Falls Dam	54,810

12.2.4 Alewife

The goal for alewife it to restore a self-sustaining annual migration to the Merrimack River watershed, with unrestricted access to all spawning and juvenile rearing habitat in the mainstem and major tributary watersheds.

Objective 026. Provide volitional passage solutions at barriers to allow alewife to access as many spawning habitats as possible.

Action(s)

- In the near-term, provide access to as much of the 5,421 acres of lentic and impounded habitat (outlined in the Interim Scenario, Section 8.1) as possible. Potential production of this habitat if accessible is 1,273,935 adult alewife.
- In the long-term, provide access to as much of the 17,284 acres of lentic and impounded habitat (outlined in the Ideal Scenario, Section 8.1) as possible. Potential production of this habitat if accessible is 4,061,740 adult alewife.

Objective 027. Ensure that the accessible spawning habitats are well distributed in the watershed to increase resiliency and avoid a single tributary watershed supporting the majority of production.

Objective 028. Maximize downstream survival of adult and juvenile alewife at hydroelectric projects.

Objective 029. Work with local communities and other stakeholders to implement upstream passage projects wherever possible.

Objective 030. Stock as necessary to establish or supplement runs of fish in suitable lentic waters until such runs are capable of sustaining their numbers without supplemental stocking

Objective 031. Conduct research on potential conflicts of alewife restoration with coldwater fisheries and water supply management to further refine restoration goals.

12.2.5 American Eel

The goal for American eel restoration is to conserve and enhance the population in the Merrimack River watershed by limiting impacts from detrimental factors, reducing anthropogenic mortality, and improving access to habitat.

Objective 032. Reduce the mortality of silver eels passing through hydroelectric facilities during their spawning migration.

Action(s)

- Provide oversight and guidance for improving the efficacy of existing eel passage facilities and investigate/develop new passage technologies for future facilities.

Objective 033. Conduct a baseline stock assessment of eel throughout the watershed.

Action(s)

- Systematically determine the current distribution and population trends of eel in the watershed. Use distribution patterns in combination with analyses of detrimental factors and habitat suitability, to prioritize restoration efforts.
- Work towards efforts to develop and implement formalized data collection protocols to characterize the eel stock in the watershed.
- Develop an American Eel population model to help evaluate and guide restoration efforts (Sweka et al. 2014; Stich et al. 2019).

Objective 034. Increase public awareness, appreciation, and knowledge of American eel to improve public support for eel conservation and enhancement activities.

Objective 035. Improve and monitor upstream passage into underutilized habitats.

Action(s)

- Given the comparative ease[69] and low cost of implementing upstream eel passage, coupled with the American eel's ability to utilize the majority of freshwater habitats in the Merrimack basin; we recommend upstream passage provision be sought or improved wherever possible.
- Monitor migration timing, migration triggers, size, and abundance of out migrating silver eels at various sites throughout the watershed to help guide management recommendations.

Objective 036. Evaluate habitat quality threats to the viability, health, and abundance of eel populations in the watershed.

Objective 037. Examine the level of impacts of legal and illegal exploitation of eel in the watershed.

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[69] Compared to structures designed for fusiform fishes, such as conventional fish lifts or ladders.

Objective 038. Determine research needs, review study results, and suggest BMPs to minimize silver eel mortality at hydroelectric facilities.

Objective 039. Develop a broad level of technical expertise in American eel biology among resource agency staff. This should include developing technical expertise in age, sex, and health determinations.

12.2.6 Sea Lamprey

Management goals for Sea Lamprey in the Merrimack River watershed are to restore and maintain sustainable runs for human and ecological benefits.

Objective 040. Improve habitat connectivity to restore and/or enhance sea lamprey runs in the watershed to support ecosystem functions.

Action(s)

- Consider adult transfers to speed the colonization of newly accessible or under-utilized habitat (e.g., upstream of the Hooksett Dam).

Objective 041. Conduct and/or support monitoring programs to assess status and trends of the lamprey population, including annual counts at passage facilities, ammocoete surveys, and habitat surveys.

Action(s)

- Conduct surveys to monitor distribution and map important lamprey spawning/rearing habitat.

Objective 042. Periodically determine and support short- and long-term research needs to support the restoration of Sea Lamprey.

Action(s)

- Support research on the marine phase of the Sea Lamprey life cycle, especially the extent to which populations are influenced by the availability of certain host species.
- Monitor Sea Lamprey runs in neighboring watersheds and adopt successful restoration efforts when appropriate (see CRASC (2018)).

Objective 043. Establish pathways for public outreach and education on the Merrimack CP and the benefits, ecological values, and historical importance of Sea Lamprey in the Merrimack River basin.

13.0 SUB-WATERSHED-LEVEL RECOMMENDATIONS AND PRIORITY ACTIONS

The following sections describe recommendations specific to the Merrimack River and its tributaries that support the goals and objectives outlined in section 12.0. These watershed and project-specific recommendations reflect our current understanding of the issues in the basin and may change with new information or goals under an adaptive management approach.

13.1 Merrimack River

13.1.1 Hydropower Barriers

13.1.1.1 Lawrence (P-2800)

As the first mainstem barrier, effective upstream and downstream fish passage at Essex Dam is paramount to the success of restoration activities in the watershed. We recommend the following actions to optimize fish passage at the Project:

1. Reduce delay during upstream passage at the Project.
    - Increase the capacity of fish passage structure(s) at the Project.
    - Manage spill to improve near- and far-field attraction to the upstream fishways.
    - Optimize near-field attraction flow emanating from the Project fishway/s to improve entrance efficiency.
2. Evaluate the efficacy of the existing fish lift.
3. Improve or replace the existing fish lift to meet current fish passage engineering design criteria and watershed restoration goals.
4. Monitor the upstream passage facilities for American eel and modify as necessary to improve performance.
5. Improve downstream survival of diadromous fish.
    - Determine the efficacy of the anadromous downstream passage facility and modify as necessary to improve performance.
    - Investigate entrainment prevention measures at the Project intake.
    - Determine if spill at the Project is a safe route of egress.
    - Silver eel downstream passage survival is estimated at 88 percent (Normandeau Associates Inc. (2019)). Evaluate options to increase eel survival to meet the performance standard of greater than 95 percent.
6. Employ consistent counting methods and equipment that maximize accuracy, precision, and reliability of annual fish counts for each species. Ensure collected data are properly archived to maintain data integrity and accessibility.

13.1.1.2 Lowell (P-2790)

The Pawtucket Dam and appurtenant facilities comprise the second major barrier to fish passage on the mainstem. Similar to Lawrence, efficient passage at Lowell is crucial to successful diadromous fish restoration. We recommend the following actions to optimize fish passage at the Project:

1. Reduce delay and improve upstream passage efficiency at the Project
    - Evaluate the zone of passage through the Project bypass (including the engineered weirs and bypass modifications) during passage season river flows and Project operations to optimize passage at the ladder.
    - Improve or replace the existing fish lift and ladder to meet current fish passage engineering design criteria and watershed restoration goals.
    - Evaluate spill management options that improve passage conditions.
    - Determine sites of American eel congregation and install passage at those locations.
2. Improve downstream survival of diadromous fish
    - For adult American eel, Normandeau Associates Inc. (2019) estimated downstream survival of adult silver-phase eel was 84 percent. Implement temporary nighttime shut downs to increase Project survival to greater than 95 percent.
    - Install entrainment prevention to keep adult American eel and alosines out of the powerhouse during downstream migration. A ¾-inch-clear trash rack or similar structure will prevent entrainment.
    - Install a new downstream bypass system that provides a safe, timely, and effective route of passage for the target species.
    - Employ strategies that prevent fish from entering the canals and other structures (e.g., ladder auxiliary water supply intake) that may delay, injure, or kill migrating species.
3. Employ consistent counting methods and equipment that maximize accuracy, precision, and reliability of annual fish counts for each species. Ensure collected data are properly archived to maintain data integrity and accessibility.

13.1.1.3 Amoskeag Development (P-1893)

Amoskeag Dam is the third barrier on the mainstem and the last with upstream fish passage. Poor passage at Lawrence and Lowell have confounded efforts to determine efficacy of the fish passage facilities at Amoskeag. We recommend the following based on best available information:

- Maintain and improve, if necessary, the recent modifications to the ladder that facilitate passage of alosines.

- Complete upstream telemetry studies that evaluate the effectiveness of the ladder. Use the data to diagnose the causes of passage failures and delay.
- Improve the auxiliary water system that provides insufficient flow and produces poor hydraulics at the fish ladder entrance.
- Maintain and monitor the upstream eel ways.
- Improve downstream survival of diadromous fish to meet the management goal of 95 percent survival.
- Employ counting methods and equipment that maximize accuracy, precision, and reliability of annual fish counts for each species.

A November 2020 USFWS memorandum[70] details a timeline for fish passage activities at the Merrimack River Project (P-1893). The following actions are included in the memo:

Year	Actions
2020	USFWS will estimate Project survival using the Turbine Blade Strike Analysis (TBSA) model and provide results to CRP for review and discussion. Discuss attraction water system improvements.
2021	CRP to perform downstream alosine study.[71] Decide/agree on attraction water system fix by 15 July for budgeting, permitting, and planning for 2022.
2022	CRP and USFWS/NMFS/NHFGD to begin discussions about downstream protection measures. CRP to implement attraction water improvements. CRP to implement interim targeted nightly shutdowns.
2023	CRP and USFWS/NMFS/NHFGD to complete downstream passage discussions relevant to Amoskeag and have a plan in place for 2024 by 15 July for budgeting, permitting, and planning for 2024. CRP to implement interim nightly shutdowns.
2024	CRP to implement permanent downstream passage and protection measures.
2025	Discussion and agreement of downstream passage alosine effectiveness study details (the need to perform said studies will be discussed as well – need will be based on TBSA model results, structures implemented, downstream alosine study results performed in previous years (2020 to 2025), etc.).
2026	If needed, CRP to conduct a downstream alosine passage effectiveness study at one of the developments to determine effectiveness of the permanent structures. Discussion and agreement of downstream passage eel effectiveness study details at Amoskeag
2027	CRP to conduct downstream eel passage effectiveness studies at Amoskeag to ensure permanent structure(s) provide proper guidance and do not need significant modification(s)

[70] FERC Accession #: 20201119-5066
[71] Based on the TBSA estimates, CRP may forgo the study and implement nightly shutdowns at Hooksett in 2022.

13.1.1.4 Hooksett Development (P-1893)

Recommendations for Hooksett Development include:

- Provide upstream fish passage by constructing a nature-like fishway at the western spillway. At the time of writing, the fishway has been delayed an additional year.
- Improve downstream survival of diadromous fish to meet the management goal of 95 percent survival.
- Monitor the effectiveness of the fish passage facilities to ensure management goals are supported.

A November 2020 USFWS memorandum[72] details a timeline for fish passage activities at the Merrimack River Project (P-1893). The following actions are included in the memo:

Year	Actions
2020	USFWS will estimate Project survival using the Turbine Blade Strike Analysis (TBSA) model and provide results to CRP for review and discussion. CRP to perform interim, targeted nightly shutdowns.[73] Nature Like Fishway design to be completed.
2021	CRP to construct Nature Like Fishway. CRP to implement interim, targeted nightly shutdowns.
2022	CRP and USFWS/NMFS/NHFGD to discuss the need for and potential study design of an upstream alosine passage effectiveness study (study to be agreed upon before 15 July for budgeting and planning). CRP to perform downstream alosine study.[74]
2023	CRP and USFWS/NMFS/NHFGD to come to agreement by 15 July for budgeting and planning on permanent downstream passage measures. CRP to conduct upstream alosine passage effectiveness study, if needed. CRP to implement interim nightly shutdowns.
2024	CRP to implement interim nightly shutdowns.
2025	CRP to implement permanent downstream passage and protection measures. Discussion and agreement of downstream passage alosine effectiveness study details
2026	If needed, CRP to conduct a downstream alosine passage effectiveness study at one of the developments to determine effectiveness of the permanent structures. Discussion and agreement of downstream passage eel effectiveness study details at Hooksett.
2027	CRP to conduct downstream eel passage effectiveness studies at Hooksett to test the effectiveness of permanent structures.

13.1.1.5 Garvin's Falls Development (P-1893)

Recommendations for Garvin's Falls Development include:

[72] FERC Accession #: 20201119-5066
[73] CRP proposes to, from dusk to dawn, reduce generation by 50% and open the tainter gate at Hooksett when river flows are less than 7,000 cfs and 0.25 inches of rain is predicted.
[74] Based on the TBSA estimates, CRP may forgo the study and implement nightly shutdowns at Hooksett in 2022.

- Determine the best-suited fish passage structure and install upstream fish passage.
- Monitor and improve upstream eel passage at the facility.
- Improve downstream survival of diadromous fish to meet the management goal of 95 percent survival.
- Monitor the effectiveness of the fish passage.

A November 2020 USFWS memorandum[75] details a timeline for fish passage activities at the Merrimack River Project (P-1893). The following actions are included in the memo:

Year	Actions
2020	USFWS will estimate Project survival using the Turbine Blade Strike Analysis (TBSA) model and provide results to CRP for review and discussion. CRP to perform downstream alosine study.
2021	CRP to implement interim, targeted nightly shutdowns. CRP and USFWS/NMFS/NHFGD to begin discussions about permanent downstream protection measures and upstream alosine passage.
2022	Complete discussions relevant to permanent downstream protection measures and have a plan in place for 2023 by 15 July for budgeting, permitting, and planning for 2023. CRP and USFWS/NMFS/NHFGD to reach agreement regarding upstream alosine fishway type and future data collection needs. CRP to implement interim, targeted nightly shutdowns.
2023	CRP to implement permanent downstream passage and protection measures.
2024	CRP to produce final designs for upstream alosine passage.
2025	Discussion and agreement of downstream passage alosine effectiveness study details.
2026	If needed, CRP to conduct a downstream alosine passage effectiveness study at one of the developments to determine effectiveness of the permanent structures. Discussion and agreement of downstream passage eel effectiveness study details at Garvin's Falls.
2027	CRP to conduct downstream eel passage effectiveness studies at Garvin's Falls to test the effectiveness of permanent structures.

13.1.2 Non-hydropower Barriers

The Merrimack mainstem basin has numerous, small, named and unnamed tributaries. Dams block many of these smaller tributary streams. For these barriers, we recommend the following:

- Explore alternatives to provide upstream fish passage wherever practical. Potential fish passage measures include: engineered fishways such as ladders, nature-like fishways, partial breach, dam removal, and weirs and traps (American eel).
- Prioritize dams that block comparatively more habitat and high-quality habitat.

[75] FERC Accession #: 20201119-5066

We recommend fish passage feasibility assessments in the following tributaries and associated lentic habitat in the lower watershed:

- Chase Brook
- First Brook (Melendy Pond, Ottarnic Pond)
- Limit Brook/Musquash Brook (Ayers Pond)
- Little Cohas Brook
- Naticook Brook (Horseshoe Pond, Greens Pond and Naticook Lake)
- Nesenkeag Brook
- Sebbins Brook (Sebbins Pond)
- Second Brook

We recommend fish passage feasibility assessments in the following tributaries and associated lentic habitat in the upper watershed:

- Bow Bog Brook
- Browns Brook (Heads Pond)
- Bryant Brook
- Cross Brook (Sondogardy Pond)
- Hayward Brook (Hoyt Marsh
- Mill Brook (Turtletown Pond)
- Peters Brook
- Punch Brook
- Shaw Brook
- Tannery Brook
- Stirrup Iron Brook
- Woods Brook

13.1.3 Stocking

In support of Objective 007, we recommend stocking target species where necessary to achieve restoration goals. Specific stocking locations and strategies are detailed in MRTC (2010, 2019).

13.1.4 Fish Population Characterization

We recommend estimating the alosine population below Essex Dam. The actual number of returning adult alosines in the 30 miles of mainstem habitat downstream of Essex Dam is unknown. Passage at Essex is used as a proxy for returns to the watershed because it represents the best available information. However, this metric is inaccurate due to passage inefficiencies at Lawrence. Many fish unsuccessfully attempt passage or do not attempt to pass, and therefore are not counted.

13.1.5 Fish Passage and Habitat Assessment

Habitat assessments and mapping are useful for understanding species distribution, limiting factors, and potential opportunities. These assessments determine the quantity (e.g., surface area, stream miles), type (e.g., spawning, rearing), and status/condition (e.g., water quality, invasive species, degree of connectivity, erosion or aggradation) of habitats. For the Merrimack mainstem subwatershed, we recommend the following assessments be conducted:

- Assess small tributary streams (less than 50 feet average width), particularly downstream of Amoskeag Dam to determine suitability for target species.
- Assess larger tributaries (greater than 50 feet average width) and mainstem habitats to confirm suitability and ground-truth assumptions used in production estimates and other analyses.

We recommend studies be conducted at Lawrence, Lowell and Amoskeag to assess the upstream passage efficiency of target species. Additionally, downstream passage studies are needed to determine survival of emigrating adult and juvenile alosines at Lawrence, Lowell, Amoskeag, Hooksett and Garvin's Falls Dams.

13.1.6 Water Quality

With several major urban centers (Lawrence, Lowell, Nashua, Manchester, and Concord) in the mainstem subwatershed, the contribution of pollution resulting from CSO discharge may be detrimental. Because storm events may occur more frequently with heavier precipitation due to climate change phenomena (Easterling et al. 2017), the risk posed to the watershed from NPS pollution increases. The potential impact of these CSOs is not well defined. In addition, dams affect both temperature and dissolved oxygen levels in rivers (Butts and Evans 1978; Lessard and Hayes 2003; Maheu et al. 2016). Dams can either reduce or increase both of these parameters depending on operations and time of year.

Merrimack Station, a large (440 MW) coal-powered steam electric generating facility, is operated by the Public Service Company of New Hampshire in Bow, NH. The facility is located on the Hooksett impoundment. During generation, the facility withdraws water (up to 200,000 gallons/minute) from the Hooksett impoundment, and discharges heated water into a cooling canal that flows directly into the river. The ecosystem impacts this heated discharge has on the river have been the subject of several investigation since the plant began operations in the 1960s. While impacts to some biota have been determined to be minimal, not all groups have been assessed. For example, alosines have been observed to successfully reproduce in the impoundment though the effect of thermal discharge, impingement, and entrainment on juvenile alosine survival has not been fully investigated.

We recommend the following actions to address water quality data needs associated with CSOs, NPS pollution, and thermal discharge:

- Conduct and/or support studies that attempt to measure nutrient and pollutant input from point sources.
- Employ strategies that optimize treatment capacity to reduce impacts of CSOs during storm or other high flow events.
- Collaborate with hydropower operators to ensure compliance with minimum flow requirements.
- Reduce NPS pollution sources wherever possible, and support programs to update and optimize performance of stormwater infrastructure.
- Develop strategies to reduce NPS pollution including BMP development, stakeholder management agreements, and public education.
- Assess the relationship between dams and water quality in the Merrimack River as budgets and staffing allow.
- Monitor seasonal water temperatures upstream and downstream of the heated discharge of the Bow Power Plant.
- Conduct additional studies on the risk of impingement and entrainment at water withdrawals.

13.2 Shawsheen River

13.2.1 Non-hydropower Barriers

The Ballardvale Dam is the only dam on the Shawsheen River. The river's location downstream from Essex Dam allows diadromous fish uninhibited access from the Atlantic Ocean to the base of the dam. The location in the watershed also means the diadromous fish production contribution of Shawsheen River habitats is unknown.[76] Spatial analysis (Section 8.1) indicates that nearly 70 percent of the river's habitat is upstream of the Ballardvale Dam. The estimated production potential increases from 6,100 American shad and 36,600 blueback herring to over 19,000 shad and 115,000 blueback herring once passage is provided at the dam. Therefore, providing passage at this dam is a priority. A feasibility study will identify the best options for the dam which are a volitional passage structure with downstream protections or partial/complete dam removal.

[76] The individual analysis in Section 8.0 excluded the Shawsheen River but the habitat is part of Ideal Scenario B.

13.2.2 Stocking

In recent years, 2,000 to 5,000 river herring collected at the Essex fish lift have been stocked in the impoundment above Ballardvale Dam. Stocking is beneficial to the restoration program as juveniles are imprinted to specific river reaches and return as adults, thus renewing a sustainable sea-run population. Therefore, we recommend this stocking effort continue until fish passage is provided at Ballardvale Dam.

13.2.3 Fish Population Characterization

We recommend a diadromous fish population study be completed to quantify the contribution of the Shawsheen River habitats and provide a baseline for future restoration activities in the watershed.

13.2.4 Fish Passage and Habitat Assessment

The Marland Place Dam removal site now comprises a high gradient reach that may be a partial obstacle for migrating fish under some flow conditions. We recommend a study to assess the site under different flow regimes to determine if further intervention is required.

13.2.5 Water Quality

Water withdrawals and NPS pollution affect the suitability of riverine habitat for aquatic species. Therefore, we recommend the following actions in support of diadromous fish restoration:

- Support planning and regulatory efforts that ensure withdrawals are carried out responsibly.
- Support the reduction of NPS pollution sources wherever possible, as well as programs to update and optimize performance of stormwater infrastructure.

13.3 Concord River (SuAsCo)

13.3.1 Hydropower Barriers

Located 1.5 miles upstream of the mouth of the Concord River, fish must pass Centennial Island Dam (P-2998) to reach the vast majority of upstream habitat on the Concord, Assabet and Sudbury Rivers. Fish passage effectiveness at the dam has not been evaluated, despite the importance as the first barrier in the system. Design flaws that prevent fish from passing upstream under many flow conditions were noticed during inspections of the existing fishway[77]. Several partners may be interested in assisting the project owner to improve passage at the dam

[77] FERC Accession # 20171019-5023

including the MRTC, Lowell Parks & Conservation Trust, and the Organization for the Assabet River (OARS, for the Assabet, Sudbury & Concord Rivers). We recommend the following actions to address fish passage at this site:

- Complete a feasibility analysis for a new ladder or nature-like fishway at the eastern abutment of the spillway.
- Evaluate the potential for the complete or partial removal of the dam while maintaining electric generation.
- Improve downstream passage and protection at the Project.

13.3.2 Non-hydropower Barriers

The lack of fish passage facilities at the Talbot Mills Dam prevents diadromous fish access to over 800 surface acres spread across 35 miles of mainstem river habitat. Providing passage at this site is a restoration priority. MADMF (2016) completed a feasibility study for diadromous fish restoration, in which the dam was identified as the primary impediment to fish passage. Several options are available to provide fish passage, ranging from installing a fish ladder to complete removal of the dam. One of the primary concerns about removing the dam is the potential affect to upstream water intakes. A follow up study to resolve this issue is planned for 2021. We anticipate the town government and other stakeholders will engage in the process to ensure their concerns are addressed. We recommend continued engagement with the dam owner and various stakeholders to address fish passage needs at this site.

13.3.3 Stocking

In recent years, 2,000 to 5,000 river herring collected at the Essex fish lift have been stocked at several locations in the Concord and Sudbury Rivers. Stocking is beneficial to the restoration program as juveniles are imprinted to specific river reaches and return as adults, thus renewing a sustainable sea-run population. Therefore, we recommend this stocking effort continue until fish passage is provided at Talbot Mills Dam.

Additionally, two lentic water bodies on the Sudbury River are potential river herring stocking locations - Farrar Pond and Lake Cochituate. We recommend the following actions to assess the viability of restoration at these locations:

- Evaluate the connectivity at these sites to determine if stocking is a viable option to increase the production potential of the Concord River watershed.
- Complete field surveys of the habitat, outlet configuration and barriers that fish must negotiate to reach the Sudbury River.

13.3.4 Fish Population Characterization

For several years MADMF and USFWS has assisted a local NGO with a video fish count at the exit of the Centennial Island fish ladder. These efforts have failed to identify passage of alosines. Therefore, we have no baseline information to evaluate restoration activities. A fish population and distribution assessment will benefit the management of these species in the watershed.

13.3.5 Fish Passage and Habitat Assessment

OARS has conducted a MA DEP approved water quality survey in the SuAsCo watershed for several years. This protocol has a high degree of overlap with the MADMF river herring habitat assessment. With minor modifications, the OARS effort could provide important Habitat information for targeted restoration efforts. We recommend that the MRTC work with OARS to include alosine habitat metrics in future surveys.

Fish passage is poorly studied in the Concord River watershed. Therefore, we recommend investigating the following passage related research questions:

- Fish passage effectiveness and efficiency at the site of the removed Middlesex Dam to determine if the removal site creates a barrier at some flows.
- Evaluate the potential success of downstream passage at the outlet of Lake Cochituate. Pending the results, this location may be suitable for stocking or a fish passage feasibility analysis.
- Investigate downstream passage efficiency and associated target species mortality at the Centennial Island Project (P-2998). Findings will help to determine if any structural or operational modifications are necessary.

13.3.6 Water Quality

The water quality in the Concord River watershed has been a concern for several decades. Superfund sites, municipal wastewater discharge, CSOs and illegal dumping all contribute to degraded water quality. Field observations have noted a smell of sewage on the water in the lower Concord River, likely indicating inadequate treatment or discharge of untreated water. Additionally, invasive plant species such as water chestnut (*Trapa natans*) are prevalent in some areas; these plants can exacerbate existing issues by reducing water circulation and dissolved oxygen concentration. In 2018, OARS completed a “River Report Card” for the system based on supported uses, all reaches received scores between C (40-60) and B (60-80). Although this is improved from past conditions, these scores indicate widespread use impairments. We recommend exploring strategies that control pollution and improve the water quality of the Concord River watershed.

13.4 Beaver Brook

13.4.1 Non-hydropower Barriers

Beaver Brook has only one mainstem dam downstream from the confluence with the Merrimack River. However, three impassable dams are located in the first few miles of the brook - Beaver Brook Dam, Unnamed Dam (MA03483), and Collinsville Dam. These dams prevent access to over 15 miles of habitat on Beaver Brook as well as many more miles of tributary streams. The town of Dracut along with the Division of Ecological Restoration and the Office of Dam Safety are in the early stages of site reconnaissance to assess the status of the dams. We support these efforts to evaluate the dams and recommend that fish passage be provided at each.

13.4.2 Stocking

The absence of hydropower dams on Beaver Brook makes this river a good candidate for stocking due to minimal concerns related to downstream survival. Habitat assessments will identify optimal stocking locations in the watershed.

13.4.3 Fish Passage and Habitat Assessment

We recommend field surveys to assess the habitat upstream of the first three dams on Beaver Brook. A habitat assessment will inform which species are best suited to colonize the habitat and guide management decisions for the watershed.

13.5 Nashua River

13.5.1 Hydropower Barriers

13.5.1.1 Jackson Mills (P-7590)

As the first dam on the Nashua River watershed, effective passage at the Jackson Mills Dam is vital to the success of restoration activities throughout the watershed. No formal studies have been completed at the Project. Therefore, we do not fully understand the efficacy of the upstream and downstream passage facilities. Observational evidence suggests the existing fish ways have several deficiencies. For the upstream fishway, the deficiencies include inadequate depth of flow in the upper leg of the fishway; poor hydraulics in the turning pools; an auxiliary water system that does not function properly; biological capacity is undersized to meet management goals; the entrances do not meet contemporary criteria; and entrance operation is difficult and unsafe. We recommend replacement of the ladder as the best option because the facilities have exceeded the design life. For the downstream fishway, the deficiencies include no guidance to the bypass entrance; poor debris management; no entrainment prevention; and high intake velocities. We recommend modifications to the downstream measures to improve performance and safety.

13.5.1.2 Mine Falls (P-3442)

Our understanding of the passage efficiency of the Mine Falls fishway is hindered by the poor passage at Jackson Mills. In addition, the previous owner of the Project neglected the facilities for many years, in some instances not operating the fishways at all. The current owner has improved the situation, but there are still deficiencies with the fish passage facilities that will be addressed through conditioning of the new license. For example, the fish lift has poor trap efficiency and the downstream bypass has poor entrance efficiency. Also, the Project has no entrainment prevention and Project survival for emigrants is low. The licensing process will inform specific recommendation to address the identified issues.

13.5.1.3 Pepperell (P-12721)

Pepperell is the next dam on the Nashua River and lacks fish passage. An upstream eelway was installed in late 2019, and the settlement agreement requires upstream passage facilities be operational after 5,000 river herring pass Mine Falls for two consecutive years, but not before 2026. Implementing fish passage at the dam is a priority for the Nashua River watershed, as there is a significant amount of habitat in both the Pepperell impoundment and the Nashua River further upstream. The project currently provides downstream protection in the form of nightly shutdowns, but no bypass structures are in place. We recommend implementing additional downstream protection measures, particularly once upstream passage measures are in place.

13.5.1.4 Ice House (P-12769)

Like Pepperell, Ice House Dam currently lacks upstream fish passage facilities. The license conditions stipulate that upstream passage must be provided if/when deemed necessary by regulatory agencies. We recommend upstream passage be considered at Ice House as soon as construction begins on facilities at Pepperell.

13.5.2 Non-hydropower Barriers

Several ruined dams are present on the Nissitissit River between Potanipo Pond at the headwaters and the Nashua River near Pepperell. Potanipo Pond is a river herring stocking location. Volitional passage to the pond may be currently possible under some flows or with minor modifications to these relic dams. However, field surveys are necessary to determine the fish passage impediments. We recommend that these ruined dams be assessed, and passage improved or provided where necessary. The next major tributary, the Squannacook River, is similar to the Nissitissit River in size and available habitat, but has more barriers. The degree of connectivity, severity, and restoration feasibility of these barriers is not known and should be assessed.

13.5.3 Stocking

The Mine Falls impoundment and Potanipo Pond receive an annual stocking of river herring. Approximately 7,000 adult river herring are stocked each spring. Additionally, Flints Pond has been identified as a potential stocking location, but has yet to receive fish. Flints Pond is located at the head of Flints Brook, a Nashua tributary that enters the river near the upstream extent of the Mine Falls impoundment. Observations at Potanipo Pond suggest successful juvenile production with hundreds of young river herring moving downstream in the fall near Pepperell, MA (Benjamin German, Integrated Statistics, pers. comm., November 6, 2020). Stocking should continue where possible until upstream passage improves and the river herring population is sustainable without intervention.

13.5.4 Fish Passage and Habitat Assessment

We recommend field surveys be completed to assess habitat suitability for migratory fish in the Nashua River and tributaries. A habitat assessment will inform which species are best suited to colonize the habitat and guide management decisions for the watershed.

13.5.5 Water Quality

Invasive water chestnut is pervasive in the Pepperell and Mine Falls impoundments, with nearly 100 percent surface coverage in some areas during the summer. At this level, the plants can disrupt diffusion of oxygen from the atmosphere potentially leading to stagnation and anoxia in the water below. This can have negative impacts on fish and other aquatic organisms not only in the immediate area, but also downstream as the oxygen depleted water flows downriver. Unfortunately, aggressive plant management (such as widespread herbicide use) can result in a large-scale die-off and subsequent decomposition of plant material, which can also lead to anoxic conditions in the river. Excess nutrients are often the root cause of nuisance plant growth, and proper nutrient and plant management are both important aspects of maintaining water quality. Responsible plant management should be carried out in a manner and timing that minimizes potential impacts on migratory and resident fish.

13.6 Souhegan River

13.6.1 Hydropower Barriers

Pine Valley Mills (P-9282) currently lacks upstream fish passage facilities. Passage is necessary at the McLane and Goldman Dams downstream before diadromous fish reach Pine Valley. We recommend conditioning fish passage facilities during the 2027 licensing because downstream restoration objectives (See Objective 017) and activities will allow fish to reach Pine Valley during the next license term.

13.6.2 Non-hydropower Barriers

13.6.2.1 McLane and Goldman Dams

The McLane and Goldman Dams represent barriers that prevent access to over six miles or 70 acres of diadromous fish habitat. These dams are obsolete[78] with operation and maintenance costs that burden the owner. Recently, woody debris loads have necessitated the removal of some of the flashboards creating an ongoing maintenance issue. Additionally both impoundments created by the dams have been listed on the NH Department of Environmental Services 303(d) list of impaired waters (dissolved oxygen and *E. coli*).

In support of Objective 017, we recommend providing fish passage through either dam removal or installation of upstream passage structures as soon as possible. Considering the factors identified, dam removal may be the most economical long-term solution. Funding for restoration activities may be available through grants, partnerships or other pathways.

13.6.2.2 Stowell Pond Dam and Baboosic Brook Ruins

Baboosic Lake has approximately 218 acres of river herring habitat and is a potential stocking location. Stowell Pond Dam currently prevents fish from reaching the lake. There is also at least one ruined dam on the upper Baboosic Brook that may represent an additional barrier. We recommend this reach be surveyed to catalog and assess connectivity effects of ruined dam(s) and to determine the best way to provide upstream passage for diadromous fish. In support of Objective 027, we recommend passage to Baboosic Lake be made possible through upstream passage facilities or barrier removal on Baboosic Brook.

13.6.3 Stocking

The Souhegan River has been stocked with shad on at least one occasion, though the outcome of this stocking is unknown. The lower mainstem and tributaries have great potential for blueback herring, and stocking these reaches is a viable strategy until volitional access can be restored. Stocking Baboosic Lake is a viable alternative until volitional access can be reestablished; restoring alewife to the Lake would directly support Objective 027.

13.6.4 Fish Population Characterization

Sea lamprey have been incidentally encountered during fisheries surveys conducted by NHFGD near the mouth of the Souhegan River – one of the few places in the watershed where presence is confirmed. Spawning nests (redds) have also been observed in this area. Ammocoete surveys may determine the importance of this habitat and its contribution to the population

[78] Gomez and Sullivan Engineers conducted a feasibility study in 2010 that suggests these dams may even worsen flooding impacts.

overall. In support of Objective 041, the lower Souhegan River should be an initial focus area to understand lamprey populations in the Merrimack basin.

13.6.5 Fish Passage and Habitat Assessment

Fish passage assessments are needed at several locations in the Souhegan watershed. Wildcat Falls – a natural feature in the lower river – may be a velocity barrier for alosines during some flows.[79] Similarly, the removal site of the Merrimack Village Dam has a series of bedrock sluices that may be an impediment that should be surveyed. Downstream eel monitoring at the McLane/Goldman complex for emigrating silver eels is recommended to determine the contribution of upstream habitats to the eel population.[80]

13.7 Cohas Brook

13.7.1 Non-hydropower Barriers

13.7.1.1 Pine Island Pond Dam

The dam at Pine Island Pond is a complete barrier to anadromous fish preventing access to the entire Cohas Brook watershed with the exception of the approximately 1,000-foot reach between the dam and the mouth of the brook. Removing the dam is preferable, but may not be feasible. Therefore, we recommend supporting a study to determine a suitable alternative for upstream fish passage, including a zone of passage assessment in the reach between the dam and the confluence with the Merrimack.

13.7.1.2 Massabesic Lake Dam

At 500 feet long and 27 feet tall, the dam at the outlet of Massabesic Lake is a barrier to migrating fish. Massabesic Lake supported a large annual alewife run that was extirpated. With 2,500 surface acres of potential spawning habitat, Massabesic Lake has the potential to produce over 500,000 alewife annually. This habitat has immense potential for the restoration of alewife if access were provided. We recommend working with Manchester Water Works to evaluate the possibility of implementing upstream fish passage improvements. Flow at the outlet is regulated based on available water and demand. This water management can result in low water in the brook and has the potential to intermittently prevent fish from reaching the dam or passing downstream.

13.7.2 Stocking

Pine Island Pond has been stocked annually with river herring for a number of years. Pine Island Pond provides 50 acres habitat, a fraction of the habitat that Massabesic Lake once

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[79] Sea lamprey have been observed on at least one occasion passing the falls.
[80] This type of monitoring has been done at McLane Dam; but contemporary data is desirable.

provided, but this stocking supports Objective 007 and Objective 027. We recommend continuing the stocking, pending funding and staff availability, until upstream passage allows fish to reach the pond without intervention.

Water supply management can conflict with diadromous fish restoration goals during low flow years due to obligatory juvenile alosine emigration in the late summer and fall. Heavy water use over the summer leads water supply reservoir managers to store water in the reservoir when river herring migrate out of the system. Water storage and limited releases delay or prevent downstream migration. However, there are regional examples where water supply management and alewife habitat successfully overlap (e.g., Assawompsett Pond in MA, China Lake in ME) suggesting that there may be opportunities to restore the once prolific diadromous fish runs into Lake Massabesic.

There are no current plans to stock Massabesic Lake with river herring; however, if future conditions at the outlet are conducive to downstream fish passage and stakeholders come to consensus on stocking, there is great restoration potential.

13.7.3 Fish Passage and Habitat Assessment

Fisheries and habitat research that supports management decisions includes assessing the river reach below Pine Island Dam, assessing the habitat connectivity for eel in Cohas Brook, and evaluating minimum flow requirements below Massabesic Lake dam. The reach below Pine Island Pond Dam is high gradient. Investigating the navigability of this reach for alosines is needed to ensure that upstream passage facilities are effective. We recommend installing an eel trap at Pine Island Dam to assess the number of immigrating eel entering Cohas Brook. Due to the accessible location of the dam, partnerships with local schools or conservation organizations may provide volunteers to check the trap through a citizen science initiative. A hydrologic analysis that estimates the minimum flow required to support fish passage measures at Massabesic Lake is a first step to determine feasibility of implementing fish passage at the dam.

13.8 Piscataquog River

13.8.1 Hydropower Barriers

13.8.1.1 Kelley’s Falls (P-3025)

Two miles above the Merrimack confluence, the Kelley’s Falls Dam is the first barrier on the Piscataquog River. There are no upstream passage facilities at the dam, limiting the extent of anadromy in the Piscataquog River to the short reach from the dam to the river mouth. MRTC member agencies are actively engaged in the pre-filing stages of the licensing process. We recommend upstream fish passage be provided at the project with the design and timeline for implementation an important consideration during the licensing proceedings. We also recommend improving the downstream passage and protection measures at the project. These recommendations directly support Objective 001, Objective 015, and Objective 016.

13.8.1.2 Greggs Falls (P-3180)

The second barrier on the Piscataquog River, Greggs Falls Dam is a large obstacle to diadromous fish. The size and height of the dam along with the license exemption make implementing upstream passage more difficult. The dam is owned by the state and leased to Eagle Creek Renewable Energy (ECRE) to operate the hydroelectric facility. Even though conditions exist under the license exemption to provide fish passage, nontraditional sources of funding outside of the regulatory process may be required to implement upstream passage at this site because of the agreement between the state and ECRE. We recommend implementing both upstream and downstream fish passage measures at the project in support of Objective 001 and Objective 015.

13.8.1.3 Hadley Falls (P-5379)

Hadley Falls, like Greggs Falls, has a license exemption with the dam owned by the state and an exemption allowing a lessee to operate the hydroelectric facility. However, the hydroelectric facility has fallen into disrepair and has not been operated in many years. Hadley Falls blocks access to nearly 100 surface acres of potential spawning habitat on the mainstem, north and south branch of the Piscataquog River, and there are lentic waters above this reach that receive stocked fish highlighting the need for both upstream and downstream passage at the project. Because the hydroelectric facilities are non-functioning and the impoundment serves no purpose, dam removal is the preferred option to provide fish passage. Therefore, in support of Objective 001 and Objective 011, we recommend investigating dam removal at this project.

13.8.2 Stocking

In the Piscataquog watershed, there are several potential stocking sites including the Kelley's Falls impoundment, Glen Lake, Gorham Pond, the Hadley Falls impoundment, Everett Lake, and the Weare Reservoir. We recommend stocking as staff and funding allow until volitional fish passage in the Piscataquog River improves and diadromous fish populations are sustainable. Downstream protection at each dam is vital to the success of these stocking efforts and should be established and/or maintained in support of Objective 015.

13.8.3 Fish Passage and Habitat Assessment

The USACE operates the dam at Everett Lake located on the North Branch Piscataquog River in Weare, NH, along with the dam at Hopkinton Lake, located on the Contoocook River in Hopkinton, NH. A two-mile-long canal connects the two dams, which operate as a single project to mitigate impacts during moderate to severe flooding events. Everett Lake along with several other associated lentic and lotic waters in the project area contain over 150 acres of potential diadromous fish habitat. The Riverdale Dam is a low-head dam that requires removal or fish passage construction for river herring to reach spawning habitat in the north branch Piscataquog River, including potential access to Everett Lake, in the town of Weare. We recommend surveying this area to determine the restoration potential and feasibility of providing fish access to these habitats.

13.9 Black Brook

13.9.1 Non-hydropower Barriers

13.9.1.1 Kimball Pond Dam

Kimball Pond lies at the headwaters of Black Brook, and at 90 acres, is the largest lentic habitat in the watershed. Identified by MRTC (2019) as a potential stocking site, and stocked for the first time in 2020, Kimball Pond has excellent restoration potential for river herring. The Kimball Pond Dam is owned by the town and the small size makes upstream passage relatively straightforward and cost effective. We recommend upstream fish passage be provided at this dam to allow fish volitional access to the habitat in Kimball Pond.

13.9.1.2 Pierce Brook Dam

Pierce Brook Dam is a relatively large ruined dam on lower Black Brook that is likely a barrier to both up- and downstream passage for much of the year (there is some spill during high flows; otherwise the brook flows through the dam). We recommend this dam be removed or breached in such a way that fish passage in both directions is reliably provided.

13.9.2 Stocking

Kimball Pond was stocked in 2020 with adult river herring. We will estimate the success of this stocking in 2024 when adult fish attempt to return to the natal spawning habitat. We recommend stocking continue as staff and funding allow until volitional passage to the pond is provided.

13.9.3 Fish Passage and Habitat Assessment

We recommend surveying the dam ruins in the Black Brook corridor to determine whether any intervention is necessary to facilitate fish passage past these obstacles.

13.10 Suncook River

13.10.1 Hydropower Barriers

13.10.1.1 China Mill Dam

As the first barrier to diadromous fish on the Suncook River, the China Mill Dam prevents migratory fish access to the entire Suncook watershed less than 0.5 miles above the Merrimack confluence. With plans for a fishway at Hooksett underway, fish will soon have access to the base of this dam for the first time in many decades. Due to the amount of both lotic and lentic habitats in the watershed, exploring options to implement upstream fish passage at the dam is recommended. Because the operation of the hydroelectric facilities predate the Federal Water Power Act of 1920, the Project is non-jurisdictional and the traditional regulatory pathway is not an option. We consider the significant restoration potential of the Suncook watershed justification to explore alternative pathways to provide fish passage.

13.10.1.2 Webster-Pembroke (P-3185)

The Webster-Pembroke Project is a two-dam hydroelectric project located immediately upstream of the China Mill Dam. The lower dam was partially removed in 2020 but remains a barrier to anadromy due to the remnants of the dam and steep ledge chutes. There are no upstream fish passage provisions at either dam and the project has a license exemption. Over 260 surface acres of Suncook mainstem habitat (not including associated lentic waters and tributaries) would become accessible with upstream passage at China Mill Dam and Webster-Pembroke. These potentially productive habitats highlight the importance of downstream passage at China Mill and Webster-Pembroke projects to ensure a sustainable run. We recommend upstream and downstream fish passage improvements be explored at these dams in support of Objective 001, Objective 015, Objective 026, and Objective 027.

13.10.2 Stocking

The Suncook River watershed has a high concentration of river-connected lentic habitats compared to other watersheds in the Merrimack basin. Many of these have potential as river herring spawning habitat. These include: Brindle Pond, Crystal Lake*, Halfmoon Lake, Harvey Lake, Jenness Pond, Locke Lake, Long Pond, Northwood Lake*, Pleasant Lake, Suncook River Reservoir*, and Upper and Lower Suncook Lakes*.[81] We recommend the continuation of stocking (as funding and staffing allow) until volitional access is restored.

[81] *Indicates previously or currently stocked waterbodies

13.10.3 Fish Passage and Habitat Assessment

Many of these waterbodies in the Suncook watershed will require passage assessments to determine if there are upstream barriers preventing access once passage is provided at the hydroelectric projects near the river mouth. American eel are able to pass the dams in this system, though the downstream survival is unknown. We recommend further evaluation of upstream and downstream passage effectiveness and survival through this system. The data provided by this type of study will directly inform management decisions in support of Objective 032.

13.11 Soucook River

13.11.1 Non-hydropower Barriers

The Soucook River differs from many of the tributaries in the upper Merrimack watershed in that it is largely free flowing, with few mainstem dams and no hydropower projects. The first barrier on the mainstem is the Louden Village Dam in the town of Louden, NH. In addition, a series of ledges located near the Cascade Campground in Louden, NH may constitute a barrier for some species under certain flow conditions. A field assessment is needed to determine the impact of this obstacle. Once upstream passage is provided at Hooksett Dam, we recommend exploring the feasibility of providing fish passage at the Louden Village Dam.

13.11.2 Stocking

Three waterbodies have been identified as having stocking potential in the Soucook watershed; Rocky Pond, Shellcamp Pond, and the Fox Run Impoundment (Soucook mainstem). Of these, Shellcamp Pond and the Fox Run impoundment have received stockings of adult river herring on multiple occasions. We recommend this effort continue as funding and staff allow until the run of river herring in the Soucook River is self-sustaining in support of Objective 027 and Objective 030.

13.11.3 Fish Passage and Habitat Assessment

We recommend investigating the navigability (for target species) of the natural ledges found near Cascade Campground in Louden, NH.

13.12 Turkey River

13.12.1 Non-hydropower Barriers

Two barriers are present on the Turkey River between the headwaters at Turkey Pond and the confluence with the Merrimack River. The Lower St. Paul’s School Dam impounds the Turkey River on the St. Paul’s campus below Turkey Pond in Concord, NH. Three-quarters of a mile further upstream is the second barrier, Turkey Pond Dam. These two barriers block access to the Turkey Pond complex, which comprises over 400 acres of potential spawning habitat. We recommend exploring options to provide upstream fish passage at these two dams. Working with the school has the potential to create a partnership that results in both fish passage and public outreach. With the lower dam located on a visible part of the campus there is great potential to implement an educational passage facility in support of Objective 012.

13.12.2 Stocking

Stocking is currently the only pathway for diadromous fish to reach the system because the Turkey River confluence is above both Garvin's Falls and Hooksett Dams. Turkey Pond has been stocked in the past. We recommend this effort continue as funding and staff allow until the run of river herring in the Turkey River is self-sustaining in support of Objective 027 and Objective 030.

13.12.3 Fish Population Characterization

13.12.4 Fish Passage and Habitat Assessment

We recommend surveying the mainstem of the Turkey River to assess the severity and configuration of the known barriers and to identify any additional obstacles that may be present.

13.12.5 Water Quality

Work has recently begun on a watershed management and restoration plan for the Turkey River. Funding for this project was provided in part by a Watershed Assistance Grant from the NH Department of Environmental Services with Clean Water Act Section 319 funds from the U.S. Environmental Protection Agency. We recommend collaborating with stakeholders developing the Turkey River plan to synergize management goals and outcomes with those outlined in this CP.

13.13 Contoocook River

13.13.1 Hydropower Barriers

Penacook Lower Falls (P-3342), Penacook Upper Falls (P-6689), & Rolfe Canal (P-3240), located near the mouth of the Contoocook River, are situated in close proximity, share a common owner, and are on the same licensing schedule. Therefore, for the purposes of our recommendations we consider the Projects together. Over 500 surface acres of habitat are located upstream of these projects on the Contoocook, Blackwater, and Warner Rivers. With fishway planning underway at Hooksett and Garvin's Falls in the next decade, these three projects will be the only remaining barriers blocking fish access to the upstream habitat. We recommend the following fish passage actions:

- Install upstream fish passage for anadromous species at these projects after passage at Garvin's Falls is complete. We will evaluate several options during licensing to provide passage during the new licenses, ranging from the installation of passage structures on each dam, to trapping fish at Penacook Lower Falls and hauling the short distance to the York impoundment.
- Install upstream eel passage at each project.
- Install and/or improve downstream passage and protection measures for diadromous species at each project based on the outcome of licensing studies.

13.13.2 Stocking

River herring have been stocked in Lake Todd and Lake Massasecum on the upper Warner River, and Lake Winnepocket. Walker Pond and Pillsbury Pond on a tributary to the Blackwater River have also been identified as potential stocking sites. As fish access is restored to the Contoocook River, stocking adult fish at these sites, and any others identified through habitat assessments will accelerate recovery of the stocks in this watershed. Stocking in the Contoocook watershed is encouraged as funding, staff, and fish availability permit, until a self-sustaining population is achieved in support of Objective 027 and Objective 030.

13.13.3 Fish Passage and Habitat Assessment

Several ponds in the watershed have been identified as river herring spawning sites. Numerous other lentic waters on the Contoocook River and tributaries may support runs of fish in the future, but surveys are needed to determine the accessibility and suitability of these habitats. We recommend surveying these habitats to guide future restoration activities.

Upstream and downstream passage studies are being requested through the licensing process to help guide decision making and to determine the best strategies for each barrier.

13.14 Winnipesaukee River

13.14.1 Hydropower Barriers

Downstream protections for diadromous fish are a management priority at each project in the Winnipesaukee River because of the ongoing stocking effort in Lake Winnisquam as well as the presence of American eel. Providing for upstream fish passage at the first four dams[82] is desirable, but will be a practical and regulatory challenge; four of the six projects on the Winnipesaukee River operate with license exemptions. In addition, there is a potential long-term conflict with coldwater fisheries management in Lake Winnisquam, where juvenile river herring may compete with Rainbow Smelt, which is the primary forage species for landlocked Atlantic

[82] Franklin Falls (P-6950), Stevens Mill Dam (P-3760), Clement Dam (P-2966), and Lochmere Dam (P-3128)

Salmon and Lake Trout (Kircheis et al. 2004). The interactions between river herring, smelt, and coldwater fish species require further study to help inform management decisions. We recommend upstream fish passage as a long-term goal for the system, provided these challenges can be resolved.

As one of two licensed hydroelectric projects on the Winnipesaukee, the Clement Dam provides a regulatory pathway to investigate fish passage. The current license expires in 2032 and the MRTC will engage in the licensing process to investigate fish passage feasibility.

13.14.2 Stocking

Until the river herring population can support the goals and objectives outlined in Section 12.2 without supplemental stocking, we recommend stocking in Winnisquam continue as funding and staff allow. Silver Lake has also been stocked on multiple occasion in the past offering an additional 200+ acres of spawning and rearing habitat. Silver Lake is located downstream from Lochmere Dam which is one less hydropower project that juveniles and adults must negotiate during their downstream migration as compared to Winnisquam.

13.14.3 Fish Passage and Habitat Assessment

One question we aim to answer is whether lentic waters throughout the Merrimack are sufficient to produce as many alewife as Lake Winnisquam does through the current stocking effort. The sheer size of the available spawning habitat in Winnisquam is unmatched by a single waterbody elsewhere in the Merrimack watershed.[83] In order for the alewife to become self-sustaining in the Merrimack basin, access must be provided to numerous lentic spawning habitats throughout the Merrimack watershed and the population will need to reach sufficient abundance to support runs of fish to each of these habitats. Objective 026 and Objective 027 are designed to recover this sustainable alewife migration. We can re-evaluate the need for stocking in Winnisquam and elsewhere once the population reaches a self-sustaining level to a diversity of habitat locations.

Passage feasibility at each hydroelectric project on the Winnipesaukee River needs to be investigated. The high density of dams over the 20-mile river course may increase the viability of non-traditional or collaborative passage approaches. One approach is to collect fish at the Franklins Falls Project and transport them upriver to be released in the appropriate habitat.[84] We recommend completing a feasibility assessment for a range of fish passage options involving the hydropower operators. The findings of passage feasibility studies will guide management

[83] Not considering Lake Winnipesaukee, which is not stocked with or accessible for diadromous fish
[84] Eel would be transported to Lake Winnipesaukee, whereas river herring would be stocked in Winnisquam or Silver Lake.

decisions and help determine the best alternatives for both resource agencies and hydropower operators.

Additional research is needed to understand the interactions between river herring restoration and coldwater fisheries. Full support for diadromous fish restoration in the Winnipesaukee River drainage is more likely to be achieved if the goals of restoration are in alignment with the goals of inland fisheries managers.

13.14.4 Water Quality

We are unaware of any outstanding water quality issues in the Winnipesaukee River watershed. We recommend maintaining the water quality to continue to meet designated uses.

13.15 Pemigewasset River

The Pemigewasset is considered a Type IV watershed primarily because of the two[85] hydropower projects in the lower river that will not undergo licensing in the next decade. This limits the potential for engagement at these projects in the near-term for alosine restoration. However, the resource agencies are actively working to support American eel passage in this river. License conditions may allow for consideration of fish passage improvements if the need is demonstrated. With the forthcoming improvements at Hooksett and Garvin's Falls, fish will have access to Eastman Falls during the current license term. In addition, the Ayers Island Dam may be logistically challenging for upstream passage construction, but there is a significant amount of riverine habitat available upstream. We recommend exploring alternatives to provide upstream passage at these dams.

[85] Eastman Falls (P-2457) and Ayers Island (P-2456)

14.0 IMPLEMENTATION OF COMPREHENSIVE PLAN

This CP will guide the activities of the MRTC and other stakeholders in support of the restoration of diadromous fishes over the next 10 to 12 years in the Merrimack River Watershed. Recommended management and restoration actions will facilitate this process and are designed to serve the goals outlined herein. The MRTC is responsible for implementing actions proposed in this CP. However, we anticipate the implementation team will be broader; composed of state and federal resource agencies, hydropower developers, and non-government organizations working together towards restoration objectives and goals. The MRTC will track progress towards the goals established in the CP, seek solutions to obstacles, and coordinate updates to the CP as necessary.

Team members and their respective agencies are limited to implementing actions in this CP to the extent permitted by law and subject to the availability of resources, in accordance with their respective missions, policies, and regulations. The implementation team will also seek funding opportunities to implement the research and management recommendations identified in the CP. The team will meet regularly (e.g., annually), if practical, with participation from stakeholders and other partners as needed.

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APPENDIX A: ANNUAL FISH PASSAGE AND STOCKING NUMBERS

TABLE A 1 - ANNUAL FISH PASSAGE NUMBERS AT ESSEX DAM, LAWRENCE, MA

Year	American Shad	River Herring	American Eel†	Sea Lamprey	Atlantic Salmon
1982	-	-	-	-	16
1983	5,500	4,800	-	2,800	88
1984	5,500	1,800	-	2,000	104
1985	13,000	23,000	-	18,000	212
1986	18,000	16,000	-	13,000	98
1987	17,000	77,000	-	18,000	129*
1988	12,000	360,000	-	8,900	65
1989	7,900	379,000	-	12,000	85
1990	6,000	250,000	-	8,300	243
1991	16,098	379,588	-	10,000	332
1992	20,796	102,166	-	18,000	199
1993	8,599	14,027	-	11,000	61
1994	4,349	88,913	-	5,000	21**
1995	13,861	33,425	-	4,000	34
1996	11,322	51	-	3,600	76
1997	22,661	403	-	8,600	71
1998	27,891	1,362	-	4,000	123
1999	56,461	7,898	-	9,700	185
2000	72,800	19,405	-	11,000	82
2001	76,717	1,550	-	3,700	83
2002	54,586	526	-	8,100	56
2003	55,620	10,866	-	2,200	147
2004	36,593	15,051	-	6,700	129
2005	6,382	99	-	848	34
2006	1,205	1,257	-	-	91
2007	15,876	1,169	-	1,400	74
2008	25,116	108	-	4,900	119
2009	23,199	1,456	-	2,000	81
2010	10,442	518	-	3,400	85
2011	13,835	740	-	2,600	402
2012	21,396	8,992	52,707	2,100	137
2013	37,149	17,359	3,588	548	22
2014	38,107	57,213	4,388	4,900	75
2015	89,467	128,692	14,771	5,000	13
2016	67,528	417,240	1,986	5,200	6
2017	62,846	91,616	19,586	2,100	5
2018	29,060	449,356	259,976	470	10
2019	16,963	68,711	121,331	9,335	14
‡2020	31,450 (*52,539*)	257,564 (*88,795*)	94,806	5,279 (*9,734*)	1 (*4*)

†Reported count is cumulative of all passage structures that were operated in a given year i.e. lift/permanent ladder/experimental ladder.

‡Visual count vs (*Salmonsoft camera count).*

*In addition to the 129 salmon captured, 6 salmon escaped the fish trap.

**17 salmon captured, 2 salmon escaped and 2 were illegally taken by angling.

TABLE A 2 - ANNUAL FISH PASSAGE NUMBERS AT PAWTUCKET DAM, LOWELL, MA

Year	American Shad	River Herring	Sea Lamprey
1986*	1,600	570	910
1987	3,900	31,000	1,900
1988	1,300	32,000	-
1989	922	37,000	1,900
1990**	443	9,900	169
1991	-	-	-
1992***	6,600	34,000	200
1993	1,700	4,300	1,500
1994	383	34,000	340
1995	5,300	12,000	920
1996	1,300	292	395
1997	4,400	20	2,000
1998	4,200	13	545
1999	16,000	2,900	3,700
2000	13,000	673	2,300
2001	7,700	58	606
2002	5,300	-	2,000
2003	6,600	194	822
2004	11,000	7,500	2,200
2005	716	201	185
2006	-	27	9
2007	1,700	-	127
2008	4,200	-	-
2009	2,800	139	260
2010	479	43	507
2011	1,200	256	272
2012	1,800	1,800	166
2013	13,500	9,800	70
2014	3,500	24,000	691
2015	21,000	32,000	208
2016	11,000	290,000	227
2017	5,100	5,600	333
2018	14,046	311,867	2,407
2019	2,201	43,871	1,113
2020†	(799/7,673)	(141,854/40,478)	(3,200/1,014)

0-999 fish are reported to the nearest individual: 1,000-9,999 to the nearest 100: 10,000-99,999 to the nearest 1,000: 100,000 or greater to the nearest 10,000.

*Testing period - facility not fully functional.

**Lifts began 5/5, however counts did not begin until 5/30.

***Fish lift out of operation 6/2-6/18.

† (Ladder count/lift count) cumulative elsewhere.

TABLE A 3 – Annual eel passage numbers at Amoskeag Dam, Manchester, NH

Year	Ladder Eelway	Eastern Eelway	Total
2003	641	-	641
2004	2,144	-	2,144
2005	405	-	405
2006	3,144	-	3,144
2007	754	-	754
2008	2,348	-	2,348
2009	854	-	854
2010	567	-	567
2011	2,218	-	2,218
2012	2,613	123	2,736
2013	2,467	273	2,740
2014	3,325	7	3,332
2015	6,040	1,639	7,679
2016	4,026	2,287	6,313
2017	2,780	925	3,705
2018	5,116	538	5,654
2019	1,120	205	1,325
2020	970	25	995

TABLE A 4 – Annual shad and river herring stocking numbers, Merrimack River Watershed

Year	Total American Shad Stocked (Fry[86])	Total River Herring Stocked (Adults, All Sources)
1984	-	13,000
1985	-	5,500
1986	-	5,000
1987	-	4,350
1988	-	2,000
1989	-	1,077
1990	-	6,000
1991	-	600
1992	-	-
1993	-	-
1994	-	-
1995	-	8,881
1996	-	8,995
1997	-	8,746
1998	-	8,635
1999	-	7,875
2000	-	13,375
2001	-	9,640
2002	-	8,500
2003	-	13,780
2004	-	7,510
2005	-	5,000
2006	-	2,025
2007	-	-
2008	-	3,000
2009	1,299,369	-
2010	1,002,360	6,675
2011	2,855,947	11,400
2012	2,081,711	30,465
2013	4,634,166	18,260
2014	7,828,918	14,422
2015	2,296,061	31,725
2016	1,523,218	47,140
2017	4,832,379	30,170
2018	288,018	75,300
2019	594,597	38,540
2020	0[87]	31,050
Grand Total	**29,236,744**	**478,636**

[86] Eggs collected from wild shad; hatched and cultured at the Nashua Nation Fish Hatchery
[87] Zero shad fry were stocked in 2020 due to the COVID-19 pandemic. USFWS hatchery staff were not permitted to cross state lines to collect brood stock from Essex Dam

TABLE A 5 – Source and number of adult river herring transfers to the Merrimack River

Year	Merrimack River	Androscoggin & Royal Rivers	Androscoggin, Royal, & Charles Rivers	Androscoggin River	Charles River	Cocheco River	Kennebec River	Lamprey & Taylor Rivers	Lamprey River	Oyster River	Saco River	Taunton River	Grand Total
1984								13,000					13,000
1985			5,500										5,500
1986		5,000											5,000
1987		4,350											4,350
1988		2,000											2,000
1989	377	700											1,077
1990		6,000											6,000
1991	600												600
1992													-
1993													-
1994													-
1995	2,235					3,280				3,366			8,881
1996						6,955				2,040			8,995
1997						3,300				5,446			8,746
1998					750	2,600				5,285			8,635
1999						2,950				4,925			7,875
2000	4,180					1,645						7,550	13,375
2001						2,800						6,840	9,640
2002						2,900						5,600	8,500
2003	280					5,000						8,500	13,780
2004	30					1,230						6,250	7,510
2005												5,000	5,000
2006												2,025	2,025
2007													-
2008						3,000							3,000
2009													-
2010				3,875		2,800							6,675
2011						3,400	3,000		5,000				11,400
2012				13,325		3,000	9,000		5,140				30,465
2013				1,200		2,450	6,000		6,000		2,610		18,260
2014	10,050			1,372			3,000						14,422
2015	12,300					6,700			6,950		5,775		31,725
2016	29,640			4,900		6,000			6,600				47,140
2017	9,680			2,150			9,000		9,340				30,170
2018	58,700						12,000		4,600				75,300
2019	29,540			3,000			3,000		3,000				38,540
Grand Total	**157,612**	**18,050**	**5,500**	**29,822**	**750**	**60,010**	**45,000**	**13,000**	**46,630**	**21,062**	**8,385**	**41,765**	**447,586**